Economics of Climate Adaptation

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Vulnerability Report

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Flood Risk & Heat Waves

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Economics of Climate Adaptation

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List of Acronyms

BMZ	German Ministry for Economic Cooperation and Development
CCA	Climate Change Adaptation
CCCO	Climate Change Coordination Office
CRO	Climate Resilience Office
ECA	Economics of Climate Adaptation
GCM	Global Climate Models
GSO	General Statistics Office Vietnam
HCMC	Ho Chi Minh City
ISF	InsuResilience Solutions Fund
IPCC	Intergovernmental Panel on Climate Change
KfW	German Development Bank
MPI	Ministry of Planning and Investment
SEADRIF	Southeast Asia Disaster Risk Insurance Facility
UNFPA	United Nations Population Fund
UNU-EHS	United Nations University – Institute for Environment and Human Security
WSDI	Warm Spell Duration Index

1. Introduction

Storms, floods, droughts and other extreme weather events can threaten urban and rural areas, from small regions to entire nations. Along with growing populations and economies, losses from natural hazards are rising in the world's most exposed regions as our climate continues to change. The Economics of Climate Adaptation (ECA) is a decision-making support framework that integrates climate vulnerability and risk assessments with economic and sustainability impact studies to determine the portfolio of optimal adaptation measures for diverse climate risks.

The United Nations University - Institute for Environment and Human Security (UNU-EHS) in cooperation with and funded by the InsuResilience Solutions Fund (ISF), is implementing the Economics of Climate Adaptation (ECA) framework in Can Tho in Vietnam to identify the most cost-effective measures to address flood and heat wave hazards. The ISF is funded by German Development Bank KfW and commissioned by the German Ministry for Economic Cooperation and Development (BMZ). Currently, the Economics of Climate Adaptation (ECA) methodology is being implemented in three different countries (Honduras, Ethiopia and Vietnam).

After concluding the Inception Phase, compiling and validating necessary data with key stakeholders during the Base Data Phase in order to run the modelling tool CLIMADA, this report presents the final recommendations for adaptation measures suited to enhance the resilience against flood and heat wave events in the three urban districts of Can Tho.

The following chapters provide an overview of the inputs for CLIMADA in terms of hazards, assets, damage functions and adaptation measures. Assumptions made and encountered uncertainties involved in the processes are further discussed. The report closes with final conclusions and recommendations directed primarily at both, the national and regional governments as well as development partners engaging in related programmes, and an additional chapter introducing the last phase of this ECA study presenting a pre-feasibility analysis of the measures suggested for implementation.

Over the past months, a set of calls and workshops were organized for representatives of Can Tho's Climate Resilience Office, the Can Tho Climate Change Coordination Office (CCCO) and the People´s Committee of Can Tho, and further stakeholders to provide input and request clarification on the subjects of the asset valuation methods and the modelled adaptation measures. The flood and heat wave model used for the ECA study was specifically developed by the study team and external partners. Chapter 2 describes the developed flood and heat wave model in further detail.

During the joined asset valuation and adaptation measures webinar, the valuation method was discussed and validated for each of the asset groups identified during the Inception Phase. The recommendations provided by representatives, local consultants, partners and other invited experts were incorporated and details of the results can be found in Chapter 3. Chapter 4 further presents the applied damage functions describing each asset group's sensitivity to flood and heat events and thus the expected mean damage degree at different flood and heat intensities. Facing the scarcity of historical data on damages, different sources were applied to construct and validate the assumptions made, including data gathered through a scoping consultancy in the course of the study and literature review before starting the iterative calibration process using CLIMADA. Following the same approach as was done with regard to the assets' valuation, the participants' knowledge and expertise was leveraged to coordinate a prioritization methodology based on given criteria, scoring the adaptation measures to better reflect the local conditions.

Adaptation measures were selected based on a comprehensive literature review, and a consultation process with key experts, partner organisations and government representatives, which is described in Chapter 5. In total 37 adaptation measures against heat waves and flood were initially identified and reduced to 17 measures, which have been introduced to CLIMADA. Measures include nature-based solutions, technical and engineering solutions (grey measures), measures drawing from both categories, as well as risk transfer/ insurance solutions. The measure selection process including the longlist of measures and their corresponding scoring is described in ANNEX 2, and the final short list including a detailed description of those can be found in ANNEX 3.

The final results as computed by CLIMADA, as well as a comprehensive discussion on their expected costs and benefits, and the related uncertainties, can be found in Chapter 6. Chapter 7 compiles the conclusions and recommendations of the report.

2. Hazard Modelling

In this chapter, we describe the assumptions and validity of the flood models (fluvial, pluvial and tidal) and the heat wave module developed and used in this report. Key findings are presented below, whereas additional details on the flood model are provided in ANNEX 1.

2.1 The CLIMADA Heat Wave Risk Module

This section presents the setup of the heat wave module introduced in CLIMADA. To date, no specific heat wave module existed, and we show here how we addressed the modelling challenges.

There is increasing scientific evidence that more frequent and intense extreme weather events such as high temperatures will occur in South-East Asia.[1] The Mekong Delta Region, consisting of 13 provinces in Vietnam, is considered one of the areas in South-East Asia most vulnerable to extreme hydro-meteorological events associated with climate change.[2] Studies indicated that the mean temperature in the central Mekong Delta Region increased by 0.5°C between 1978 and 2008, and the mean temperature is predicted to increase by up to 4°C by the year 2100, and the number of days that have an average temperature higher than 35°C will increase.[3] The increasing frequency and intensity of hazardous heat waves pose a serious risk to people, environment and economy. Heat waves can vary across different locations and at differing scales due to the variability of localised microclimates, resulting from different physical and built environments, socio-economic development, and adaptation strategies.[4] Especially in urban areas, such as Can Tho City, temperatures are generally higher, and *urban heat island* effects, may amplify the regional heat load during heat wave events. Urban heat island effects can be caused by multiple factors, including a low radiant heat loss in the urban canopy layer, changes in water balances and lower wind velocities compared to rural environments. Accordingly, local and regional climates can be significantly influenced by urbanization and other land-use changes.[5,6]

Previous studies in the Mekong Delta mainly associated heat waves or the exposure of high temperatures with increases in the risk of water and vector-borne diseases, cardiovascular and respiratory diseases, and the risk of hospitalization among young and elderly people. For example, one study indicated that heat wave events caused a 12.9% increase in risk of hospitalization due to cardiovascular diseases in Ho Chi Minh City.[7] Another study in Ho Chi Minh City found significant effects of heat waves on hospitalization

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[1] Intergovernmental Panel On Climate Change (IPCC). Climate Change 2013: The Physical Science Basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*, 2014.
[2] Yusuf, A. A., & Francisco, H. (2009). Climate change vulnerability mapping for Southeast Asia.
[3] DONRE Can Tho (2009). Report on Environment Quality Monitoring: Can Tho City 10 years (1999-2008). Can Tho, Vietnam: Center of Natural Resources and Environment Monitoring (CNREM), Can Tho Department of Natural Resources and Environment (DONRE).
[4] Tran, D. N., Nguyen, V. T., Khan, A., Thai, P. K., Cunrui, H., Chu, C., & Phung, D. (2020). Spatial patterns of health vulnerability to heatwaves in Vietnam. *International journal of biometeorology*, 1-10.
[5] McGregor, G. R., Bessmoulin, P., Ebi, K., & Menne, B. (2015). *Heatwaves and health: guidance on warning-system development*. WMOP.
[6] Chaudhry, P., & Ruysschaert, G. (2008). Climate Change and Human Development in Viet Nam: A case study for how change happens. *Oxfam Policy and Practice: Climate Change and Resilience*, 4(1), 1-18.
[7] Phung, D., Guo, Y., Thai, P., Rutherford, S., Wang, X., Nguyen, M., & Chu, C. (2016). The effects of high temperature on cardiovascular admissions in the most populous tropical city in Vietnam. *Environmental pollution*, 208, 33-39.

for elderly people and people with respiratory diseases.[8] In a multi-province study for the Mekong Delta, high temperatures were significantly associated with hospital admissions of young children and gastrointestinal infections.[9] For Can Tho City, one study counted 55 heat wave events (representing 292 days) between 2003-2013, with a daily average hospitalization of 30 admissions.[10]

No universal definition of *heat wave* is suitable for the particular case of Vietnam. It is mainly because different temperatures often have varying impacts in different parts of the world or regions. Heat waves should therefore be defined using thresholds that correspond to local weather conditions and their impact on human health, built-up environments or natural ecosystems. For this reason, definitions often vary across studies in the form of the number of consecutive days that exceed a threshold temperature, the threshold temperature used, and severity. [11]

Taking into account the variance of heat waves in different locations, this study, will define heat waves by using the largely recognised ETCCDI index[12] which defines the number of days above the 90th percentile of T*max* temperature for a reference period. This index has the advantage that it does not use a reference temperature (e.g. 30°C) but is adapted to local condition. The ETCCDI is a recognised panel supported by the World Meteorological Organisation[13]. The warm spell duration index (WSDI)[14] can be derived from daily records from local weather stations (possibly refined with remote sensing data when necessary).

To date this index have been encoded in CLIMADA for application at any scale or location (a python version will be available after the final report is delivered). This index reflects the state of the art on literature related to heat wave and is applicable in a large amount of countries for various situations. In Table 1 we describe index in terms of strengths and weakness as well as the kind of input data needed to operate it. All data used for heat wave modelling in this report are open source and free to use for non-commercial purposes.

Table 1: *Description of heat wave index included in CLIMADA*

Acronym	Name	Advantages	Limitation	Data needed
WSDI	Warm Spell Duration Index	Low data requirement Easy to compute Allow gridded and station data Global	Only consider temperature, not humidity or wind speed	Daily T*max*

There are some limitations related to the use of the WSDI. Specific local phenomenon such as heat islands or wind effect are not taken into account. CLIMADA enables the user to select the length of the period to

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[8] Dang, T. N., Honda, Y., Van Do, D., Pham, A. L. T., Chu, C., Huang, C., & Phung, D. (2019). Effects of extreme temperatures on mortality and hospitalization in Ho Chi Minh City, Vietnam. *International Journal Of Environmental Research And Public Health*, 16(3), 432.
[9] Phung, D., Rutherford, S., Chu, C., Wang, X., Nguyen, M., Nguyen, N. H., & Huang, C. (2015). Temperature as a risk factor for hospitalisations among young children in the Mekong Delta area, Vietnam. *Occupational and Environmental Medicine*, 72(7), 529-535.
[10] Phung, D., Chu, C., Rutherford, S., Nguyen, H. L. T., Do, C. M., & Huang, C. (2017). Heatwave and risk of hospitalization: A multi-province study in Vietnam. *Environmental Pollution*, *220*, 597-607.
[11] Tran, D. N., Nguyen, V. T., Khan, A., Thai, P. K., Cunrui, H., Chu, C., & Phung, D. (2020). Spatial patterns of health vulnerability to heatwaves in Vietnam. *International journal of biometeorology*, 1-10.
[12] See http://etccdi.pacificclimate.org/indices.shtml
[13] http://www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMP_72_TD_1500_en_1.pdf
[14] Peterson, T.C., 2005: Climate Change Indices. *WMO Bulletin*, 54 (2), 83-86.

compensate for this issue. Prior to modelling, a variable running window of 1 to 10 days can be selected. However, we recommend a 6 days window in order to capture more sever events.

2.1.1 Input Data

As in most regions with ungauged catchments, several assumptions are necessary to represent physical processes. However, in this ECA study, we strived to collect the best available data. All input data were carefully quality checked and discarded or improved if necessary. The following sections describe the main inputs.

2.1.1.1 Temperature Time Series for Validation

A wide range of satellite-derived temperature products have emerged in the last decades, providing a spatial coverage that is superior to gauge products, considering that gauges had the obvious queries such as the density of site networks, the continuous time series, or financial limitation. To satisfy the demand of studies and applications of climate, some of these satellite-based estimations provide long-term temperature records. Unfortunately, most of previous satellite temperature products had short historical record (less than 30 years) and lower spatial resolution. Accurate long-record (at least 30 years) temperature data are helpful. Fortunately, several alternatives exist, such as the Climate Prediction Center (*CPC) Global Temperature data provided by the NOAA/OAR/ESRL PSL.*[15] It has long time-series records (more than 40 years) and high spatial resolution (0.5°). Compared to other products, the CPC showed the highest agreement with gauge observations and has been shown to be a useful substitute for gauge data in Asia.[16] The CPC data set is gridded at 0.5° latitude by 0.5° longitude resolution. This dataset merges three types of information: global climatology, satellite estimates, and in situ observations, generating daily temperature, precipitation, wind speed and other meteorologically relevant products between 1979 and 2021. Another source of long term re-analysis data is provided by the high resolution CHIRTS dataset[17,18] which provides daily temperature data set derived by merging weather forecasts information with stations climate record for the period 1983-2016. Both data sets will be used to validate the heat wave model in CLIMADA.

2.1.1.2 Temperature Time Series for Simulations and Future Scenarios

In this study, we suggest using runs from RCA4 driven by the Had-CGCM2-ES circulation model for present and future simulation of temperature within the heat wave module. RCA4, a regional climate model, offer high resolution simulation of temperature, taking into account the local topography for higher accuracy. As discussed in the data report, the climate scenarios RCP4.5 (weak climate change signal) and RCP8.5 (strong climate change signal) are selected simply because they are most consistent.

[15] Nashwan, M.S., Shahid, S. & Chung, ES. (2019) Development of high-resolution daily gridded temperature datasets for the central north region of Egypt. *Sci Data* 6, 138. https://doi.org/10.1038/s41597-019-0144-0
[16] Zhanmei Yang & Jingyong Zhang (2020) Dataset of high temperature extremes over the major land areas of the Belt and Road for 1979-2018, Big Earth Data, 4:2, 128-141, DOI: 10.1080/20964471.2020.1718993
[17] Verdin, A. et al. (2020) Development and validation of the CHIRTS-daily quasi-global high resolution daily temperature data set. Nature: Scientific Data 7:303 https://doi.org/10.1038/s41597-020-00643-7
[18] Funk, C. et al. (2019) A high-resolution 1983–2016 Tmax climate data record based on infrared temperatures and stations by the Climate Hazard Center. J. Clim. 32, 5639-5658

2.1.2 Results and Validation

2.1.2.1 Heat Wave Module Simulation Performance

In this section we estimate the performance of how WSDI is simulated by CLIMADA using the RCA4 dataset performs when compared to two other datasets (CPC and CHIRTS). To do so, we prepared three (3) types of maximum temperature time series, comprising two observations datasets CHIRTS (1983-2016, 0.05 degrees), CPC NOAA (1979-2021, 0.5 degrees), and simulated time series (as used in CLIMADA) RCA4 (1951- 2021, 0.5 degrees).

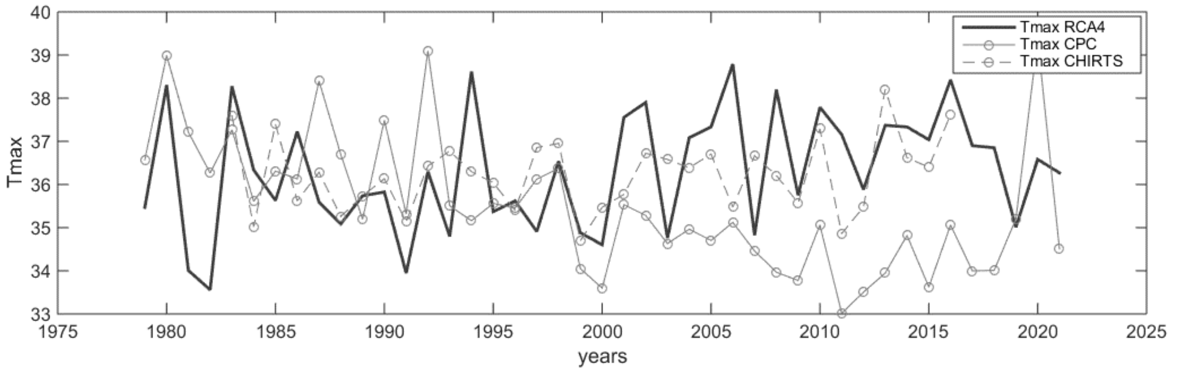

Figure 1: *Maximum temperature (Tmax) for two observed (CPC, CHIRTS) and on simulated (RCA4) time series.*

These three time series are presented below in Figure 1 representing the maximum annual T*max* in Can Tho between 1979 and 2021. RCA4 is displayed in bold dark grey, whereas observed time series are in light grey. Important differences in the three time series are apparent. Figure 2 explores further anomalies between CHIRTS and the simulated RCA4 and highlight significant differences between the time series. These differences might lead to differences in how WSDI is simulated using one or the other time series. In our case, observed data cannot be used for simulation of future scenarios. Therefore, because RCA4 performs well in the region, it is used for the simulation of WSDI today and in the future. Because results vary so greatly between data set, a validation against similar data cannot be performed for Vietnam. However, in the next section we explore how the model in CLIMADA is able to simulate T*max* and reduce uncertainties between simulations and observations.

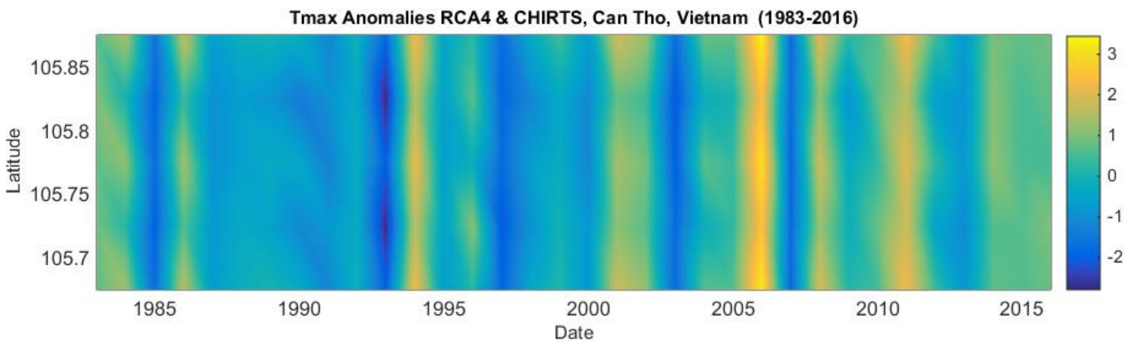

Figure 2: *Anomalies in maximum temperature (Tmax) for Vietnam between RCA4 and CHIRTS.*

2.1.2.2 Stochastic Modelling of Future Heat Wave Events

From a stochastic point of view, the problem of forecasting future values of a random variable is equivalent to the determination of the probability density function of future values conditioned by past observations. Once the conditional distribution is known, the forecast is usually defined as the expected value or a quantile of such distribution, and confidence intervals of the forecast values can be computed.

In this case the WSDI index is selected to simulate heat wave for Vietnam using the RCA4 historical time series. The 1951-1991 time period is used to determine the probability density function. The validation of 10 000 CLIMADA simulations is done for the period 1991-2021. The CLIMADA WSDI simulations are presented in Figure 3. 10 000 stochastic simulations of WSDI are represented by the boxplots showing the median (line), the 75% quantile (box) and the 95% quantile (whiskers). The CLIMADA WSDI values are plotted (green line) against T*max* calculated with the CPC and CHIRTS historical values, assimilated to observations and therefore constituting a control time series. In both regions, the stochastic CLIMADA simulations are in strong agreement with observations reflection the robustness of the heat wave module at simulating heat wave accurately.

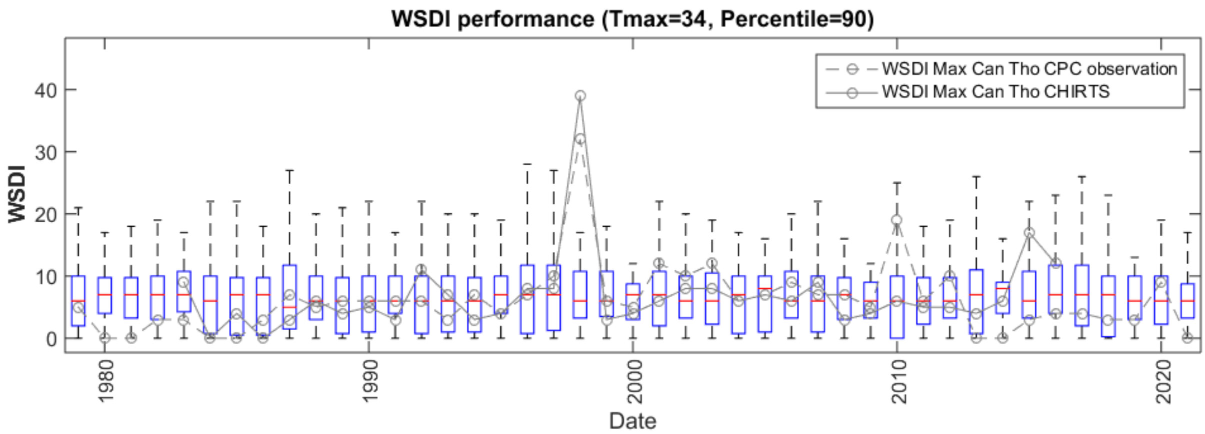

Figure 3: *Probabilistic simulations (boxplots) of the new CLIMADA heat wave module against observations (CPC and CHIRTS historical time series) for Can Tho province.*

2.1.3 Limitations and Conclusion

This section presents the methods, data and parameters used for the setup of the heat wave module for Vietnam. This new module constitutes a significant add-in to CLIMADA in terms of hazard modelling in Vietnam but also for other regions. Nevertheless, an honest and careful discussion regarding limitations and uncertainties linked with the forecasting exercise is necessary to further improve future iterations of the model.

Another source of uncertainty lies in the difficulty to grasp heat wave in its complexity. While we decided to use WSDI for its flexibility, its outcome is limited by record length and the time scale calculation. Some heat wave events might be underestimated, whereas physical factors such as wind speed and humidity are not considered. In addition, building and pavement reflectivity and vegetation can play a major role in urban areas.

Finally, climate scenarios, GCM and downscaled data offer a series of biases due to resolution, orographic changes and temporal issues which impair the forecasting power of drought models in general.

In conclusion, the outputs of the study included heat wave estimations for five return periods (5, 10, 25, 50 and 100 years) for the present and the future (RCP4.5 and RCP8.5). As a new module for heat wave risk in CLIMADA, significant improvements have been made, which can be applied in other regions. The results of this modelling exercise are explicitly fit for purpose for the scope of this study and, beyond, are also to be considered for a basis to further planning in Vietnam.

2.2 Flood Risk Modelling

This section presents the setup of the inundation model as introduced in CLIMADA. The flood model in this report includes three types of flood commonly seen in Can Tho: Fluvial floods, pluvial floods and tidal floods. Whereas pluvial/fluvial inundation model are quite common, a tidal flood approach is novel for the city and provide useful insights for adaptation planning. A general description is provided below. For additional technical details and parameters, please refer to ANNEX 1.

2.2.1 Context

With a topography ranging between 0.6 to 1.2 m above sea level[19], the central region of the Delta around Can Tho faces every year seasonal flooding events, often caused and influenced not only by a single flood regime but also by a combination of tidal floods from the sea, riverine floods from the upstream Mekong and strong precipitation (pluvial floods).[20,21] The occurrence of floods with increasing severity become more damaging and unpredictable for the people and local governments, due to a multitude of factors such as climate change and rapid urban development[22].

There are a number of factors causing urban flooding in Can Tho City. The main factor of urban flooding are Mekong River upstream floods combined with the high-tide regime of the Eastern Sea, which usually occurs at the start and middle of the lunar month.[23] These factors can often occur combined with a third flood regime caused by rain. Rainfall is also a major factor causing urban flooding, in terms of timing and scale. Rainfall in Can Tho City usually lasts from 30 minutes to 2 hours with precipitation at 40–70 millimetres. In the middle of the rainy season, from August to October, urban flooding usually occurs right after the rain, especially in the lower areas inside the city.[24] Commonly, river discharges in Can Tho are high every season from September to November, whereas tidal flood often occur from October to

[19] Siddiqua, A. (2019) Emergence of Water Urbanism for Water Born “Can Tho”. *Journal of Water Resource and Protection*, 11, 166-180.
[20] Do, T.C., Nguyen, D., Gain, A.K., Kreibich, H. (2017): Flood Loss Models and Risk Analysis for Private Households in Can Tho City, Vietnam. - Water, 9, 5.
[21] Hung, N.N.; Degado, J.M.; Tri, V.K.; Apel, H. Floodplain hydrology of the Mekong delta, Vietnam. Hydrol. Processes 2012, 26, 674–686.
[22] Ibid.
[23] Danh, V. T. (2019). Household economic losses of urban flooding. In *Groundwater and Environment Policies for Vietnam’s Mekong Delta* (pp. 119-146). Springer, Singapore.
[24] Ibid.

January.[25] In 2008, 21 main streets were inundated to a depth up to 50 centimetres by high tides and a combination of heavy rains.[26]

Besides rapid urbanization, one important factor which influences floods in Can Tho, is the water-system infrastructure. The different flood types increase the already high pressure on water supply-, sewage and drainage systems even further, while the sewer system is only partially capable of draining flood either from the river or from rain.[27] Sewer overflows induced by floods also present an increased health risk to the general population.[28] Also, rapid urbanization has reduced the natural infiltration of surface water and has decreased the natural reservoir capacities inside the city.

Can Tho evidenced several major flooding events in the past twenty years. In 2000, rainfall occurred earlier than usual in the rainy season and caused flooding in the lower Mekong River Delta with observed flood levels in Can Tho just 1-3 centimetres below a 40 year record level.[29] These floods inundated more than 110 000 houses and 26 000 hectares of rice paddies.[30] In 2008, 21 streets were inundated with depths between 30-50 centimetres, largely due to high tide, and heavy rainfall. On 5th October 2009, heavy rains (more than one hour) caused serious inundation to the city as well. The peak of the flood of October 2011 reached a water level of 2.15 meters, above Warning Scale III at 25cm, the highest level since 1940 and peaked the levels of year 2000.[31] This flood inundated almost the whole city as a result based on the combination of high tides and sea level rise.[32] Some parts of the city, close to the river, were inundated for several months, with the consequence of 27.000 houses inundated and a total economic loss of 11.3 million USD towards the city's infrastructure, businesses and agriculture.[33]

A household survey conducted in 2009 in Can Tho indicated the number of flooded sites attributed to the causing flood regimes. This survey illustrates that especially the combination of rain and high tides leas to a large number of flooded sites. The flooding of urban sites, mainly streets, cause damage and loss not only to physical infrastructures but also to livelihoods and businesses. Collapsed and damaged houses along riverbanks during flood periods mainly result from unsafe constructions. Some surveys also highlight critical numbers of schools affected from flood events.

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[25] Chinh, D. T., Gain, A. K., Dung, N. V., Haase, D., & Kreibich, H. (2016). Multi-variate analyses of flood loss in Can Tho City, Mekong Delta. Water, 8(1), 6.
[26] Danh, V. T. (2019). Household economic losses of urban flooding. In *Groundwater and Environment Policies for Vietnam's Mekong Delta* (pp. 119-146). Springer, Singapore.
[27] Neumann, L., Nguyen, M., Moglia, M., Cook, S., & Lipkin, F. (2013). Urban Water Systems in Can Tho, Vietnam: Understanding the current context for climate change adaptation.
[28] Ibid.
[29] Huong, H. T. L., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrology and Earth System Sciences*, 17(1), 379.
[30] Ibid.
[31] Vo, D. T. (2018). Household economic losses of urban flooding: case study of Can Tho City, Vietnam. *Southeast Asia Review of Economics and Business*, 1(1).
[32] Can Tho Urban Development And Resilience Project, *Environmental And Social Impact Assessment (ESIA)*, People's Committee Of Can Tho City (2015).
[33] Chinh, D. T., Gain, A. K., Dung, N. V., Haase, D., & Kreibich, H. (2016). Multi-variate analyses of flood loss in Can Tho City, Mekong Delta. Water, 8(1), 6.

2.2.2 Simulation Domain and Input Data

The domain for the hazard simulation encompasses the districts Binh Thuy, Ninh Kieu and Cai Rang of Can Tho province. Figure 4 shows the simulation domain including the planned flood protection dike ring of Ninh Kieu-Binh Thuy, which is currently under construction. These three districts are the most populated in Can Tho.

2.2.2.1 Spatial and Elevation Data

A high resolution LIDAR digital elevation model (DEM) with 5m resolution, providing the highest accuracy possible in the region. To date, no other studies attempted simulation at this resolution for such a large area. The DEM was enhanced by buildings locations (relevant for water flows) using the latest generation of high resolution satellite imagery (Quickbird) (2012) provided by German Aerospace Center (DLR). Furthermore, a FAO land use classification of 2017 was used for setting up basic model inputs. Table 2 provides an overview of the base data used in this flood hazard analysis study.

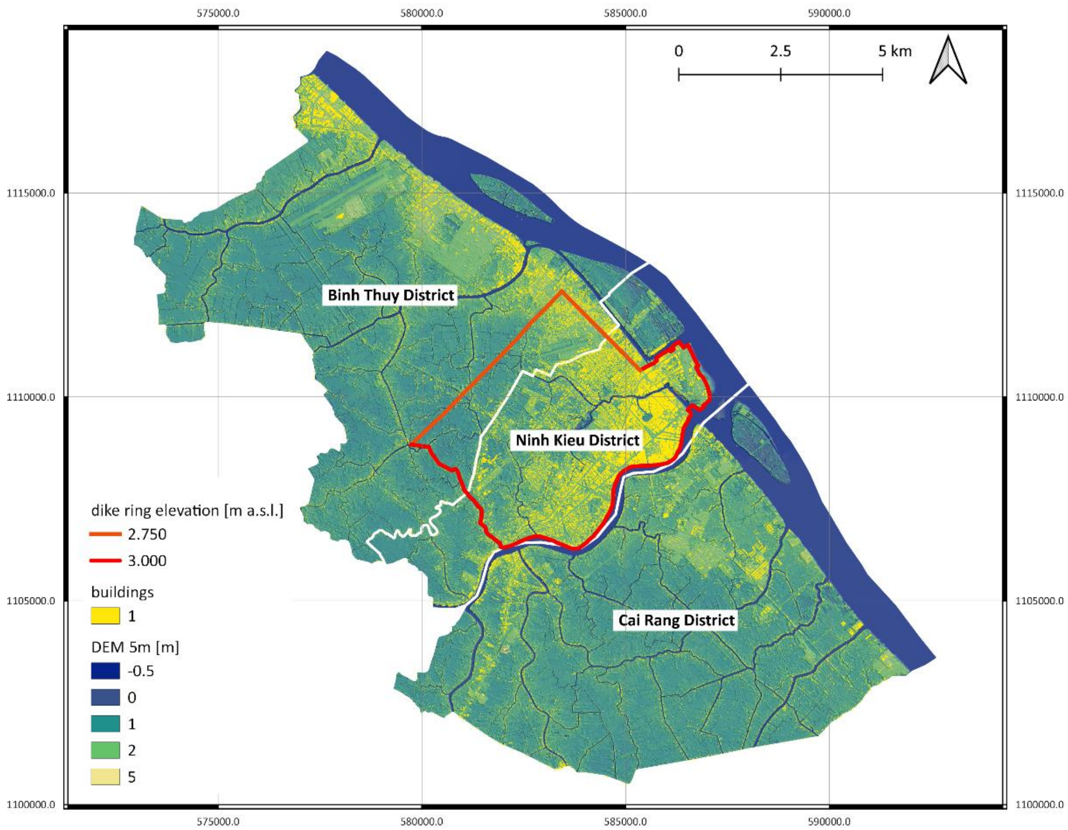

Figure 4: *The geographical setting of the project simulation domain with the districts Binh Thuy, Ninh Kieu and Cai Rang.*

Table 2: *Annual damage calculation for Pluvial/Fluvial Floods in Can Tho.*

Content	Type	Source
LiDAR based Digital Elevation Model DEM	Raster, 5 m resolution	GFZ (Catch-Mekong project)
Land use classification	Vector shape file	FAO
Building inventory (as of 2021	Vector shape file	DLR
Dike ring Ninh Kieu-Binh Thuy	Vector shape file	Compiled on the basis of information from CTU

2.2.2.2 Precipitation and Water Level

Water level records were collected for the main river gauge of Can Tho in the Hau River and a gauging station was installed in the Can Tho River within the Water-related Information System for a Sustainable Development of the Mekong Delta (WISDOM) project.[34]

For the pluvial flood hazard analysis, hourly rainfall records from the rainfall gauge at Can Tho airport were obtained. These span a time series from 1982 to 2020. The time series shows that the rainfall is distinctively seasonal with high rainfall amounts during the monsoon season (May-October) and little rainfall during the remaining time of the year.[35]

2.2.2.3 Future Scenarios

The presented study also attempts to estimate the changes in flood hazard driven by climate change in future. In order to do so, a delta (Δ) approach was applied, identical to Apel et al. (2016) "*which derives delta changes in the boundary conditions for the different hazard types in Can Tho. The delta values were taken from scientific literature. However, only a few studies are available that provide quantitative information about the changes in flood water levels in Can Tho or of changes in extreme precipitation in future. An analysis of the available literature revealed, that harmonized delta changes can only be collected for a future time horizon around 2050 (mid-21st century), and the RCP4.5 concentration pathway. For other time horizons or different concentration pathways the literature does not provide sufficient information for all hazard categories. The following publications were used for estimating the Δ-values for the different hazard categories:*

*For the **fluvial hazard**, the ΔH for climate change impact on maximum water levels was taken from Triet et al. (2020). This study estimated the mean change of maximum flood water levels in the Mekong delta including Can Tho under the RCP4.5 concentration pathway. There is no similar study using RCP8.5 for the Mekong.*

*For the **pluvial hazard** the ΔP was estimated from a report of the Vietnamese Ministry of Natural Resources and Environment (MONRE, 2016). This report contains large scale figures showing the percentage change of maximum 1-day precipitation for the whole of Vietnam, both for RCP4.5 and RCP8.5.*

*For the **tidal hazard** the study of Manh et al. (2015) was used. The authors compiled information about maximum and minimum reported changes in effective sea level rise for mid-21st century and used these values in a sensitivity-based impact assessment for the Mekong Delta. In order to use a number that is in line with the RCP4.5 scenario as in the fluvial and pluvial hazard, the median of the reported range was used*".

More details and the actual Δ-values used are available in ANNEX 1.

[34] See http://www.wisdom.eoc.dlr.de
[35] Apel H, Martínez Trepat O, Hung NN, Chinh DT, Merz B, Dung NV. 2016. Combined fluvial and pluvial urban flood hazard analysis: concept development and application to Can Tho city, Mekong Delta, Vietnam. Nat. Hazards Earth Syst. Sci., 16: 941-961. DOI: 10.5194/nhess-16-941-2016

2.2.3 Hydraulic Modelling

The design of the study is based on the previous flood hazard analysis[36] in Can Tho performed by GFZ with a combined probabilistic fluvial-pluvial flood hazard analysis for downtown Ninh Kieu. The core concept the original model was adapted to the extended geographical coverage, the higher data resolution, and the new urban hydraulic inundation model, in order to analyse the fluvial, pluvial, combined fluvial-pluvial, and the tidal flood hazard for the three districts shown in Figure 4.

The inundation model used in this report is RIMurban[37], a 2D hydraulic inundation model specifically developed by GFZ for urban flooding. RIMurban is the latest of several iterations of high resolution flood simulations.[38,39] RIMurban has been successfully tested in Can Tho urban area.[40] The original model was further developed for this ECA Case study in order to consider the specific features of urban flood routing and inundation. These improvements are:

1. **Consideration of the built-up area**: In this study buildings (Figure 4) are considered in the flow routing. This is achieved by excluding the footprints of the buildings from the flow simulation, thereby simulating the flow around buildings.

2. **Inclusion of the sewage system**: the effect of the sewer system on the inundation dynamics is simulated using spatially distributed information on sealed surfaces and the estimation of the sewer capacity.

3. **Consideration of soil infiltration**: The effect of infiltration is included using non-sealed surfaces and an estimation of the infiltration capacity.

These improvements enable more realistic simulations of the urban inundation dynamics.

2.2.4 Results and Conclusions

The results of the 2D hydraulic simulations are provided as maximum inundation depths at a spatial resolution of 5 m. Fluvial and pluvial inundation are combined and tidal is presented separately for different return periods (T2, T5, T10, T20, T50, T100). Two scenarios are presented (“present”) and future climate (“2050”) for pluvial/fluvial inundations in Figure 5. The figure confirms the conclusion drawn from observations with an effect of combined fluvial-pluvial flood hazard, increasing the affected areas. The strong protecting effect of the dike is also particularly clear. The hazard maps show that the planned dike ring of Ninh Kieu-Binh Thuy is sufficiently designed to protect the city centre against 100-year fluvial flood events.

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[36] Idib.

[37] Ibid.

[38] Bates PD, Horritt MS, Fewtrell TJ. 2010. A simple inertial formulation of the shallow water equations for efficient two-dimensional flood inundation modelling. Journal of Hydrology, 387: 33-45. DOI: DOI 10.1016/j.jhydrol.2010.03.027.

[39] Almeida GAMd, Bates P, Freer JE, Souvignet M. 2012. Improving the stability of a simple formulation of the shallow water equations for 2-D flood modeling. Water Resources Research, 48. DOI: W05528, doi: 10.1029/2011WR011570.

[40] See Apel et al. (2016)

Figure 6 presents the outcome of the tidal simulations for the 25yr return period for three types of tides. In CLIMADA, only strong tides (for different return periods) have been included, as the scope of the study is to account for larger events.

In summary, the statistical (see ANNEX 1) and visual evaluation of the simulation results underline the validity of the hazard analysis with a high confidence in the simulations.

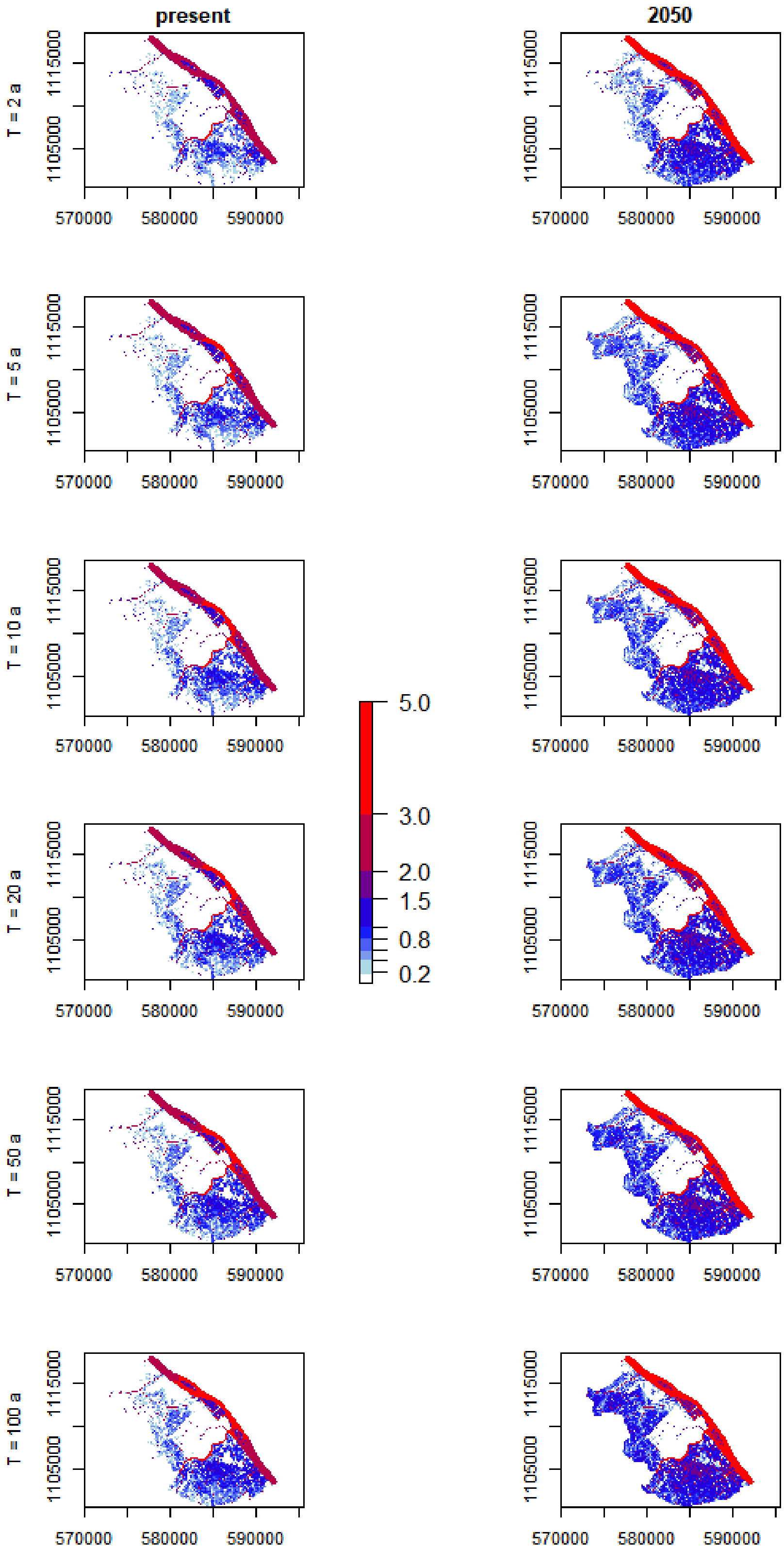

Figure 5: *Fluvial-pluvial hazard maps showing the maximum inundation depths in meter for present day situation and for mid-21st century under the RCP4.5 scenario.*

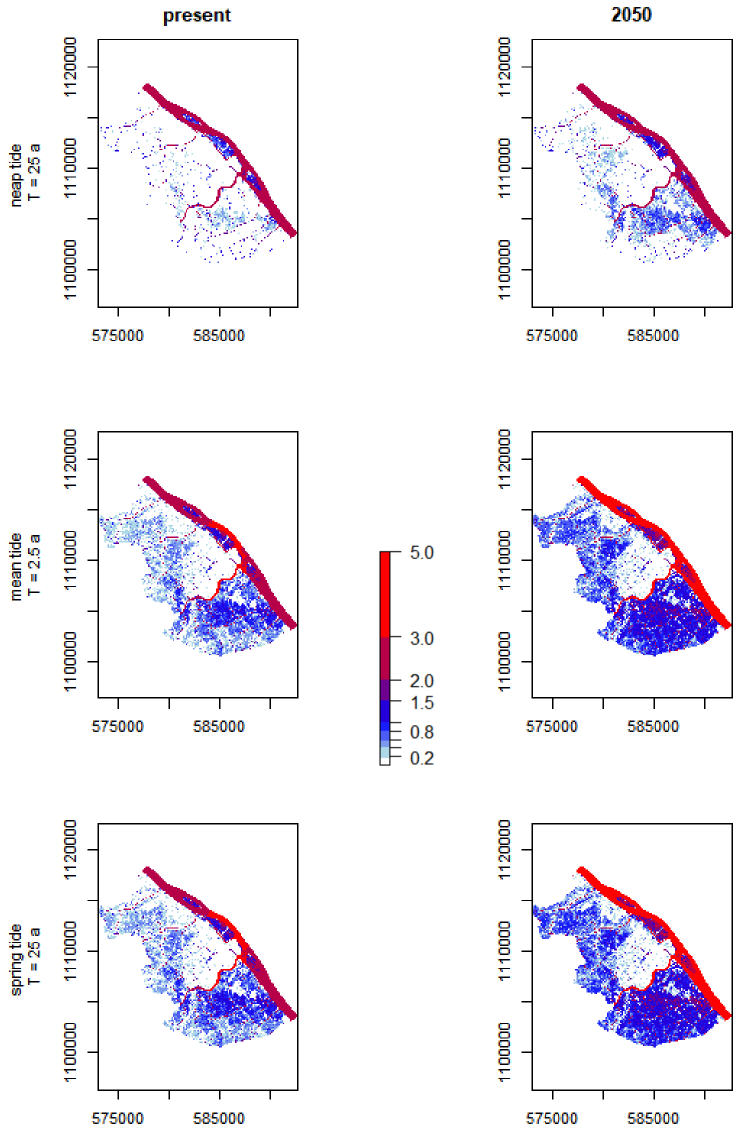

Figure 6: *Tidal flood hazard maps showing the maximum inundation depths in meter for common flood (i.e. derived from T = 25 years return period fluvial scenario) for present day situation and for mid-21st century under a sea level rise assumption.*

3. Assets Valuation

3.1 Methodology

The following chapter describes how the different types of assets and their values were estimated. As CLIMADA relies on georeferenced data, both, risk scenarios and damage to assets, have to be simulated based on georeferenced information. Therefore, previous to the valuation exercise, all assets had to be geo-located and partitioned where necessary, such as e.g. larger agriculturally used areas, as described in further detail in the corresponding subchapters below.

In general the methodologies used in this study to estimate asset values, including probabilities/ likelihoods of being affected by climate hazards, were

- Literature review,
- Discussions with experts and feedback during and following the webinars of the previous project phases.

Additional to the data available online at different research centres and databases data was provided by Vietnamese organisations and institutes who also contributed greatly by translating and explaining the data to the team in detail.

3.2 Assets Categories

The assets examined in this study were confirmed during an iterative process through (a) the inception workshop and the corresponding report and (b) through the validation webinar and its report. Hence, the final list of assets, and simultaneously the order in which they, their corresponding valuation method and results will be more closely described in this chapter, is as outlined below.

1. People
2. Housing
3. Public Buildings
    a. Educational Facilities
    b. Health Facilities
    c. Administrative Buildings
4. Road Network
5. Electric Grid
6. Natural Resources
    a. Aquaculture
    b. Cash Crops
    c. Orchards
    d. Triple Rice Crop
    e. Green Spaces

3.2.1 People

As the first asset group 'people' were identified. People and their level of vulnerability are defined here according to the definition of the Intergovernmental Panel on Climate Change[41] based on the three components of vulnerability, namely

- exposure,
- adaptive capacity, and
- sensitivity.

Other than the other assets considered in this study, people are not valued in financial terms but simply as individual human beings of equal worth.

To take **exposure** into account appropriately**,** in line with guidelines provided by IPCC, the population living within the area of the maximum expected pluvial-fluvial flood hazard extent (100 year return period in 2050[42]) were assumed to be exposed. This expected maximum extent of flooding results from the above described model. Similarly, for the tidal flood hazard the maximum extent of a spring tide was used to identify exposed people. Finally, in the case of heat wave all people are assumed to be exposed, as heat waves, even though there may be (very) localised differences due to e.g. urban heat islands[43], can be expected to cover areas that reach even beyond the here relevant geographic extent.

Adaptive Capacity, as by the 5th IPCC report[44] defined as 'the ability to adjust, take advantage of opportunities, or cope with consequences' has the potential to differ greatly between individual households, communities, and livelihood zones at different locations. Since no reliable data was available to distinguish or categorise population groups by a significant difference, a uniform adaptive capacity had to be assumed for all three observed hazards.

Finally, **sensitivity** describes to which degree a system is affected, in this case by floods and heat waves. This parameter will be defined by the modelling exercise in CLIMADA.

Since no specific data on people's location, such as e.g. cadastre data, were available, data on population density per ward provided by the respective districts (Ninh Kieu, Binh Thuy, and Cai Rang) Statistics Books of 2019[45] and an average of 3.60 persons/household [46] were used to randomly determine household sizes following a zero-truncated Poisson distribution ranging from 1 to 11 and a mean of 3.6.[47]

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[41] IPCC. (2014). *Impact, adaptation and vulnerability. Part A: Global and sectoral Aspects Working Group (WG) II Report.* P. 118.

[42] I.e. the extent of a flood event that should statistically happen only once every 100 years on average as estimated from the expected scenario in 2050

[43] I.e. a metropolitan area that is much warmer than rural souring, due to e.g. reduced air flow through buildings, excess heat from cars, air-conditioning units, industry etc.

[44] Ibid.

[45] General Statistics Office of Viet Nam (2020). Statistical Yearbook of Viet Nam 2019.

[46] See e.g.: https://vietnam.unfpa.org/en/news/results-population-and-housing-census-2019 (retrieved on 26th March 2021).

[47] The Poisson distribution, other than e.g. a Normal distribution, is typically left skewed with low means as is the case here with a mean of 3.6. This means the distribution seems to be pushed toward zero with a longer tail to the right, i.e. high values, and is hence not symmetric. This characteristic is well suited to

Figure 7 to Figure 9 display the exposed population (sub-) groups according to the respective hazard. Since heat wave affects all people, Figure 7 highlights simultaneously all people, or rather households, in colour according to household size in the research area. The following two figures only highlight those affected while showing unaffected households in a darker grey.

Table 3 summarises exposed people by observed hazard and district. As described above, it is assumed that heat wave affect the total population and hence the heat wave column also represents the total population in the given district.

Table 3: *Exposed people by hazard and district. Source: Authors' own compilation.*

Exposed People (% of total population)			
District	Pluvial/ Fluvial Flood	Tidal Flood	Heat Wave
Binh Thuy	52 806 (32.3%)	30 558 (18.7%)	163 357 (100%)
Cai Rang	44 143 (39.2%)	41 426 (36.8%)	112 557 (100%)
Ninh Kieu	70 626 (25.6%)	8 236 (3.0%)	275 998 100%)
Total	167 575	80 220	551 912

describe household sizes if 0 values are being omitted, i.e. if no households with no household members are allowed in the distribution.

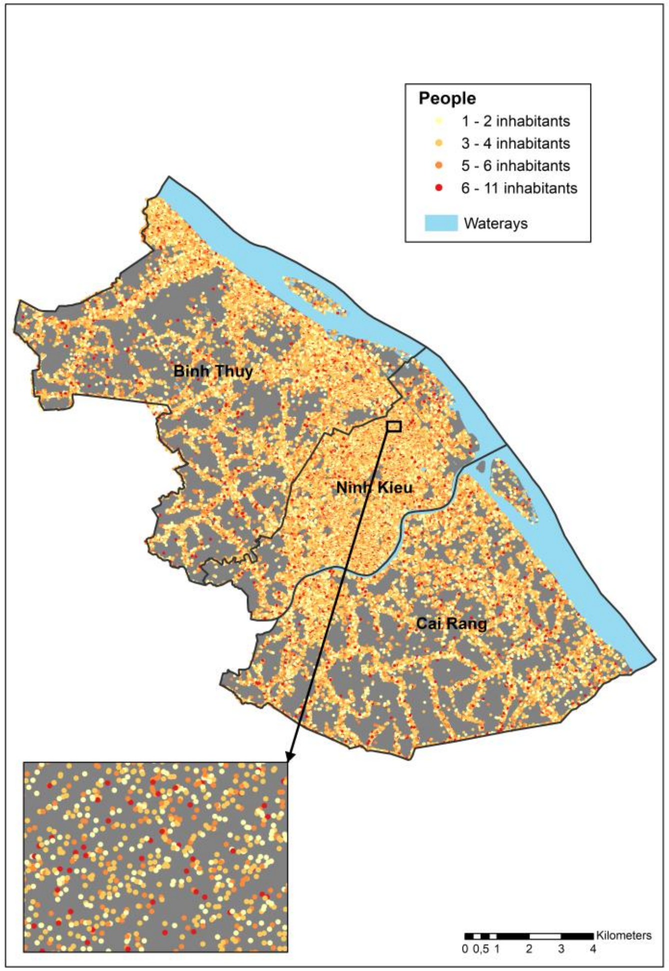

Figure 7: *People affected by heat wave.*

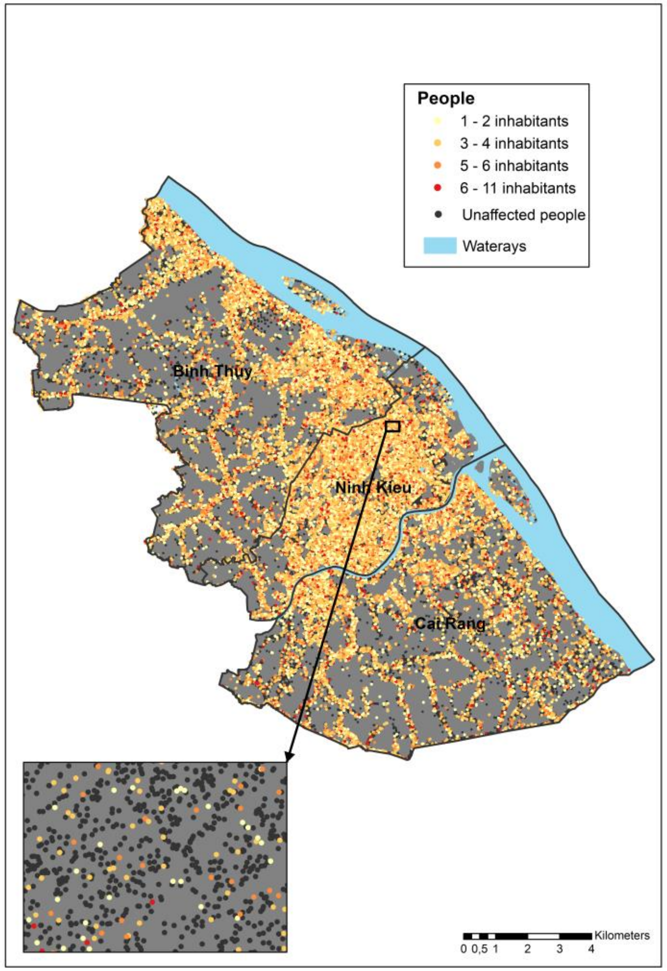

Figure 8: *People affected by pluvial/ fluvial floods.*

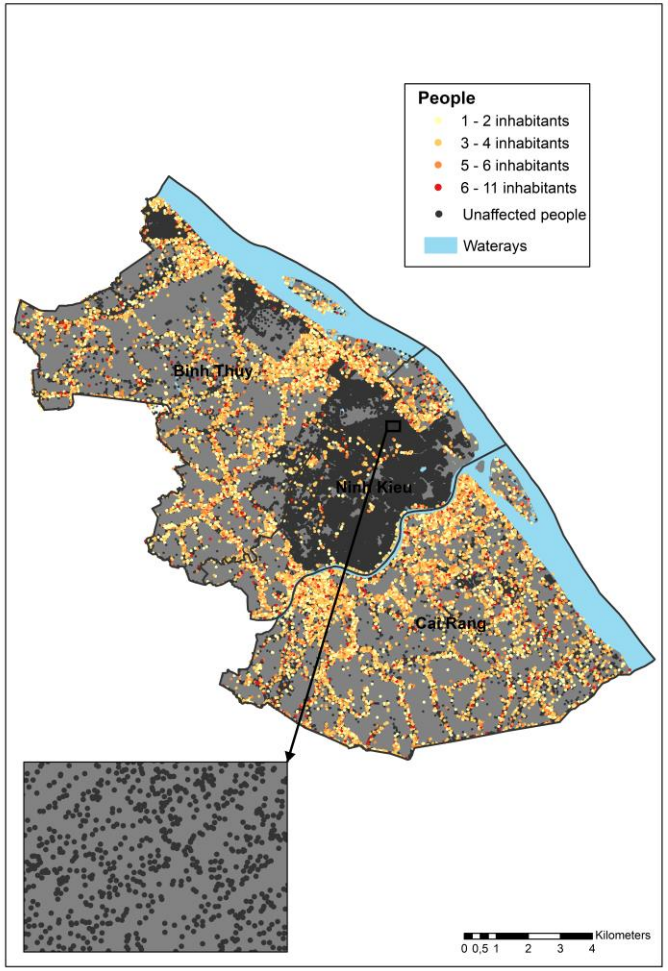

Figure 9: *People affected by tidal floods.*

3.2.2 Housing

Just as people, people's housing was selected as a key asset for the two flood type hazards while it is not considered in the analysis of the heat wave hazard.

As mentioned above, no comprehensive cadastre or comparable data indicating geo-location of individual houses were available. Hence, using data on build-up area in Can Tho as of 2012 as well as recent satellite images build-up areas, and where possible individual buildings as indicated, where identified.[48] Subsequently, within the build-up area, fictitious housing assets were randomly generated based on the respective ward's population density and the above outlined 3.6 persons per household on average. This practice is necessary as each considered asset needs to be associated with a specific location for the further analysis in CLIMADA. Unavoidably, this ignores the reasonable assumption of several household occupying one building. However, the resulting slight overestimation of physical damage on housing can easily be accounted for in the calibration process of the damage functions as described in the following chapter.

In a next step, assumptions were made about the housing quality and thus the property value base of each individual house. As again very limited information about the distribution of the four different types as commonly used in Vietnam was available, it was assumed that closest to the roads property would be more valuable, and hence of higher quality, while with increasing distance to the roads the quality of housing decreases. To further specify, the type of road was further taken into account while being closer to main roads leads to a higher value assumption than being close to smaller road or alleys. Additionally, it was assumed that the highest housing category is only present in 'urban' parts of the observed districts. The four categories are based on three structural elements: walls, roof and floor. Depending on the quality of the structural elements the following four categories result[49]:

- Permanent (all structural elements are classified as ‚sturdy')
- Semi-permanent (at least two of the three structural elements are classified as ‚sturdy')
- Less-permanent/ temporary (only one of the structural elements is classified as ‚sturdy')
- Simple (all three structural elements are classified as ‚flimsy')

Applying the above approximated household size to data provided by the General Statistical Office on the average dwelling area per capita by type of housing allows calculations on the average floor size of the individual houses. In a final step of the estimation process construction cost per m^2, as an approximation of re-construction cost, of the respective housing classification were applied accordingly to estimate the value of the houses.[50] Table 4 summarizes the distribution of the different housing types as well as their value[51]. Figure 10 and Figure 11 display the distribution of the housing categories while again grey dots depict unaffected houses.

[48] Provided by the German Aerospace Center, German Remote Sensing Data Centre, accessible at https://catchmekong.eoc.dlr.de/Elvis/

[49] Central Population and Housing Census Steering Committee. (2019). The Viet Nam Population and Housing Census Of 00:00 Hours on 1 April 2019. Implementation Organisation and Preliminary Results. Ha Noi.

[50] Data on average area per capita by housing type were obtained from the General Statistics Office of Viet Nam (2020). Statistical Yearbook of Viet Nam 2019. Data on construction prices were compiled by a team of local experts on the matter of climate change adaptation over the course of a scoping exercise for this study.

[51] As cost and price estimates were provided in VND an exchange rate of 23286.4 VND = 1 USD was applied

__Table 4:__ Exposed housing by type, incl. USD value. Source: Authors' own compilation.

Housing type	m^2 per Household member	USD per m^2	Exposed houses; pluvial/ fluvial (%)	USD total; pluvial/ fluvial exposed (%)	Exposed houses; tidal (%)	USD total; tidal exposed (%)
Permanent	30.7	356	5 265 (11.3%)	102 051 405 (17.3%)	1 927 (8.6%)	37 443 439 (13.6%)
Semi-Permanent	23.4	294	32 556 (69.8%)	402 731 784 (68.4%)	15 858 (71.1%)	196 522 654 (71.4%)
Less-Permanent	16.8	191	6 594 (14.1%)	76 417 572 (13.0%)	3 188 (14.3%)	36 602 782 (13.3%)
Simple	13.6	73	2 204 (4.7%)	7 947 364 (1.3%)	1 319 (5.9%)	4 794 231 (1.7%)
Total			46 619	589 148 125	22 292	275 363 106

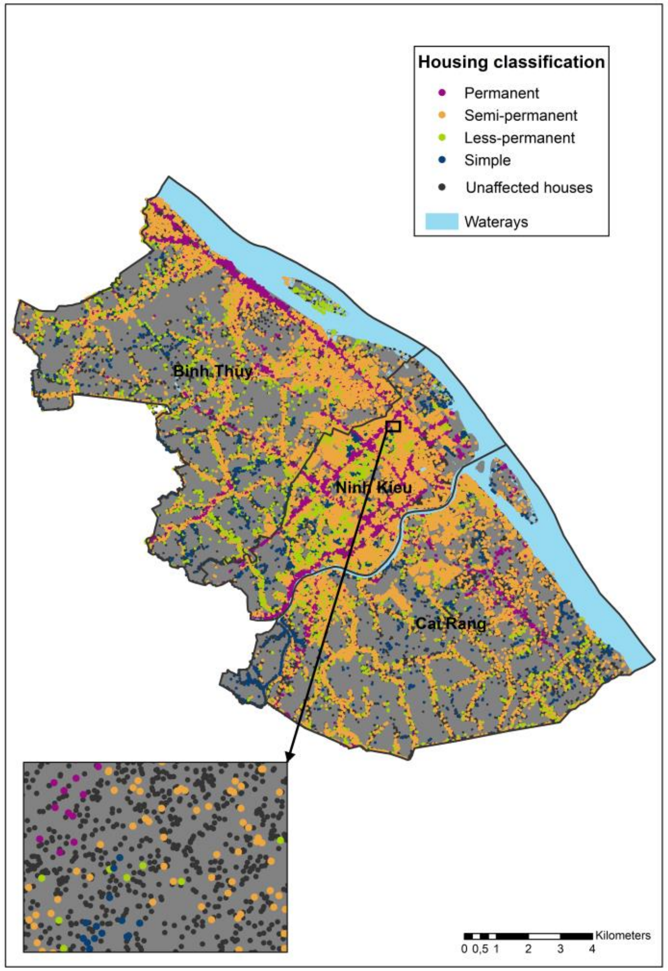

Figure 10: *Houses affected by pluvial/ fluvial floods.*

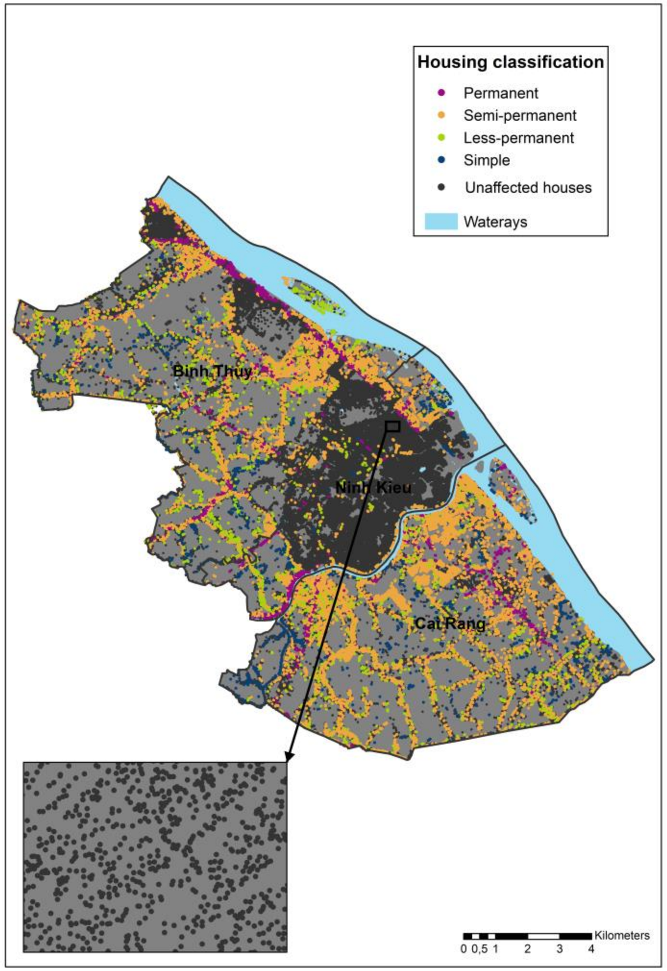

Figure 11: *Houses affected by tidal floods.*

3.2.3 Public Buildings

The asset category *Public Buildings* comprises the three types of educational Facilities, such as schools, different health facilities, as well as administrative buildings, as for instance Wards' People Committee offices, police departments, and other public buildings.

For all three types geo-locations, approximate reconstruction values, as well as types as outlined in the Table 5 below were gathered during a scoping exercise over the course of the study. For both, educational as well as medical facilities construction values, as approximation for re-construction values, were available per student and per sick bed capacity, respectively. As there were no indication on the capacities, i.e. students or available beds, of the individual facilities the average of the respective scale had to be applied as the best-guess approximation. For administrative buildings construction values were available per square meter. For those buildings mapped out individually in the previously mentioned data on build-up areas the square footage was available, however, some buildings are located in areas where no clear data on building shapes and sizes where available. As the number of those where quite limited, approximations were made using satellite imagery. Figure 12 and Figure 13 show the respective location as well as the buildings' exposure to the two different flood hazards.

Table 5: *Value estimates of exposed public buildings.*

Type	USD per unit	Exposed facilities; pluvial/ fluvial flood	Total USD value exposed to pluvial/ fluvial flood (% of facility class)	Exposed facilities; tidal flood	Total USD value exposed to tidal flood (%of facility class)
Educational Facilities		58	205 554 262	25	55 499 831
1. Nursery	408 235	4	1 632 938 (0.8%)	2	816 469 (1.5%)
2. Primary	649 199	15	9 737 981 (4.7%)	9	5 842 788 (10.5%)
3. Secondary	1 613 533	24	38 724 792 (18.8%)	11	17 748 863 (32.0%)
4. Tertiary	10 363 903	15	155 458 551 (75.6%)	3	31 091 710 (56.0%)
Health Facilities		22	394 914 081	6	29 973 638
1. Small (approx. 50 - 200 sick beds)	3 123 159	14	43 724 223 (11.1%)	5	15 615 794 (52.1%)
2. Medium (approx. 250 - 1 000 sick beds)	14 357 844	5	71 789 220 (18.2%)	1	14 357 844 (47.9%)
3. Central Hospitals (> 1 000 sick beds)	93 133 546	3	279 400 637 (70.7%)	0	0
Administrative Buildings	280 USD/m^2	47 (78 402 m^2)	21 952 664	12 (22 106 m^2)	6 189 630

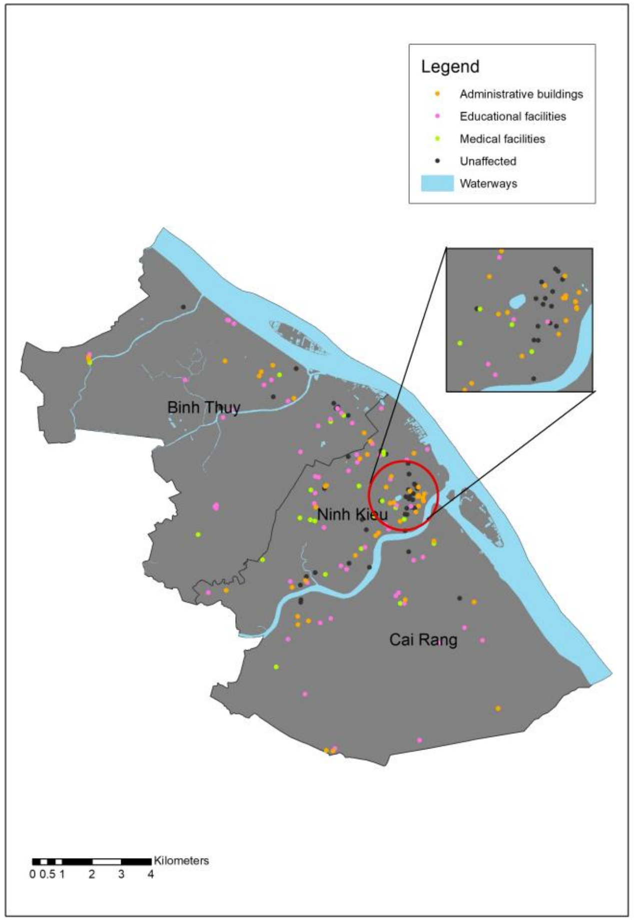

Figure 12: *Public buildings affected by pluvial/fluvial floods.*

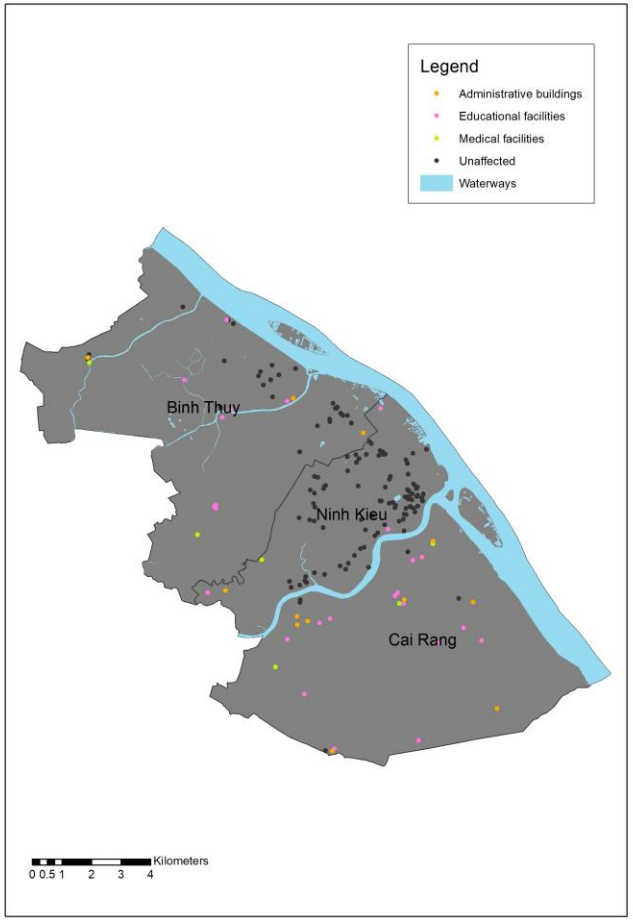

Figure 13: *Public buildings affected by tidal floods.*

3.2.4 Road Network

The road network of Can Tho is being considered for all three analysed hazard types. Reasonably detailed data on the road network is provided by Humanitarian OpenStreetMap Team for all of Vietnam, which were cut to only encompass the roads of the research area.[52] In order to estimate the value of the roads they were categorized into four broad categories[53]:

1. Major roads (road bed approximately 31m wide, road surface approximately 22m)
2. Secondary roads (road bed approximately 12m wide, road surface approximately 7m)
3. Tertiary roads (road bed approximately 9m wide, road surface approximately 7m)
4. Alleys (road bed approximately 6.5m wide, road surface approximately 3.5m)

The approximate (re-)construction values are drawn from the *Investment rate of construction and general construction price of construction parts in 2018* by the Ministry of Construction.[54] Table 6 summarizes the length and reconstruction values of the road types. Figure 14 to Figure 16 show the roads exposed to the respective hazard by their respective type, grey depicts unaffected roads.

Table 6: *Exposed road network length and value estimates per hazard.*

Road Type	USD / km	Heat wave km (%)	Heat wave USD (%)	Pluvial/ fluvial flood km (%)	Pluvial/ fluvial flood USD (%)	Tidal flood km (%)	Tidal flood USD (%)
Major roads	2 328 226	136.7 (12.5%)	318 205 308 (33.9%)	136.6 (12.6%)	317 959 933 (34.2%)	83.4 (11.4%)	194 197 525 (32.1%)
Secondary roads	889 618	35.3 (3.2%)	31 365 544 (3.3%)	34.0 (3.1%)	30 268 521 (3.3%)	20.0 (2.7%)	17 757 779 (2.9%)
Tertiary roads	663 177	863.1 (78.7%)	572 389 161 (61.0%)	854.0 (78.6%)	866 383 936 (60.9%)	569.7 (77.9%)	377 824 517 (62.5%)
Alleys	251 950	62.3 (5.7%)	15 704 970 (1.7%)	61.5 (5.7%)	15 501 248 (1.7%)	57.9 (7.9%)	14 583 651 (2.4%)
Total		**1 097.4**	**937 664 983**	**1 086.2**	**930 113 638**	**731.0**	**604 363 201**

[52] Accessible at https://data.humdata.org/dataset/hotosm_vnm_roads
[53] These are based on a broader set of categories and specifications of the *Investment rate of construction and general construction price of construction parts in 2018* by the Ministry of Construction, available at https://moc.gov.vn/Images/FileOld/29703/104404/BXD_44-Q%C4%90-BXD_14012020_congbosuatvon.pdf
[54] Ibid.

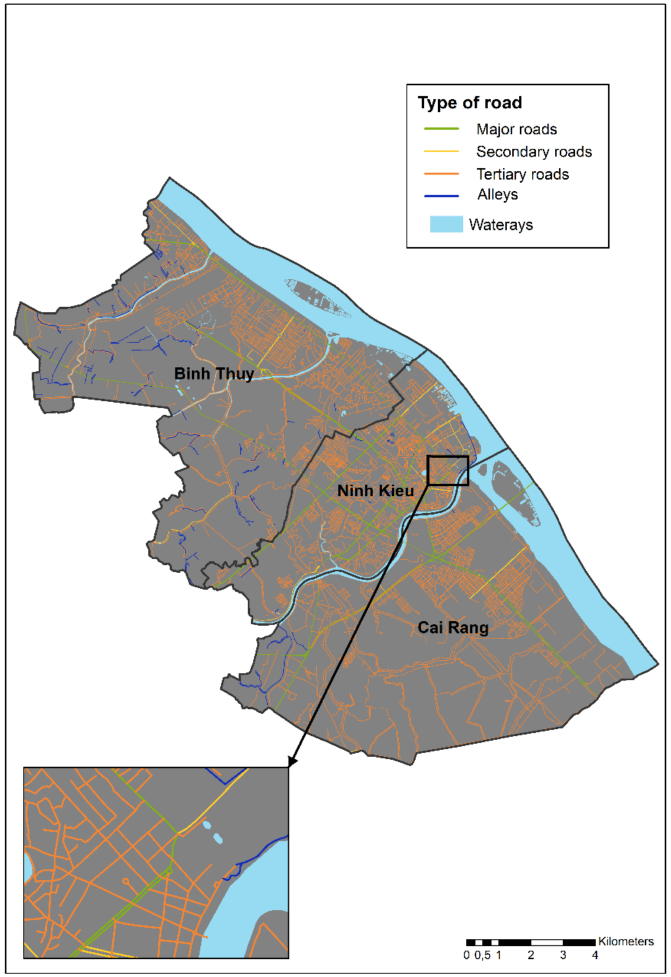

Figure 14: *Roads affected by heat waves.*

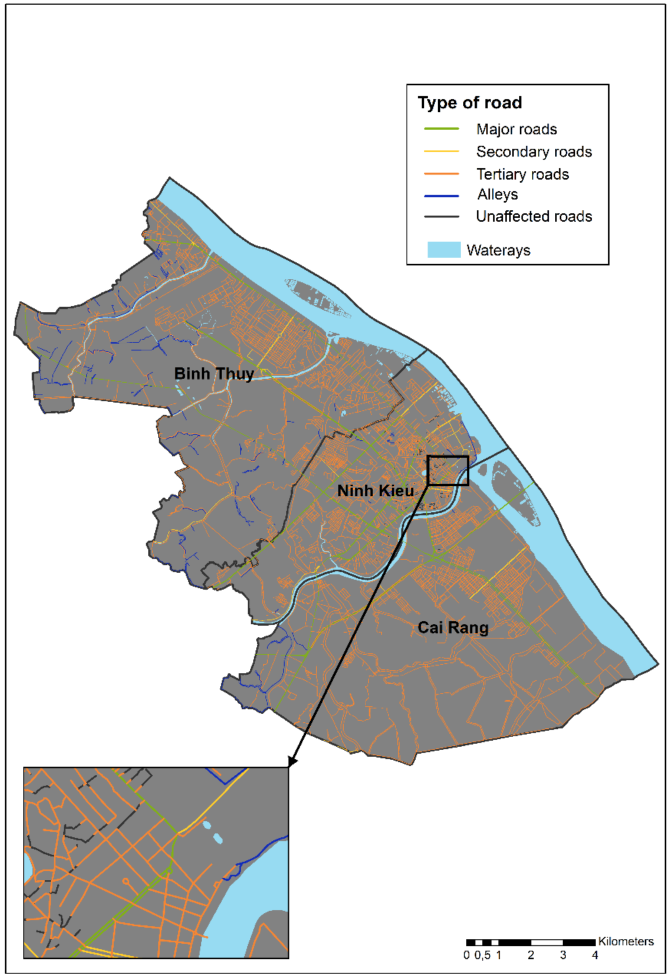

Figure 15: *Roads affected by pluvial/ fluvial floods.*

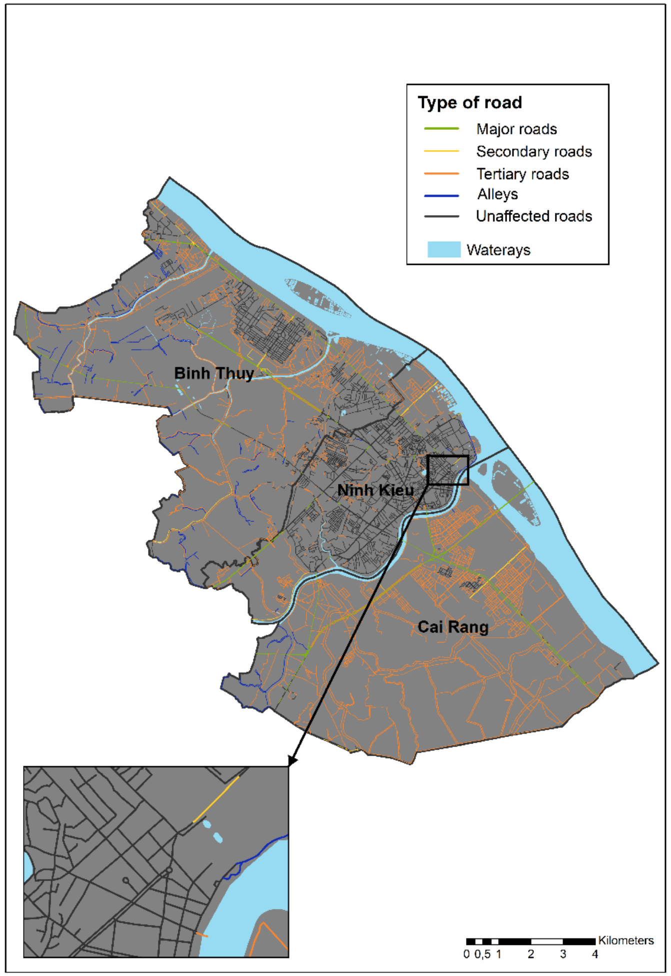

Figure 16: *Roads affected by tidal floods.*

3.2.5 Electric Grid

For the electrical grid in the research area no data of sufficient quality could be obtained. It is therefore assumed that powerlines follow the road network in order to connect households with the electrical grid. In the same line, very limited relevant information could be found on the value of urban low voltage electricity grids. A wide literature review focusing on similar contexts in the wider geographical area had to be conducted due to a lack of local estimates. Estimates range from 3 000 USD/km up to 10 000 USD/km over the past two decades.[55] Following the lack of a single indicative value an estimate of 6 000 USD/km was chosen. Table 7 summarizes the length and value estimation of the observed electric grid while Figure 17 and Figure 18 highlight the potentially affected electric grid by the two different observed flood types.

Table 7: *Electric grid length and cost estimate.*

	USD/km	Length in km, pluvial/ fluvial flood	Total USD, pluvial/ fluvial flood	Length in km, tidal flood	Total USD, tidal flood
Electric grid	6 000	1 086.5	6 518 852	729.1	4 374 857

[55] See e.g. Innovation Energie Développement (IED). Support Study for DFID. Low Carbon Mini Grids. "Identifying the gaps and building the evidence base on low carbon mini-grids";. Final Report. Innovation Energie Développement, Francheville, France (2013) 20 pp.

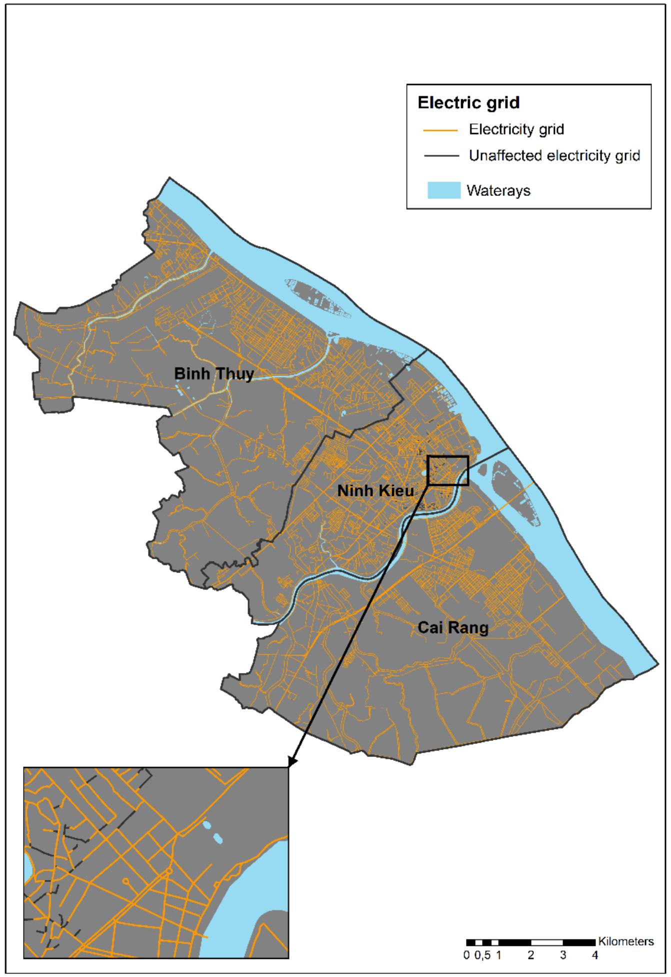

Figure 17: *Electricity grid affected by pluvial/ fluvial floods.*

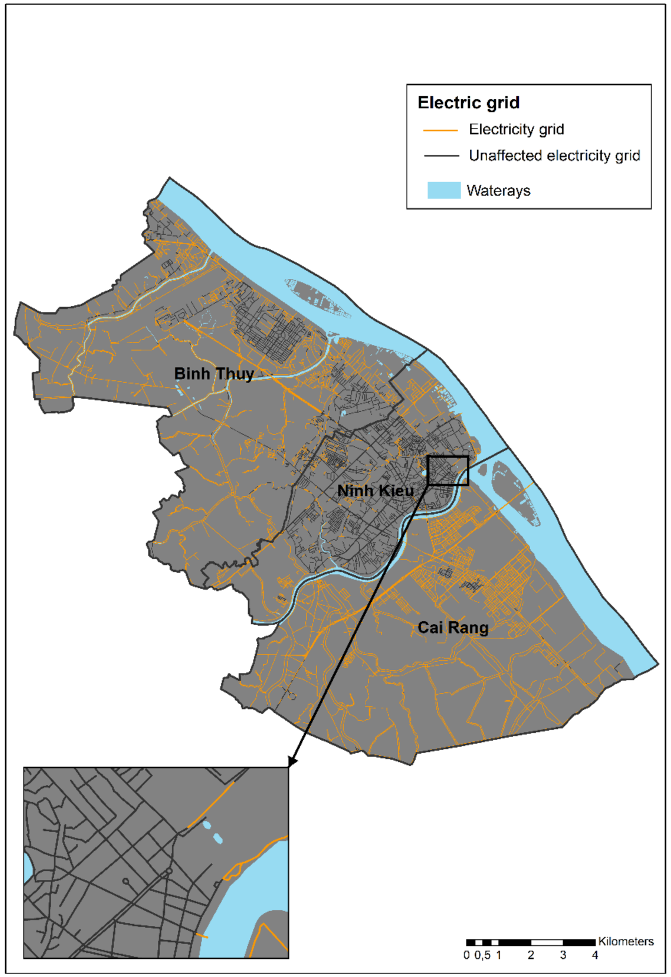

Figure 18: *Electricity grid affected by tidal floods.*

3.2.6 Natural Resources

3.2.6.1 Aquaculture

In the research area predominantly quite resistant pangasius catfish species are being farmed on about 81 ha.[56] Over the last decades pond farming has become dominant because of faster growth rates and higher quality and thus increased marketability, especially overseas.[57] As pangasius catfish are quite tolerant regarding oxygen saturation as well as overall water quality they are quite suitable for intensive pond farming. Annual yields can exceed 700t per hectare per year. Following a study comparing Vietnamese and Bangladeshi farming practices, production cost per kilogram of 0.75 USD can be assumed.[58] Further, two crop seasons per year of 350t/ha can be inferred.[59] As it can be considered that a single flood or heat wave will only affect one of the crop seasons, the value at risk is here represented as only one of the two crop seasons. Following that, the estimated production value per ha and crop season is about 262 500 USD.

3.2.6.2 Cash Crops

With regard to cash crop especially maize is of key importance on the 626 ha allocated to cash crops in the research area. Following a report analyzing the agriculture in the entire Mekong Delta an annual yield of roughly 7 t/ha can be assumed.[60] In order to account for other cash crops of higher production value 10% of the 270 USD/ha value estimate provided by the Food and Agriculture Organization of the United Nations[61] were added resulting in roughly 300 USD/ha. Combined with the just above 7 t/ha this results in an estimate of 2 100 USD/ha.

3.2.6.3 Orchards

In the research area about 85% of the harvest in orchards are oranges while mangoes, pomelos, coconuts, and longans have a rather small share of the total harvest. For simplicity, we therefore assume an average yield of 17 t/ha[62] at 780 USD/t[63] resulting in an estimate of 13 260 USD/ha.

3.2.6.4 Triple Rice Crop

Finally, triple rice crop[64] as one of the staple crops is being considered in this study. About 963 ha of the overall research area are occupied by triple crop rice paddies. Following the above mentioned report on

[56] General Statistical Office of Viet Nam (2020). *Socio-Economic Statistical Data of 63 Provinces and Cities*. Ha Noi. Viet Nam.
[57] Lam T. Phan, Tam M. Bui, Thuy T.T. Nguyen, Geoff J. Gooley, Brett A. Ingram, Hao V. Nguyen, Phuong T. Nguyen, Sena S. De Silva (2009). *Current status of farming practices of striped catfish, Pangasianodon hypophthalmus in the Mekong Delta, Vietnam*. Aquaculture. Volume 296. Issues 3-4.
[58] Ben Belton, Mohammad Mahfujul Haque, David C. Little, Le Xuan Sinh. (2011). *Certifying catfish in Vietnam and Bangladesh: Who will make the grade and will it matter?* Food Policy. Volume 36. Issue 2.
[59] This is also supported by Ben Belton, David C. Little, Le Xuan Sinh. (2011) *The social relations of catfish production in Vietnam*. Geoforum. Volume 42. Issue 5.
[60] Smith, W. (2013). *Agriculture in the central Mekong Delta: Opportunities for donor business engagement*. Report. ODI.
[61] Accessible at http://www.fao.org/faostat/en/#data/PP
[62] Food and Agriculture Organization of the United Nations. (2004). *Fruits of Vietnam*. Regional Office for Asia and the Pacific. Bangkok, Thailand
[63] Obtained on 16.02.2021 from http://www.fao.org/faostat/en/#data/PP
[64] Triple rice crop means that there are three cropping seasons for the chosen rice variety/ies per year.

the agricultural sector in the Mekong Delta a yield of roughly 6.2 t/ha can be expected.[65] Multiplying that by 285 USD/t as is suggested by the FAO for rice results in a value estimate of about 1 773 USD/ha.

3.2.6.5 Green Spaces

Green spaces, such as parks, are here considered as true natural assets providing a multitude of ecosystems services rather than simply considering e.g. the material value of trees or other resources. For that a rather broad approach is being applied reflecting a variety of ecosystem services provided by different biomes[66]. The Ecosystem Services Valuation Database (ESVD) considers a wide range of ecosystem services (23) based on one of the most widely used ecosystem service classification systems as a follow up to the "The Economics of Ecosystems and Biodiversity" (TEEB) database.[67] Taking this 'true value' of nature, biodiversity and corresponding ecosystems into account inevitably results in larger value estimates compared to simpler value estimates. In this case the value estimate of 'urban green-blue' areas reflects best the here relevant green areas of 40.2 ha and 22.5 ha respectively at 11 759 USD/ha.

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[65] Smith, W. (2013). *Agriculture in the central Mekong Delta: Opportunities for donor business engagement*. Report. ODI.

[66] Biomes are (larger) units/ areas of characteristic by their climate, soil, vegetation and wildlife in response to a shared local or regional climate. See e.g. https://www.nationalgeographic.org/encyclopedia/biome/

[67] The 23 ecosystem services considered are: food, water, raw materials, genetic resources, medicinal resources, ornamental resources, air quality regulation, climate regulation, moderation of extreme events, regulation of water flows, waste treatment, erosion prevention, maintenance of soil fertility, pollination, biological control, maintenance of life cycles of migratory species, maintenance of genetic diversity, aesthetic information, opportunities for recreation and tourism, inspiration for culture, art and design, spiritual experience, information for cognitive development, existence and bequest values. Each represented ecosystem service is being valued with regard to different biomes based on over 600 independent studies evaluating those. Selected studies are examined for relevant ecosystem services valuated and the respectively applied valuation methodology. Values are subsequently standardized considering price levels, currencies, and spatial and temporal dimensions. Further, the project team undertakes a beneficiary standardization in order to be able to compare value observations to the same specific beneficiary. The chosen common specification is the total population of beneficiaries, i.e. the 'market size' or 'economic constituency' for the respective ecosystem. The database hence aims to summarise and condense the existing knowledge and data to a handier overview.
As the database comprises data and values from many different countries and contexts values are standardized and reported in international USD (Int USD) and are not converted into local currency as this analysis too is done in USD. For further information see: R. De Groot, Brander, L., Solomonides, S. (2020). *Ecosystem Services Valuation Database (ESVD). Update of global ecosystem service valuation data*. FSD report No 2020-06 Wageningen, The Netherlands (58 pp).

Table 8: Summary table for value estimates of Natural Resources.

	USD/ha	Area in ha, heat wave (%)	Total USD, heat wave	Area in ha, pluvial/ fluvial flood (%)	Total USD, pluvial/ fluvial flood	Area in ha, tidal flood (%)	Total USD, tidal flood
Aquaculture	262 500	81 (1.0%)	21 350 554 (18.8%)	81 (1.0%)	21 350 554 (18.6%)	81 (1.0%)	21 650 554 (19.1%)
Cash crop	2 102	626 (7.4%)	1 431 346 (1.3%)	626 (7.4%)	1 315 089 (1.1%)	625 (7.6%)	1 312 642 (1.2%)
Orchards	13 260	6 842 (80.4%)	89 200 020 (78.5%)	6 841 (80.4%)	90 715 892 (78.8%)	6 577 (79.8%)	87 207 351 (78.2%)
Triple rice	1 773	963 (11.3%)	1 632 933 (1.4%)	963 (11.3%)	1 706 932 (1.5%)	963 (11.7%)	1 706 932 (1.5%)
Sub-sum Aqua- & Agriculture		8512	113 614 853	8511	115 088 556	8245	111 577 478
Green Spaces	11 759			40.2	472 982	22.5	264 362
Sum Natural Resources		**8512**	**113 614 853**	**8551**	**115 561 538**	**8268**	**111 841 840**

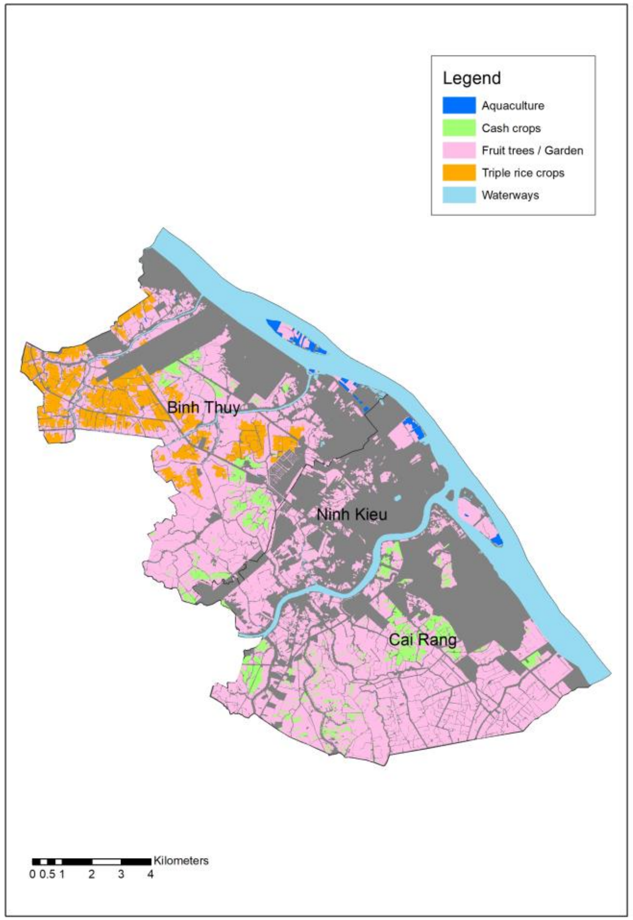

__Figure 19:__ Affected aqua- and agricultural areas, heat waves.

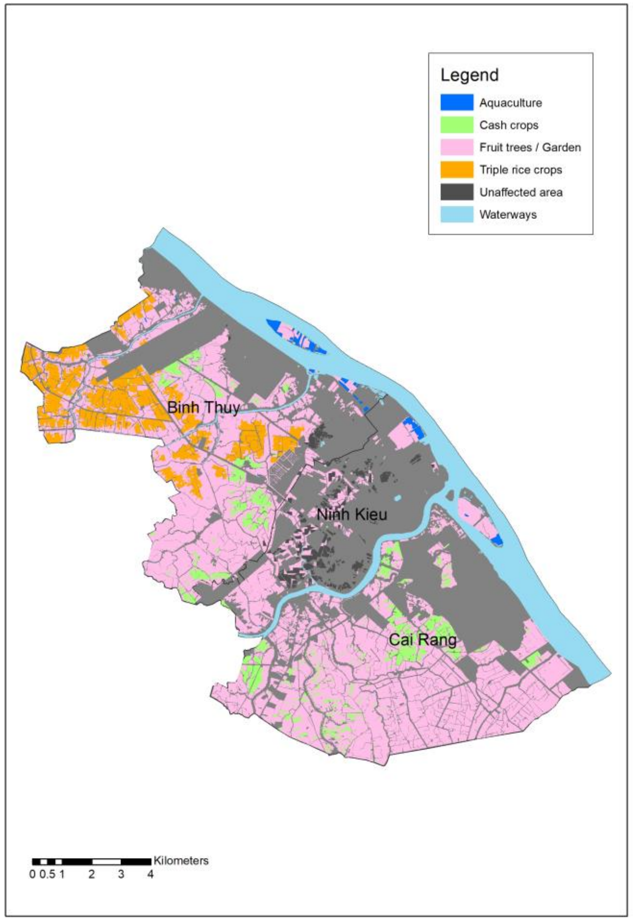

__Figure 20:__ Affected aqua- and agricultural areas, tidal floods.

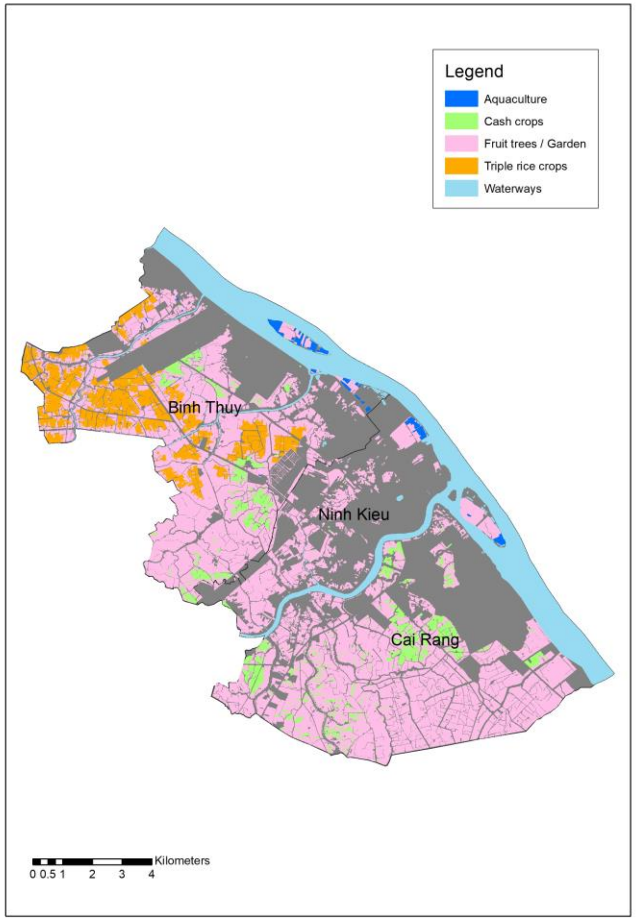

__Figure 21:__ Affected aqua- and agricultural areas, pluvial/ fluvial floods.

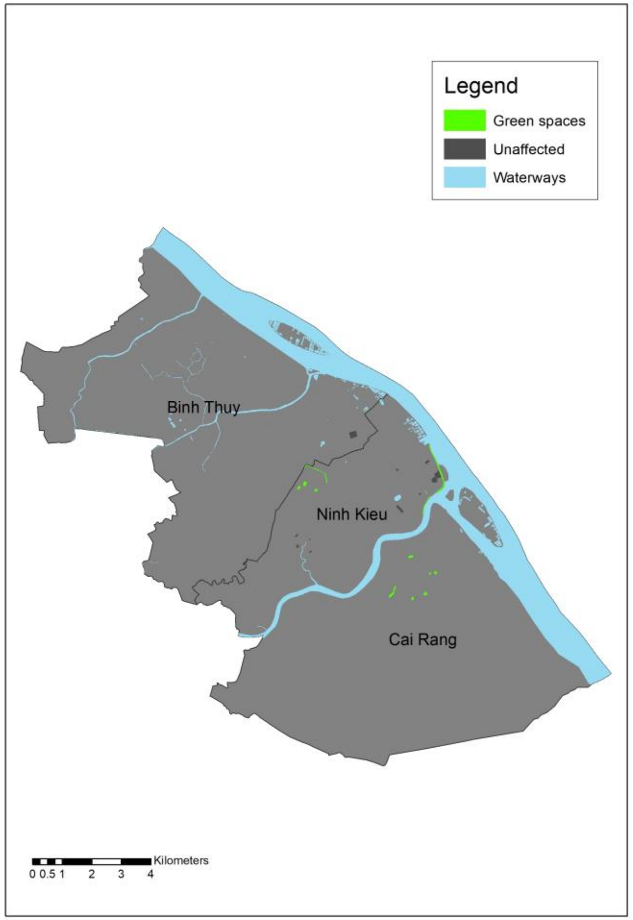

__Figure 22:__ Affected green spaces, tidal floods.

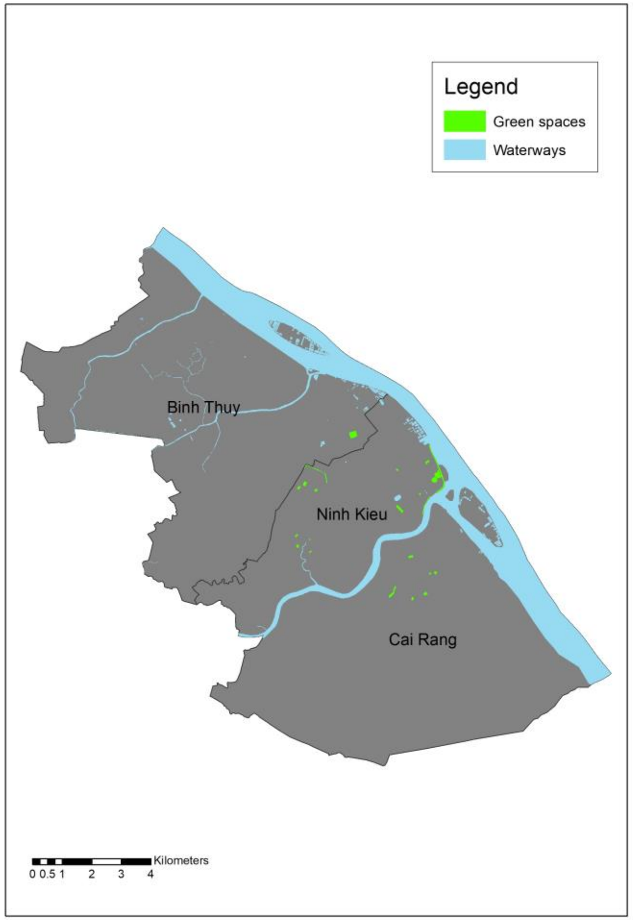

Figure 23: *Affected green spaces, pluvial/ fluvial floods.*

3.3 Results

As this study considers three distinct hazards, this section briefly summarizes the value estimation results of each asset category per hazard type in Table 9. Since the underlying assumption is that heat wave affects the whole research area, the respective columns (columns 2 and 3) are used to indicate both, the values relevant for the heat wave analysis (black) and the total sum over the whole research area independent from any hazard (grey).

Table 9: *Summary asset number/ size and value estimation by hazard.*

	Heat wave		Pluvial/ fluvial floods		Tidal floods	
	No / area / length	Total in m USD	No / area / length	Total in m USD	No / area / length	Total in m USD
People	551 912		167 557		80 220	
Houses	*153 424*	*1 970.98 405*	46 619	589.15	22 292	275.36
Educational Facilities	*77*	*279.31*	58	205.55	25	55.50
Medical Facilities	*40*	*653.62*	22	394.91	6	29.97
Administrative Buildings	*51 (80 439 m^2)*	*22.52*	47 (78 402 m^2)	21.95	12 (22 106 m^2)	6.19
Road network	1 097.4 km	937.66	1 086.2 km	930.11	731.0 km	604.36
Electricity grid	*1097.4 km*	*6.58*	1 086.5 km	6.52	729.1 km	4.37
Natural Resources	8 512 ha *(8 552 ha)*	113.61 *(114.09)*	8 551 ha	115.56	8 268 ha	111.84
Total		1 051.75 *(3 984.76)*		2 263.76		1 087.61

3.4 Limitations

While the worth of a human life can be estimated in financial terms by a multitude of approaches, it was decided for ECA studies not to consider a financial value but rather to consider every person's life as being worth exactly the same: one human life.

The value estimation of any other tangible asset observed in the quite specific context of any given ECA study is often challenging. Although many different valuation approaches for most potential assets are described in the literature, all of those approached depend on high-quality data. Therefore, data availability and data quality presents a serious bottleneck in the asset value estimation. In the case of tradable assets, prices often change and are determined by numerous factors. Contrary to the fluctuating nature of prices and values, an ECA study aims at estimating expected costs and damages. Consequently, seasonal fluctuations of assets cannot be and do not necessarily need to be reflected in the valuation process. Therefore, reasonable estimates have to be applied, such as e.g. annual average values or the typical price at time of purchase as an estimate for replacement cost, construction cost, or the maximum expected value expected within a given year.

In this study different approaches were chosen depending on the respective data situation in order to reach the best possible price estimate. For example, construction cost per m^2 of public buildings were used to estimate the reconstruction/ repair cost of the respective building as a value proxy. For agriculture on the other hand, the estimated value of the harvest at risk of a given disaster was chosen as the value proxy. Natural resources that are not necessarily valued for their tangible and tradable goods, such as raw material, but rather for their non-tangible contribution to the ecosystem and their surroundings, for instance the value of shade, biodiversity, and effects on the local climate present a special challenge. The green spaces, i.e. parks, considered in this study fall into this category and do not contribute specific material value but rather its ecosystem and environmental services are of value to the city. In this field too, approaches were developed to estimate natural resources, or environmental assets, with different foci. In this case, an approach was chosen for the green spaces that specifically aims at valuing ecosystem services in order to reflect their contribution beyond material value. Consequently, this leads to higher values as compared to rather simple resell values of corresponding materials.

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4. Damage Functions

4.1 Introduction

Potential future damage, independent from the observed hazard, depends on multiple parameters including: 1) Climatic and socio-economic conditions, which were described in detail within the Data Report, their incorporation into CLIMADA, and their effects on the estimation of damages are explained in Chapter 6. 2) The asset valuation, which is presented in Chapter 3. And 3) Sensitivity to the respective hazard, which is commonly assessed using damage curves, also known as damage functions or vulnerability curves, denoting to what degree a certain asset type can be expected to be affected at different the hazard intensity levels, in this case inundation levels for the two observed flood types or the intensity of heat waves. Resulting damage functions should however always be considered only in the given context, i.e. considering the specific flood type and the underlying asset category and the considered subgroup of that category.

To construct damage functions different approaches can be followed. One approach relies on historical data on both hazard intensity and recorded damages, reconstruction cost or depreciated values of the assets. With sufficient data available this approach is very precise within a reference context. Alternatively, it is possible to estimate probable damages based on expert opinions or similar reports regarding materials used and their respective durability, animals', plants', or peoples' water requirements and other characteristics of the respective assets.[68] This method is particularly helpful when no or insufficient historical records are available. Lastly, one can rely on generic or empirical damage functions and subsequently calibrate them using (household) surveys. The calibration using (household) surveys can be done by comparing the generic or empirical damage functions with the specific local data obtained through the survey and adjusting for observed differences, e.g. in human mortality / hospitalization or crop loss data. In any case, an iterative calibration process of the resulting damage functions is necessary to ensure that the damages simulated by CLIMADA reflect historical damages in the region (e.g. obtained from international databases such as EM-DAT[69] or DesInventar[70], national and local statistical offices/agencies, or individual surveys and case studies).

The following section presents the carefully calibrated final damage functions as applied in CLIMADA per asset group. Due to the differing nature of the hazards observed, the respective potentially affected assets and the corresponding reference data for calibration, the resulting damage functions may look differently, which may seem counter intuitive, especially with regard to the two different flood hazards. However, considering the significant difference in the exposed assets in the two flood cases due to excluding large parts of Ninh Kieu it is reasonable to reach differing damage functions.

[68] In this case e.g. SCE. 2013. Comprehensive Resilience Planning for Integrated Flood Risk Management. Technical report. proofed to be quite helpful for most asset groups providing largely qualitative and indicative insights.
[69] EM-DAT. (2020). *EM-DAT Data Base*. https://www.emdat.be/
[70] United Nations Office for Disaster Risk Reduction (UNDRR). (2020). *DesInventar Sendai*. https://www.desinventar.net/DesInventar/profiletab.jsp

4.2 People

In the case of flooding, a distinction has to be made between the two flood hazards considered in this case study. Based on the differing exposed population sub groups different damage functions resulted from the calibration exercise. Figure 24 presents an S-shaped damage function for people[71] and the pluvial / fluvial flood hazard reaching the maximum Mean Damage Degree (MDD) at an inundation level of about 3.6m. Figure 25 presents a rather steep damage function for people for the hazard of tidal floods reaching the maximum MDD already at an inundation level of 80cm. This difference may seem counterintuitive, however, it is to be interpreted in such a way that on *average* a certain share of the considered people is *affected* by flooding, which does not necessarily has to lead to hospitalization or death. Lastly, the here presented damage functions are the result of the calibration exercise using data on affected people by different flood types provided by EM-DAT[72].

With regard to the additionally considered heat wave hazard little concrete literature on constructing related damage functions for people was available. However, the effects of heat on people and their health have been well researched. Apart from death excessive heat stress can affect people in the form of e.g. heat cramps, heat exhaustion, heat rash, heat oedema, or a life-threatening heat stroke.[73] As death can be defined as the ultimate 'damage' a person can experience the damage function is assumed to continuously rise up to the theoretical maximum mean damage degree of 100%. However, since the increase of experienced impairment and morbidity starts slowly with increasing heat stress as people, especially in sub-tropical settings such as Can Tho, are able to withstand and adapt to shorter periods of only slightly higher temperatures. With increasing heat stress however, the mean damage degree rises with increasing 'speed' as more people of less vulnerable population groups, e.g. younger people, are affected to a higher degree. With further increasing heat stress this observation is expected to be accelerated resulting in the function as highlighted in Figure 26 after the calibration process. Please not, the abscissa (x-axis) denotes days which are counted as being part of a heat wave as described in Chapter 2, however, those do not need to be consecutive days but much rather represent the total number of heat wave-days in a given year.

[71] A good starting point for further information on flood damage functions for people and their properties is given by Jonkman, S. N.; Vrijling, J. K.; Vrouwenvelder, A. C. W. M. (2008): *Methods for the estimation of loss of life due to floods. A literature review and a proposal for a new method*. In Nat Hazards 46 (3), pp. 353-389. DOI: 10.1007/s11069-008-922 and Jonkman, S.N. (2007). *Loss of Life Estimation in Flood Risk Assessment: Theory and Applications*. PhD thesis, Delft University of Technology.

[72] EM-DAT. (2020). *EM-DAT Data Base*. https://www.emdat.be/

[73] MO, WHO. (2015). *Heatwaves and health: guidance on warning-system development*. Geneva.

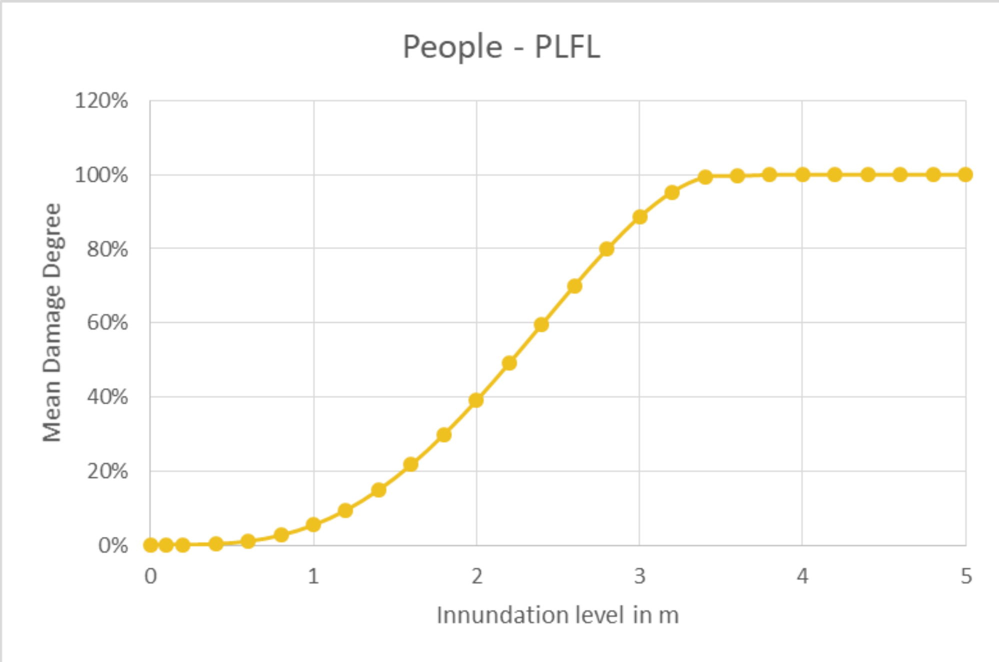

Figure 24: *Damage function for pluvial / fluvial floods for people.*

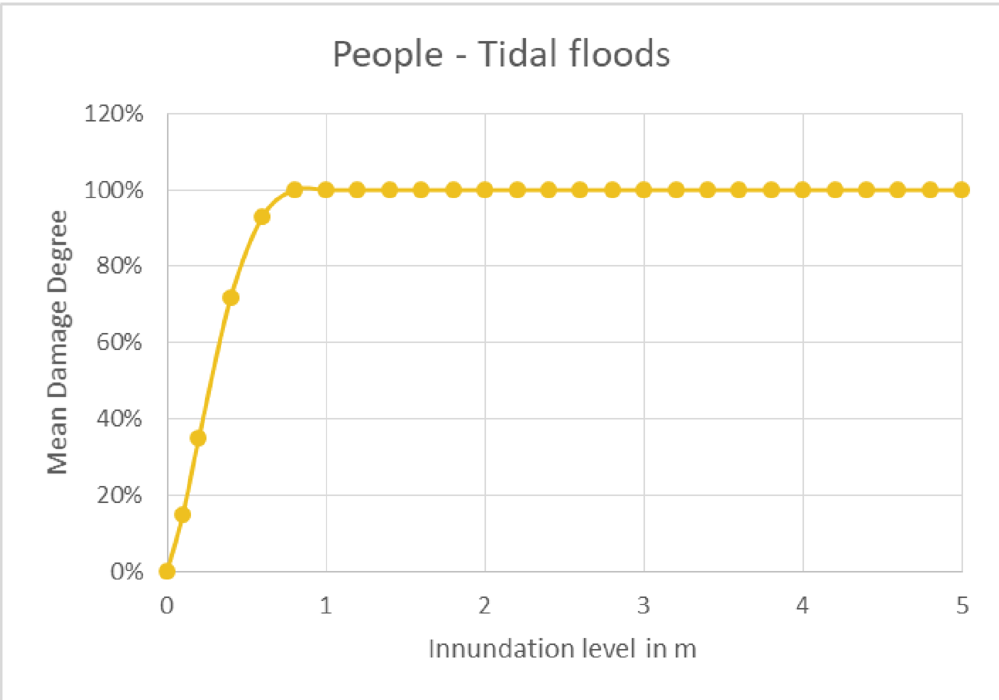

Figure 25: *Damage function for tidal floods for people.*

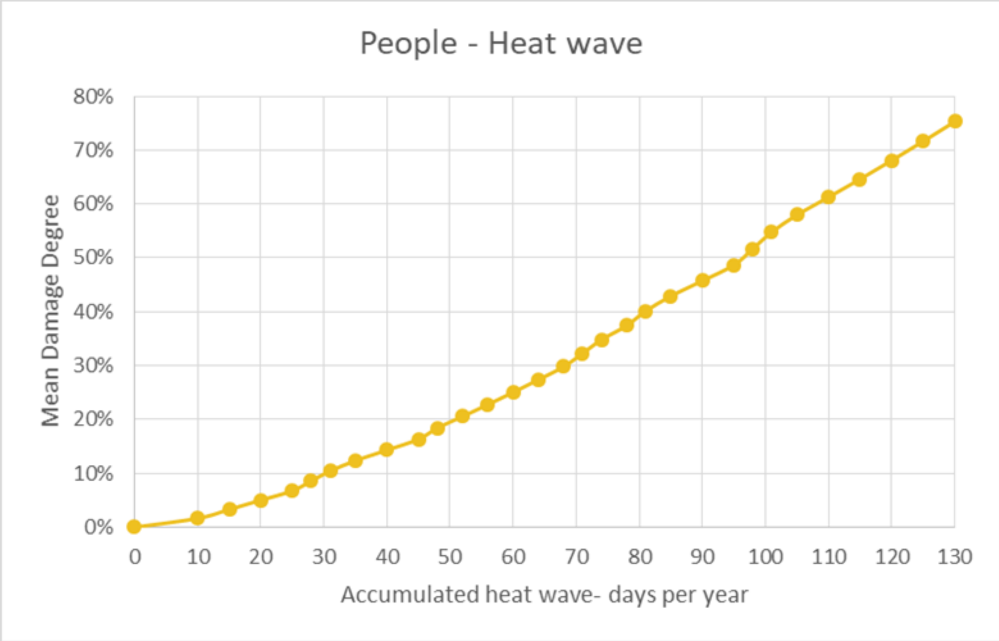

Figure 26: *Damage function for heat waves for people.*

4.3 Housing

With regard to housing the resulting damage functions for both flood hazards analysed follow an S-shaped curve.[74] This implies that with relatively low flood levels no or very little damage should be expected which however starts to rise increasingly with higher flood levels before it slows down again eventually settling on a plateau value, the respective maximum MDD. For the pluvial / fluvial flood case the maximum MDD is reached at 3 m of inundation with approximately 13% (Figure 27) while the calibration process revealed a maximum MDD of about 30% at 4m inundation for the tidal flood case (Figure 28).

[74] See e.g. K. Zabert et al. (2018). *Development of model for the estimation of direct flood damage including the movable property*. J Flood Risk Management. 11. S527-S540. DOI: 10.1111/jfr3.12255 or Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

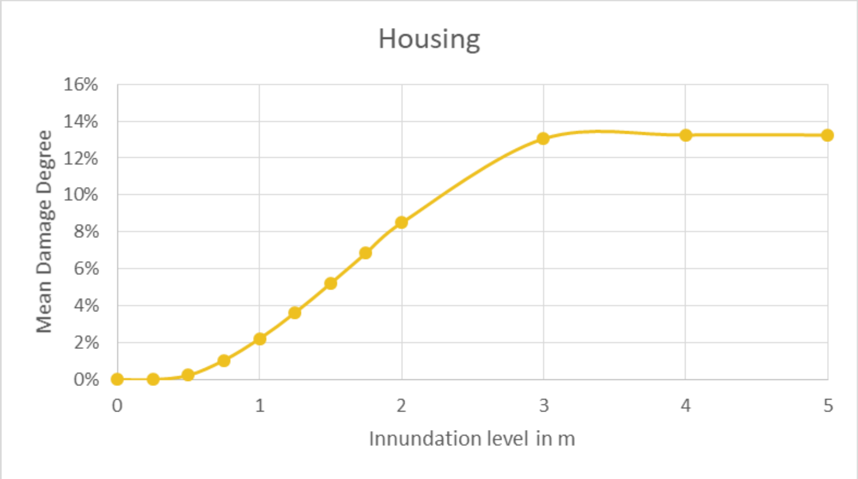

Figure 27: *Damage function for pluvial / fluvial floods for housing.*

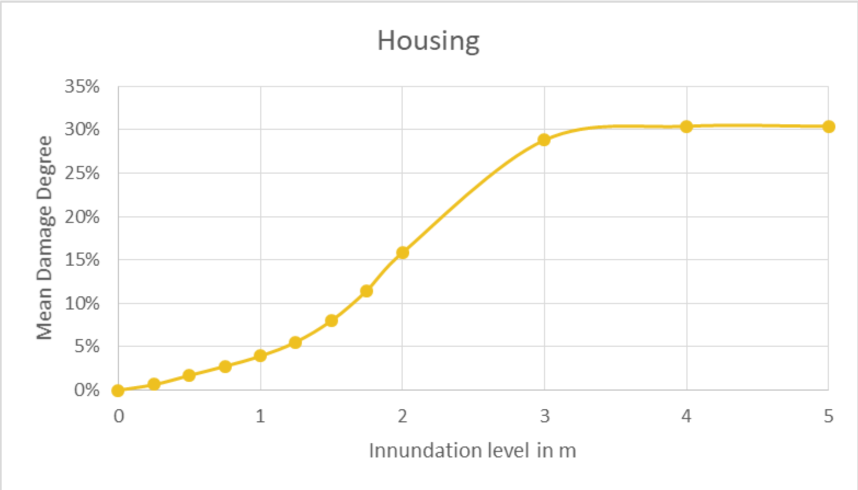

Figure 28: *Damage function for tidal floods for housing.*

4.4 Public Buildings

The damage curves for the public buildings depend on their specific purpose, their corresponding interior fittings and structural requirements. In the following separate damage functions for Educational Facilities, Health Facilities and Administrative Buildings are presented which largely draw from desk research.[75,76,]

Flood damage functions for (public) buildings generally can be expected to be S-shaped with initially low impacts at low flood levels which then increases more sharply before settling on a maximum MDD. Depending on specific characteristics of sub-groups the rise in increasing damage may differ as presented by the below graphs showcasing the different damage functions (Figure 29, Figure 30, Figure 31).

[75] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

[76] M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

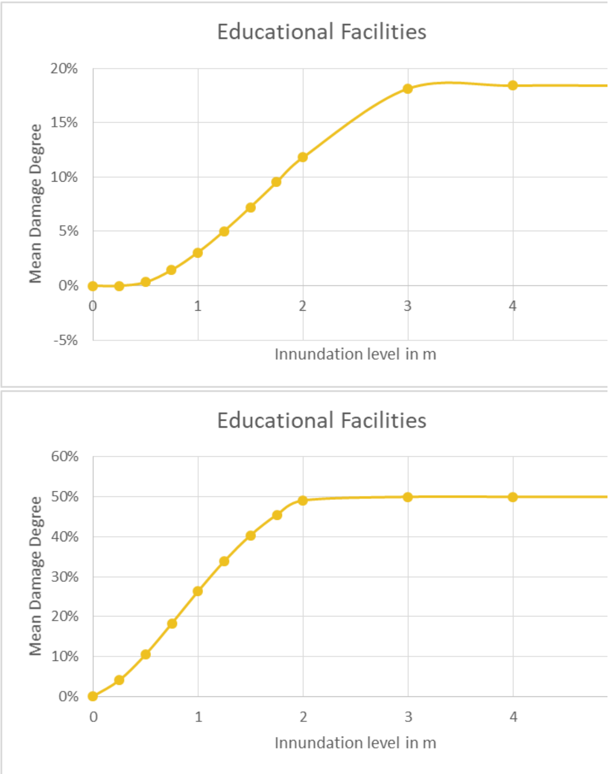

Figure 29: *Damage functions for pluvial / fluvial (top) and tidal (bottom) floods for Educational Facilities.*

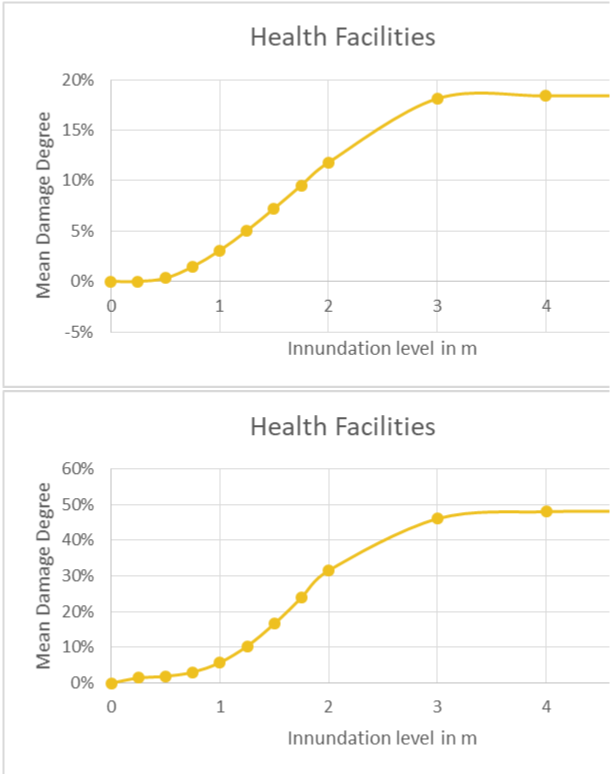

Figure 30: *Damage functions for pluvial / fluvial (top) and tidal (bottom) floods for Health Facilities.*

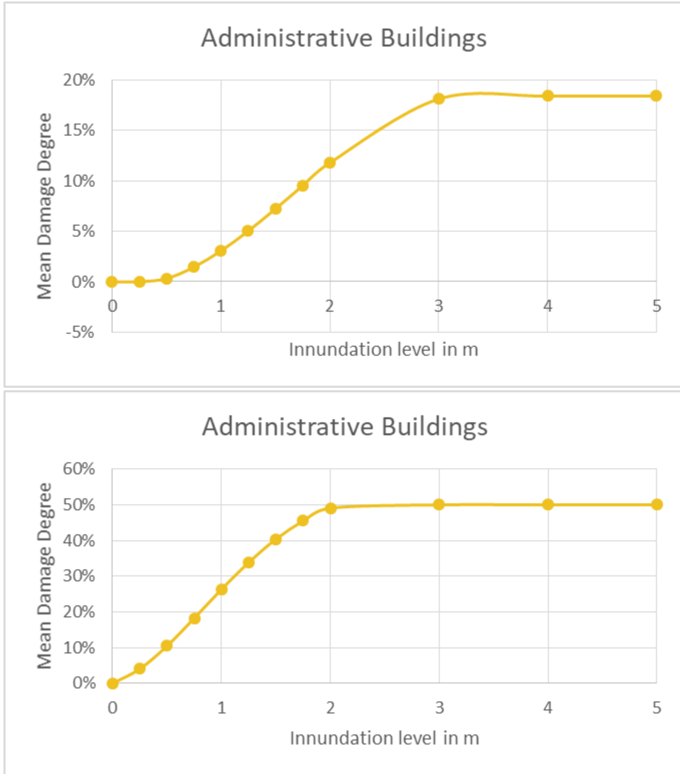

Figure 31: *Damage functions for pluvial / fluvial (top) and tidal (bottom) floods for Administrative Buildings.*

4.5 Road Network

The road network considered in the study is mostly considered to be paved with slightly differing durability as it is built for different purposes. The here presented damage functions aim to cover the entire asset group for the respective hazard.[77][78] Figure 32 presents the calibrated damage function for road networks for pluvial / fluvial floods, Figure 33 for tidal floods, both follow an S-shape and reach their respective maximum MDD at 4m inundation level.

During heat waves the road surface, especially in combination with intense sunshine, can heat up to very high temperatures quickly exceeding the measured air temperature. Whether and to what degree asphalt and similar materials used in road construction get damaged depends on several factors. For example, if the sun is shining directly onto the road with no wind the dark material can absorb much more heat compared to a similar road in the shade and hence, not only the ambient temperature but also the exposure plays an important role. Assuming that the roads can withstand shorter periods of heat without lasting damage, softening leading to deformed roads due to e.g. heavy loads becomes more and more likely with both, increasing number of consecutive days of heat as well as with an increasing number of total days of heat per year. Finally, it is assumed that extreme heat over several days will however not substantially damage lower levels of the road, and hence a maximum mean damage degree is reached at 75%. These assumptions and the calibration process reveal the S-shaped damage function as portrayed in Figure 34.

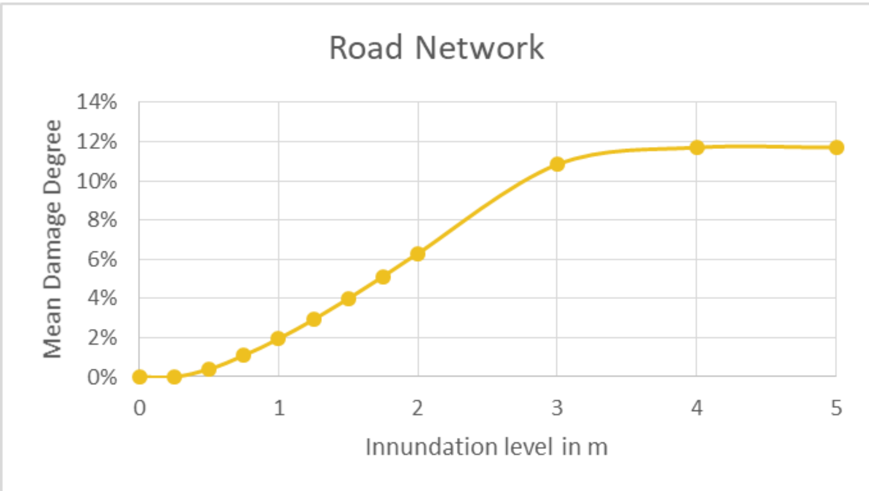

Figure 32: *Damage function for pluvial / fluvial floods for the road network.*

[77] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/16510

[78] M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

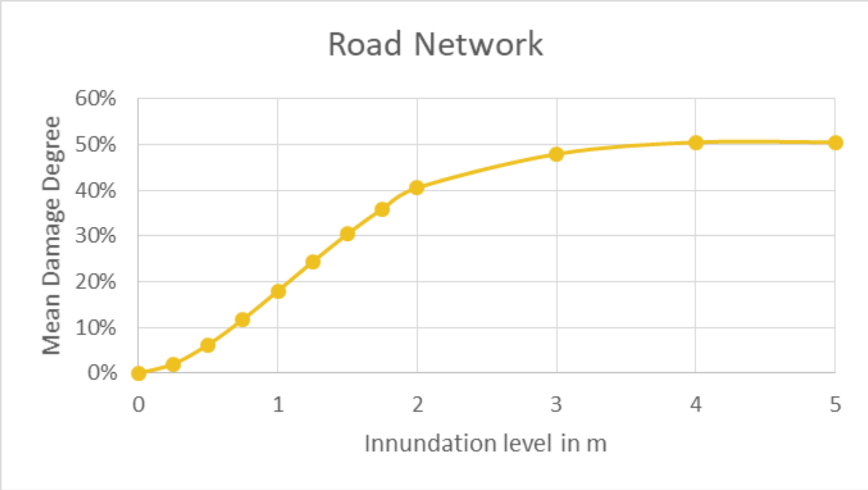

Figure 33: *Damage function for tidal floods for the road network.*

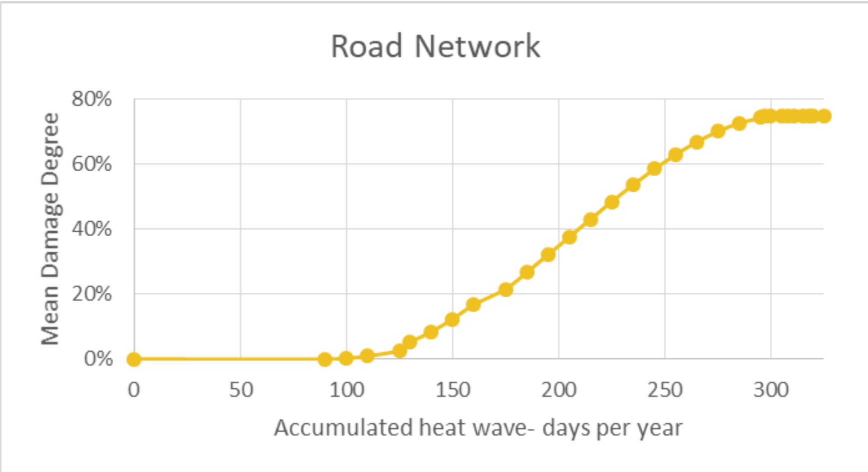

Figure 34: *Damage function for heat waves for the road network.*

4.6 Electric Grid

For the electrical grid the two flood damage functions take differing shapes although both feature a linear element.[79] While the calibration for pluvial / fluvial floods resulted in a damage function indicating first damages at an inundation level of 0.75m and reaching its maximum MDD at 4m (Figure 35), the resulting damage function for the tidal case starts off immediately and reaches its maximum MDD at 3m (Figure 36).

[79] See e.g. M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

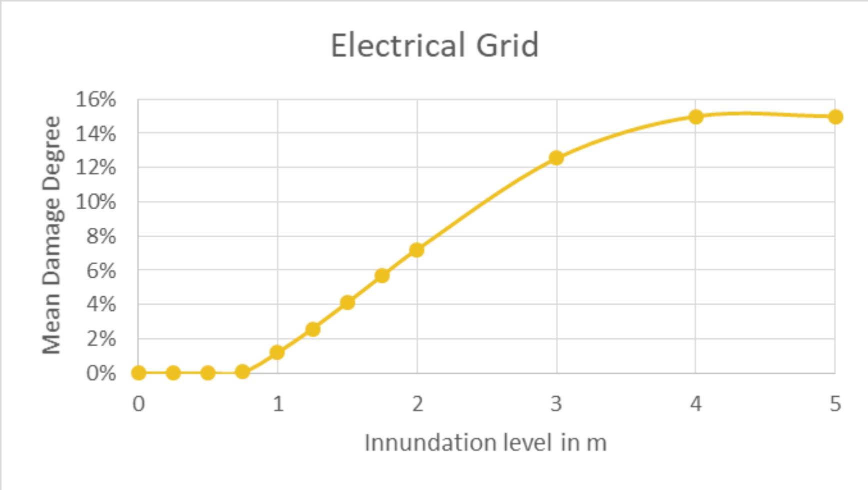

Figure 35: *Damage function for pluvial/ fluvial floods for the electrical grid.*

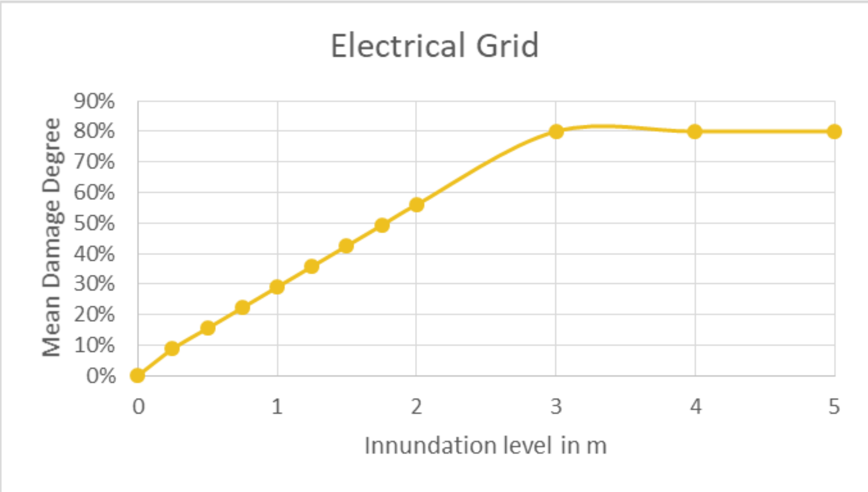

Figure 36: *Damage function for tidal floods for the electrical grid.*

4.7 Natural Resources

4.7.1 Aquaculture

The information and literature available on quantifiable damages on natural resources, crops and aquaculture in general is quite limited.

For water bodies different literature sources were consulted with studies suggesting all three, positive, negative and neutral effects for smaller floods[80,81]. Eventually, whether the positive or the negative effects

[80] See e.g.: C. J. Talbot et al. (2018). *The impact of flooding on aquatic ecosystem services*. Biogeochemistry 141. 439-461. https://doi.org/10.1007/s10533-018-0449-7
[81] Or see: T. Hrdinka et al. (2012). *Possible impacts of floods and droughts on water quality*. Journal of Hydro-environment Research 6 (2012) 145 - 150

take the upper hand during smaller floods depends on many factors such as seasonal, climatic, and weather conditions prior and after to the flood event or for instance characteristics of the river bed sediments.

Extreme floods, on the other hand, are almost unanimously considered to have no positive effect due to increasing soil erosion, pollutant contamination or organic matter.

As described in the chapter on asset valuation, the predominant species considered here are rather resistant pangasius catfish species that are quite tolerant regarding oxygen saturation as well as overall water quality.

Based on the outlined assumptions both flood damage curves for aquaculture initially drop below 0% MDD which translates to net benefits of smaller limited floods as shown below. However, with increasing flood levels the calibrated expected mean damage increases reaching its maximum at 3m (Figure 37) and 4m (Figure 38) respectively.

Increased water temperatures, as can be expected especially in the portions of ponds and rivers, negatively influence oxygen levels in the water resulting in hypoxia.[82] This may first lead to stunted growth but sooner or later results in death of the animals. Further, heat waves can boost algae blooms further influencing the nutritional and chemical balance of the water, potentially resulting in a toxic environment for the fish. However, the widely farmed pangasius catfish is a facultative air breather allowing rather low levels of dissolved oxygen and polluted waters (making it suitable for intensive farming). Its preferred water temperature lies between 22 and 26 °C.[83]

Based on the above outlined rather high resilience of the predominantly farmed fish it can be assumed that noticeable damages on fish stock only start to materialize after some accumulated days of heat and hence increased water temperature as shown in Figure 39, while they keep increasing steadily without reaching a plateau eventually leading to a complete loss in the extreme case (not pictured here).

[82] Talbot, C.J., Bennett, E.M., Cassell, K. et al. (2018). *The impact of flooding on aquatic ecosystem services.* Biogeochemistry 141, 439–461. https://doi.org/10.1007/s10533-018-0449-7)

[83] FAO 2010-2021.Cultured Aquatic Species Information Programme. Pangasius hypophthalmus. Cultured Aquatic Species Information Programme. Text by Griffiths, D., Van Khanh, P., Trong, T.Q. In: FAO Fisheries Division [online]. Rome. Updated.

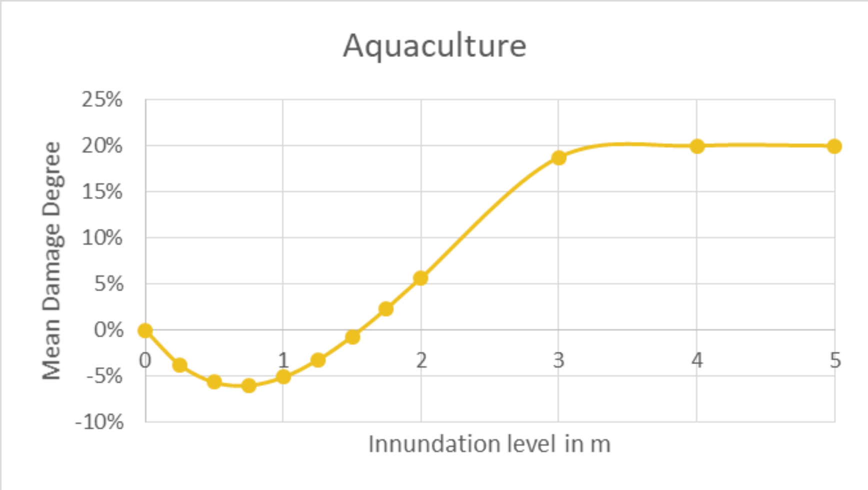

Figure 37: *Damage function for pluvial / fluvial floods for aquaculture.*

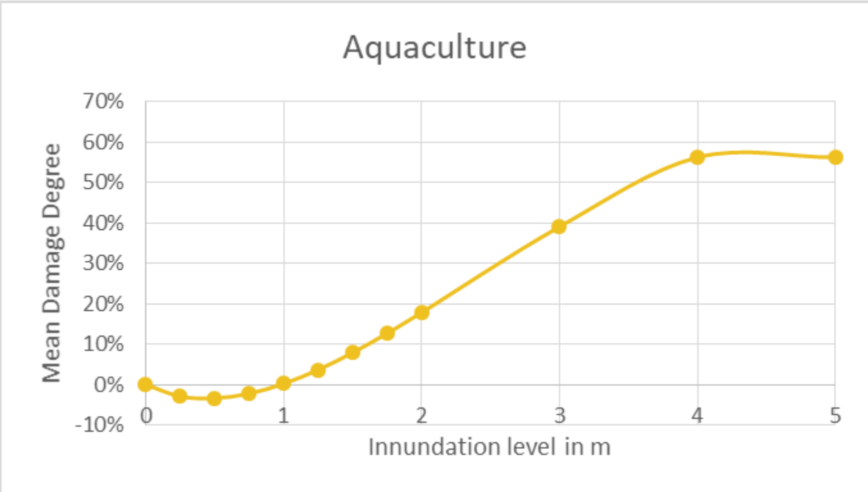

Figure 38: *Damage function for tidal floods for aquaculture.*

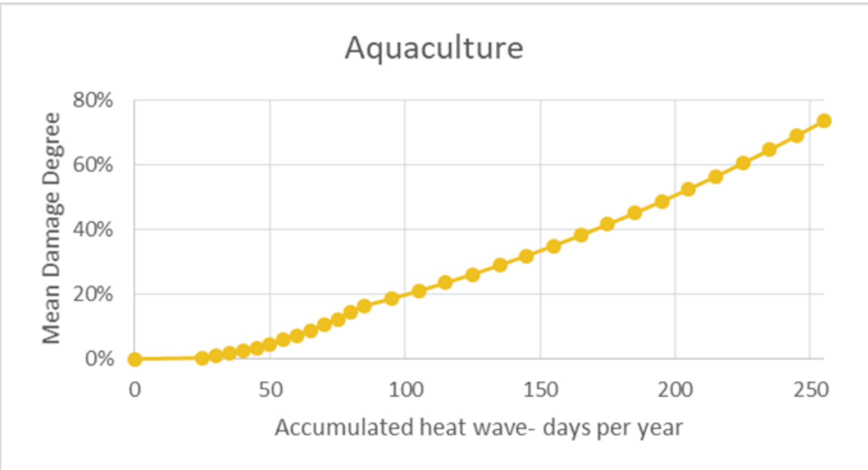

Figure 39: *Damage function for heat wave for aquaculture.*

4.7.2 Cash Crops

With cash crops, in this case mainly maize as explained above, similar to aquaculture initial positive yet much significantly smaller, effects, are assumed. Figure 40 presents the S-shaped damage function for the pluvial / fluvial flood case which reaches the maximum MDD at 4m inundation. Figure 41 presents the steeper damage function for the tidal case, in which the positive effect of very limited flooding seems to fade behind larger negative effects.

All plants are affected by heat and heat stress such as during germination, as well as plant development, but also processes like photosynthesis with potentially severe impact on crop yield.[84,85] The damage function presented in Figure 42 presents an increasing trend with more and more damage on crops as heat wave- days accumulate eventually resulting in total crop loss in the extreme case.

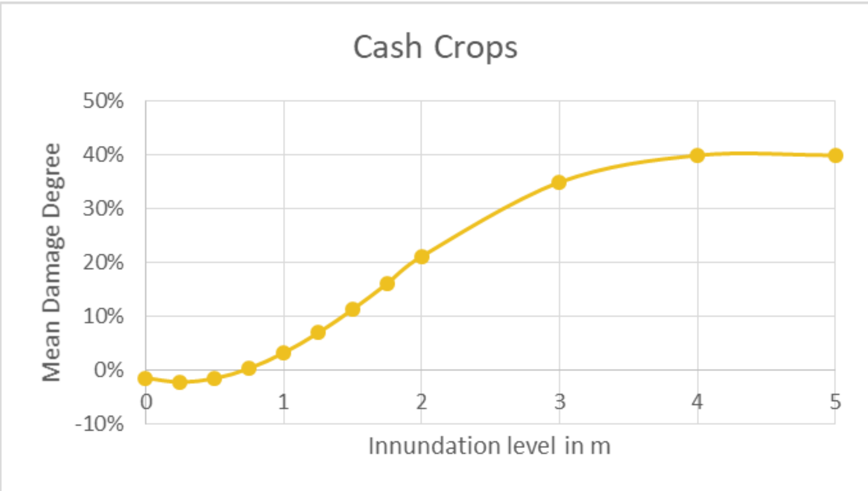

Figure 40: *Damage function for pluvial / fluvial floods for cash crops.*

[84] Nadeem, Muhammad, Jiajia Li, Minghua Wang, Liaqat Shah, Shaoqi Lu, Xiaobo Wang, and Chuanxi Ma. 2018. *Unravelling Field Crops Sensitivity to Heat Stress: Mechanisms, Approaches, and Future Prospects.* Agronomy 8, no. 7: 128. https://doi.org/10.3390/agronomy8070128

[85] Elias, E., Marklein, A., Abatzoglou, J.T. et al. (2018). *Vulnerability of field crops to midcentury temperature changes and yield effects in the Southwestern USA*. Climatic Change 148, 403–417.

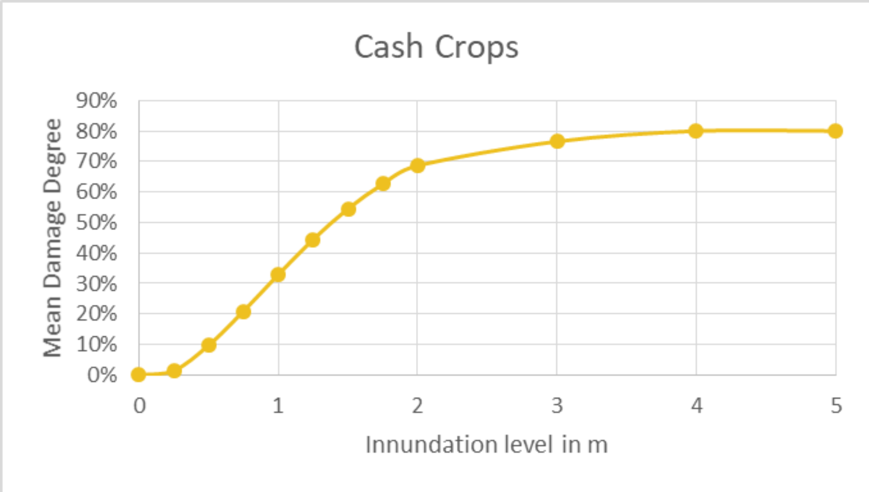

Figure 41: *Damage function for tidal floods for cash crops.*

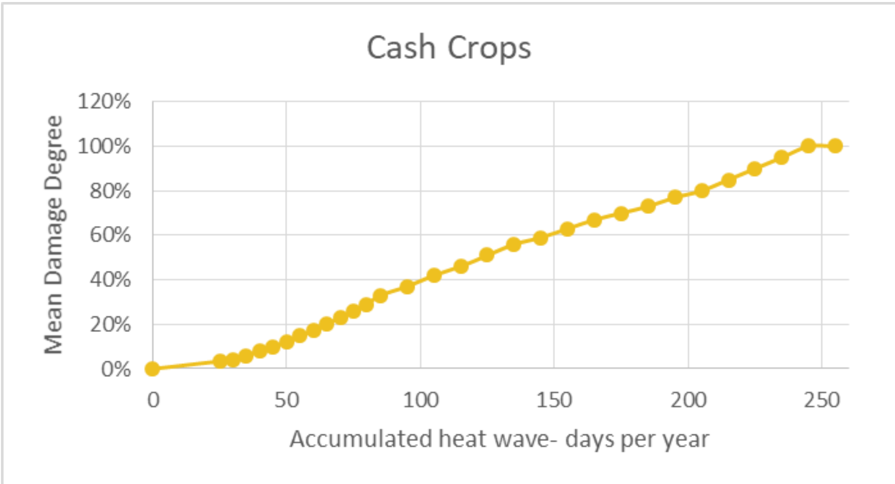

Figure 42: *Damage function for heat waves for cash crops.*

4.7.3 Orchards

Orchards again slightly different damage functions result from the calibration exercise. In the pluvial / fluvial floods case again a slight initial positive effect is being represented in the damage function (Figure 43) while this is not the case for tidal floods (Figure 44).[86] However, both reach their maximum MDD at 4m inundation level.

[86] For a reference see e.g. SCE. 2013. Comprehensive Resilience Planning for Integrated Flood Risk Management. Technical report.

For the case of heat waves limitations in available targeted literature and the calibration process result in a similar damage function as presented for the cash crop – heat wave combination above (see Figure 45).

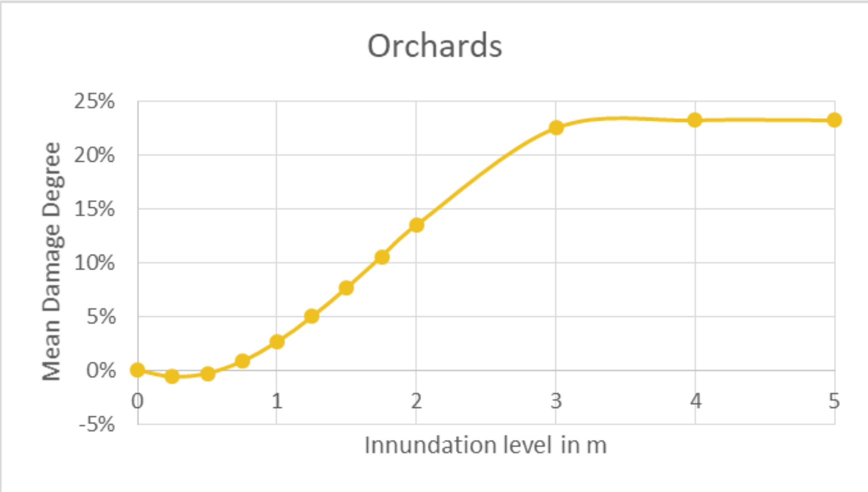

Figure 43: *Damage function for pluvial / fluvial floods for orchards.*

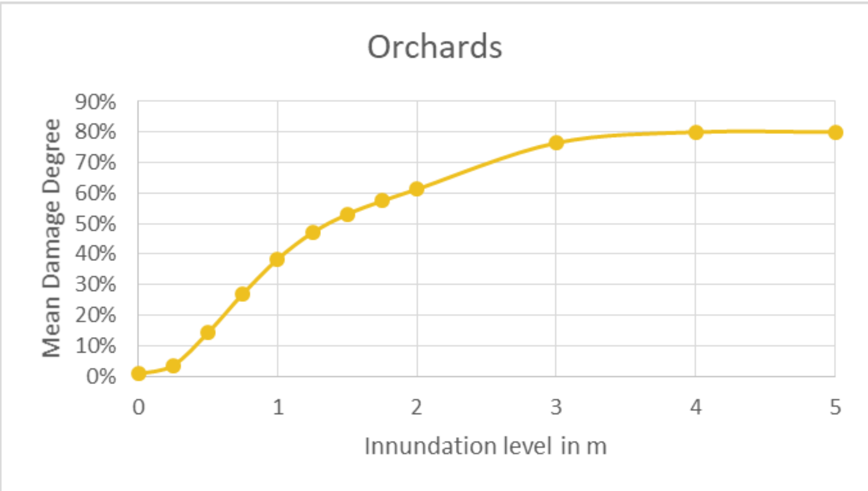

Figure 44: *Damage function for tidal floods for orchards.*

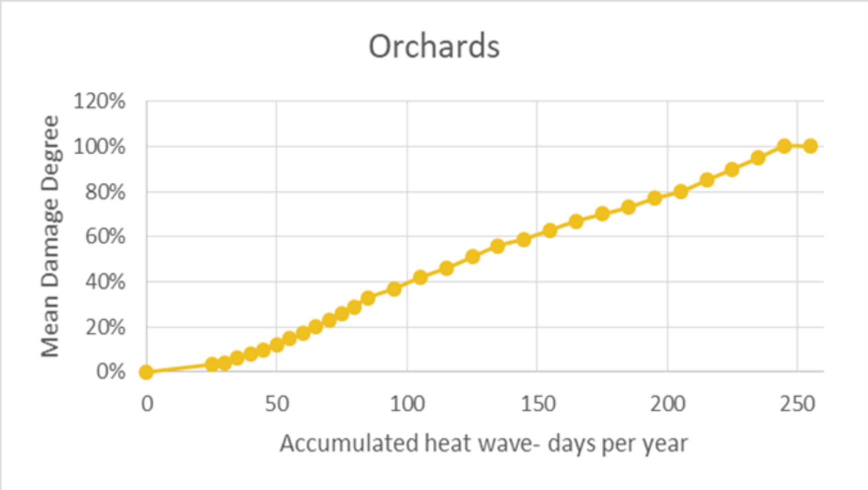

Figure 45: *Damage function for heat waves for orchards.*

4.7.4 Triple Rice Crop

The flood damage functions for rice crops are S-shaped again with initially no damage caused by minor floods in both cases and reaching their respective maximum MDD at 4m in both cases. Although minor floods do not lead to any, or very limited damages, with increasing flood level the mean damage degree rises noticeably. Figure 46 presents the pluvial / fluvial flood case and Figure 47 the tidal flood case.

Facing again limitations in related literature and loss data the calibration process resulted in a similar damage function as for cash crops and orchards, however representing slightly lower vulnerability levels (see Figure 48).[87]

[87] Elias, E., Marklein, A., Abatzoglou, J.T. et al. (2018). *Vulnerability of field crops to midcentury temperature changes and yield effects in the Southwestern USA*. Climatic Change 148, 403–417.

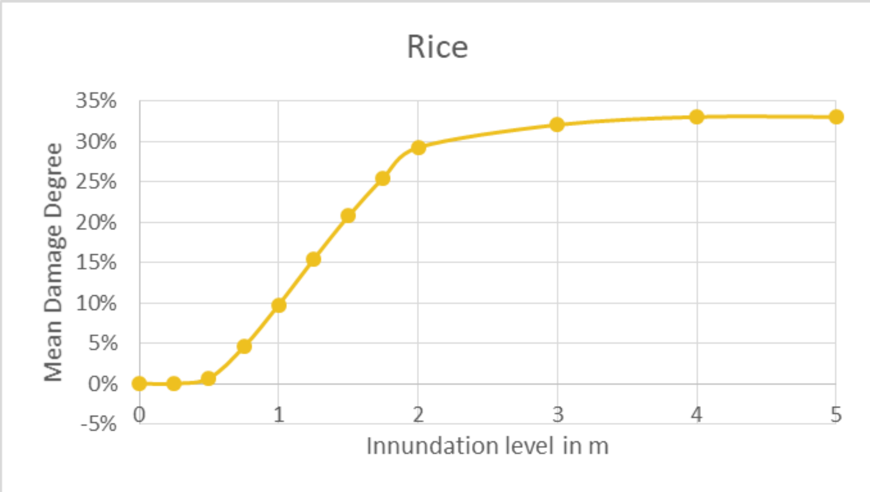

***Figure 46:** Damage function for pluvial / fluvial floods for triple rice crops.*

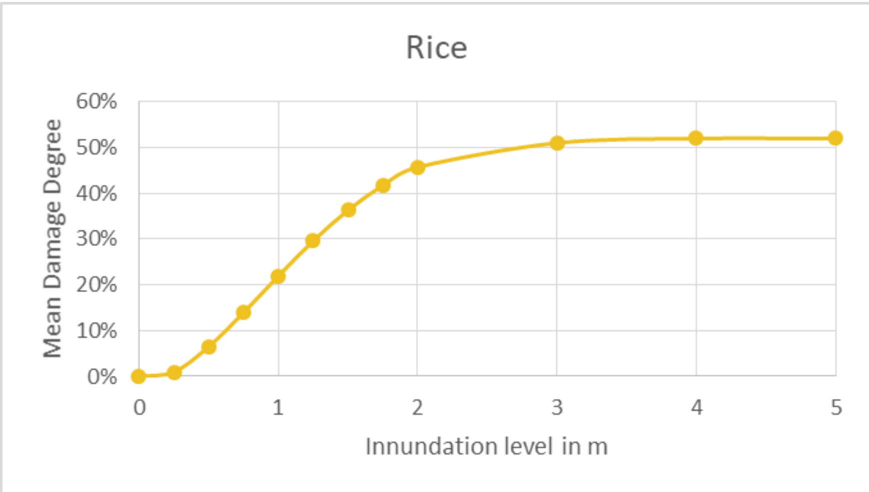

***Figure 47:** Damage function for tidal floods for triple rice crops.*

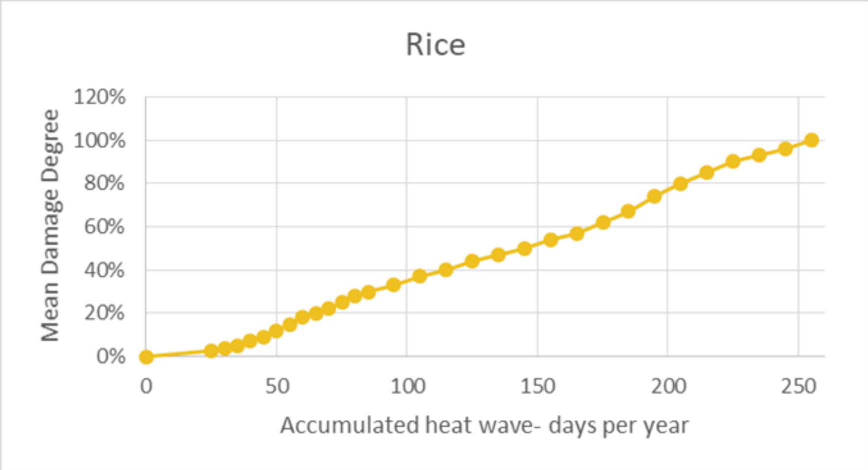

Figure 48: *Damage function for heat waves for triple rice crops.*

4.7.5 Green Spaces

Finally, the damage functions for urban green spaces, i.e. parks, too are S-shaped with no or little damage at low inundation levels and increasing mean damage degrees with rising flood levels approaching a plateau level of the maximum MDD at an inundation of 4m in both, pluvial/fluvial (Figure 49) and tidal flood (Figure 50) cases.[88]

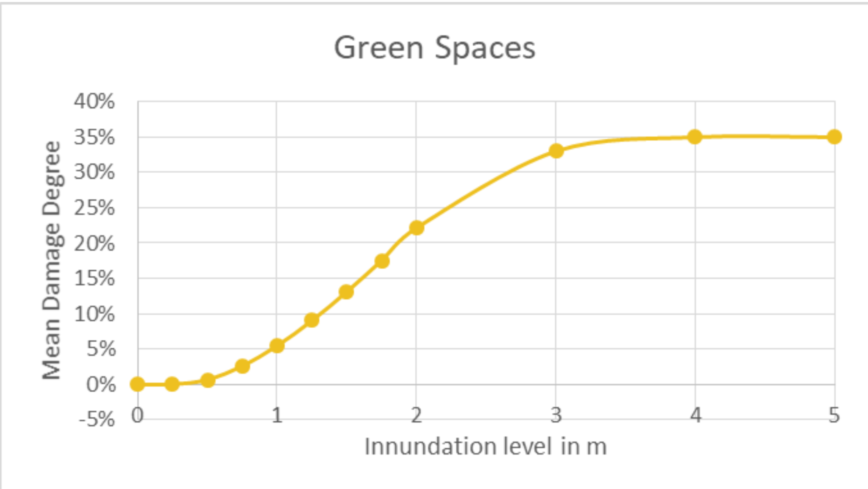

Figure 49: *Damage function for pluvial / fluvial floods for urban green spaces.*

[88] See e.g. M. Kok et al. (2005). *Standard Method 2004 Damage and Casualties by Flooding*. Ministerie von Verkeer en Waterstaat. Rijkswaterstaat.

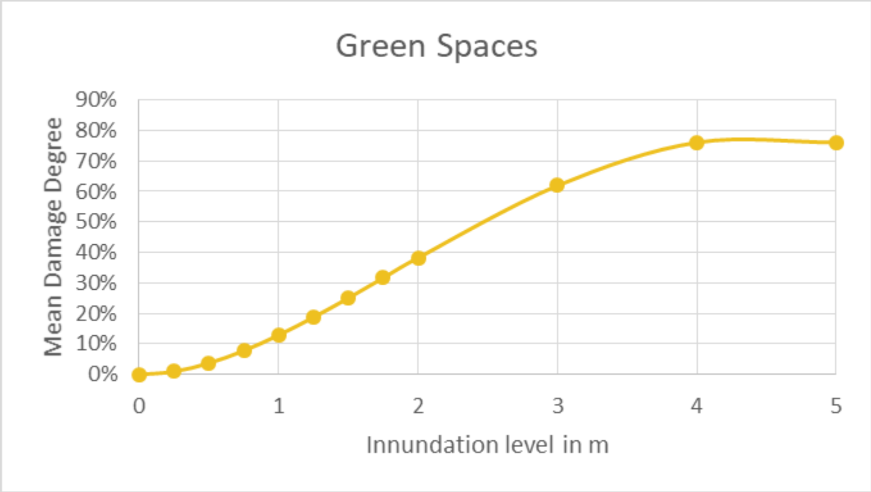

Figure 50: *Damage function for tidal floods for urban green spaces.*

5. Adaptation Measures

5.1 Introduction

This chapter presents the list of flood and heat wave adaptation measures identified for the three urban districts, Binh Thuy, Ninh Kieu and Cai Rang of Can Tho City (see Figure 45). These measures will serve to reduce the vulnerability of the key assets and population groups selected during the Inception Workshop, by reducing either the number of assets expected to be affected, the intensity of the impact, or in some cases both. The benefit of each measure was linked to the potential averted damage.

The adaptation measures were selected based on a comprehensive literature review, and a consultation process with key experts, partner organisations and government representatives. In total 27 flood adaptation measures and 10 heat wave adaptation measures (in total 37) were initially identified (referred to as a 'long list') and reduced to 17 measures (referred to as a 'short list'), which have been introduced to CLIMADA.

Reducing the list of measures from 37 (flood & heat wave) to 17 involved a transparent and participative selection process, including stakeholder validation workshops and a concluding Multi-Criteria Analysis. A detailed description of the measures selection procedure can be found in ANNEX 2 and 3.

5.2 Overview Adaptation Measures

For Can Tho City, 17 adaptation measures have been identified to address urban flooding and heat waves. From these 17 measures, 10 measures will address urban flooding solely, 4 measures deal with urban heat waves and 3 measures will mitigate impacts of both risks, flooding and heat waves. The identification of measures was based on specific selection criteria (see ANNEX 2). The selection of measures is classified into different adaptation types, of which four are categorized as 'Nature-based Solutions' (NbS), two as 'Hybrid', indicating a mix of NbS elements combined with 'Grey' infrastructure interventions. Six measures can be considered as solely 'Grey' adaptation types, referring to engineered solutions. In addition, one flood index insurance solution has been selected. Four measures refer to 'Systemic' measures and relate to behaviour change or policy planning. All measures have been introduced to the CLIMADA modelling tool. The list of selected measures is shown below in Table 10.

Table 10: *Overview List of Flood and Heat Wave Adaptation Measures for Can Tho City. 'Grey' measures refer to technological and engineering solutions. 'NbS' measures refer to ecosystem-based (or nature-based) solutions and make use of multiple services provided by ecosystems. 'Hybrid' solutions indicate a combination of NbS and Grey types of measures. 'Insurance' solutions cover residual risks, which remain after a set of adaptation measures has been implemented. 'Systemic' measures relate to behaviour change or policy planning:*

#	Name of Measure	Type of Measure	Hazard
1	Retention reservoirs	NbS	Flood
2	Detention swales along roads	NbS	Flood
3	Improved solid waste management	Systemic	Flood
4	Rehabilitation of existing drainage canals	Grey	Flood
5	Flood awareness campaign	Systemic	Flood
6	Road spillways as bio-retention systems	NbS	Flood

7	Rain collection tanks for existing buildings	Grey	Flood
8	Mobile flood embankments	Grey	Flood
9	Flood wall	Grey	Flood
10	Flood protection storage facilities (incl. sandbags)	Systemic	Flood
11	Index insurance	Insurance	Flood & Heat Wave
12	Green roofs	Hybrid	Flood & Heat Wave
13	Green spaces (Urban forestry)	NbS	Flood & Heat Wave
14	White roofs	Grey	Heat Wave
15	Cooling centres	Systemic	Heat Wave
16	Climate smart agriculture	Hybrid	Heat Wave
17	Climate proofed road design	Grey	Heat Wave

To better define the location of each measure a zoning of the study area has been introduced. The identified flood and heat wave adaptation measures have been allocated to the three urban districts of Can Tho, representing Zone 1, 2 and 3. A map of the different zones, which correspond to the study area of the three urban districts is shown in Figure 51.

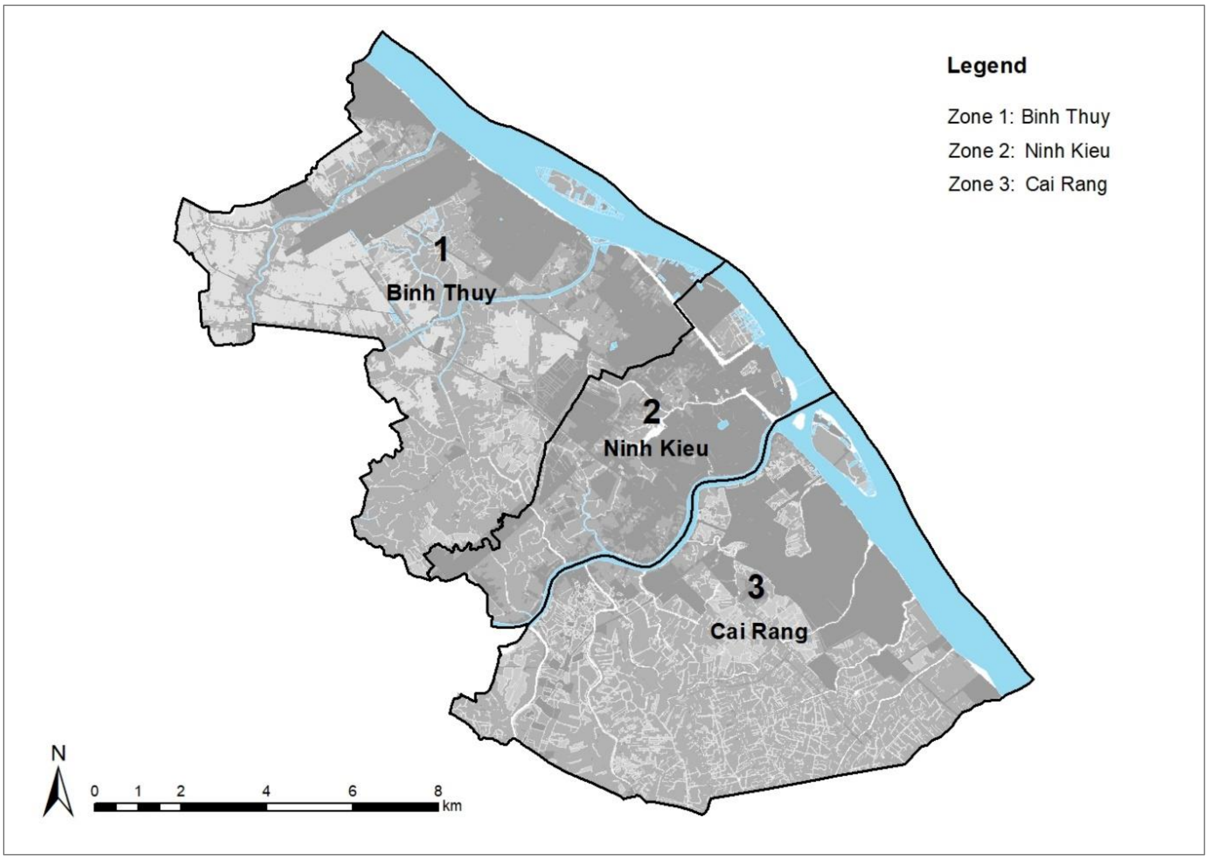

Figure 51: *Overview of zoning. Zones correspond to the study areas' district boundaries. Source: UNU-EHS.*

The measures are described in brief in the following overview tables (Table 11), Table 12 summarises the measures' cost and their respective locations, in either Zone 1, 2 or 3. Each overview table provides information about the cost per assigned location (Zone 1, 2, and/or 3), the implementation time, expected life span, complexity, and maintenance intensity. A more precise description of each measure can be found in ANNEX 3.

Table 11: *Description of intended flood and heat wave adaptation measures (17 measures). For each measure the table provides the cost per assigned location, implementation time, expected life span, complexity of the measure (in high, medium, low), maintenance intensity (in high, medium, low), and the hazard type (fluvial/pluvial, tidal and/or heat wave).*

1. Retention reservoirs

Retention reservoirs are artificial ponds with vegetation around the perimeter and include a permanent pool of water in their design. They are usually designed to provide short-term storage of water. Retention reservoirs can retain flood events, reducing peak flows and limiting the risk of flooding. In addition, reservoirs keep deposited sediments at the bottom of the holding area and is able to treat contaminated storm water runoff. In Can Tho, each reservoir is planned to be designed with a depth of 2 meters to provide the necessary treatment and sediment capture. In total, 12 retention reservoirs are planned with a combined water storage capacity of 502 172 m^3 and area of ca. 25 hectares.

Total Cost (USD)	1 150 825		
Implementation Time	1 – 2 years	Complexity	Low
Life Span	>30 years	Maintenance	Medium
Hazard	Pluvial-fluvial & tidal floods	Type of measure	NbS

2. Detention swales along roads

Detention swales are broad shallow channels topped with vegetation, also referred to as 'bioswales'. It is designed to attenuate and in some cases infiltrate runoff volume from adjacent impervious surfaces such as roads, allowing some pollutants to settle out in the process. Detention swales can be a 'green' alternative to conventional piping or drainage canal systems. Swales avoid the need for expensive roadside curbs, gullies, and related maintenance and can enhance the aesthetic value of a site through the selection of appropriate native vegetation. This measure proposes the establishment of dry grass swales of parabolic form to reduce runoff from roadways and/or sidewalks by allowing water to infiltrate. It is planned to establish swales of 1.5 meters depth and 2.5 meters width, representing 3,75 m^3 per linear meter. In Can Tho, it is intended to establish grass swales along roads with up to 4 lanes and a maximum width of 12 meters. In total, 64 km of road network has been identified of being suitable for detention swales.

Total Cost (USD)	3 554 522		
Implementation Time	2 – 3 years	Complexity	Low
Life Span	>30 years	Maintenance	Low
Hazard	Pluvial-fluvial & tidal floods	Type of measure	NbS

3. Improved solid waste management

Solid waste collection schemes should be organized and scheduled among communities living close to riverbeds and canal systems. The primary goal is to remove accumulating trash within the riverbeds and canals and respective slopes. Attention is given to areas with a high risk of trash accumulation, such as bridges or street culverts. These areas should remain garbage-free on an annual basis. Such a community waste management and collection scheme for watercourses will also reduce the vulnerability of people who live in the immediate proximity of rivers or water canals.

Such a program will raise social awareness for solid waste management and its relation to urban flood risk.

Total Cost (USD)	1 566 192		
Implementation Time	< 1 year	Complexity	Low
Life Span	>30 years	Maintenance	Low
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Systemic

4. Rehabilitation of existing drainage canals

Stormwater drainage systems in urban areas are a deterministic flood management system, especially in light of the current climate changes and intensified risks of severe floods. Irregular maintenance of urban drainage systems and canals may cause problems that reduce the efficient conveyance of water, especially the blockage or sedimentation of network pipes, which affects the efficiency of the network. To guarantee the efficient conveyance of canal systems, dredging can be a suitable rehabilitation method. The term dredging is routinely used to refer to the systematic removal of accumulated material from watercourses, canals, or drainage systems. In its most extreme form dredging may be used to re-align canalized watercourses. The term dredging covers a range of activities from the removal of sedimentation in open drainage canals or pipes, or the wholesale straightening (canalization) and/or deepening of watercourses. The main objective of this drainage rehabilitation method is to increase the cross-sectional area (and hence its volume), as well as a reduction in the roughness of the channel. These effects can increase the efficiency of the canal in moving water. Hence increasing the conveyance. In total, ca. 68 km are subject of a rehabilitation monitoring, with varying pipe/canal diameters from 0.2 to 1.2 meters.

Total Cost (USD)	3 185 343		
Implementation Time	2 – 3 years	Complexity	Medium
Life Span	>30 years	Maintenance	Medium
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Grey

5. Flood awareness campaign

Flood awareness programmes should inform individuals about the risks as well as flood preparedness measures. Activities to prepare against flood should be planned in advance. Through flood preparedness programmes, understanding and awareness regarding the flood events is strengthened among the local community. Community members are focal point of preparedness programmes, therefore, informing the public and providing training for flood preparedness is vital. Some of the activities could include dissemination of the latest information and updates about the flood from local radio, TV stations, or any other communication portal; dissemination of information about local emergency shelter, etc. Awareness and preparedness campaigns should also include information on what should be done during and after a flood event. Awareness programmes should be designed community and context-specific. The framework for raising awareness comprises seven steps: (1) identify awareness level, (2) find need of the target groups, (3) find best ways for information dissemination, (4) start the campaign, and (5) evaluation. If planned appropriately, an awareness and preparedness campaign should include social aspects as well, such as using a (6) participatory approach (involvement of all community members), in which vulnerable people are identified and prioritised, and (7) taking a gender-based approach.

Total Cost (USD)	1 165 785		
Implementation Time	1 – 2 years	Complexity	Low
Life Span	>30 years	Maintenance	Medium
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Systemic

6. Road spillways as bio-retention systems

To deal with increasingly regular flooding, a network of spillways as bio-retention systems will be created for roads with 6 to 8 lanes (width 22.5 meters). The primary purpose of a spillway is to discharge flows that cannot either be used immediately or stored in a reservoir for future use. Spillways act as a linear greenway, bringing life and activity to city streets. When the seasonal flooding arrive and the tide rises, the spillways absorb water which would normally flood the surrounding streets. This will allow for water to more easily move through the city and rain water to be held and released. It is intended that this network of canal-like spillways will be cut through existing overbuilt roads, reviving a 'lost' system of tandem road and canal based development. For Can Tho, it is intended to establish spillways as bio-retention systems on roads with 6 to 9 lanes that have a width of minimal 22.5 meters. The planning foresees to use and transform one lane (ca. 3.75 meters) of the roads into a bio-retention spillway. The spillways will replace and become a new median strip on the roads. The spillways will have a width of ca. 4 meters and an excavated depth of 2 meters. All districts combined, the total length of planned spillways counts to 53.43 kilometres.

Total Cost (USD)	9 414 001		
Implementation Time	3 – 5 years	**Complexity**	Medium
Life Span	>30 years	**Maintenance**	Medium
Hazard	Pluvial-fluvial & tidal floods	**Type of measure**	NbS

7. Rain collection tanks for existing buildings

This measure aims to collect rainwater in public and private buildings that have the capacity to accommodate one or more rainwater collection tanks with a specified capacity ca. 3500 litres. These collection tanks will be connected to public storm drainage systems or other waterways for discharge. Its effective use depends on the acceptance and uptake of potential users, who can be companies and commercial buildings, public buildings or private residential buildings and households who want to contribute to reducing the effects of flooding. This measure aims to lower runoff peak by collecting volumes of water in tanks. In Can Tho, circa 10% of all existing buildings that are affected by pluvial and fluvial flooding should be considered to be equipped with water collection tanks. This amounts to 4662 buildings that are subject to the installation of tanks with a water storage capacity of each 3534 cubic meters.

Total Cost (USD)	222 999		
Implementation Time	1 – 2 years	Complexity	Low
Life Span	20 – 30 years	Maintenance	Low
Hazard	Pluvial-fluvial floods	Type of measure	Grey

8. Mobile flood embankments

This measure introduces mobile flood embankment systems, consisting of inflatable tube (hose) segments that are used to insulate/dam flood water. These robust flood protection segments are first inflated with air by a compressor, brought into position and then filled with water. While filling the segments with water, it is possible to take water from the raising water (flood) body for this purpose. Compared to sand-based dams (e.g. made of sandbags), the construction time and complexity is much lower. It requires significantly fewer labour and there is no disposal of contaminated dam protection material, such as contaminated sandbags after their use. After protection from the flood, the hose dams are dismantled, cleaned and stored again. The advantage of mobile flood embankment systems is their immediate use and protection. These mobile systems can protect roads, buildings and critical infrastructure from flood waters. The barriers are reusable, which make them a more sustainable and effective solution. Normally the hose dam segments can be combined to reach dam heights varying from 50 cm to 250 cm, if necessary. Also, based on a sleeve system, different segments can be combined to any length or height and suited to any topographical conditions or surface composition. It is intended to introduce mobile flood embankment systems for a length of 3 km. For this, 30 hose modules with a diameter of 1.1 meter and length of 100 meters are needed.

Total Cost (USD)	1 719 204		
Implementation Time	<1 year	Complexity	Low
Life Span	30 years	Maintenance	Medium
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Grey

9. Flood wall

A floodwall is a freestanding, permanent, engineered structure designed to prevent encroachment of floodwaters. Floodwalls, which are typically constructed of reinforced concrete or masonry, provide a barrier against inundation, protect structures from hydrostatic and hydrodynamic loads, and may deflect flood-borne debris from buildings or any other exposed objects. Depending on the site topography, floodwalls may protect only the low side of the site (and must tie into the high ground), or they may surround the site. The option of establishing flood walls is of particular interest in locations where space is limited, for example, densely populated or built-up river banks. For this measure, it is intended to establish a reinforced flood wall embankment along the Can Tho River on the shore side of the Cai Rang district with a length of 6 km. Hence, this flood wall embankment shall protect Cai Rang district against pluvial/fluvial and tidal floods.

Total Cost (USD)	7 380 000		
Implementation Time	2 – 3 years	Complexity	Medium
Life Span	>30 years	Maintenance	Low
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Grey

10. Flood protection storage facilities (incl. sandbags)

This measure intends to establish a storage facility for mobile flood protection elements such as sandbags. These storage facilities are very common buildings or warehouses, located in municipalities and are often managed by local authorities and respective fire or disaster risk management departments. These storage facilities often keep sandbags in stock, in the event of a rapid deployment against flood. Sandbags are easily stored ahead of time because they can lay flat and do not take up much space. Once there is a flood risk reported, they can be quickly put into action. In the event of a flood emergency, the use of sandbags from municipal stocks is regulated and prioritized. The sandbags will be used primarily for repairs to existing flood defences such as flood walls or other embankment systems. This accounts especially for protected assets such as hospitals, schools, communication centres, and or operational emergency centres, but also critical transportation routes. Local authorities will be also responsible for the pre-positioning of sandbag stocks in those areas for distribution in the event of a flood. In Can Tho, it is planned to establish one storage (warehouse) facility with a capacity to store 564 500 filled polypropylene sandbags (40 cm x 60 cm). The number of sandbags was calculated based on the assumption that they would provide (in theory) protection for a flood depth of 50 cm for a length of 10 000 meters.

Total Cost (USD)	921 557		
Implementation Time	1 – 2 years	Complexity	Low
Life Span	>30 years	Maintenance	Medium
Hazard	Pluvial-fluvial & tidal floods	Type of measure	Grey

11. Index Insurance

Index-based flood and heat wave insurance is an innovative approach to developing effective payout schemes for low-income, flood and heat wave prone communities. Index insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation payouts. Effective end-to-end solutions will be developed in collaboration with a range of organizations and experts from central and state government bodies, private insurance firms, community-based organizations (CBOs) and nongovernmental organizations (NGOs).

Insurance Premium Cost (USD) per year	2 200 000 (Flood), 500 000 (Heat Wave)		
Insurance Premium cost (USD) over 30 years	66 000 000 (Flood), 15 000 000 (Heat Wave)	Complexity	-
		Maintenance	
Hazard	Pluvial-fluvial & tidal floods, heat waves	Type of measure	-

12. Green roofs

Green roofs consist of a growing material placed over a waterproofing membrane on a relatively flat roof. Green roofs not only provide an attractive roofing option but also use evapotranspiration to reduce runoff volume, and provides some detention storage. Green roofs may reduce some pollutants from the rainwater as well, they usually are significant sources of phosphorus due to leaching from the growing media. In addition, they can create habitats for wildlife and help to lower urban air temperatures, and also positively influence the temperature of the building itself. There are two types of green roofs, extensive and intensive. An extensive green roof has low-lying plants designed to provide maximum ground cover, water retention, erosion resistance, and transpiration of moisture. In Can Tho, 46 619 buildings are affected by pluvial and fluvial flooding. It is intended to establish green roofing on at least 5% of these buildings, which represents 2 330 buildings that are subject to harvest rainwater and to mitigate urban heat island effects through evapotranspiration. The average rooftop surface area of these buildings is 46.2 square meters.

Total Cost (USD)	3 435 119		
Implementation Time	3 – 4 years	Complexity	Medium
Life Span	40 years	Maintenance	Medium
Hazard	Pluvial-fluvial floods & heat wave	Type of measure	Hybrid

13. Green spaces (Urban forestry)

Urban forestry can be described as the science and art of managing trees, forests and natural ecosystems in and around urban communities to maximise the physiological, sociological, economic and aesthetic benefits that trees provide society. It is distinct from arboriculture and horticulture, and considers the cumulative benefits of an entire tree population across a town or city. Urban forests provide critical ecosystem services such as air and water filtration, shade, habitat, oxygen, carbon sequestration, and nutrient cycling. Urban forests also provide a connection to nature that is often perceived to be missing in urban areas. The introduction of urban forestry, will contribute to both, flood and heat wave mitigation. Tree canopies and root systems reduce stormwater flows and nutrient loads that end up in waterways. Tree canopies intercept and mitigate the impact of heavy rainfalls. In Can Tho, 416 hectares of green spaces have been identified. These green spaces already exist and will be subject for enrichment planting with tree species. It is assumed that 45% of the total area is suitable for re- and afforestation purposes. This means, out of 416 hectares of green spaces, 187.2 hectares will be used for reforestation purposes.

Total Cost (USD)	1 525 341		
Implementation Time	2 – 3 years	Complexity	Low
Life Span	>50 years	Maintenance	Medium
Hazard	Pluvial-fluvial, tidal floods & heat wave	Type of measure	NbS

14. White Roofs

A potential measure to mitigate overheating and to decrease urban temperatures are so-called ‘White Roofs’ also referred to as ‘Cool Roofs’. The basic principle of this measure is based on the reflection of sunlight. The materials that comprise most city buildings and especially their roofs reflect much less solar radiation than the vegetation they have replaced. Reflective ‘white’ roofs have a higher albedo (i.e. sunlight reflectivity) compared with ordinary roofs, which increases the amount of reflected solar radiation. They reflect incoming solar radiation more efficiently than darker roofs, reducing the amount of heat that is absorbed by the rooftop and the building itself and ultimately transferred to the atmosphere. This potentially reduces urban daytime temperatures, and building energy consumption for cooling demand. Besides the direct impacts of ‘white’ roofing strategies, there are also some indirect benefits. For residential buildings without air conditioning, ‘white’ roofs can provide an important public health benefit during heat waves. The annual decrease in cooling electricity consumption can cause cost savings from downsizing cooling equipment. At building scale, the application of cool materials results in the reduction of cooling energy use and peak energy demand for cooling, as less heat is transferred from the cooler roof into the building. It is intended to introduce 'white' roofing to at least 20% of all available roof surfaces with elastomeric coatings.

Total Cost (USD)	2 658 463		
Implementation Time	2 – 3 years	Complexity	Low
Life Span	5-10 years	Maintenance	Low
Hazard	Heat wave	Type of measure	Grey

15. Cooling centres

To protect vulnerable groups against heat waves, so-called 'Cooling Centres' being established in periods of extreme urban heat. Cooling centres (or 'cooling shelters') are typically air-conditioned or cooled buildings that have been designated as a site to provide respite and safety during extreme heat. This may be a government-owned (public) building such as a library or school, an existing community centre, religious centre, recreation centre, or a private business such as a coffee shop, shopping mall, or movie theatre. Cities must promote awareness of the locations of these centres ahead of, and during, a heat wave, for example by using billboards, phone applications, or text messages. Cities can also map these using online platforms. During power outages, centres can be opened to provide public information, charging stations for electronic devices, and power for medical equipment. Cooling centres may be operated by a health department, city government, non-profit groups, or a combination of agencies and/or partners. Generally, cooling centres are a relatively low-cost strategy that can utilize existing infrastructure and personnel and are relatively easily implemented. It is intended to establish at least 10 cooling centres in the study area. With respect to the population count per district, this would mean for Ninh Kieu five centres, for Binh Thuy three centres and for Cai Rang two centres. The centres should be accessible to the vulnerable population with an age above 65 (ca. 8%, 44 152 people). It is advised to involve 'local emergency managers' who will manage the lists of identified official cooling centres.

Total Cost (USD)	4 439 100		
Implementation Time	<1 year	Complexity	Low
Life Span	1 year	Maintenance	Low
Hazard	Heat Wave	Type of measure	Systemic

16. Climate smart agriculture

Climate smart agricultural practices are being introduced to orchards and triple rice systems: (1) *Intercropping.* Intercropping in fruit orchards allows improved heat stress management and aims to regulate microclimate and soil moisture content. The development of intensive fruit tree production systems with intercropped vegetable crops (preferably legumes such as peanut, *Arachis pintoi*, etc., due to N-fixation) is recommended, as well as the development of sub-urban vegetables or flower and fruit tree farming areas for domestic consumption and agro-eco-tourism attraction. (2) *Smart water and irrigation management.* The need to improve the efficiency of agricultural water use has become a necessity in addressing periods of extreme heat and droughts, especially in the Mekong Delta and specifically in Can Tho, with crucial agricultural export markets. Hence, this intervention proposes piped irrigation systems such as drip or sprinkler irrigation systems that support traditional open canal flood irrigation systems and aim to use water supply more efficiently and precisely for high-value fruit crops. (3) *Alternate wetting and drying (AWD).* More efficient water management practices are needed so that rice production levels can still be maintained or increased even with the use of less irrigation water. One form of a water-saving technique is alternate wetting drying. AWD is an irrigation technique where intermittent periods of submergence occurred during the growing stages of rice. This is in contrast to the traditional irrigation practice of continuous flooding. This means that the rice fields are not kept continuously submerged but are allowed to dry intermittently during the rice-growing stage. (4) *Diversification of rice cropping systems with non-rice crops.* This climate smart intervention generally consists of replacing one or two rice cycles in the annual succession by other types of production. These alternatives could consist of other crops, for example, upland annual and/or perennial species, or could include the integration with aquaculture or other breeding activities.

Total Cost (USD)	1 980 250		
Implementation Time	1 – 30 years	Complexity	Medium
Life Span	>30 years	Maintenance	Medium
Hazard	Heat Wave	Type of measure	Hybrid

17. Climate proofed road design

This measure introduces so-called ‘cool’ pavements which are surfaces that aim to reduce both surface and air temperatures, hence mitigating the heat island effect in periods of extreme heat. These pavement are light-coloured and have a high solar reflectance (also called albedo). They reflect the sun’s radiation rather than storing it. It is advised to apply strategies for existing pavements, hence using so-called surface applications that can be applied to existing conventional asphalt or concrete surfaces. Surface treatments can also help to extend the road's service life by reducing the rate of deterioration. Two different surface applications should be applied. The first one is ‘Chip seals with light aggregate’ for roads with relatively low traffic volumes, and secondly, the surface application called ‘Whitetopping’, preferably for roads with high traffic volumes, such as street intersections, bus lanes, highways where rutting and shoving of asphalt surfaces is a predominant problem.

Total Cost (USD)	1 980 250		
Implementation Time	2 – 3 years	Complexity	Low
Life Span	8 – 15 years	Maintenance	Low
Hazard	Heat Wave	Type of measure	Grey

5.3 Overview of Costs

***Table 12:** Overview of all measures applied in Can Tho incl. location. The total cost until the year 2050 (incl. construction & maintenance) and the targeted hazard (pluvial-fluvial and/or tidal or heat wave) are listed.*

Can Tho			
Measure	Zone 1, 2, 3 (Districts)	Total Cost in USD (for 30 years, incl. construction & maintenance)	Hazard
1. Retention Reservoirs	1 and 3	1 150 825	pluvial-fluvial, tidal
2. Detention swales along roads	1, 2, and 3	3 554 522	pluvial-fluvial, tidal
3. Improved solid waste management	1, 2, and 3	1 566 192	pluvial-fluvial, tidal
4. Rehabilitation of existing drainage canals	1, 2, and 3	3 185 343	pluvial-fluvial, tidal
5. Flood awareness campaign	1, 2, and 3	1 165 758	pluvial-fluvial, tidal
6. Road spillways as bio-retention systems	1, 2, and 3	9 414 001	pluvial-fluvial, tidal
7. Rain collection tanks for existing buildings	1, 2, and 3	222 999	pluvial-fluvial
8. Mobile flood embankments	1, 2, and 3	1 719 204	pluvial-fluvial, tidal
9. Flood wall	3	7 380 000	pluvial-fluvial, tidal
10. Flood protection storage facility (incl. sandbags)	1, 2, and 3	921 557	pluvial-fluvial, tidal
11. Green Roofs	1, 2, and 3	3 435 565	pluvial-fluvial, heat wave
12. Green spaces (Urban Forestry)	1, 2, and 3	1 525 341	pluvial-fluvial, tidal, heat waves
13. White Roofs	1, 2, and 3	2 658 463	heat wave
14. Cooling centres	1, 2, and 3	4 439 100	heat wave
15. Climate smart agriculture	1, 2, and 3	9 600 000	heat wave
16. Climate proofed standards for road design ('Cool' pavements)	1, 2, and 3	1 980 250	heat wave
17. Index Insurance	1, 2, and 3	(2 200 000 per year/flood) (500 000 per year heat wave)	pluvial-fluvial, tidal, heat waves
TOTAL[89]		53 919 120	all

[89] Excluding costs for Index Insurance

District (Zone)	Total Cost in USD (for 30 years, incl. construction & maintenance)
Binh Thuy (1)	13 479 780
Ninh Kieu (2)	16 714 927
Cai Rang (3)	23 724 413
TOTAL	53 919 120

6. Results

6.1 Introduction

In this section, results from CLIMADA are presented and show i) the annual expected damage for different scenarios, ii) a cost-benefit analysis of selected measures for inundation (Fluvial/Pluvial and Tidal) and heat wave and iii) a comparison of measures according to their mitigation effect in Can Tho.

In the previous sections, asset values and population estimation have been presented and discussed thoroughly. Further, different climate and socio-economic scenarios have been introduced. Last, a list of measures, specific to the study region and dedicated to mitigation of inundation and heat wave risk have been designed and parameterized into CLIMADA. This data was processed by CLIMADA against the information described below.

In the ECA Methodology, the benefit of a given adaptation measure reflects the expected damage that can be averted by its implementation in the future. Because all measures are described on a monetary basis, results are comparable, and the efficiency of each measure (in terms of impact or investment) can be quantified. In doing so, a set of "best" measures can be considered for a feasibility study, prior to investment.

6.2 Flood Risk

Can Tho's topography ranges between 0.6 to 1.2 m above sea level.[90] The central region of the Delta around Can Tho faces every year seasonal flooding events, often caused and influenced not only by a single flood regime but also by a combination of tidal floods from the sea, riverine floods from the upstream Mekong (fluvial flood) and strong precipitation (pluvial floods).[91,92] This section presents the expected damages and the ranking of adaptation measures for tidal and pluvial/fluvial risks separately.

6.2.1 Annual Expected Damage

Annual expected damage represents the damage expected on assets and people in Can Tho on average annually. This annual expected damage is the percentage, or absolute value of asset or persons affected by the set of extreme events. The set of extreme events, or the value of assets or number of persons can be affected by climate change and socio-economic scenarios. Figure 52 and Figure 53 show annual expected damage in Can Tho for assets in USD (graph a and b) and for people (graph c and d). The first bar (today) in yellow represents annual expected damage today. The second bar (economic development) represents the increase of the expected annual damage over the next 30 years due to economic development (for persons, it represent the population growth). The light red bar represents the additional

[90] Siddiqua, A. (2019) Emergence of Water Urbanism for Water Born "Can Tho". *Journal of Water Resource and Protection*, 11, 166-180.

[91] Do, T.C., Nguyen, D., Gain, A.K., Kreibich, H. (2017): Flood Loss Models and Risk Analysis for Private Households in Can Tho City, Viet Nam. - Water, 9, 5.

[92] Hung, N.N.; Degado, J.M.; Tri, V.K.; Apel, H. Floodplain hydrology of the Mekong delta, Viet Nam. Hydrol. Processes 2012, 26, 674–686.

annual expected damage due to climate change in Vietnam. Last, the red bar represents the total aggregated expected annual damage in 2050, when economic growth (and population growth) and climate change are considered.

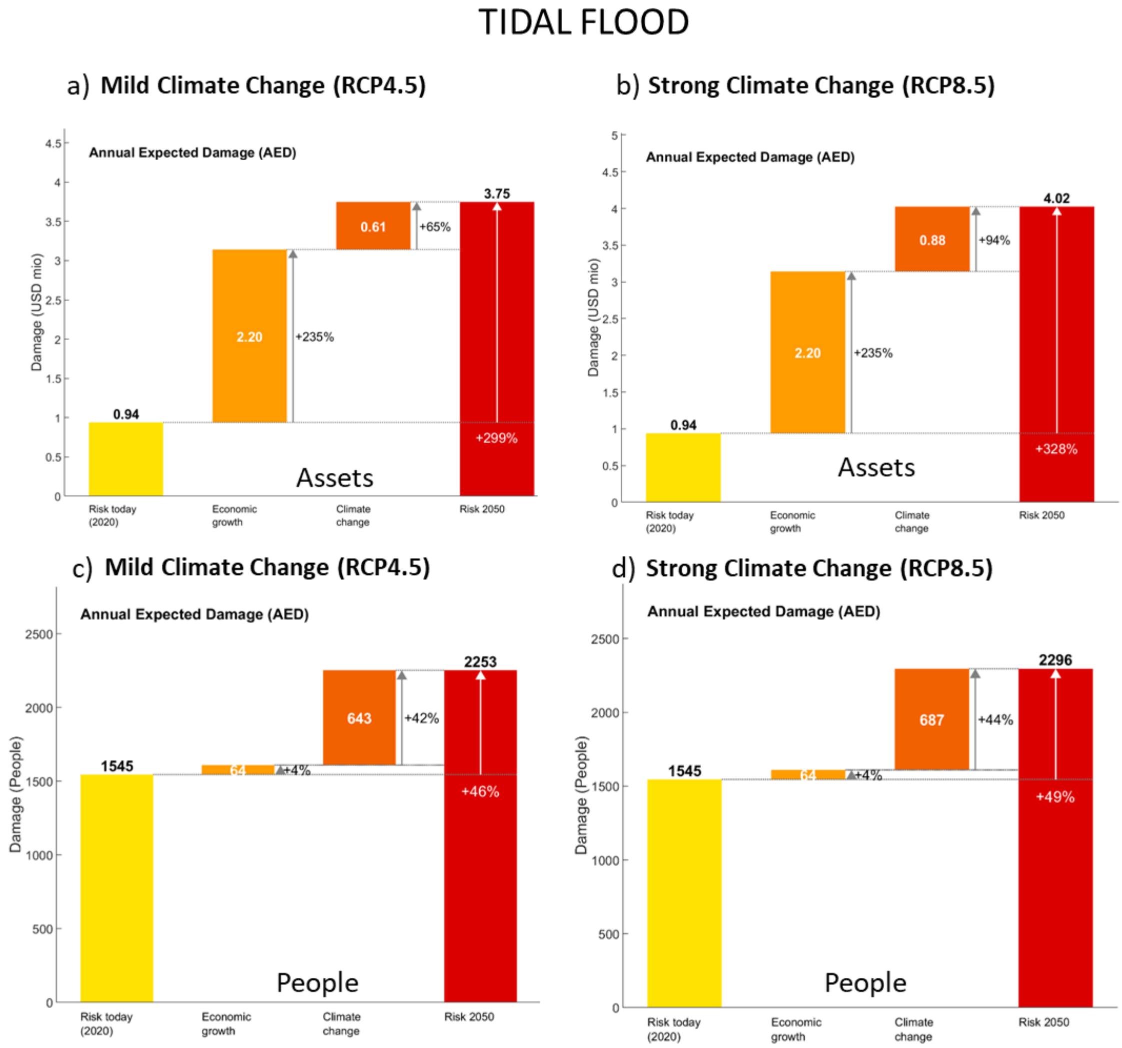

Figure 52: *Annual expected damage (AED) for Tidal Flood in Can Tho for Assets (graphs a & b in USD) and People affected (graph c & d in people).*

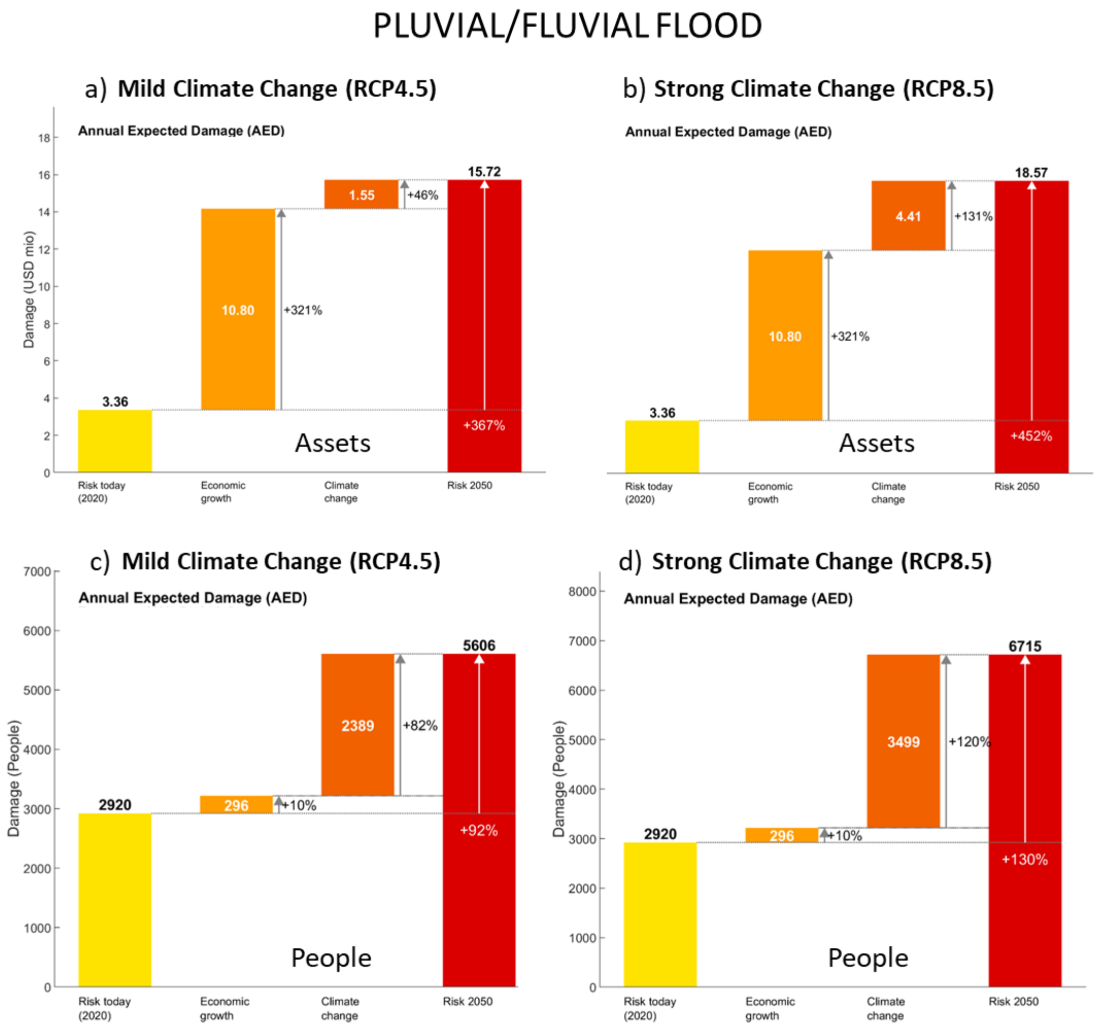

Figure 53: *Annual expected damage (AED) for Pluvial fluvial flood in Can Tho for Assets (graph a & b in USD) and people affected (graph c & d in people).*

Annual damage for assets and persons are summarized in Table 13 and Table 14. Results are presented for all scenarios separately and aggregated with today's expected damage. Today is set in 2020 in alignment with discussions with stakeholders.

Tidal Flood Risk: In Can Tho, the total expected damage from Tidal flood for assets of USD 940k (2020) is expected to rise to 235% due to the strong economic growth and of 65% due to climate change (94% with extreme climate scenario). A total of USD 3.7m (USD 4m for extreme climate change scenario) are simulated for the time horizon 2050. The increase in annual expected damage in 2050 represents a raise of more than 300% in Can Tho, due both to economic growth (assets will be more valuable) and climate change (hazard will be more frequent and more intense). This large increase is mostly reflected by a strong economic growth prediction. In addition, flood events are expected to worsen in the coming decades. Regarding the population, more than 1500 people are expected to be affected by flood annually in 2020. In line with a relatively low population growth in the area, an increase of 4% is expected in the future. More intensive climate, in return is expected to affect more persons with an increase of 42% for a moderate climate and 44% for extreme climate. A total of 2253 people (2,296 for extreme climate) are expected to be affected annually in 2050, i.e. an increase of 46% and 49% compared to 2020.

***Table 13:** Summary of annual expected damages in Can Tho for different scenarios (Tidal Flood).*

ID	Asset Categories	Units	Total Value	AED Today (AED1) (USD/PPL and % of total value)		AED1+ Economic Growth (USD/PPL and % of total value)		AED total Moderate Climate Change (USD/PPL and % of total value)		AED total Extreme Climate Change	
101	People	PPL	167 575	1 545	*0,92%*	1 610	*0,96%*	2 253	*1,34%*	2 296	*1,37%*
201	Housing	USD	275 363 106	8 3643	*0,03%*	33 1577	*0,12%*	394 686	*0,14%*	447 109	*0,16%*
301	Education Facilities	USD	55 499 831	94 756	*0,17%*	32 0859	*0,58%*	325 563	*0,59%*	339 012	*0,61%*
302	Medical Centres	USD	29 973 638	4 732	*0,02%*	19 078	*0,06%*	31 155	*0,10%*	37 428	*0,12%*
303	Admin. Buildings	USD	6 189 630	9 887	*0,16%*	29 293	*0,47%*	33 215	*0,54%*	34 809	*0,56%*
401	Electrical Grid	USD	4 374 857	7 441	*0,17%*	21 051	*0,48%*	23 143	*0,53%*	23 866	*0,55%*
501	Road Network	USD	604 363 201	57 5242	*0,10%*	1 890 685	*0,31%*	2 316 069	*0,38%*	2 483 437	*0,41%*
601	Aquaculture	USD	21 350 554	21 066	*0,10%*	85 146	*0,40%*	102 321	*0,48%*	118 378	*0,55%*
602	Cash Crops	USD	1 312 642	2 368	*0,18%*	7 319	*0,56%*	7 838	*0,60%*	8 181	*0,62%*
603	Orchards	USD	87 207 351	139 264	*0,16%*	433 656	*0,50%*	506 860	*0,58%*	523 855	*0,60%*
604	Rice	USD	1 706 932	722	*0,04%*	2 906	*0,17%*	6 347	*0,37%*	7 397	*0,43%*
701	Green Spaces	USD	264 362	136	*0,05%*	467	*0,18%*	671	*0,25%*	713	*0,27%*
All Assets		USD	1 087 606 102	939 257		3 142 036		3 747 869		4 024 186	
Persons		PPL	167 575	1 545		1 610		2 253		2 296	

Pluvial/Fluvial Floods: In Can Tho, the total expected damage from pluvial and fluvial flood combined for assets of USD 3.3m (2020) is expected to rise to 321% due to the strong economic growth and of 46% due to climate change (131% with extreme climate scenario). A total of USD 15.7m (USD 18.7m for extreme climate change scenario) are simulated for the time horizon 2050. The increase in annual expected damage by 2050 represents a raise of more than 360% in Can Tho, due both to economic growth (assets will be more valuable) and climate change (hazard will be more frequent and more intense). This large increase is mostly reflected by a strong economic growth prediction. In addition, flood events are expected to worsen in the coming decades. Regarding the population, more than 2920 people are expected to be affected by flood annually in 2020. In line with a relatively low population growth in the area, based on the analysis the number of people expected to be affected will increase by 10% in the future. More intensive climate, in return is expected to affect more persons with an increase of 82% for a moderate climate and 120% for extreme climate. A total of 5600 people (6700 for extreme climate) are expected to be affected annually in 2050, i.e. an increase of 92% and 130% compared to 2020.

Table 14: *Summary of annual expected damages in Can Tho for different scenarios (Pluvial/Fluvial Flood).*

ID	Asset Categories	Units	Total Value	AED Today (AED1) (USD/PPL and % of total value)		AED1+ Economic Growth (USD/PPL and % of total value)		AED total Moderate Climate Change (USD/PPL and % of total value)		AED total Extreme Climate Change	
101	People	PPL	16 7575	2 920	*1,74%*	3 217	*1,92%*	5 606	*3,35%*	6 715	*4,01%*
201	Housing	USD	27 536 3106	1 014 221	*0,37%*	4 088 976	*1,48%*	4 186 799	*1,52%*	4 863 981	*1,77%*
301	Education Facilities	USD	55 499 831	267 074	*0,48%*	1 076 747	*1,94%*	1 385 943	*2,50%*	1 659 910	*2,99%*
302	Medical Centres	USD	29 973 638	26 841	*0,09%*	108 215	*0,36%*	257 976	*0,86%*	328 783	*1,10%*
303	Admin. Buildings	USD	6 189 630	34 905	*0,56%*	140 723	*2,27%*	152 780	*2,47%*	177 593	*2,87%*
401	Electrical Grid	USD	4 374 857	13 030	*0,30%*	52 533	*1,20%*	52 265	*1,19%*	62 580	*1,43%*
501	Road Network	USD	604 363 201	1 840 585	*0,30%*	7 420 583	*1,23%*	7 513 325	*1,24%*	8 654 755	*1,43%*
601	Aquaculture	USD	21 350 554	23 580	*0,11%*	474 592	*2,22%*	710 267	*3,33%*	986 432	*4,62%*
602	Cash Crops	USD	1 312 642	1 233	*0,09%*	17 309	*1,32%*	35 971	*2,74%*	46 831	*3,57%*
603	Orchards	USD	87 207 351	137 031	*0,16%*	766 402	*0,88%*	1 369 020	*1,57%*	1 724 637	*1,98%*
604	Rice	USD	1 706 932	2 844	*0,17%*	11 465	*0,67%*	44 472	*2,61%*	57 262	*3,35%*
701	Green Spaces	USD	264 362	1 616	*0,61%*	6 514	*2,46%*	8 021	*3,03%*	9 452	*3,58%*
All Assets		USD	1 087 606 102	3 362 959		14 164 061		15 716 845		18 572 222	
Persons		PPL	167 575	2 920		3 217		5 606		6 715	

To better define the location of each measure a zoning of the study area has been introduced. Adaptation measures have been allocated to the three urban districts of Can Tho, representing Zone 1, 2 and 3. A map of the different zones, which correspond the study area of the three urban districts is shown in Figure 54.

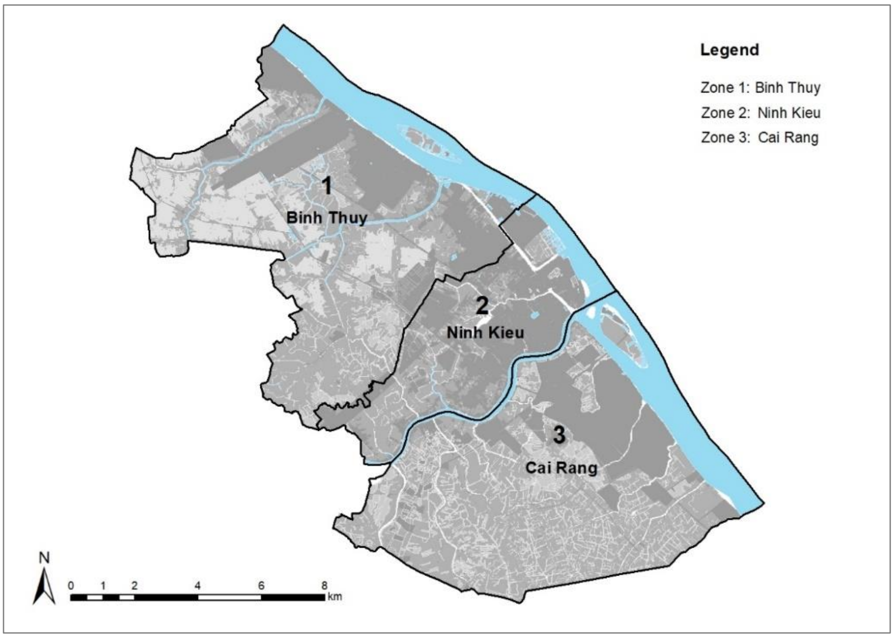

Figure 54: *Overview of zoning. Zones correspond to the study areas' district boundaries. Source: UNU-EHS.*

In order to validate these results against existing events, the annual expected damage (AED) for Can Tho was compared to damage from previous large flood events. Information about historical events can be found in the open-source EM-DAT data base.[93] Table 15 offers an overview of the last 58 years on record for flood events in Vietnam. Tidal and pluvial/fluvial flood historical events have been presented separately and span different periods.

Although EM-DAT is an internationally recognized compilation of disaster damages, some local sources propose different figures[94] for overall damages for certain events, which were included in our database. A household survey from 2009, conducted in the urban centre, i.e. Ninh Kieu district (Zone 2), found that the total annual economic losses caused by flooding during the year 2008 was VND 13.5m (approximately USD 640) per household. With a mean annual income of VND 121m (approximately USD 5800), the percentage of economic losses due to flooding in a household's income was approximately 11% per year.[95] It should be noted that a large amount (90%) of households' economic losses were indirect costs during a flood event, including own labour, missed work and lost revenues.[96] Henceforth, 11% is likely to be an overestimated value. In a more recent study[97], findings suggest a more realistic estimation of 2.5% of household income for AED in Can Tho. It adds to USD 3.3m of AED for pluvial and

[93] http://www.emdat.be/country_profile/index.html
[94] Oxfam (2011) Briefing on the Horn of Africa Flood 2011, Disaster risk reduction. Oxfam. 17pp
[95] Vo, D. T. (2018). Household economic losses of urban flooding: case study of Can Tho City, Viet Nam. *Southeast Asia Review of Economics and Business*, 1(1).
[96] Ibid.
[97] Chinh DT, Dung NV, Gain AK, Kreibich H. Flood Loss Models and Risk Analysis for Private Households in Can Tho City, Viet Nam. *Water*. 2017; 9(5):313. https://doi.org/10.3390/w9050313

fluvial flood. Because of very few entries available with EM-DAT for the city of Can Tho, we suggest to use this figure as an orientation for pluvial fluvial flood calibration. For tidal flood, with extremely little literature available, we propose to compare our calibration results with the EM-DAT.

Table 15: *Flood events in Vietnam from the EM-DAT international disaster database.*

Year	Disaster Subtype	Country	Total Affected	Total Damages (USD m)
1992	Tidal flood	Vietnam	58 000	-
1999	Tidal flood	Vietnam	3 504 412	237 000
2001	Tidal flood	Vietnam	3 000	-
2003	Tidal flood	Vietnam	221 774	32 000
2007	Tidal flood	Vietnam	416 130	130 000
2007	Tidal flood	Vietnam	150 000	350 000
1964	Pluvial/Fluvial flood	Vietnam	195 902	10 000
1978	Pluvial/Fluvial flood	Vietnam	4 079 000	-
1985	Pluvial/Fluvial flood	Vietnam	2 800 000	-
1986	Pluvial/Fluvial flood	Vietnam	-	-
1990	Pluvial/Fluvial flood	Vietnam	10 200	725
1991	Pluvial/Fluvial flood	Vietnam	4 014	3 200
1991	Pluvial/Fluvial flood	Vietnam	2 706 00	5 000
1991	Pluvial/Fluvial flood	Vietnam	21 000	38 500
1992	Pluvial/Fluvial flood	Vietnam	51 698	47 700
1994	Pluvial/Fluvial flood	Vietnam	382 000	206 000
1995	Pluvial/Fluvial flood	Vietnam	400 000	86 000
1996	Pluvial/Fluvial flood	Vietnam	375 000	138 000
1998	Pluvial/Fluvial flood	Vietnam	32 505	13 700
1999	Pluvial/Fluvial flood	Vietnam	2 163 694	53 000
2000	Pluvial/Fluvial flood	Vietnam	5 000 004	250 000
2000	Pluvial/Fluvial flood	Vietnam	25 003	15000
2001	Pluvial/Fluvial flood	Vietnam	1 570 270	84 000
2002	Pluvial/Fluvial flood	Vietnam	2 000	2 200
2002	Pluvial/Fluvial flood	Vietnam	1 138 200	23 900
2002	Pluvial/Fluvial flood	Vietnam	291 616	58 000
2003	Pluvial/Fluvial flood	Vietnam	194 049	35 000
2003	Pluvial/Fluvial flood	Vietnam	1 000	38 000
2004	Pluvial/Fluvial flood	Vietnam	30 000	-
2004	Pluvial/Fluvial flood	Vietnam	5 000	-
2005	Pluvial/Fluvial flood	Vietnam	18 000	27 000
2005	Pluvial/Fluvial flood	Vietnam	593	-
2005	Pluvial/Fluvial flood	Vietnam	30 000	-

2005	Pluvial/Fluvial flood	Vietnam	10 000	15 000
2006	Pluvial/Fluvial flood	Vietnam	50 020	8 000
2006	Pluvial/Fluvial flood	Vietnam	-	-
2006	Pluvial/Fluvial flood	Vietnam	-	-
2007	Pluvial/Fluvial flood	Vietnam	22 000	10 000
2007	Pluvial/Fluvial flood	Vietnam	94 042	300 000
2008	Pluvial/Fluvial flood	Vietnam	-	-
2008	Pluvial/Fluvial flood	Vietnam	600 000	479 000
2008	Pluvial/Fluvial flood	Vietnam	20 000	-
2009	Pluvial/Fluvial flood	Vietnam	700 000	-
2009	Pluvial/Fluvial flood	Vietnam	40 000	-
2010	Pluvial/Fluvial flood	Vietnam	761 000	154 000
2010	Pluvial/Fluvial flood	Vietnam	39 008	107 700
2010	Pluvial/Fluvial flood	Vietnam	10 000	256 000
2011	Pluvial/Fluvial flood	Vietnam	300 000	44 000
2011	Pluvial/Fluvial flood	Vietnam	600 000	175 002
2011	Pluvial/Fluvial flood	Vietnam	461 584	-
2012	Pluvial/Fluvial flood	Vietnam	17 540	30 000
2013	Pluvial/Fluvial flood	Vietnam	-	-
2013	Pluvial/Fluvial flood	Vietnam	1 000	-
2013	Pluvial/Fluvial flood	Vietnam	5 000	6 500
2013	Pluvial/Fluvial flood	Vietnam	-	-
2013	Pluvial/Fluvial flood	Vietnam	25 000	-
2013	Pluvial/Fluvial flood	Vietnam	2 130 001	72 000
2016	Pluvial/Fluvial flood	Vietnam	659 615	104 280
1964	Pluvial/Fluvial flood	Vietnam	-	-
1970	Pluvial/Fluvial flood	Vietnam	204 000	-
1980	Pluvial/Fluvial flood	Vietnam	628 000	-
1984	Pluvial/Fluvial flood	Vietnam	38 000	-
1996	Pluvial/Fluvial flood	Vietnam	-	13 400
2001	Pluvial/Fluvial flood	Vietnam	175	-
2007	Pluvial/Fluvial flood	Vietnam	280 000	-
2015	Pluvial/Fluvial flood	Vietnam	100	-
2016	Pluvial/Fluvial flood	Vietnam	562 121	35 000
2016	Pluvial/Fluvial flood	Vietnam	206 340	22 000
2016	Pluvial/Fluvial flood	Vietnam	509	-
2017	Pluvial/Fluvial flood	Vietnam	4 104	355

2017	Pluvial/Fluvial flood	Vietnam	400	1 300
2017	Pluvial/Fluvial flood	Vietnam	40 038	88 000
2017	Pluvial/Fluvial flood	Vietnam	41 500	-
2018	Pluvial/Fluvial flood	Vietnam	6 000	-
2019	Pluvial/Fluvial flood	Vietnam	265	-
2019	Pluvial/Fluvial flood	Vietnam	26 255	-
2019	Pluvial/Fluvial flood	Vietnam	61 540	-
2019	Pluvial/Fluvial flood	Vietnam	36 450	-

Tidal Flood Calibration: Table 16 summarizes historical events over the last decades in Vietnam. Only Tidal Flood will be considered in our analysis. Damages due to flood over the last 16 years average USD 749, a figure possibly underestimated, due to the lack of records in EM-DAT (6 records in 16 years). Due to the lack of alternative sources, we suggest to use this figure for comparing the model performance. AED for Can Tho is derived based on the respective GDP and population ratio of the Can Tho districts considered in this study. With USD 0.94m AED and over 1500 persons affected for its "today" scenarios, CLIMADA is in strong agreement with these figures.

***Table 16:** Annual damage calculation for tidal floods in Can Tho.*

Catastrophe Type	Total damage per catastrophe type (USD m/people)		
	Accumulated (16 years)	AED Vietnam	Can Tho
Tidal Flood (USD m)	749	47	0.936
Tidal Flood (people)	4 353 316	272 082	1 551

Pluvial/Fluvial Flood Calibration: Table 17 summarizes historical events over the last decades in Vietnam. Only Pluvial/Fluvial Flood will be considered in our analysis. Damages due to flood over the last 58 years average USD 3665m, AED for Can Tho is derived based on the respective GDP and population ratio of the Can Tho districts considered in this study. Due to relatively few data in the districts of Can Tho, we suggest to consider the findings of a recent study[98], estimating AED in Can Tho to USD 3.3m for pluvial and fluvial flood. With USD 3.36m AED and over 2920 persons affected for its "today" scenarios, CLIMADA is in strong agreement with these figures.

[98] Chinh DT, Dung NV, Gain AK, Kreibich H. Flood Loss Models and Risk Analysis for Private Households in Can Tho City, Viet Nam. *Water*. 2017; 9(5):313. https://doi.org/10.3390/w9050313

Table 17: *Annual damage calculation for pluvial/fluvial floods in Can Tho.*

Catastrophe Type	Total damage per catastrophe type (USD m/people)		
	Accumulated (58 years)	AED Vietnam	Can Tho (3 Districts)
Pluvial/Fluvial Flood (USD m)	3 665	126	2.52
Pluvial/Fluvial[99]	-	-	3.3
Pluvial/Fluvial Flood (people)	28 810 573	496 734	2 920

6.2.2 Cost Benefit Analysis (TIDAL and PLUVIAL/FLUVIAL risk)

In this section, the existing relationship between costs (investment costs and maintenance) and net averted damage of a given measure is analysed. In the case of climate change, net averted damage can be understood as the benefit of a measure. Therefore, this section presents a cost-benefit analysis of selected mitigation measures.

A so-called adaptation cost curve plots benefit/cost ratio (vertical axis) against aggregated averted damages (horizontal axis) for each measures. The dotted line (at value 1) represents the threshold for the benefit/cost ratio, in other words, values above it are cost efficient, where expected benefits exceed implied costs of the respective measure, and value below it are not cost efficient. On the Y axis, the larger a measure, the larger the damage averted by a measure, therefore the larger the benefit or the mitigation or adaptation impact of a measure. Hence, with this figure, each measure can be analysed in terms of mitigation/adaptation efficiency and cost efficiency and compared with one another.

TIDAL FLOOD: Figure 55 a) and b) displays impacts of measures applied to assets in Can Tho. Figure 56 a) and b) displays impacts measures applied to persons as in 2050 under moderate and extreme climate scenarios. In the case of flood risk, a large number (13) of measures were selected for the cost benefit analysis. Low cost infrastructural measures, such as “Mobile flood embankments” (20% reduction of total climate risk)[100] or “Rehabilitation of Drainage” (20% reduction of total climate risk) are efficient in terms of averted damage, and show a good cost/benefit ratio for each invested dollar. In Figure 55 b), for Can Tho, not all measures are cost efficient, and account altogether to more than USD 75 m of averted damage, if combined without overlapping effect and without insurance. These measures, although being cost efficient, have a low adaptation/mitigation impact with exception of “Flood wall” (32% reduction of total climate risk). Insurance for assets will be considered separately in a following section.

Figure 56 presents the impact of measures on affected persons in Can Tho for tidal flood risk. All measures, and account altogether to a reduction of almost 150,000 affected persons per invested 1000 USD. It means that the measures selected for assets have the potential to protect population at risk. Nevertheless, only three measures are cost- efficient for population, namely “Flood Awareness” (25% reduction of total climate risk), “Waste management” (32% reduction) and “Mobile flood

[99] Chinh DT, Dung NV, Gain AK, Kreibich H. Flood Loss Models and Risk Analysis for Private Households in Can Tho City, Viet Nam. *Water*. 2017; 9(5):313. https://doi.org/10.3390/w9050313
[100] For the moderate RCP45 scenario

embankments" (16% reduction). "Mobile flood embankment" and "Flood awareness" are both efficient at protecting assets and population, and they should therefore be considered.

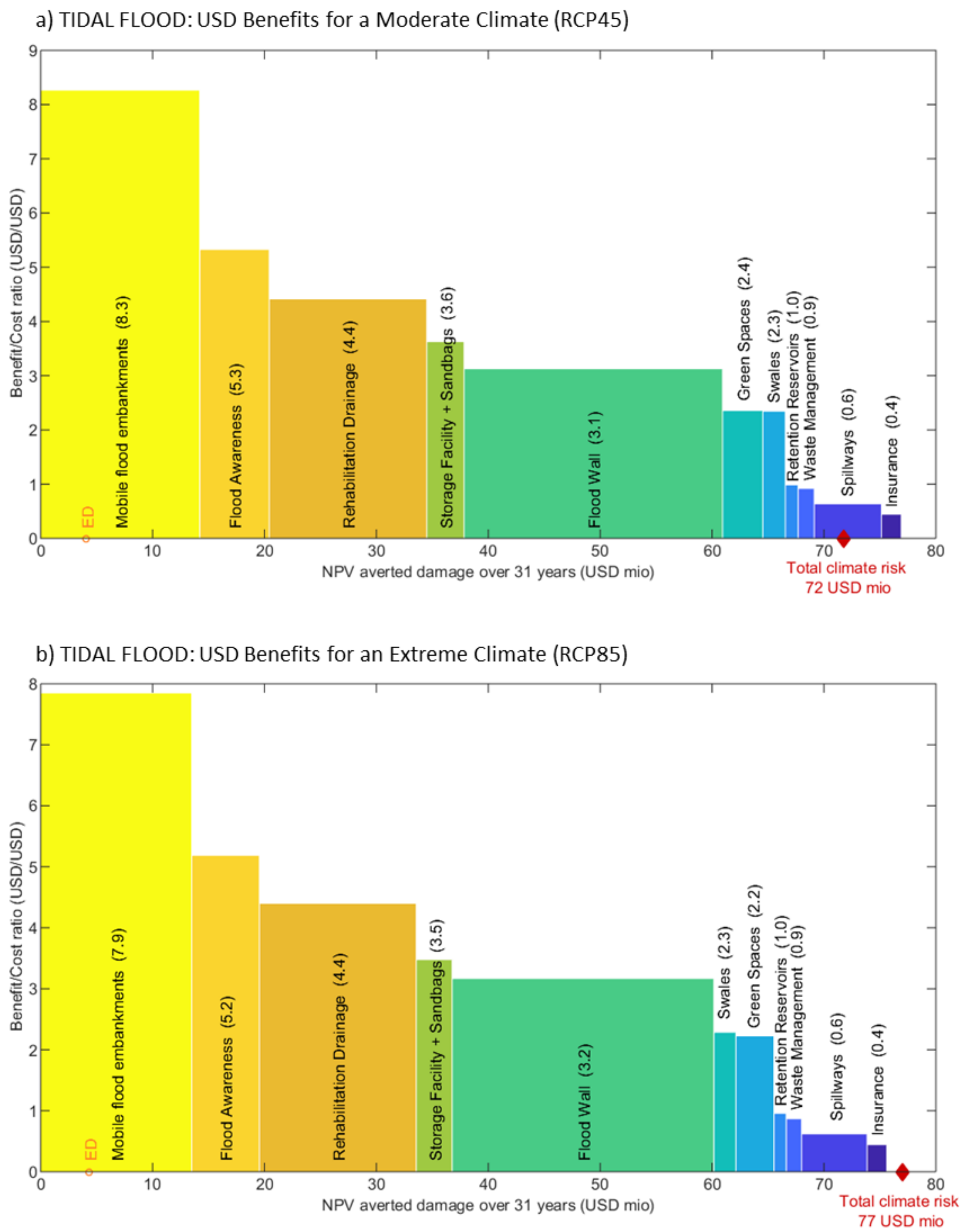

Figure 55: *Adaptation cost curve for assets damage for Tidal flood in USD a) moderate and b) extreme climate scenarios.*

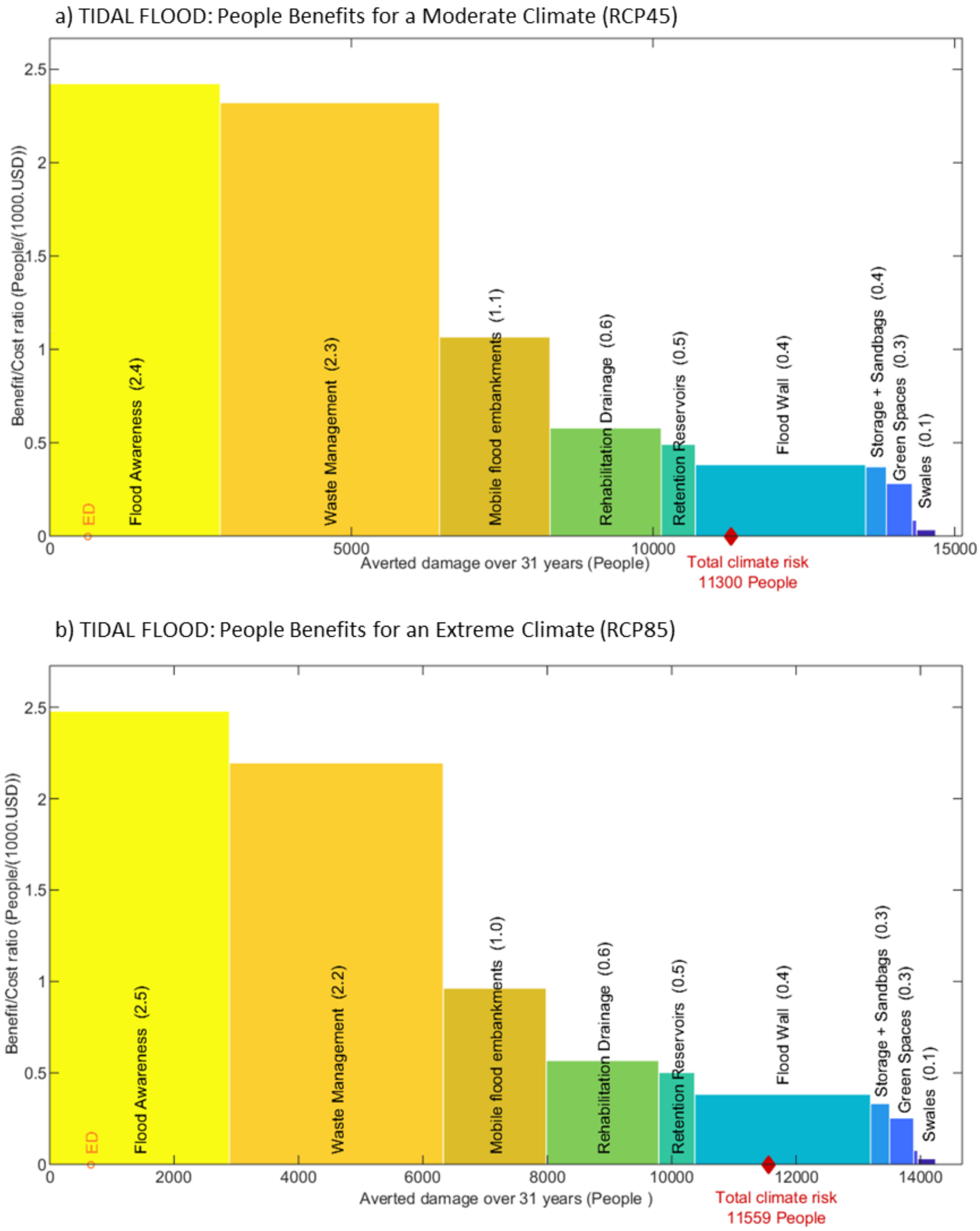

Figure 56: *Adaptation cost curve for affected persons for tidal flood a) moderate and b) extreme climate scenarios.*

PLUVIAL/FLUVIAL FLOOD: Figure 57 a) and b) displays impacts of measures applied to assets in Can Tho. Figure 58 a) and b) displays impacts measures applied to persons as in 2050 under moderate and extreme climate scenarios. In the case of pluvial/fluvial flood risk, a large number (13) of measures were selected for the cost benefit analysis. Infrastructural measures, such as "swales" (16% impact reduction for moderate scenario) and low-cost approaches such as "Mobile flood embankments" (30% impact reduction) or "Rehabilitation of Drainage" (34% impact reduction) are efficient in terms of averted damage, and show a good cost/benefit ratio for each invested dollar. In Figure 57 b), for Can Tho, all measures are cost efficient, and account altogether to more than USD 650 m of averted damage, if combined without overlapping effect and with insurance. Flood risk Insurance for assets will be considered separately in a following section. In addition, it should be mentioned that "Flood Walls" reduce expected future losses to a great extent as well (to a greater extent than e.g. swales). Yet as a flood wall is associated with less benefits for each dollar invested, this measure is less cost-effective than e.g. swales.

Figure 58 presents the impact of measures on affected persons in Can Tho for pluvial/fluvial flood risk. All measures, and account altogether to a reduction of almost 2m affected persons per invested 1000 USD. It means that measures selected for assets remain have the potential to protect population at risk. All measures but one are cost-efficient with, namely “Waste management” (12% impact reduction), “Flood Awareness” (8% impact reduction) and “Swales” (10% impact reduction) showing the highest cost-benefit ratios. “Mobile flood embankment” (10% impact reduction) is also very efficient and might be considered while discussing measures that protect both population and assets. Therefore, “Swales”, “Mobile flood embankments”, “Rehabilitation of drainage”, “Flood awareness”, and “Waste management” should be considered.

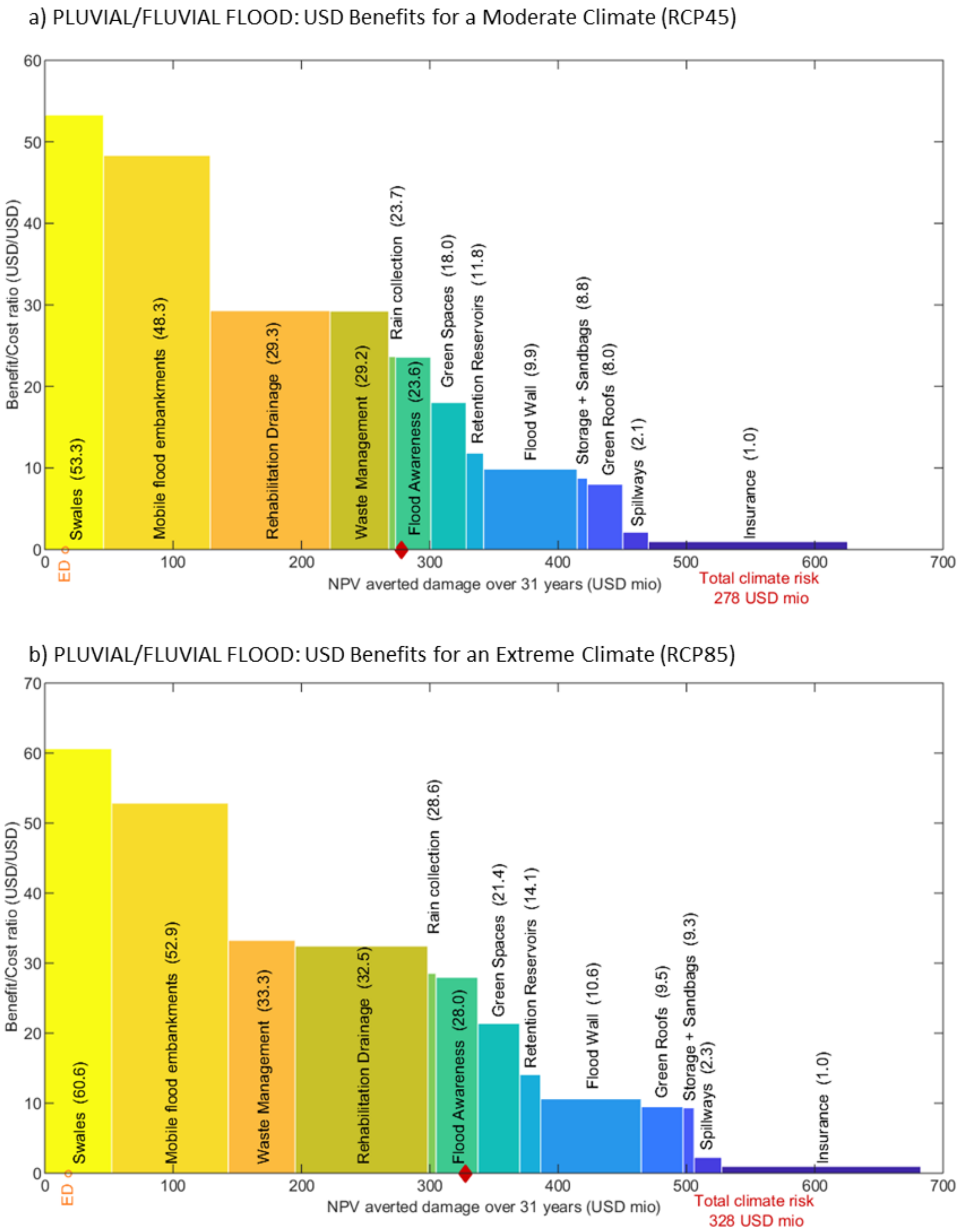

Figure 57: *Adaptation cost curve for affected assets for pluvial/fluvial flood a) moderate and b) extreme climate scenarios.*

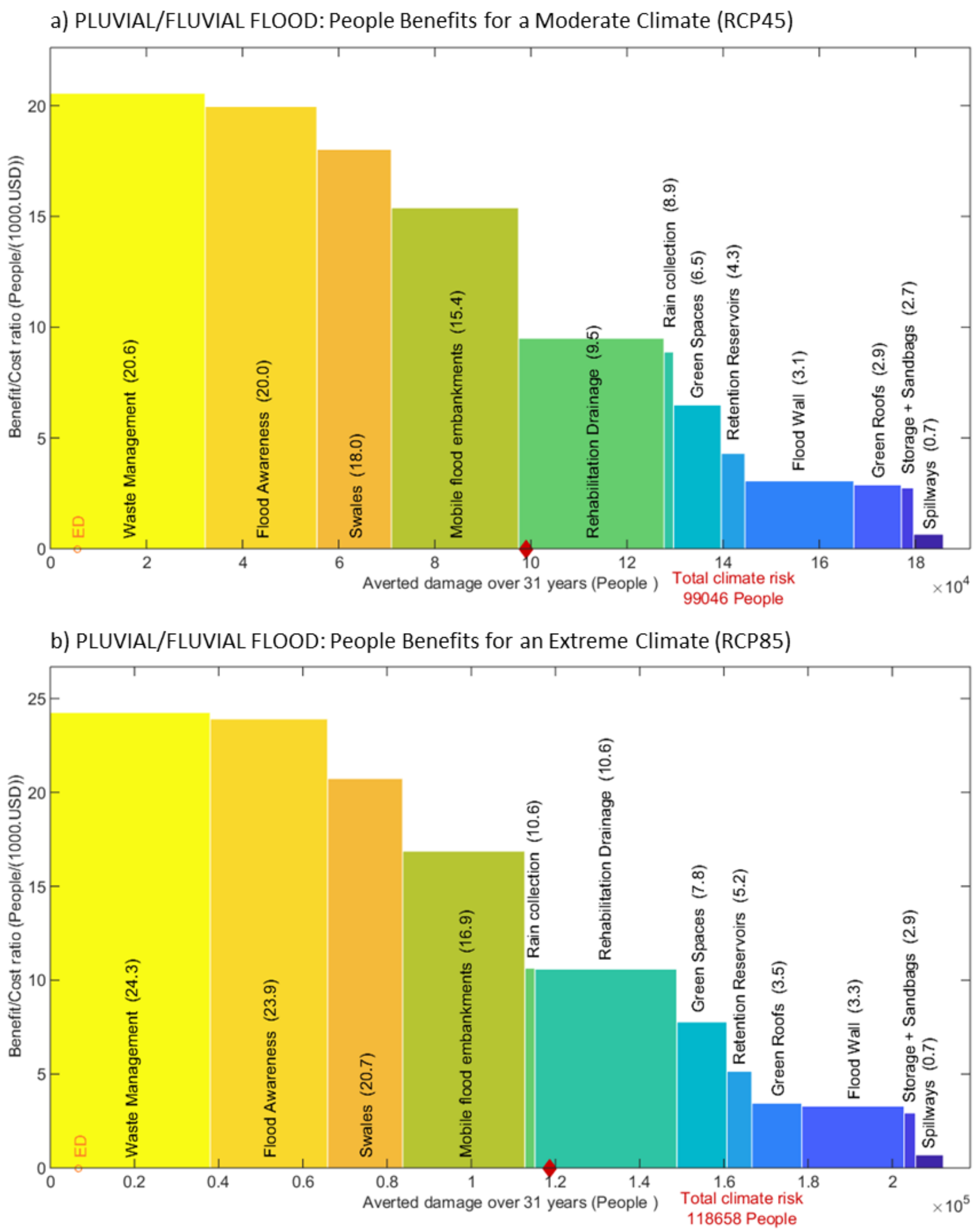

Figure 58: *Adaptation cost curve for affected persons for pluvial/fluvial flood a) moderate and b) extreme climate scenarios.*

6.2.3 Spatial Distribution of Benefits (Flood)

The figures below showcase illustrate the spatial distribution of benefits on selected assets resulting from the respective measure as indicated. Due to limitations in the hazard resolution, the highlighted areas of benefit are only indicative and not to be understood as exact locations. The benefits are presented as the annual averted damages averaged over the here relevant period of 31 years. In Figure 59 and Figure 60, for instance, the benefits of the rehabilitation of drainage for housing for tidal and pluvial fluvial floods is being displayed. It highlights that the measure can have very different benefits deepening on the location of the assets considered. The same applies to mobile flood embankments in Figure 61 and Figure 62.

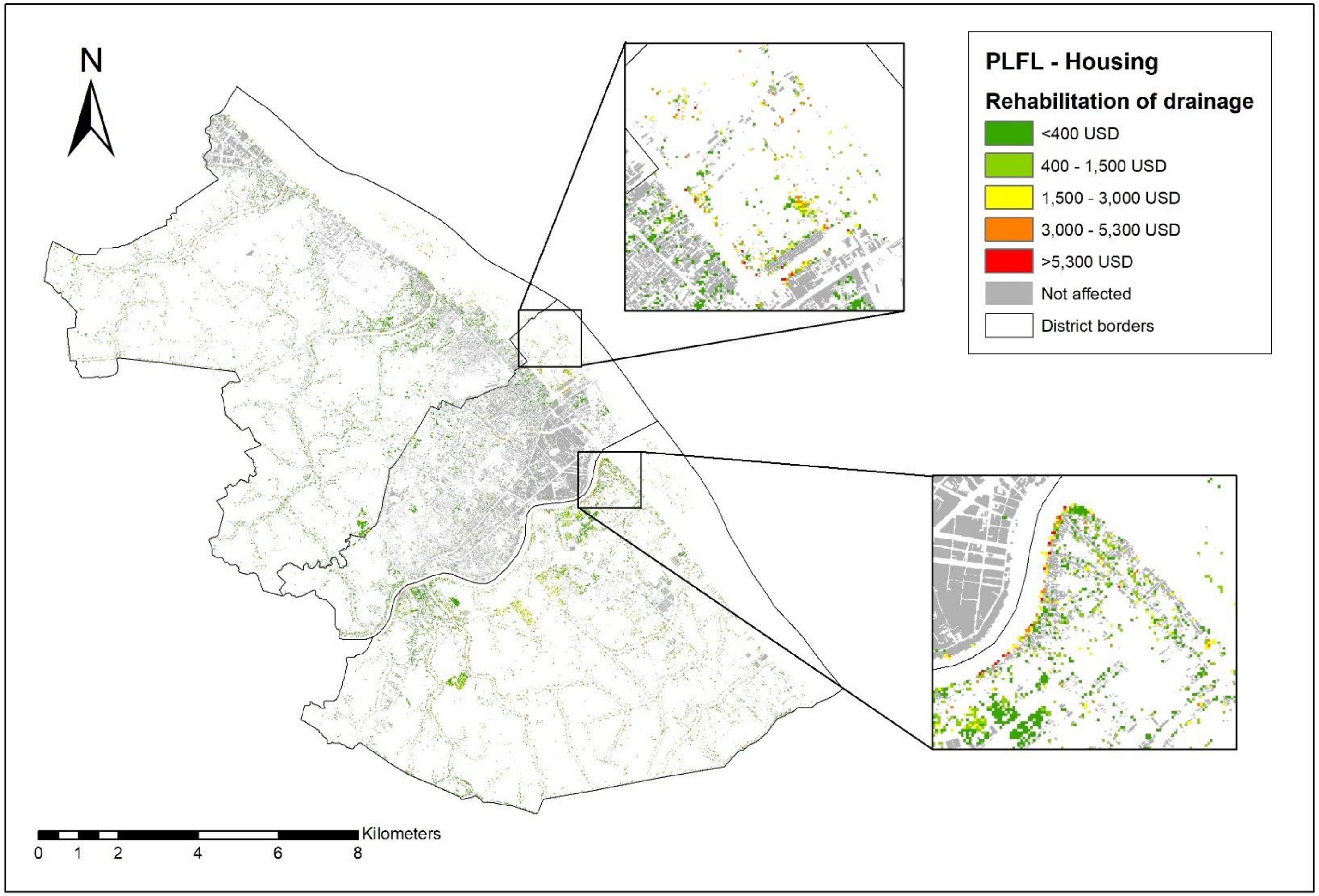

Figure 59: *Spatial location of benefits for rehabilitation of drainage for housing (pluvial/fluvial risk)*

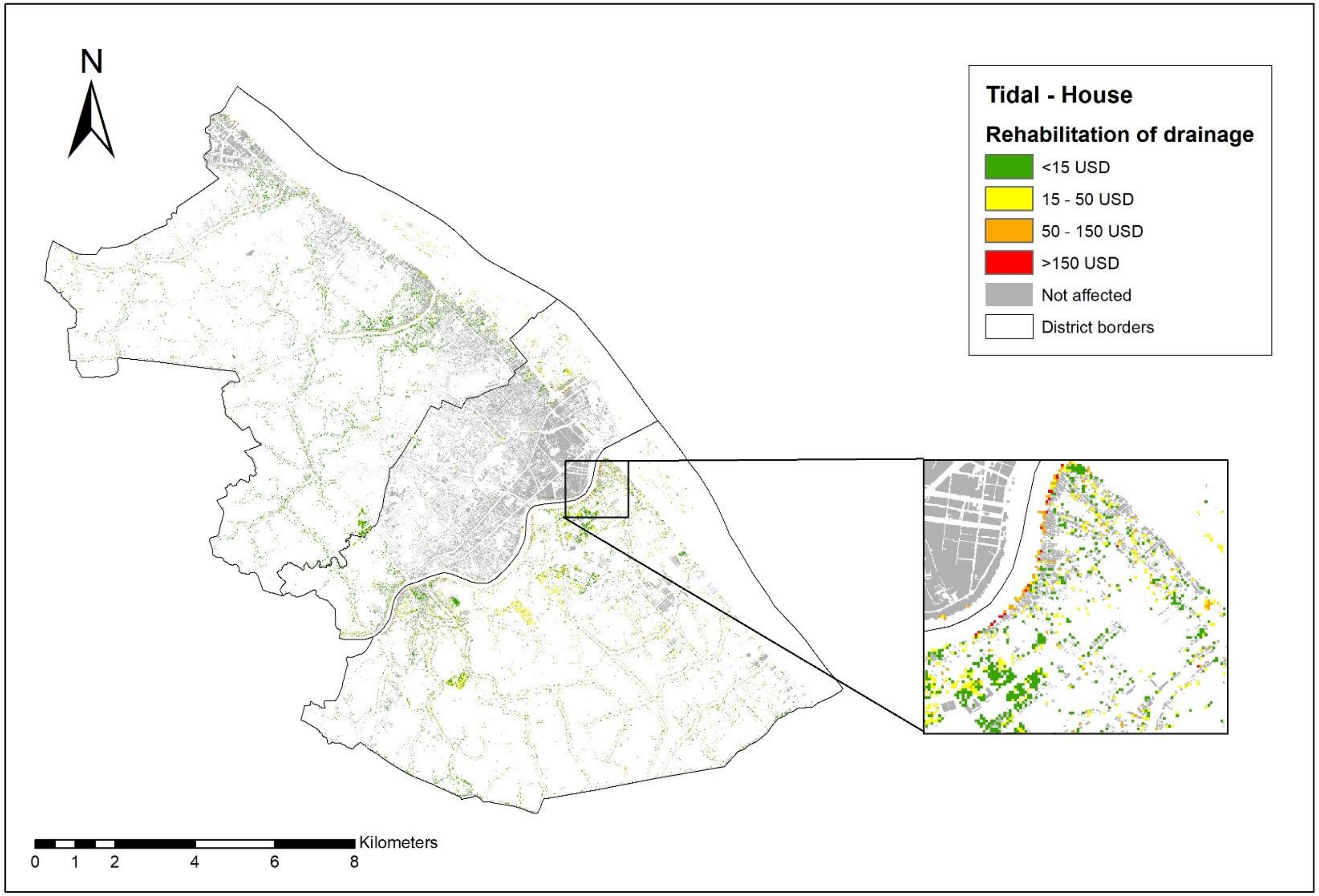

Figure 60: *Spatial location of benefits for rehabilitation of drainage for housing (tidal flood risk)*

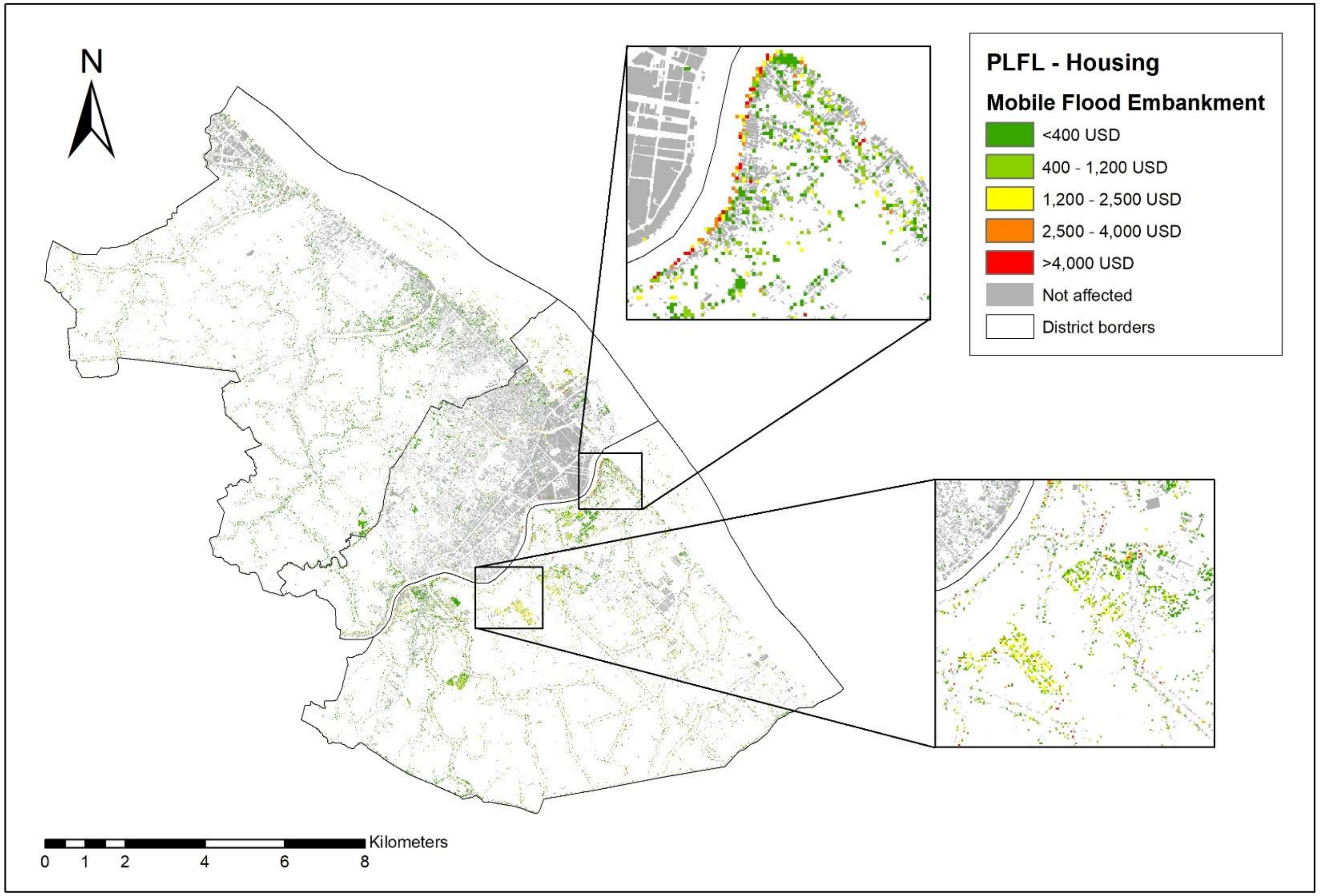

Figure 61: *Spatial location of benefits for mobile flood embankment for housing (pluvial/fluvial risk)*

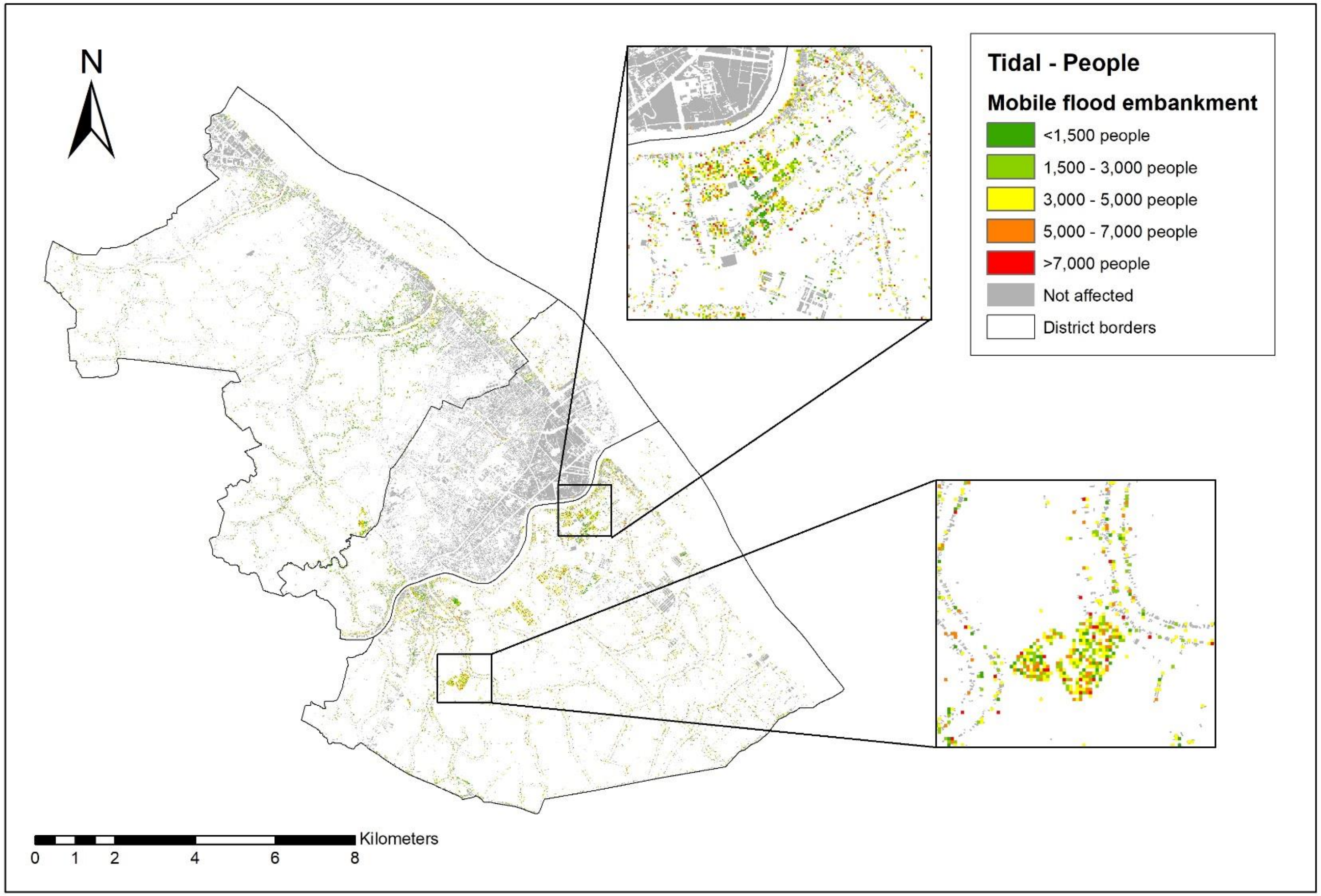

Figure 62: *Spatial location of benefits for mobile flood embankments for people (tidal flood risk)*

6.3 Heat Wave Risk

Previous studies in the Mekong Delta mainly associated heat waves or the exposure of high temperatures with increases in the risk of water and vector-borne diseases, cardiovascular and respiratory diseases, and the risk of hospitalisation among young and older adults. For example, heat wave events caused a 12.9% increase in the risk of hospitalisation due to cardiovascular diseases in Ho Chi Minh City.[101] Heat wave can also significantly affect hospitalisation for young children[102], older adults and people with respiratory conditions.[103] In Can Tho City, one study counted 55 heat wave events (representing 292 days) between 2003-2013, with a daily average hospitalisation of 30 admissions.[104] This section presents the simulated expected damages and the ranking of adaptation measures for heat wave.

6.3.1 Annual Expected Damage

Annual expected damage represents the damage expected on assets and people in Can Tho in average and annually. As for flood risk, this annual expected damage is the percentage or absolute value of assets or persons affected by the set of extreme events. The set of extreme events, or the value of assets or number of persons, can be affected by climate change and socio-economic scenarios. Figure 63 shows annual expected damage in Can Tho for assets in USD (a and b) and for people (c and d). The first bar (today) in yellow represent the actual annual expected damage. The second bar (economic development) represent the expected annual damage due to economic development (for persons, it represent the population growth). The light red bar represents the additional annual expected damage due to climate change in Vietnam. Last, the red bar represents the total aggregated expected damage in 2050, when economic growth (and population growth) and climate change are considered.

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[101] Phung, D., Guo, Y., Thai, P., Rutherford, S., Wang, X., Nguyen, M., & Chu, C. (2016). The effects of high temperature on cardiovascular admissions in the most populous tropical city in Vietnam. *Environmental pollution*, 208, 33-39.

[102] Phung, D., Rutherford, S., Chu, C., Wang, X., Nguyen, M., Nguyen, N. H., & Huang, C. (2015). Temperature as a risk factor for hospitalisations among young children in the Mekong Delta area, Vietnam. *Occupational and Environmental Medicine*, 72(7), 529-535.

[103] Dang, T. N., Honda, Y., Van Do, D., Pham, A. L. T., Chu, C., Huang, C., & Phung, D. (2019). Effects of extreme temperatures on mortality and hospitalization in Ho Chi Minh City, Vietnam. *International Journal Of Environmental Research And Public Health*, 16(3), 432.

[104] Phung, D., Chu, C., Rutherford, S., Nguyen, H. L. T., Do, C. M., & Huang, C. (2017). Heatwave and risk of hospitalization: A multi-province study in Vietnam. *Environmental Pollution*, *220*, 597-607.

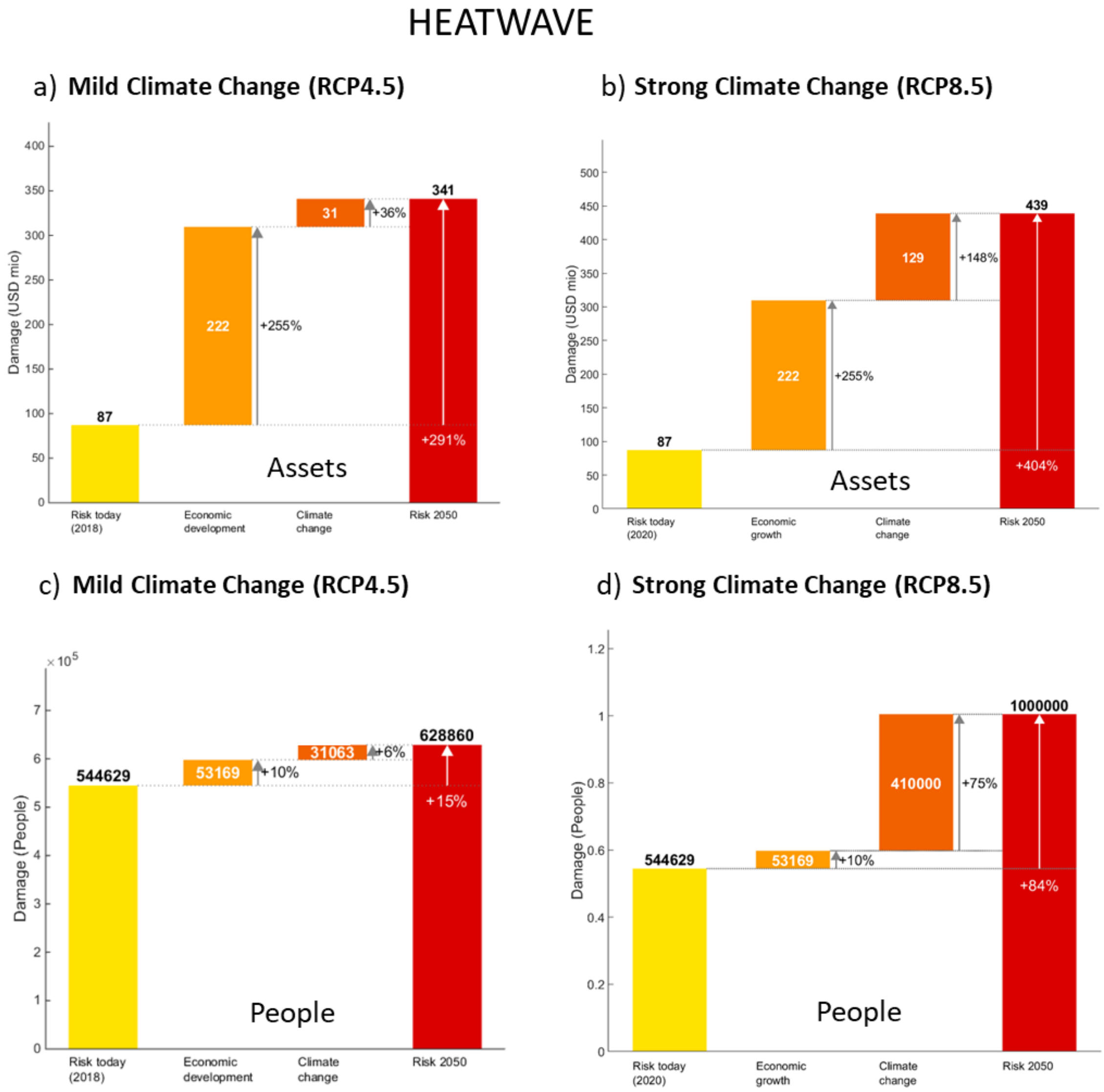

Figure 63: *Annual expected damage (AED) for heat wave in Can Tho for Assets (a & b in USD) and People (c & d in people)*

Annual damage for assets and persons are summarised in Table 18. Results are presented for all scenarios separately and aggregated with today's expected damage. Today starts in 2020 in alignment with discussions with stakeholders.

In Can Tho, a total expected damage from heat wave for assets of USD 87m (2020) are expected to rise to 222% due to the strong economic growth and to 36% due to climate change (148% with extreme climate scenario). A total of USD 341m (USD 439m for extreme climate change scenario) are simulated for the time horizon 2050. The increase in annual expected damage in 2050 represents a rise of more than 400% in Can Tho, due both to economic growth (assets will be more valuable) and climate change (hazard will be more frequent and more intense). This large increase is mainly reflected by a robust economic growth prediction. In addition, heat wave events are expected to worsen in the coming decades.

Regarding the population, more than 540 000 people are expected to be affected by heat wave annually in 2020. In line with a relatively low population growth in the area, an increase of 10% is expected in the future. Increasing temperatures, in return, are expected to affect more persons with an increase of 6% for a moderate climate and 75% for extreme climate. A total of ca. 630 000 people (1m for extreme climate) are expected to be affected annually in 2050, i.e. an increase of 16% (RCP4.5) and 85% (RCP8.5) compared to 2020.

Table 18: *Summary of annual expected damages in Can Tho for different scenarios (heat wave)*

ID	Asset Categories	Units	Total Value	AED Today (AED1) (USD/PPL and % of total value)		AED1+ Economic Growth (USD/PPL and % of total value)		AED total Moderate Climate Change (USD/PPL and % of total value)		AED total Extreme Climate Change	
501	Road Network	USD	486 500 000	15 419 570	3,2%	96 309 066	2,0%	22 886 342	4,7%	32 622 500	6,5%
601	Aquaculture	USD	3 561 300 000	7 292 091	0,2%	28 284 482	0,8%	31 792 892	0,9%	21 577 102	0,6%
602	Cash Crops	USD	65 400 000	904 166	1,4%	2 595 048	4,0%	4 018 507	6,1%	1 429 898	2,2%
603	Orchards	USD	1 817 300 000	62 497 187	3,4%	179 117 871	9,9%	277 587 270	15,3%	98 651 563	5,4%
604	Rice	USD	963 100 000	1 028 771	0,1%	3 313 515	0,3%	4 777 039	0,5%	1 855 950	0,2%
All Assets		USD	6 893 600 000	87 141 787		309 619 981		341 062 050		156 137 013	
Persons		People	675 562	0		0		0		0	

To validate these results against existing events, the annual expected damage (AED) for Can Tho would need to be compared to damages from previous large heat wave events. Unfortunately, no information about historical events can be found on the EM-DAT database[105] or similar sources. Even if few events are accounted for in the database, their limited number and substantial gaps in the data does not allow a reliable comparison.

For people, a relatively recent publication mention the increased risk factor for the population under a heat wave and rising temperature; younger and older people are significantly more impacted (an increase of 4-7%) by heat waves[106]. Because of the lack of literature for impacts on people in general, we, therefore, recommend considering that all population is impacted and we calibrated the model accordingly. Concerning assets, the ILO estimates that heat wave will account for 5.7% of its GDP in damage[107]. For the three districts in this report, it represents approximately USD 90m per year.

6.3.2 Cost-Benefit Analysis (Heat Wave)

In this section, the existing relationship between costs (investment costs and maintenance) and net averted damage of a given measure is analysed. In the case of climate change, net averted damage can be understood as the benefit of a measure. Therefore, this section presents a cost-benefit analysis of selected mitigation measures.

A so-called adaptation cost curve plots benefit/cost ratio (vertical axis) against aggregated averted damages (horizontal axis) for each measure. The dotted line (at value 1) represents the threshold for the benefit/cost ratio, in other words, values above it are cost-efficient, and values below it are not cost-efficient. On the Y axis, the larger a measure, the larger the damage averted by a measure, therefore the larger the benefit or the mitigation or adaptation impact of a measure. Hence, with this figure, each measure can be analysed in terms of mitigation/adaptation efficiency and cost efficiency and compared with one another.

Figure 64 a) and b) displays the impacts of measures applied to assets in Can Tho. Figure 65 a) and b) displays impacts measures applied to persons as in 2050 under moderate and extreme climate scenarios. In the case of heat wave risk, a reduced number (6) of measures were selected for the cost-benefit analysis. Low cost infrastructural and green measures, such as "Green roofs" or "White roofs" are generally less efficient in terms of averted damage but show a good cost/benefit analysis for each invested dollar. "Climate smart agriculture" shows the best cost/benefit ratio for assets in Can Tho. In Figure 64 in Can Tho all measures are cost efficient and account altogether to more than USD 350 m of averted damage, if combined without overlapping effect without insurance. It means that all measures combine, even with insurance, are not enough to cover the expected damages in the region. Insurance for assets will be considered separately in the following section.

Figure 65 presents the impact of measures on affected persons in Can Tho for heat wave risk. All measures, and account altogether to a reduction of almost 1.5m affected persons per invested 1000

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105 http://www.emdat.be/country_profile/index.html

106 Phung, Dung & Rutherford, Shannon & Chu, Cordia & Wang, Xiaoming & Nguyen, Minh & Nguyen, Nga & Do, Cuong & Trung, Nguyen & Huang, Cunrui. (2015). Temperature as a risk factor for hospitalisations

107 ILO (2019) Working on a warmer planet. The impact of heat stress on labour productivity and decent work. International Labor Office, Geneva. ISBN 978-92-2-132968-8

USD. It means that measures selected for assets have the potential to protect population at risk. Nevertheless, all measures combined together cove only a small part of expected damaged on population, and indicate therefore a large protection gap when it comes to heat wave. "White roofs" and "Cooling centres" are the most cost-efficient measures.

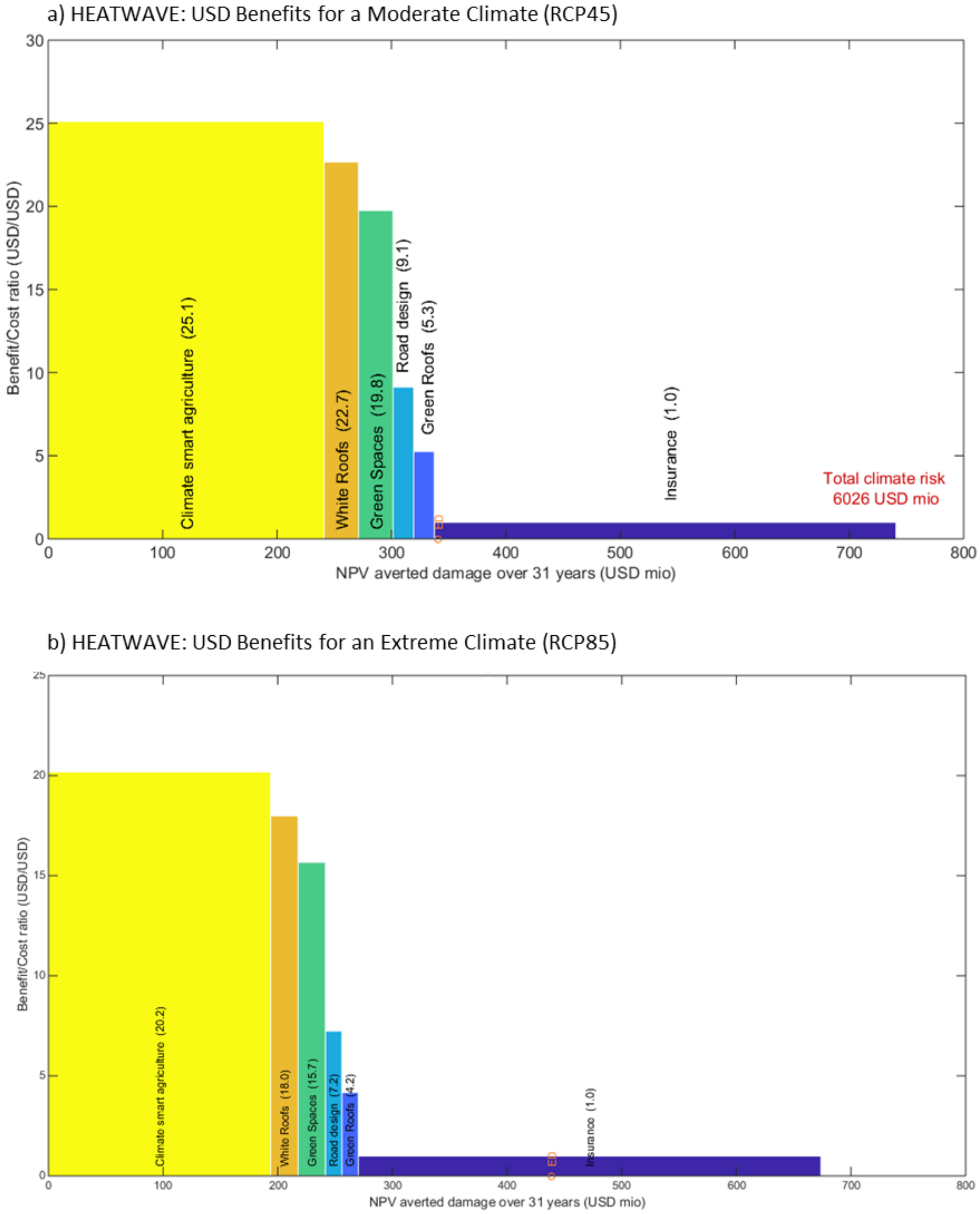

Figure 64: *Adaptation cost curve for assets damage for heat wave in USD a) moderate and b) extreme climate scenarios*

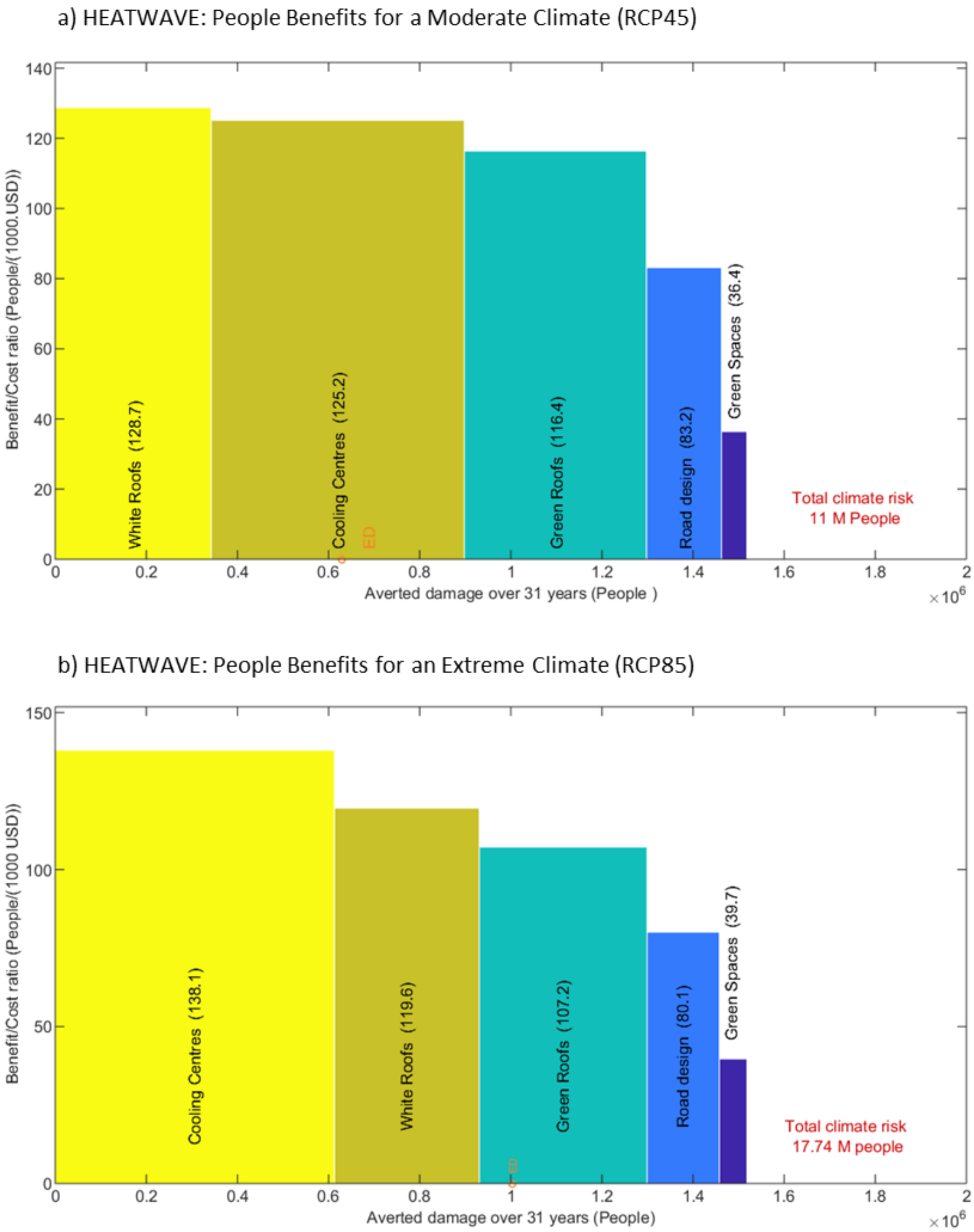

Figure 65*: Adaptation cost curve for damage on people for heat wave in a) moderate and b) extreme climate scenarios*

6.3.3 Spatial Distribution of Benefits (Heat Wave)

The Figures 66-68 below showcase illustrate the spatial distribution of benefits on selected assets resulting from the respective measure as indicated. Due to limitations in the hazard resolution, the highlighted areas of benefit are only indicative and not to be understood as exact locations. The benefits are presented as the annual averted damages averaged over the here relevant period of 31 years for selected measures and assets.

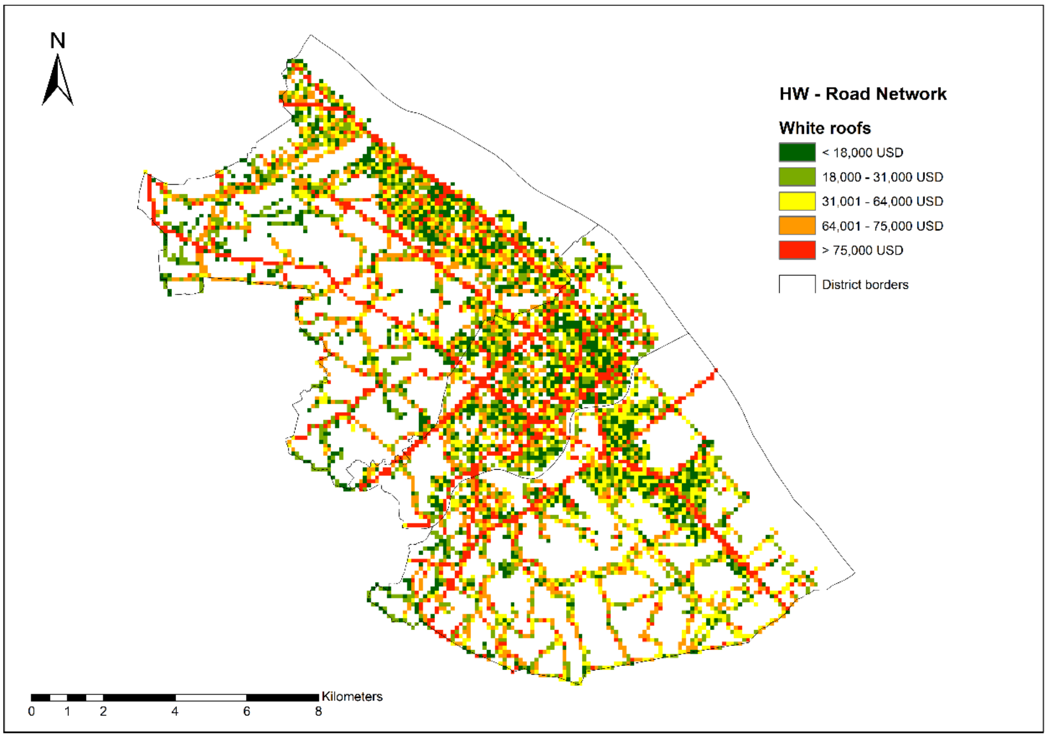

Figure 66: *Spatial location of benefits of white roofs for road networks (heat wave risk)*

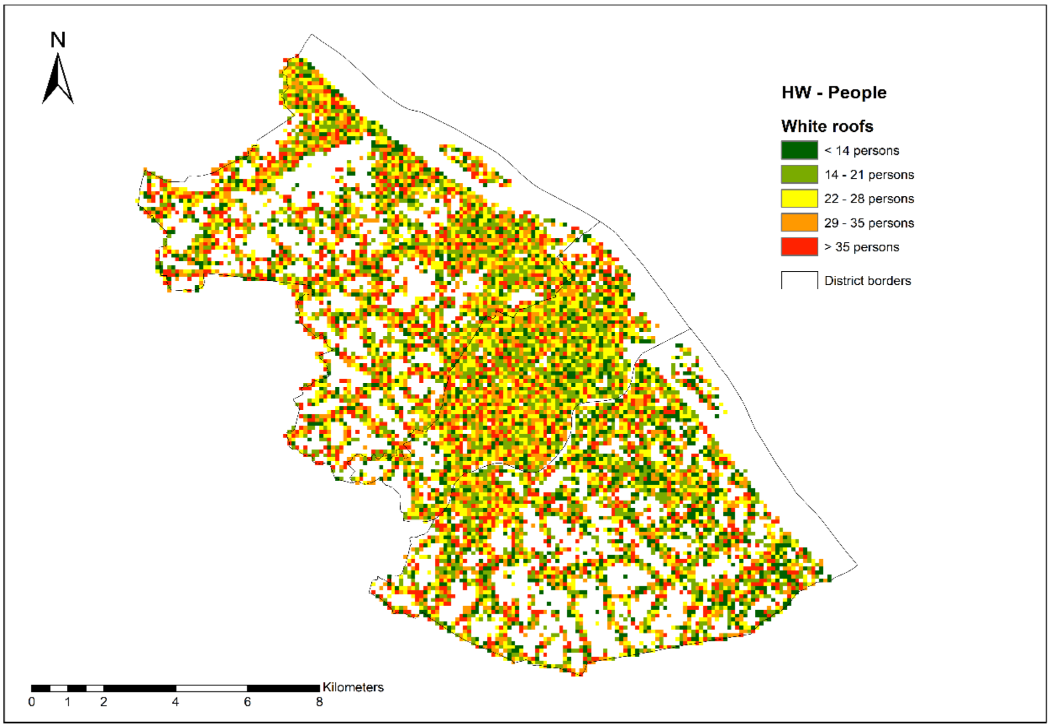

Figure 67: *Spatial location of benefits of white roofs for people (heat wave risk)*

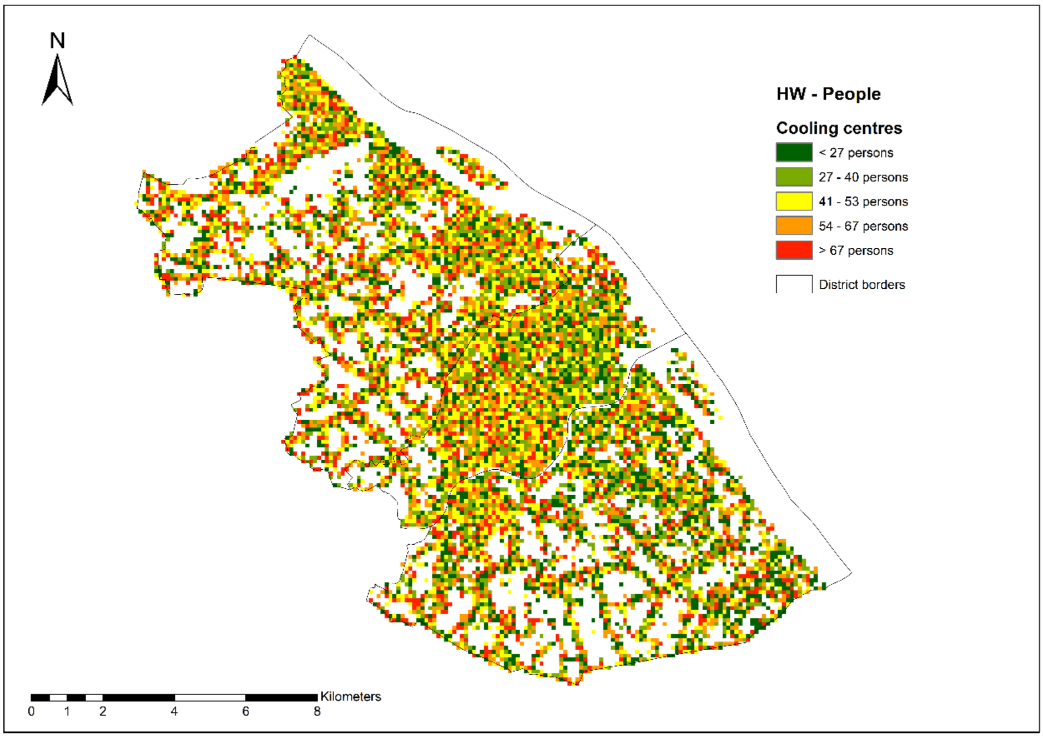

Figure 68: *Spatial location of benefits of cooling centres on people (heat wave risk)*

6.4 Climate Insurance

In many cases, not all potential future damages can be avoided by physical or community based adaptation measures. This protection gap can be fully or partly filled by risk transfer measures. For instance, Insurance can provide an effective instrument to cover the remaining risks and thus further increase resilience against climate change Risk transfer measures, such as climate insurance, unlike other measures, do not directly reduce the impact of flood or heat wave on assets. However, fast insurance pay-outs after a severe event, over additional funds and liquidity, which can be used to reduce the financial impact on these assets, speeding up recovery. A climate flood insurance is an innovative approach to developing effective pay-out schemes for low-income, at-risk communities. Climate insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation pay-outs. Effective solutions can be developed in collaboration with a range of organizations and experts from local and national government bodies, private insurance firms, community-based organizations (CBOs) and non-governmental organizations (NGOs). The insurance solution can be developed for agricultural and infrastructure assets. We have proposed an attachment[108] (USD 5Mio) and cover[109] (USD 10mio), resulting in a total cost of USD 2.2m. Parametric and index-triggered products are common for low-frequency, but high-severity events. In general, combined with other adaptation measures, index insurance can help cover the resulting risk for large events. The choice to

[108] The attachment is the damage value from where the insurance scheme kicks in.
[109] The cover is what damages the insurance scheme covers. In this case damages up to USD 15Mio (Cover plus attachment).

prioritize insurance over adaptation measures should be driven by the investment ability of the government. Adaptation measures require larger investment to be made, whereas insurance runs usually on yearly contracts. Nevertheless, one should bear in mind that the insurance premium diminishes with an increased number of adaptation measures (mainly because the total risk is reduced). In the case of Can Tho, climate insurance seems to provide a significant coverage of the residual risk compared to other type of measures. Such a strong coverage comes with a large coverage (>30% of all assets are covered in our simulation). The low cost-benefit can be increased with commercial incentives (add-on on the premium to cover delivery, administration costs and profit) which are not included in this study. In addition, additional incentives such as subsidies can make insurance schemes even more attractive. Nevertheless, they introduce additional limitations in term of sustainability of the product. In this report we only considered climate insurance, as modelled by CLIMADA, but other types of risk transfer could also be considered (especially pooling risk with other cities or regions). This approach has been successfully implemented in Asia by the World Bank and partners with the Southeast Asia Disaster Risk Insurance Facility (SEADRIF).[110]

6.5 Discussion on Uncertainties

In this section, we will discuss uncertainties associated with simulations done in this chapter. In a modelling exercise, uncertainties are inevitable and should be qualified whenever possible. In Figure 55, uncertainties associated with each component of the CLIMADA modelling chain is displayed.

The four components of CLIMADA are displayed in different colours in order to ease identification of the main sources of uncertainties. Within the component "flood modelling", the quality of the observation data is key to reduce uncertainties. Tested re-analysis product such as the one used in this report are one example on how precipitation data from remote sensing can reduce uncertainties in data scarce areas. In term of heat wave modelling, uncertainties lie in the conceptualization of heat wave Indeed, different indices return different heat wave signals. Nevertheless, to date there is no scientific consensus on which heat wave index performs best. Nevertheless, trough validation by existing observation, there is high confidence in the outputs of the heat wave and flood model.

An important source of uncertainty in the ECA methodology is introduced by economic and climate scenarios. Indeed, producing scenarios always introduce uncertainty in a modelling exercise. The economic and population growth scenarios, although based on actual observations, are simple and do not reflect possible fluctuations. Nevertheless, they provide a good estimation of a mean trend and should be treated as such. Climate scenarios are more challenging to evaluate. Although the scenarios used are based on validated scientific data and models, not all climate scenarios are consistent in their conclusions. In addition, models are seldom calibrated for a certain region and especially precipitation simulations are sensitive to scale. Last, there is usually less confidence in extreme scenarios than in moderate scenarios, the latter being often the results of a consensus among different models.

[110] Further information here: https://www.artemis.bm/news/parametric-disaster-insurance-facility-for-asean-to-get-japanese-funding/.

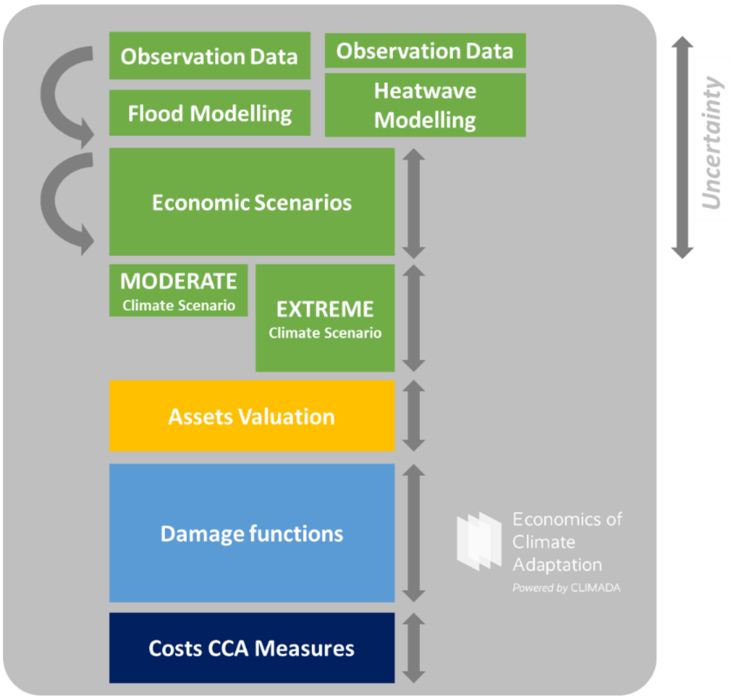

Figure 69: *Uncertainty cascade for the CLIMADA modelling chain.*

Asset valuation is difficult at the regional level, and although more confidence is placed in these values, they are difficult to calibrate properly with observations.

Further, damage functions are the most sensitive parameter in the ECA methodology. Damage functions can be determined by mathematic formula or using expert knowledge. In our case, we have tried to reduce uncertainty in using both approaches. Nevertheless, as damage functions cannot be validated we assume a quantitative bias introduced by this component. There is also extremely few literature on heat wave damage curves.

The quantification, valuation and parameterization of adaptation measures is a challenging exercise for any type of risk. The location and exact size of a project might influence greatly the cost and benefit calculated. In this study, costs, maintenance costs and parameterization was done in close cooperation with local and international experts in order to achieve a reduced uncertainty related to measures. Nevertheless, unless using time-consuming modelling tools, the exact estimation of measures introduced in CLIMADA is difficult. We assume therefore a moderate confidence[111] concerning the costs and impact of measures presented in this report.

[111] Cost of measures are time dependent and can vary greatly during the procurement process. In addition, the respective impact of the measures depends on various factors that are not necessarily modelled CLIMADA. For instance, the exact location of the measures in an area can have slightly different effects on several assets. Therefore, we suggest a moderate confidence in the output regarding the measure, offering nonetheless a strong indication on what adaptation strategies might be the best for the region.

6.6 Conclusions

In this section, inundation measures were analysed in Can Tho in terms of cost-efficiency and adaptation/mitigation efficiency. A total of 17 measures (13 measures for flood and 4 for heat wave) were successfully introduced in CLIMADA. The main findings are summarised below:

TIDAL FLOOD

1) A majority of selected measures are cost efficient for the asset selected;
2) All measures combined are not sufficient to account for the total climate risk (94% averted damaged for extreme climate);
3) Climate insurance for asset is can help cover residual risk after the most effective three (3) measures have been implemented;
4) By 2050 most measures for flood will be efficient for assets, with co-benefits for the population at risk; under extreme climate conditions;
5) The top three measures for TIDAL FLOOD are:
    a. "Mobile flood embankment"
    b. "Flood awareness"
    c. "Rehabilitation of drainage"

PLUVIAL/FLUVIAL FLOOD

1) All but one of the selected measures are cost-efficient for the asset selected;
2) All measures combined are sufficient to account for the total climate risk (for extreme climate) but are unlikely to be financed at the same time;
3) Climate insurance for asset can help cover residual risk after the three (3) most cost-effective measures have been implemented;
4) Climate insurance has the highest risk mitigation potential;
5) By 2050 most measures for pluvial/fluvial flood will be efficient for assets, with co-benefits for the population at risk; under extreme climate conditions;
6) The top three measures for PLUVIAL/FLUVIAL FLOOD are:
    a. "Swales"
    b. "Mobile flood embankments"
    c. "Rehabilitation of drainage"

In addition, we recommend considering implementing measures for both tidal and pluvial/fluvial flood, therefore increasing the overall efficiency. Although damages are different in scale, the most efficient measures for one hazard seem to apply to the other.

HEAT WAVE

1) All selected measures are cost-efficient for the chosen asset;
2) All measures combined are not sufficient to account for the total climate risk and a large protection gap remains (only 6% averted damage);
3) Climate insurance for assets is can help cover residual risk after the three (3) most cost-effective measures have been implemented;
4) Climate insurance has the highest risk mitigation potential;
5) By 2050 measures for heat wave will be efficient for assets, with co-benefits for the population at risk; under extreme and moderate climate conditions;
6) The top three measures for HEAT WAVE are:
    a. "Cooling Centers"
    b. "Climate Smart Agriculture"
    c. "White Roofs"

7. Conclusions and Proposal for Pre-Feasibility

7.1 Conclusions

Can Tho, as other urban areas in the world, is threatened by flood and other extreme weather events. Along with growing populations and economies, losses from natural hazards are rising. In this report, we applied the Economics of Climate Adaptation (ECA), a decision-making support framework, to integrate climate risk assessments and optimal adaptation solutions.

In its first part, this report recalls decisions made in coordination with all stakeholders regarding the scenarios (climatic and economic) to be applied and what assets should be considered in the analysis. During several workshops and webinars, a portfolio of measures (from a long list to a short list) have been discussed. Values have been validated by stakeholders' concertation and expert interview.

Further, this report presents the results, assumptions and limitations of the development of a flood and heat wave model for the region of Can Tho. The flood model developed for the purpose of this report provides unique improvement in resolution and quality to the simulation of different types of floods in the region. The heat wave model is based on internationally recognised indices and has been developed for the purpose of this study. Its integration into CLIMADA, a modelling platform, provide an estimation of impacts of future heat wave risk impact for the selected assets. These results for future damages have been successfully validated against existing historical observations. By 2050, flood and heat wave damages in Can Tho are expected to rise by a fourfold (Flood), due to both, economic growth (assets will be more valuable) and climate change (hazards will be more frequent and more intense).

The introduction of a selection of adaptation measures provide insights for the development of a sound climate adaptation portfolio under the selected scenarios. Green measures and grey measures provide the best return on investment, while offering a good protection against future climatic risks.

Finally, the quantification, valuation and parameterization of adaptation measures is a challenging exercise. The location and exact size of an engineering project might influence greatly the cost and benefit calculated. Although great care has been given to the modelling exercise, the outcome of the study are not meant to replace a more detailed engineering screening of the measures to be introduced and offer a decision support, to be added to other tools and discussion already on-going within the municipality. It is important to consider these uncertainties while making climate impact decisions.

Building on these conclusions, this section contains the work plan for the pre-feasibility analysis that will be carried out as the last stage of the ECA study in Can Tho. With the goal of facilitating the implementation of the identified adaptation measures discussed in the vulnerability report, the analysis will cover the technical, economic, environmental, social and regulatory frameworks relevant for this case study. These further analyses meets the demands of international donors, such as KfW, to evaluate possible investments.

Regarding the scope of the pre-feasibility study, it will include: a background, beneficiary and feasibility analysis, an institutional analysis of the executing agencies and a budget and execution schedule. The following sections provide some further details.

7.2 Recommendation for a Pre-feasibility Study

7.2.1 Background Analysis

For this study the background analysis covers the institutional context, ongoing programs and initiatives, challenges and opportunities relevant to flood and heat wave Disaster Risk Management (DRM) and its interdependence, both at the city and/or provincial level. These items entail:

Institutional context: Identification of the institutions best equipped to carry out the adaptation measures suggested by the ECA study, in terms of *efficiency*, *effectiveness* and accountability.

Ongoing programs and initiatives: Verification of the ongoing programs and activities related to climate change, urban flooding or heat waves on the provincial/city level. Point out relevant policies, strategies or regulative documents.

7.2.2 Beneficiary Analysis

This analysis will include both direct and indirect beneficiaries, including aspects of gender and poverty:

Direct beneficiaries: Defined by local population in the intervention area, and disaggregated by gender, age group, socio-economic characteristics, etc.

It will also include the institutions that have received, are receiving or will potentially receive institutional strengthening and actively participate in the implementation of the proposed measures.

Indirect beneficiaries: Constituted by the general population, disaggregated as well by urban or peri-urban location, gender, socio-economic characteristics, etc. Local businesses will also be included, as well as the main existing equipment and infrastructure.

7.2.3 Feasibility Analysis

This analysis will be carried out to establish the feasibility of at least four of the priority measures proposed by the ECA Vulnerability Report for Can Tho. Considering technical, economic, environmental, social and legal aspects.

Technical feasibility: Assessment of the availability of technical and technological means within the beneficiary to carry out the measures. The following four topics will be included:

- Applicable regulations, guidelines of good design practices and other instruments that regulate the technical aspects of the project.
- Existence of base studies of the land in terms of topography, geotechnics and hydrology, among others.
- Available technology in terms of accessibility to technological knowledge to implement and operate the measures, as well as the capacity to supply inputs, capital goods including civil work and equipment, labour and maintenance services.
- Sustainability, which includes the identification of possible failure modes, as well as the ability to obtain funding sources to cover project costs throughout its life cycle.

Identification of co-benefits: Assessment of co-benefits that could occur during the design, implementation and operation of the proposed priority measures. That are, additional positive impacts such as increased employment, increased income, reduction of negative health effects and other qualitative co-benefits.

Environmental and social risks: Assessment of possible negative social and environmental impacts that could occur during the implementation and operation of the proposed measures will be identified, as well as the methods available to mitigate or prevent them.

Legal feasibility: Assessment of the current Vietnamese legal framework that the measures of infrastructure and institutional strengthening, as well as of education-communication and citizen organization that will be proposed in the pre-feasibility study.

7.2.4 Proposed Executing Entity

In this section, an analysis of the institution identified as executing agency for the proposed measures and the recommended strengthening needs will be carried out. This analysis will ensure that such an institution has the proven capacity to manage the infrastructure project cycle and citizen management, as well as the adequacy of its procurement and contracting rules and procedures, accounting records and accountability. However, the study will also identify the types of support it needs as an executing agency to successfully implement the proposed measures.

In order to establish the execution structure, a matrix of roles and responsibilities will be prepared to assign these functions to each of the actors involved in the planning, execution and operation of the measures.

7.2.5 Implementation Structure

This section will define the scope of the program through a broken-down work structure, to which time and resources will be allocated to develop the schedule and budget for its implementation. Pre-define/assess roles and responsibilities of the involved actors, including executing agency, relevant local stakeholders (e.g. in form of an Implementation Chronogram). Who will do what?

Breakdown of work structure: It will consist of the hierarchical decomposition of the work to be done to achieve the program objectives and the required products.

Project schedule: It will consist of the presentation of all the logical sequence and the steps to be followed to deliver the program's outcomes or results.

7.2.6 Implementation Budget

This section provides an indicative budget to implement the program, according to KfW Standards.

Program budget: It will consist of the allocation of the financial resources of the program, to complete and achieve the objectives and products.

7.2.7 Feasibility Report

The feasibility report will be the final step of the study, for which a vulnerability webinar will be held online beforehand.

ANNEXES

Economics of Climate Adaptation

ANNEX 1: Flood Model Report (GFZ)

UNU-ECA study for Can Tho city, Vietnam

Flood hazard analysis study

performed by

GFZ German Research Centre for Geoscience

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Section 4.4 Hydrology

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Content

Geographical setting and data

The domain for the hazard simulation encompasses the districts Binh Thuy, Ninh Kieu and Cai Rang of Can Tho province. Figure 70 shows the simulation domain with the districts with the used LiDAR Digital elevation Model (DEM) with 5 m resolution. It also shows the houses in Can Tho city as of 2012 generated by German Aerospace Center (DLR) based on high resolution Quickbird satellite images (Quickbird image courtesy of Digital Globe). Additionally, information about the planned flood protection dike ring of Ninh Kieu-Binh Thuy, which is currently under construction, were collected and considered in the hazard analysis. The DEM was modified according to the dike lines and elevations in m a.s.l. as shown in Figure 70.

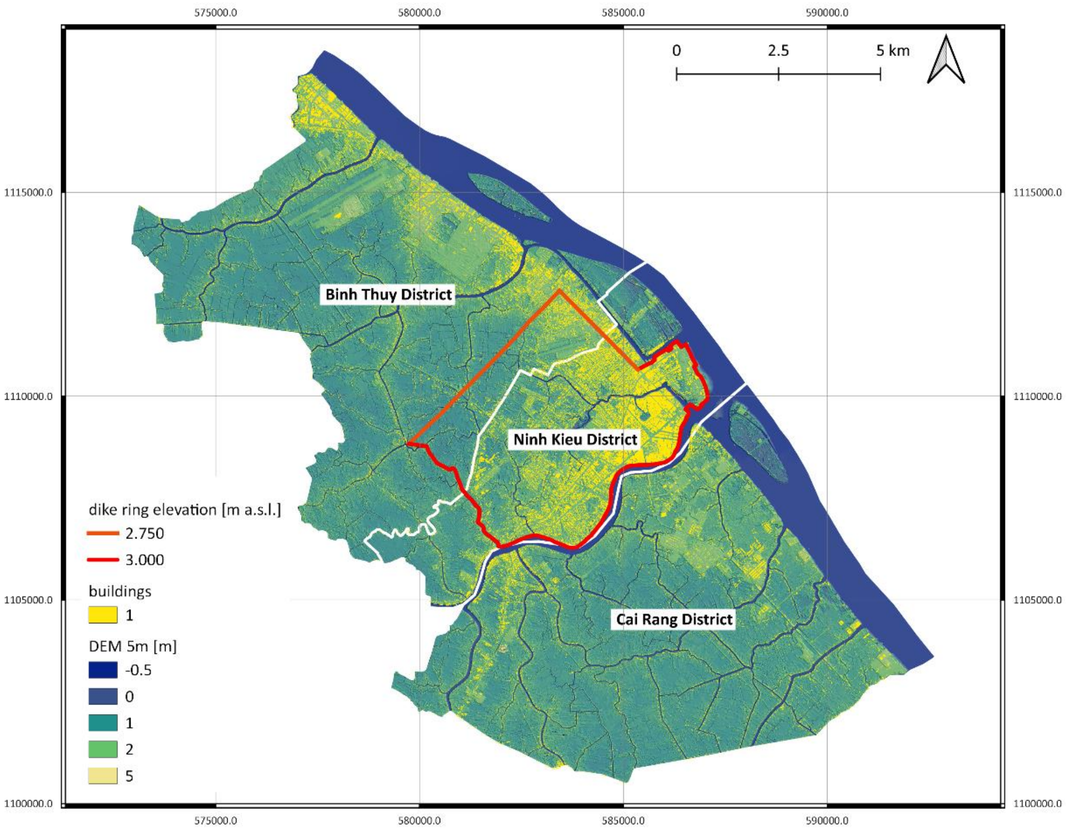


Figure 70: *The geographical setting of the project simulation domain with the districts Binh Thuy, Ninh Kieu and Cai Rang, the underlying 5m LiDAR DEM, the considered dike ring of Ninh Kieu-Binh Thuy, and the building mapped by DLR (based on Quickbird images courtesy of Digital Globe).*

Furthermore, a land use classification of 2017 provided by UNU-EHS was used for setting up basic mode inputs. Figure 71 shows the study area with land use classified into 5 categories. Note: the main channels were not classified.

Table 19 provides an overview of the base data used in this flood hazard analysis study.

Table 19: Overview of the base data used in the flood hazard analysis study

Content	Type	Source
LiDAR based Digital Elevation Model DEM	Raster, 5 m resolution	GFZ (Catch-Mekong project)
Land use classification	Vector shape file	UNU-EHS
Building inventory (as of 2012)	Vector shape file	DLR
Dike ring Ninh Kieu-Binh Thuy	Vector shape file	Compiled on the basis of information from CTU

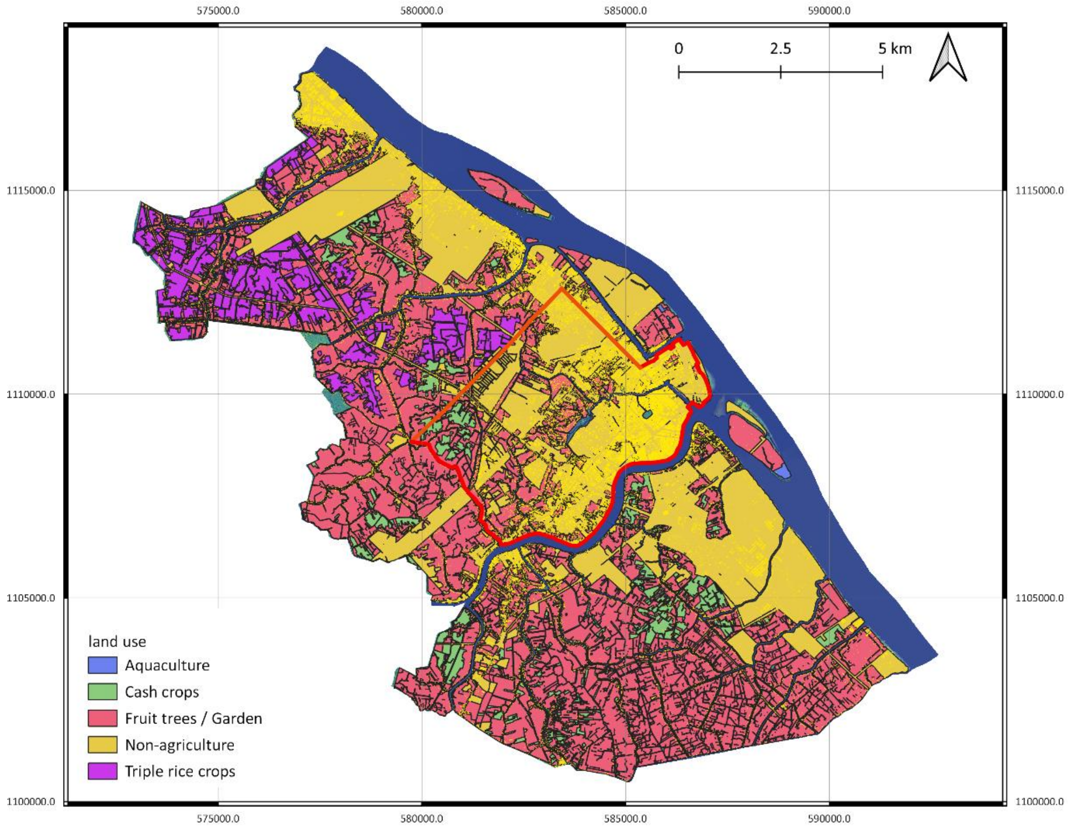


***Figure 71:** Land use classification for 2017 for the districts Binh Thuy, Ninh Kieu and Cai Rang as provided by UNU-EHS. The main channels were not classified, thus they do not appear in the legend.*

Study design

The design of the study is based on the flood hazard analysis published by Apel *et al.* (2016), who performed a combined probabilistic fluvial-pluvial flood hazard analysis for downtown Ninh Kieu. This study serves as a blueprint for the flood hazard analysis presented in this report. The core concept of (Apel *et al.*, 2016) was adapted to the extended geographical coverage, the higher data resolution, and the new urban hydraulic inundation model developed by GFZ, in order to analyse the fluvial, pluvial, combined fluvial-pluvial, and the tidal flood hazard for the three districts shown in Figure 70. The following sections provide details of the methods used in the hazard analysis

Hydraulic model

The hydraulic model used in this study is RIMurban, a 2D hydraulic inundation model specifically developed by GFZ for urban flooding. RIMurban is based on the inertial approximation of the shallow water equations as published by Bates *et al.* (2010), with the improved stability by introducing numerical diffusion as published by Almeida *et al.* (2012). RIMurban solves these equations by a finite difference scheme on a regular raster grid, with de-coupled flows in x- and y-direction. As in Apel *et al.* (2016), RIMurban is implemented on NVIDIA Tesla Graphical Processor Units (GPUs), which are specifically designed for highly parallelised computing. Apel *et al.* (2016) show that the hydraulic model is able to reasonably simulate the inundation dynamics by a plausibility test against recorded inundation reports during the flood 2011.

However, compared to Apel *et al.* (2016) the model was further developed in order to consider the specific features of urban flood routing and inundation. These improvements are:

1. Consideration of the built-up area: In this study the buildings as shown in Figure 70 were considered in the flow routing. This is achieved by excluding the footprints of the buildings from the flow simulation, thereby simulating the flow around buildings.

2. Consideration of the drainage effect of the sewer system: RIMurban uses a capacity-approach to simulate the sewer drainage, as proposed by (Kaspersen and Halsnæs, 2017). This approach is able to simulate the lumped effect of the sewer system on the inundation dynamics, without the excessive calculation costs of an explicit sewer system model coupled to the 2D surface routing model (Glenis *et al.*, 2018). The capacity approach requires spatially distributed information on sealed surfaces and the estimation of the sewer capacity.

3. Consideration of effect of soil infiltration to inundation dynamics: The effect of infiltration of ponding water into the soil is simulated similarly to the sewer system by a capacity-approach. This requires a map of the non-sealed surfaces and an estimation of the infiltration capacity.

These improvements enable more realistic simulations of the urban inundation dynamics.

Derivation of model inputs and parameters

DEM for simulation: The base 5 m resolution DEM was modified for the simulations. Firstly, the building footprints were “burned” into the DEM by setting the DEM elevation to “nodata”. This excludes the cells covered by building footprints from the flow routing. Secondly, the cells covered by the dike ring of Ninh Kieu-Binh Thuy were set to the elevation of the planned dike elevation. This includes also the elevation of channel bed, which are crossed by the dike ring. This imitates the foreseen closure of the planned sluice gates to prevent flooding within the dike ring in case of a flood event.

Hydraulic roughness: The hydraulic roughness, which is required for the inundation simulation, was estimated based on the land use map. Different manning roughness parameter values were assigned to each land use class. The assignment was done by associating the land use classes to standard engineering roughness parameterisation as listed at:

https://www.engineeringtoolbox.com/mannings-roughness-d_799.html

Table 20 Lists the Manning roughness values assigned for the different classes, and Figure 72 shows the roughness map used in the modelling.

__Table 20:__ Manning's roughness classification based on land use classification. The classification in brackets indicate the standard engineering roughness class used.

	Aquaculture	Cash crops	Fruit trees / gardens	Non-agriculture	Triple rice crop	Rivers & channels
Manning's roughness n	0.035 (sluggish streams with pools)	0.035 (farmland)	0.025 (between trees and farmland)	0.02 (rough concrete surfaces)	0.035 (farmland)	0.03

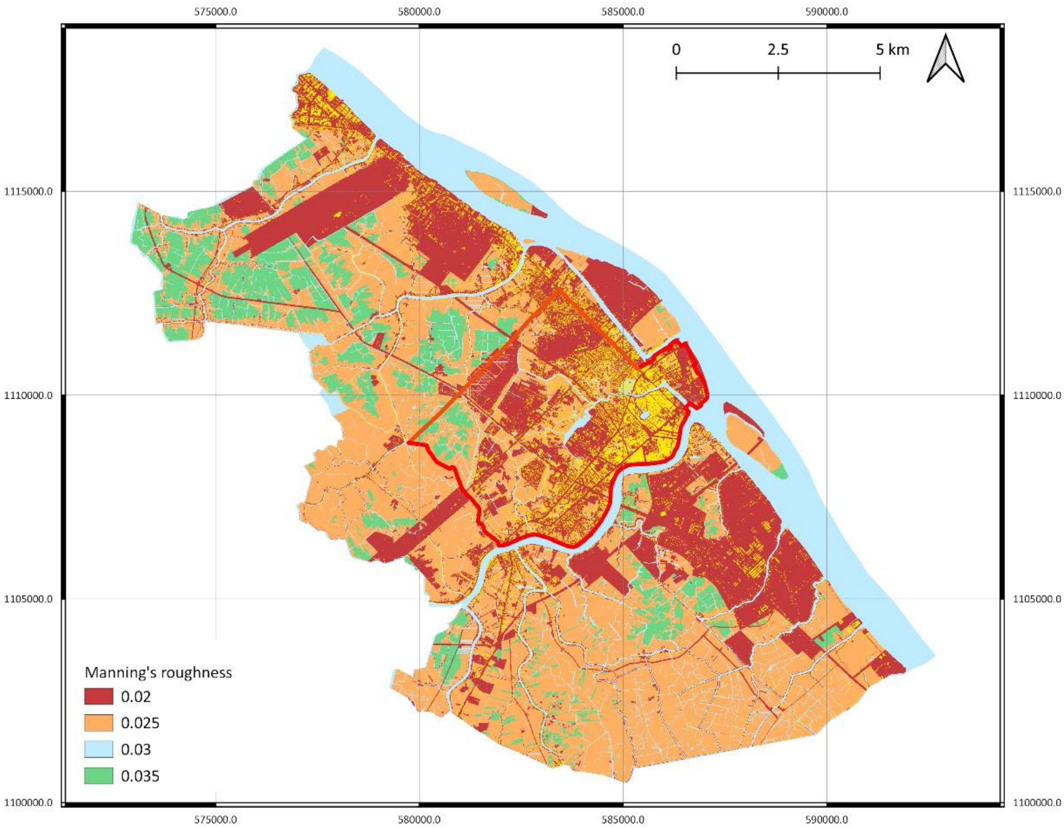


***Figure 72**: Hydraulic roughness classification based on land use map and roughness values listed in Table 20, which was used for the inundation simulation.*

Sealed/non-sealed surfaces: The sealed surfaces were also derived from the land use map. Here, the non-agricultural areas were classified as sealed surfaces. In order to account for the different settling density and thus sealed surface fraction in the three districts, the following classification was used: In Ninh Kieu district it is assumed that non-agricultural areas are completely sealed, i.e. the sealed surface fraction was set to 1. In Binh Thuy and Cai Rang a lower surface sealing in the non-agricultural areas was assumed, i.e. the sealed surface fraction was set to 0.5. For all other land use classes the surface sealing was set to 0. Figure 73 shows the resulting surface sealing map. The non-sealed surfaces were derived by setting it to 1-"sealed surface fraction".

Infiltration capacity: The flooding in Can Tho occurs during the monsoonal period, when heavy rainfall saturates the soil. Therefor the infiltration capacity was set to 0 mm/h.

Sewer system capacity: The sewer system capacity was derived from a hydraulic simulation performed by CTU using the 10-year design rainfall for the sewer system as input. This simulation quantified the total rainfall volume over downtown Ninh Kieu to 2,220,000 m^3, which is reduced by surface storage to a rainfall volume of 1,690,000 m^3, which is conducted by the sewer system. Considering the total surface area of the simulation domain of 2490 ha, this amounts to a sewer capacity of 45 mm/h. However, it is reported by CTU that most of the main sewer pipes of 1 m diameter are blocked by sediment up to 0.3 m. This is equivalent to a reduction of the flow cross section of the pipes of 25% (calculated by circle segment formulas). Therefor the sewer system capacity was reduced to 45*0.75 = 33.75 mm/h ~ 34 mm/h effective capacity, which was used in the simulations. This capacity is assumed to be effective for all flood of different magnitudes. During the simulations, the ponding surface water was reduced on every raster grid cell by multiplying the effective sewer capacity with the surface sealing fraction of the cell and the cell area. This means that the effect of the sewer is only active in the areas classified as urban/sealed surface. The sewer system is activated if the surface inundation exceeds 2 mm.

Figure 73: *Sealed surface fraction derived from land use map.*

Design of the hazard analysis

The design of the hazard analysis, i.e. the inundation simulations for different return periods and the derivation of the associated boundary conditions, is based on the methodology of Apel *et al.* (2016). In this study a fully probabilistic hazard analysis was performed for fluvial, pluvial and combined fluvial-pluvial flood hazard for downtown Ninh Kieu on a 15 m resolution raster. The hazard analysis was performed for present day situation. The likely future changes in flood hazard were, however, not included in the study.

In this updated and larger scale hazard analysis the same procedure was followed for present day hazard, but some modifications had to be made, due to the substantially longer simulation times required for the much larger simulation area and finer spatial resolution. These longer simulation times do not allow for a fully probabilistic hazard analysis with several hundreds or thousands of inundation simulations for each return period, as performed in Apel *et al.* (2016). Instead only the most likely hazard scenarios were considered for the selected return periods T = 2, 5, 10, 20, 50, and 100 years, i.e. the uncertainty stemming from the natural variability of the flood causing processes could not be considered. The hazard analysis comprises the analysis of fluvial flood hazard, pluvial flood hazard, combined fluvial-pluvial flood hazard, and tidal flood hazard. Details about the hazard analysis is given in the following sections.

Future flood hazard

The presented study also attempts to estimate the changes in flood hazard driven by climate change in future. In order to do so, a delta (Δ) approach was applied, which derives delta changes in the boundary conditions for the different hazard types in Can Tho. The delta values were taken from published studies. However, only a few studies are available that provide quantitative information about the changes in flood water levels in Can Tho or of changes in extreme precipitation in future. An analysis of the available literature revealed, that harmonized delta changes can only be collected for a future time horizon around 2050 (mid-21st century), and the RCP4.5 concentration pathway. For other time horizons or different concentration pathways the literature does not provide sufficient information for all hazard categories. The following publications were used for estimating the Δ-values for the different hazard categories:

For the fluvial hazard, the ΔH for climate change impact on maximum water levels was taken from Triet *et al.* (2020). This study estimated the mean change of maximum flood water levels in the Mekong delta including Can Tho under the RCP4.5 concentration pathway. There is no similar study using RCP8.5 for the Mekong.

For the pluvial hazard the ΔP was estimated from a report of the Vietnamese Ministry of Natural Resources and Environment (MONRE, 2016). This report contains large scale figures showing the percentage change of maximum 1-day precipitation for the whole of Vietnam, both for RCP4.5 and RCP8.5. The percentage change were taken from these figures (Figures 5.11 and 5.12 in the report). Due to the large-scale resolution of the figures the numbers can, however, only be approximately derived. In order to use the same concentration pathway as for the fluvial hazard, the figure showing the RCP4.5 was used. However, it has to be noted that the differences in maximum 1-day precipitation change between RCP4.5 and RCP8.5 are comparatively small for the Mekong delta.

For the tidal hazard the study of Manh *et al.* (2015) was used. The authors compiled information about maximum and minimum reported changes in effective sea level rise for mid-21st century and used these values in a sensitivity-based impact assessment for the Mekong Delta. This means there is no concentration pathway assigned to the possible changes in sea level rise. In order to use a number that is in line with the RCP4.5 scenario as in the fluvial and pluvial hazard, the median of the reported range was used. This can be loosely related to RCP4.5, which is a moderate greenhouse gas emission scenario, that is associated to a global warming of +1.5K.

More details and the actual Δ-values used are reported in the following sections describing details of the different hazard categories.

Fluvial flood hazard

The first step in the fluvial hazard analysis is the definition of the hydraulic boundaries. In the present setting the fluvial inundation is mainly initiated either by river bank overtopping of the large rivers, the Hau river and Can Tho river, or by bank overtopping of the many distributaries fed by the large rivers. Therefor the fluvial boundaries, i.e. river water levels, were set along the Hau and Can Tho rivers. Figure 74 shows the fluvial boundary. In order to simplify the model setup, uniform water levels were defined for the both Hau and Can Tho rivers. This neglects the slight temporal offset of a few minutes of flood waves at the upstream and downstream of the Hau river stretch, and also the minor differences in water levels between the Hau river and Can Tho river (usually < 5 cm event for a 100-year flood). Due to the minor differences these simplification are justifiable within the frame of a probabilistic hazard analysis (Apel *et al.*, 2009).

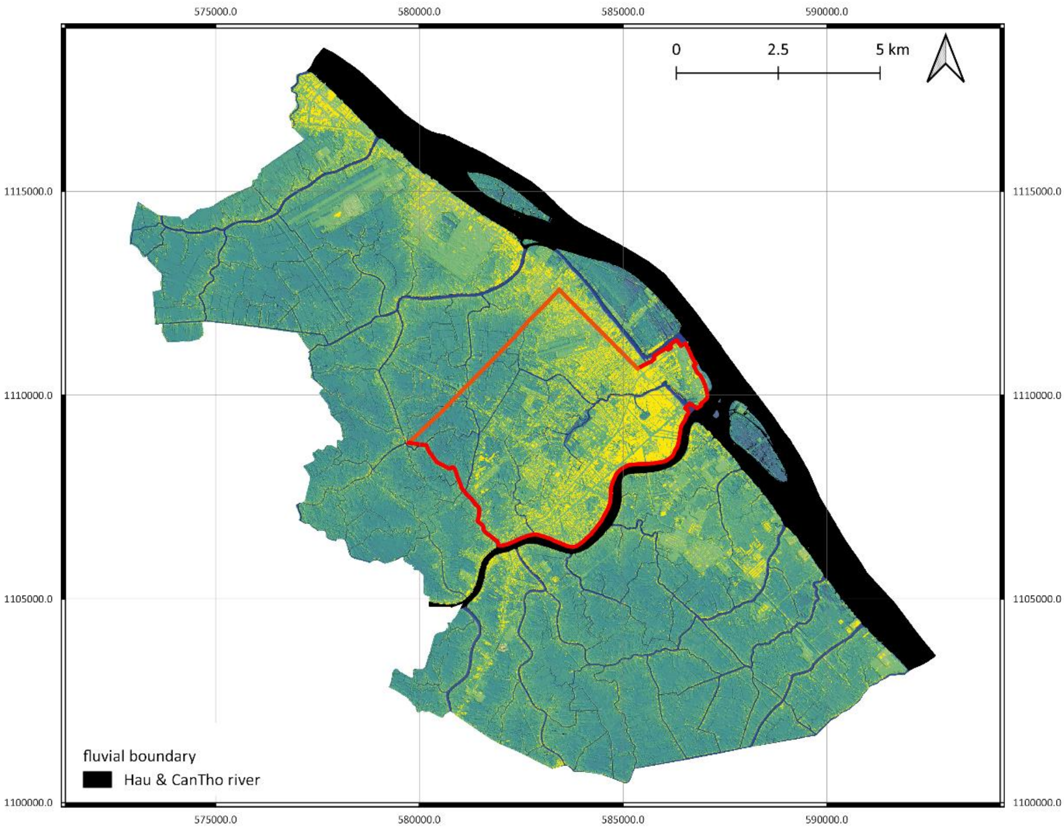
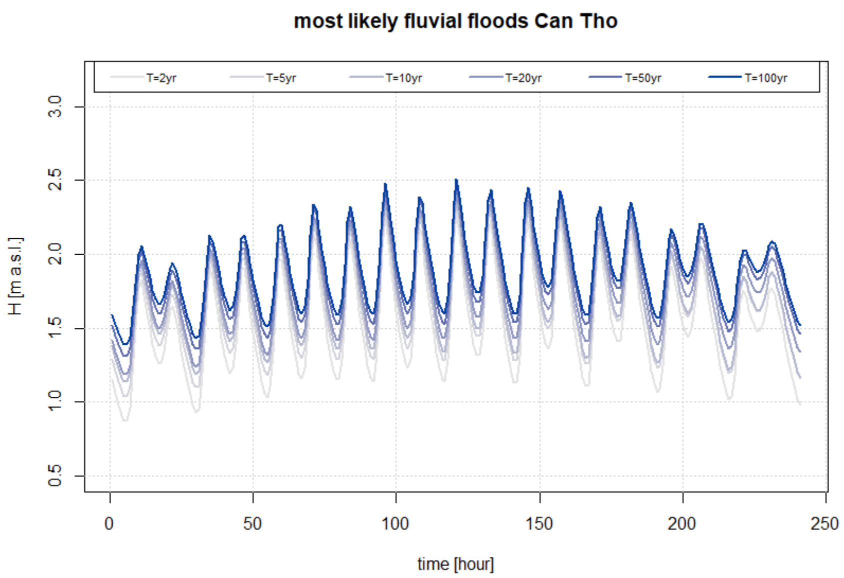


Figure 74: *Fluvial boundary (black) defined for the inundation simulation (Hau River and Can Tho River).*

The boundary time series hydrographs for the different return periods were derived from the bivariate extreme value statistics for flood peak discharge Qp and flood volume V at Kratie, the apex of the Mekong delta, published by Dung *et al.* (2015). Apel *et al.* (2016) used 140 pairs of Qp and V for each return period (i.e. Qp-V-pairs of equal probability of occurrence). With these Qp-V-pairs synthetic flood hydrographs were generated and flood simulations were performed by the large scale quasi-2D model of the Mekong delta (Dung *et al.*, 2011), thereby generating the hydraulic boundary conditions in terms of water levels for the fluvial flood hazard simulations in Can Tho. Because of the long simulation times for the extended 2D hydraulic model in this study, which amounts to roughly 60% of the simulated real time (the simulation of a 48 hours event last approximately 30 hours), a fully probabilistic hazard simulation considering all 140 synthetic flood events for each return period was not possible. Therefor only the most likely synthetic flood event for each return period at Can Tho was identified, taking the median maximum water level of all 140 synthetic events as indicator. Figure 75 (top panel) shows the 10-day water level hydrographs around the peak water level at t = 121 hours for each return period. In order to keep the required simulation times in a practicable time frame, only the 48 hours around the maximum water levels were simulated by the extended 2D hydraulic model (Figure 75 middle and bottom panel). These water levels were assigned to the fluvial boundary area as indicated in Figure 74.

It has to be noted that the same necessary datum correction as in Apel *et al.* (2016) was applied to the simulated water levels of the large scale hydraulic model, in order to harmonize the different vertical datum of the hydraulic model and the DEM.



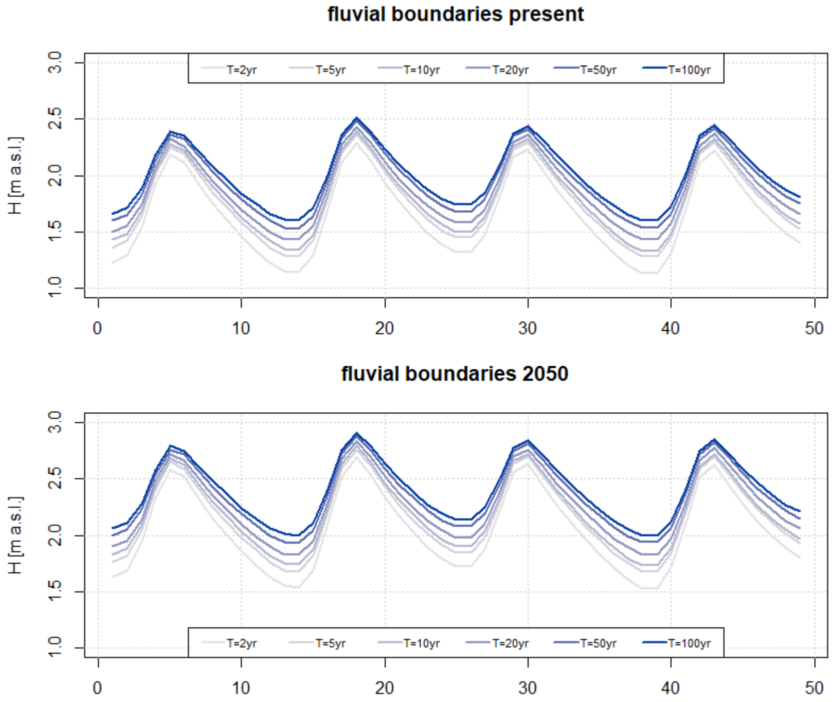


***Figure 75**: Top panel: Hydrographs of the 10 days around the maximum water level of the most likely synthetic flood hydrographs at Can Tho for each return period, taken from Apel* et al. *(2016). Middle panel: Water level boundary hydrographs for the fluvial flood hazard analysis for the present time period. Bottom panel: Water level boundary hydrographs for the fluvial flood hazard analysis for the future time horizon 2050.*

In order to account for the inundation processes the may occur before the simulated 48 hours, the initial water depths in the simulation domain were derived using the initial water level of each scenario as vertical reference. This reference water level was intersected with the DEM and all areas below this level were filled with water up to the reference levels. In order to consider the flood protection of the dike ring of Ninh Kieu-Binh Thuy, the initial water depths in this area was always set to the initial water level of a 2-year return period.

This procedure of setting initial water depths does not only guarantee numerical stability of the simulations, but also considers the likely inundation of area following the already high water levels prior to the start of the scenarios. A comparison of the 48-hour hydrographs with the 10-day hydrographs in Figure 75 shows, that this initial water level is repeatedly exceeded before the start of the simulation period. If these water levels are already above bank and ground level, it is very likely that they would be inundated already at the start of the simulation period, because of the very flat terrain of the simulation area and the high density of channels, which connect practically every area of the simulation domain to the main channels. However, it has to be noted that this procedure might overestimate the inundation in remote areas without channel connection. But Figure 74 shows, that these areas hardly exist.

The future fluvial flood hazard was estimated using a delta-approach. In this approach the present period fluvial hazard scenarios are upscaled by a ΔH of peak water levels taken from published studies. In this study the results of Triet *et al.* (2020) were used. Triet *et al.* (2020) quantified the mean change of peak water levels from the period 1971-2000 to the period 2036-2065, using a climate projection by the MPI-ESM-LR (MPI) global simulation model under the Representative Concentration Pathway 4.5 (RCP 4.5) scenario for Kratie. This discharge projections were routed through the large-scale hydraulic model of the delta mentioned above, in combination with an effective sea level rise scenario for 2050, which considers the combination of climate change induced sea level rise with land subsidence projections of the delta. These simulations were evaluated to obtain mean changes in peak water level, the ΔH, at different locations in the delta. For Can Tho the simulations indicate a ΔH of +0.03m by climate change induced higher discharge of the Mekong, and + 0.37m caused by effective sea level rise. Combining these two values, the ΔH for Can Tho in 2050 was set to +0.4 m. The bottom panel of **Figure 75** shows the upscaled synthetic flood hydrographs used for the future fluvial flood hazard analysis. The initial water depths for the future scenarios were derived in a similar manner as for the present hazard.

Pluvial flood hazard

The pluvial flood hazard is based on design rainfalls for Can Tho, as reported by CTU. The design events are assumed to last 90 minutes, with intensities for different return periods as listed in Table 21.

Table 21: *Present day and future (2050) 90 minutes design rainfall intensities for the selected return periods as used in the pluvial hazard analysis.*

Return period	T = 2 yr	T = 5 yr	T = 10yr	T = 20 yr	T = 50 yr	T = 100 yr
Present	67 mm	81 mm	89 mm	95 mm	102 mm	107 mm
Future	104 mm	126 mm	138 mm	147 mm	158 mm	166 mm

In order to simulate the pluvial inundation assumptions about the spatial and temporal distributions of the rainfall have to be made. Unfortunately, no information about spatial extend and spatial and temporal intensity of the typically convective rainstorm during the monsoon season in the Mekong delta are available. Therefore the following simplifying assumptions were made:

Assumption on spatial rainfall distribution: uniform over whole simulation domain. This is unrealistic, but justifiable because of the low topography of the area and thus the low spatial redistribution of the rainfall induced surface runoff. Moreover, the alternative approach of defining spatially limited rainfall events in combination with a Monte Carlo simulation varying the location of the convective storms, as performed in Apel *et al.* (2016), is not feasible because of the long simulation runtimes in this study.

Assumption on temporal rainfall distribution: uniform over reference rainfall duration of 90 minutes. This assumption is likely not realistic, but without further data this is the procedure with the least assumptions to be taken, and thus best justifiable. The design rainfall intensities of Table 21 are thus distributed uniformly in 5-minute intervals over the 90 minutes event duration.

For the estimation of the future rainfall intensities a delta approach as for the fluvial flood hazard was applied. The ΔP for the precipitation was taken from a report about climate change and sea level rise scenarios for Vietnam of the Vietnamese Ministry of Natural Resources and Environment (MONRE) (MONRE, 2016). In this report the change in average maximum 1-day rainfall for the central part of the Mekong delta was estimated at about ~50-55% for RCP4.5. Based on these estimations and taking the assumption that usually only one severe convective storm hits an area per day in the Mekong delta, the ΔP was assumed to be +55%. Table 21 lists the resulting 90-minutes intensities. The assumptions of spatial and temporal distribution were kept identical to the present-day pluvial hazard analysis.

The pluvial hazard simulations had a duration of 180 minutes, in order to allow for possible spatial redistribution of the inundation after the end of the actual rainfall event.

Combined fluvial-pluvial flood hazard

The combined flood hazard analysis assumes a joint occurrence of peak fluvial water levels with a heavy rainstorm. Also here a fully probabilistic analysis is not possible due to the simulation runtimes. Moreover, a complete permutation of joint occurrences of different return periods of fluvial and pluvial hazard is also not possible, thus only the combination of fluvial and pluvial scenarios with the same return period will be considered, analogously to Apel et al. (2016). This is performed for the present day scenarios, as well as for the ΔH and ΔP scaled future scenarios. In these combinations, the rainfall event is coinciding with the peak fluvial flood water level, starting 30 minutes before the peak water level and lasting for 90 minutes.

The combination of the fluvial and pluvial events change the probabilities of the combined events, which are much smaller as the individual hazard events. The calculation of the probabilities follows Apel et al. (2016):

P(fl*pl) = P(fl) * P(pl) * P(co)

With P(fl*cl) as the probability of occurrence of combined fluvial-pluvial events, P(fl) the probability of occurrence fluvial events, P(pl) the probability of occurrence of pluvial flood events, and P(co) the probability of coincidence of high fluvial water levels and the rain storm of the pluvial hazard event. P(fl) and P(pl) are calculated directly from the return periods, while P(co) is calculated by the length of the flood season, the length of the tidal flood peaks, and the length of the rainfall events. Apel et al. (2016) quantified P(co) to 0.2. Thus the probabilities of the combined events evaluate to the probabilities and return periods listed in Table 22.

Table 22: *Probabilities and return periods of the combined fluvial-pluvial flood hazard scenarios.*

Return period combination fluvial * pluvial	T = 2 * T = 2	T = 5 * T = 5	T = 10 * T = 10	T = 20 * T = 20	T = 50 * T = 50	T = 100 * T = 100
Probability P(fl*pl)	0.05	0.008	0.002	0.0005	0.00008	0.00002
Return period for P(fl*pl) [years]	20	125	500	2000	12500	50000

These reduced probabilities of the combined fluvial-pluvial hazard scenarios need to be considered when calculating the risk based on these scenarios.

Tidal flood hazard

The tidal flood hazard analysis used a different as used in the fluvial and pluvial hazard analysis. This is due to the lacking statistics of coincidence of different tidal level at the estuaries with high water levels at Can Tho that eventually might cause inundation. Such an analysis would require long time series of tidal and river water levels and a complicated bi-variate extreme value statistics. Both the data and the analysis are not available in literature, therefor an empirical approach was developed. Here a tidal inundation is defined as flood events in Can Tho, that are solely caused by high tidal water levels, whereas the river water levels and discharge are normal. In this context it has to be noted, that the fluvial flood scenarios and also real flood events already contain a tidal flooding element, as clearly visible in Figure 75. However, in the fluvial hazard scenarios the tidal water level boundary was the same for all fluvial scenarios and return periods, thus the effect of tidal water levels on inundation cannot be isolated.

This is performed in this study by simulating an average flood events, here defined as the most likely 2-year fluvial flood event at Kratie, with temporarily varying tidal water levels. For the analysis of the tidal water level the time series of the flood season in 2011, the last severe flood in the delta, was used. The tidal water level was shifted in time, that the lowest tidal water levels (neap tide), the mean tidal water level (mean tide) and the highest tidal water level (spring tide) coincide with the period of peak discharge at Kratie. The large scale hydraulic model simulated the flood propagation under these boundary conditions through the Mekong delta, and the resulting water levels at Can Tho were then used for the 2D inundation modelling in the same was as for the fluvial hazard scenarios. This results in three hazard simulations for the present period denoted as “neap tide”, “mean tide”, and “spring tide”.

The probabilities of these temporal coincidences are empirically derived by the length of the flood event and the length of the spring and neap tides (6 days, each). Assuming a normal flood with high water levels lasting from mid-September to end of November, i.e. 76 days, the probability of a spring or neap tide coinciding with high water levels is 6/76 = 0.079. Accordingly, the probability of coincidence of high water levels with mean tidal level is 0.842. The probability of occurrence of these tidal flood events is calculated as for the combined fluvial-pluvial events:

$P(ti) = P(fl_{T=2}) * P(co)$

With $P(fl_{T=2}) = 0.5$ and P(co) as defined above. Table 23 lists the probabilities of coincidence, occurrence and the associated return periods. This means, that the 2-year events can be split up into three different events with different tidal magnitudes. These scenarios and probabilities can be used in the risk assessment instead of the 2-year event with fixed tidal boundary to estimate the total flood risk for Can Tho, but also for calculating the isolated flood risk caused by high tidal water levels under normal flood conditions.

***Table 23**: Probabilities and return periods of the tidal flood hazard scenarios.*

Scenario	Neap tide	Mean tide	Spring tide
Probability of coincidence	0.079	0.842	0.079
Probability of occurrence	0.0395	0.421	0.0395
Return period [years]	25	2.5	25

For the future period a ΔH_{tidal} was added to the tidal water levels, resulting in scenarios for the neap, mean, and spring tidal flood hazard for the future period 2050. ΔH_{tidal} was taken from (Manh *et al.*, 2015), who estimated the mean effective sea level rise consisting of climate change induced sea level rise at the coast of the Mekong Delta, natural sediment compaction and anthropogenic induced land subsidence at +0.4 m. This ΔH_{tidal} was added to the tidal boundary conditions of the present tidal scenarios. The hydraulic simulations were then performed as for the present scenarios.

Results

The results of the 2D hydraulic simulations are provided as maximum inundation depths per raster grid cells for each scenario. All the raster grids have a spatial resolution of 5 m, and are in ESRI ASCII raster format (*.asc) and in UTM zone 48N projection. The file names of the raster grids indicate the hazard type (fluvial, pluvial, fluvialpluvial, tidal), the return period (T2, T5, T10, T20, T50, T100), the present ("present") or future ("2050") time period, and parameters of the simulation (infiltration capacity "inf", sewer capacity "sew", and sewer system activation threshold "thresh").

NOTE: The raster files names for the fluvialpluvial scenarios indicate the combination of the return levels, e.g. T10 stands for the combined T10*T10 scenarios. Thus, the probabilities of these events cannot be calculated from the return period indicated in the file name. The probabilities listed in Table 22 have to be used instead. The tidal flood hazard scenarios do not indicate a probability or return period in the file names, but the scenario ("neap", "mean", "spring"). The probabilities of these events are listed in Table 23.

The results are summarized in Table 24 and Table 25 in terms of the maximum, mean and standard deviation of the maximum inundation depth for the whole study domain. All the statistics show an increase from low to high return periods, and from present to future, as had to be expected from the extreme value statistics and the definition of the boundary conditions. Moreover, the figures indicate that the expected future changes in flood hazard are substantial. The change in mean inundation depths for the fluvial and pluvial hazard from present to future are in the same range (pluvial) or even larger (fluvial) than between the 2-year return period and the 100-year return period estimated for the present situation. This means that a 2-year return period event in future might be as severe as a common flood event at present.

Figure 76 to Figure 79 show the hazard maps with the maximum inundation depths in meter for each hazard category, return period and present day and future situations. The Figures visually confirm the conclusion drawn from the inundation statistics. They also visualize the effect of combined fluvial-pluvial flood hazard, which mainly increases the affected areas. In summary, the presented statistical and visual evaluation of the simulation results underline the plausibility of the hazard analysis.

The hazard maps also show that the planned dike ring of Ninh Kieu-Binh Thuy is sufficiently designed to protect the city centre against 100-year fluvial flood events, even under the assumed climate change and sea level rise scenarios. In this context it has to be noted that the future scenarios in this study represent the most likely changes, i.e. in a 1.5K warmer world, based on the current knowledge. But it must be acknowledged that there might be even dramatic changes in future, depending on the actual greenhouse gas emissions in the coming decades and the consequent changes of the Earth's climate.

***Table 24**: Statistics of the fluvial, pluvial and fluvial-pluvial hazard analysis in terms of maximum (max), mean (mean), standard deviation (sd) of the surface inundation in meter, and total inundation area (area) in km² of the maximum inundation for each scenario and return period. For max, mean and sd the area of the boundaries, i.e. the Hau and Can Tho rivers were excluded.*

T = 2 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.20	3.72	1.33	1.56	3.20	3.72
mean	0.10	0.22	0.02	0.04	0.13	0.26
sd	0.27	0.44	0.06	0.09	0.28	0.45
area	12.30	19.22	26.26	26.26	26.27	26.27
T = 5 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.29	3.80	1.46	1.61	3.29	3.81
mean	0.12	0.27	0.03	0.04	0.16	0.29
sd	0.31	0.47	0.07	0.10	0.32	0.48
area	13.97	21.30	26.26	26.26	26.27	26.27
T = 10 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.34	3.86	1.51	1.64	3.33	3.86
mean	0.13	0.28	0.03	0.05	0.17	0.30
sd	0.32	0.48	0.08	0.10	0.34	0.49
area	14.55	21.30	26.26	26.27	26.27	26.27
T = 20 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.39	3.91	1.53	1.66	3.39	3.91
mean	0.15	0.29	0.03	0.05	0.19	0.32
sd	0.34	0.50	0.08	0.11	0.36	0.51
area	15.53	21.56	26.26	26.27	26.27	26.27
T = 50 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.45	3.98	1.56	1.72	3.45	3.98
mean	0.16	0.32	0.04	0.05	0.21	0.34
sd	0.36	0.53	0.08	0.11	0.38	0.53
area	16.61	21.94	26.26	26.27	26.27	26.27
T = 100 years						
statistic	***Fluvial present***	***Fluvial 2050***	***Pluvial present***	***Pluvial 2050***	***Fluvialpluvial present***	***Fluvialpluvial 2050***
max	3.48	4.02	1.57	1.75	3.48	4.02
mean	0.18	0.34	0.04	0.06	0.22	0.35
sd	0.37	0.55	0.09	0.12	0.40	0.55

area	17.24	22.14	26.26	26.27	26.27	26.27

Table 25: *Statistics of the tidal hazard analysis in terms of maximum (max), mean (mean), standard deviation (sd) of the surface inundation in meter, and total inundation area (area) in km² of the maximum inundation for each scenario. For max, mean and sd the area of the boundaries, i.e. the Hau and Can Tho rivers were excluded.*

neap_tide		
statistic	***Tidal present***	***Tidal 2050***
max	2.34	2.99
mean	0.03	0.08
sd	0.15	0.24
area	4.96	12.44
mean_tide		
statistic	***Tidal present***	***Tidal 2050***
max	3.17	3.61
mean	0.09	0.19
sd	0.26	0.40
area	11.72	18.74
spring_tide		
statistic	***Tidal present***	***Tidal 2050***
max	3.33	3.75
mean	0.15	0.26
sd	0.33	0.46
area	17.89	21.07

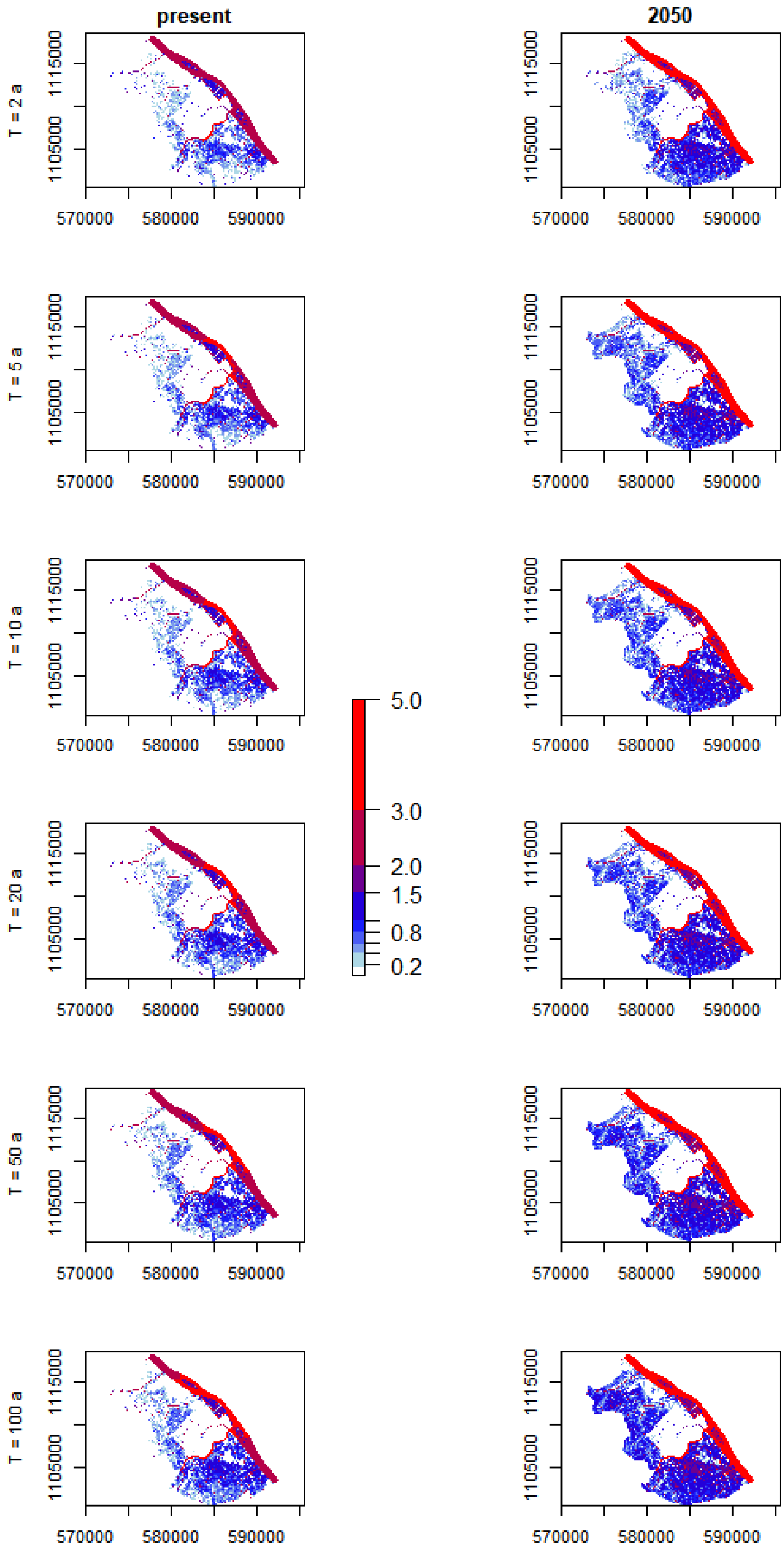


Figure 76: *Fluvial hazard maps showing the maximum inundation depths in meter for present day situation and for mid-21st century under a RCP4.5 greenhouse gas emission scenario for each return period.*

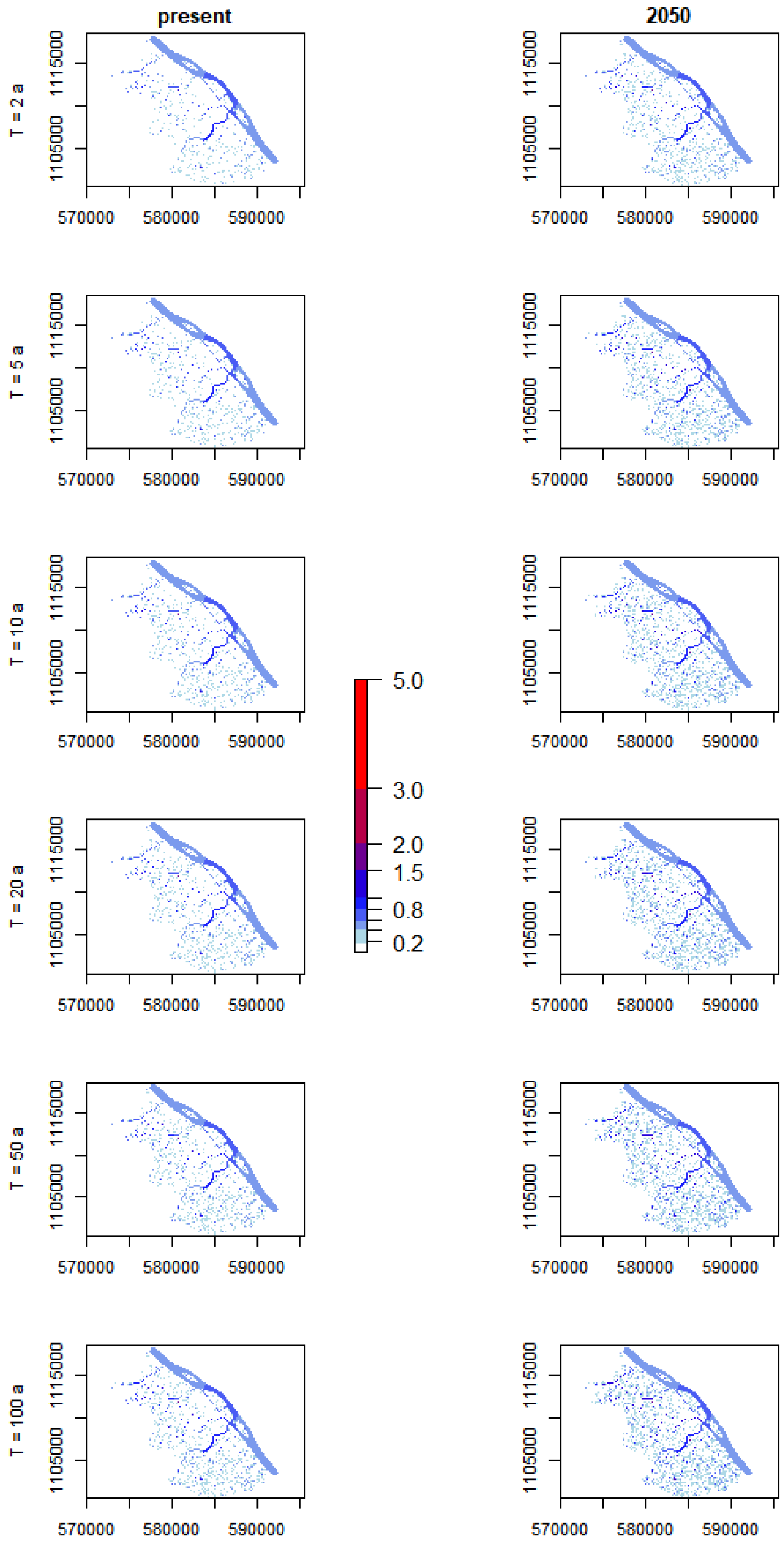


Figure 77: *Pluvial hazard maps showing the maximum inundation depths in meter for present day situation and for mid-21st century under a RCP4.5 greenhouse gas emission scenario for each return period.*

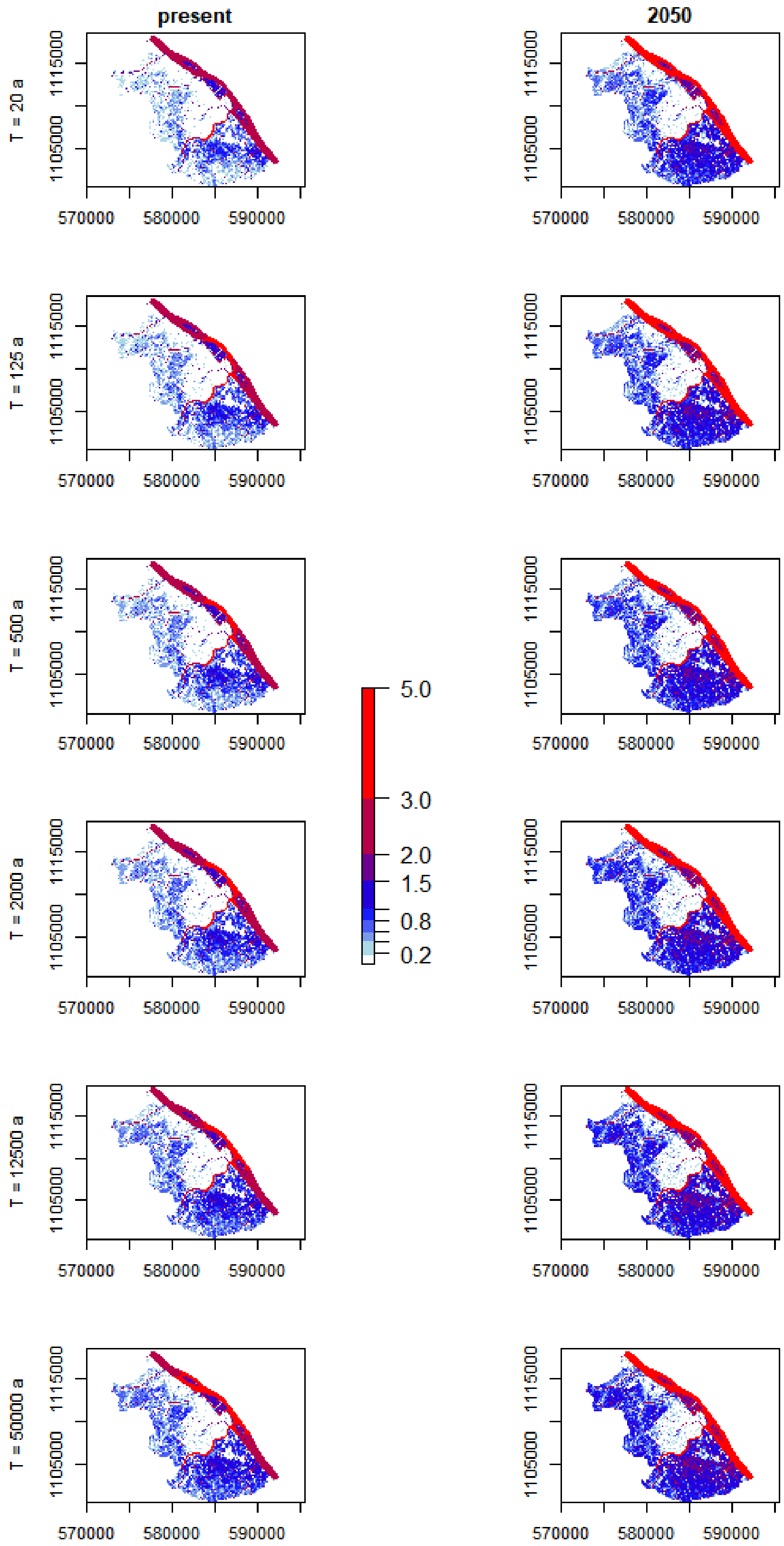


Figure 78: *Fluvial-pluvial hazard maps showing the maximum inundation depths in meter for present day situation and for mid-21st century under a RCP4.5 greenhouse gas emission scenario for each return period.*

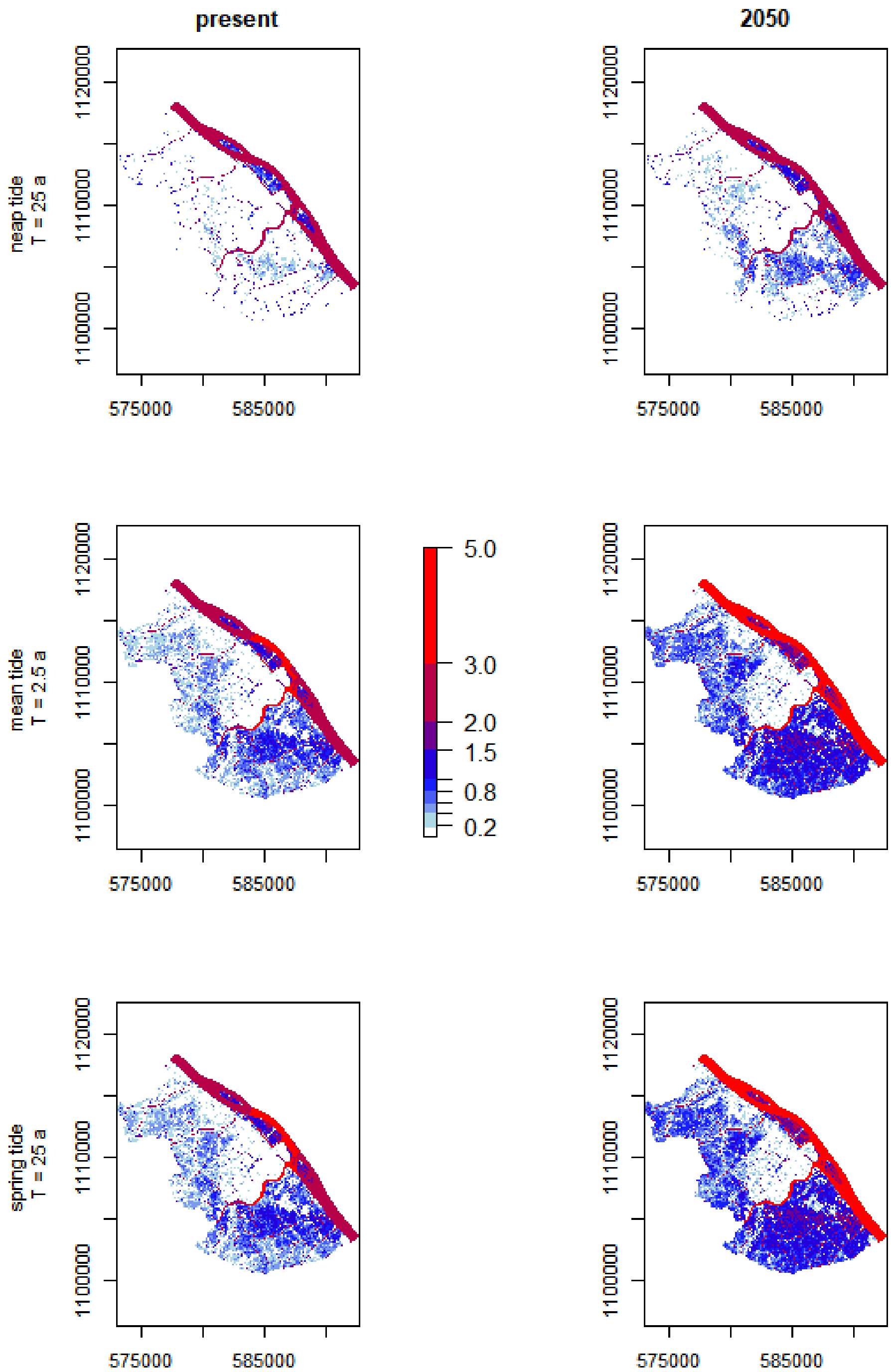


Figure 79: *Tidal flood hazard maps showing the maximum inundation depths in meter for common flood (i.e. derived from T = 2 years return period fluvial scenario) for present day situation and for mid-21st century under sea level rise assumptions that can be associated to the RCP4.5 greenhouse gas emission scenario.*

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ANNEX 2: Measures Selection Procedure

1. Background

A set of flood and heat wave adaptation measures had to be identified and tailored to the existing and projected flood (pluvial/fluvial & tidal) and heat wave risk for the selected assets and population in Can Tho city. The selection and introduction of adaptation measures is an essential part of the ECA framework and requires specific steps of engagement and participation with key stakeholders in order to determine and validate their economic viability and sustainability. The following sections describe the process of selecting appropriate adaptation measures, starting from a pre-selection (*long list*) of measures up to a final selection of measures (*short list*) that are parameterised and introduced to the probabilistic modelling tool CLIMADA.

2. Defining a Long List of Adaptation Measures

The initial phase of identifying adaptation measures has been based on comprehensive literature review, consultations with key experts and project partners of the ECA study. The following key aspects have been considered in the process of selecting a long list of adaptation measures:

- Include international best practice of flood adaptation and heat wave mitigation.
- Include and respect local and national master plans on climate adaptation and/or regional interventions of international development corporations, i.e. what flood adaptation interventions are being implemented or included in national climate strategies and action plans?
- Include best practice from the local context, i.e. what adaptation strategies are recommended from local academia and/or research institutes?

As a result, and considering the mentioned key aspects the following list of measures has been compiled, covering 37 measures in total, from which 27 measures address flood risks and 10 measures aim to mitigate heat wave impacts (see Table 26).

Table 26: *Overview List of Flood and Heat Wave Adaptation Measures for Can Tho City. 'Grey' measures refer to technological and engineering solutions. 'NbS' measures refer to ecosystem-based (or nature-based) solutions and make use of multiple services provided by ecosystems. 'Hybrid' solutions indicate a combination of NbS and Grey types of measures. 'Insurance' solutions cover residual risks, which occur when adaptation measures are not cost-efficient. 'Systemic' measures relate to behaviour change or policy planning.*

#	Name of Measure	Type of Measure	Hazard
1	Flood Wall	Hybrid	Flood
2	Mobile Embankments	Grey	Flood
3	Sluice gates	Grey	Flood
4	Ground (Building) elevation	Grey	Flood
5	Elevation of electricity substations	Grey	Flood
6	Dry flood proofing	Grey	Flood
7	Reinforced electricity poles	Grey	Flood
8	Improved drainage system	Grey	Flood
9	Rehabilitation of existing drainage canals	Grey	Flood
10	Pump Stations	Grey	Flood

11	Road spillways as bio-retention systems	Hybrid	Flood
12	Retention reservoirs	NbS	Flood
13	Detention swales along roads	Hybrid	Flood
14	Rain collection tanks for existing buildings	Grey	Flood
15	Constructed wetlands	NbS	Flood
16	Permeable pavements	Grey	Flood
17	Modular water retention systems under sealed areas	Grey	Flood
18	Green Spaces (Urban Forestry)	NbS	Flood
19	Recharge parks with bio-filtration	NbS	Flood
20	Infiltration trenches	Hybrid	Flood
21	Wet flood proofing (public buildings)	Grey	Flood
22	Flood awareness campaign	Systemic	Flood
23	Smart-City Data Hub Development	Systemic	Flood
24	Improving the hydrological and meteorological monitoring	Systemic	Flood
25	Flood protection storage facilities	Grey	Flood
26	Index Insurance	Insurance	Flood
27	Improved soild waste management	Systemic	Flood
28	White Roofs	Grey	Heat Wave
29	Climate proofed standards for road design (cool pavements)	Grey	Heat Wave
30	Cooling centres	Systemic	Heat Wave
31	Urban green spaces and corridors	NbS	Heat Wave
32	Green Roofs	NbS	Heat Wave
33	Urban gardening (farming)	NbS	Heat Wave
34	Shaded walkways	Hybrid	Heat Wave
35	Urban Forestry	NbS	Heat Wave
36	Climate smart agriculture	Hybrid	Heat Wave
37	Cooling by water spray (fountains/spray parks)	Hybrid	Heat Wave

3. Validation and Weighting of Selection Criteria

After identifying a long list of 37 measures, the most promising adaptation measures should be parameterised within CLIMADA. To do so, it is best practice to reduce the long list of adaption measures to a short list based on specific selection criteria. Selection criteria are attributes or characteristics that have been identified of being essential to address flood and heat wave risk but also to satisfy requirements such as sustainability and economic relevance. The following selection criteria have been widely adopted and used in comparable climate risk analysis projects (as for instance by the AGRICA Project[112]) and validated by key stakeholders of the ECA project:

[112] Murken, L., Cartsburg, M., Chemura, A., Didovets, I., Gleixner, S., Koch, H., Lehmann, J., Liersch, S., Lüttringhaus, S., Rivas López, M. R., Noleppa, S., Roehrig, F., Schauberger, B., Shukla, R., Tomalka, J., Yalew, A. & Gornott, C., (2020). *Climate risk analysis for identifying and weighing adaptation strategies in Ethiopia's agricultural sector.* A report prepared by the Potsdam Institute for Climate Impact Research for the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development, 150 pp. DOI: 10.2312/pik.2020.003

1. Cost-Effectiveness: Represents the absolute cost of measures, considering cost of planning, and implementing adaptation measures, including transition cost and operation and maintenance cost. Benefits/Effectiveness are the avoided damage cost or the accrued benefits following the adoption and implementation of adaptation measures.

2. Up-scaling Potential: This criterion includes the possibility of a potential extension of adaptation strategies within provinces and to other regions in Vietnam, where climate adaptation investments are required. This implies that a measure can serve a broad range of applications, independently of geographic location and potential beneficiaries.

3. No-Regret Options: This criterion refers to climate adaptation strategies that generate economic, environmental or societal benefits irrespective of the course of changing climatic conditions in the region. These adaptation strategies imply a cost-effectiveness under present and future climatic scenarios and benefit sustainable development.

4. Co-Benefits (for SDGs): Identified adaptation strategies should generate some added value (co-benefits) after implementation and maximise sustainable development by contributing to the Sustainable Development Goals (SDGs) and their targets embedded under the United Nations Agenda 2030 for Sustainable Development.

5. Mal-adaptation: Identified adaptation strategies should not (unintendedly) lead to increased vulnerability of population groups, the environment or the economy (regionally or locally) in relation to climate variability and change. Adaptation interventions should not undermine capacities and resilience processes under present and future scenarios.

6. Stakeholder Acceptance: Identified adaptation strategies should have a broad acceptance by different stakeholder groups to ensure future uptake and a sustainable use.

7. Institutional Support Requirements: Adaptation strategies, depending on their complexity, require more institutional support for implementation, operation and maintenance than others. In the long term, it is advised that implementation processes and operations of adaptation measures are supported and ideally initiated by municipal authorities.

8. Ecosystem-based Adaptation (EbA): EbA is officially defined by the Convention on Biological Diversity (CBD) as 'the use of biodiversity and ecosystem services [...] to help people to adapt to the adverse effects of climate change' which may include 'sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities'.[113]

After validating the above mentioned selection criteria, key stakeholders were asked to *weigh the criteria* for a later use in a Multi-Criteria Analysis. Stakeholders ranked the validated criteria by assigning a score varying from 8 (most important) to 1 (least important). For each criterion, the average value of all assigned scores represents the weight. This weight will be applied in the Multi-Criteria Analysis. The results of the ranking and the resulting weight of each criterion is shown in Table 27.

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[113] Lo, V. (2016). Synthesis report on experiences with ecosystem-based approaches to climate change adaptation and disaster risk reduction. *Technical series*, *85*.

Table 27: *Weighting of selection criteria. Rank from 8 (most important) to 1 (least important). Rank values could be used only once.*

CRITERION	AVG. POINTS	WEIGHT
Cost-Effectiveness	6,29	17,46%
No-Regret Options	5,43	15,08%
Stakeholder Interest (Social Acceptance)	5.00	13,89%
Nature-Based Solutions (NbS)	4.00	11,11%
Potential of Mal-Adaptation	3,93	10,91%
Institutional Support Requirements	3,86	10,71%
Up-scaling Potential	3,79	10,52%
Co-Benefits (for SDGs)	3,71	10,32%

As a result, the criterion *Cost-Effectiveness* and *No-Regret Options* were given the highest weight. The criterion *Co-Benefits (for SDGs)* has been given the lowest weight, hence less significance for a potential adaptation measure. These weights (as of Table 27) have been used in a Multi-Criteria Analysis, to further reduce measures from the long list.

4. Multi-Criteria Analysis - Defining a Short List of Adaptation Measures

A Multi-Criteria Analysis (MCA) describes a structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. MCA is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach falls short (e.g. cost-benefit), and where multiple criteria need to be included.

The MCA has been applied to further shorten the list of measures and to conclude a short list that can be introduced to CLIMADA. Results of the MCA are shown in Table 27. Some measures were merged due to their similar design and effect (e.g. infiltration trenches & vegetated swales).

The final short list of flood adaptation and heat wave measures, as a result of the MCA, is shown in Table 28). It should be noted that some measures will address two types of hazards (i.e. flood & heat have) as indicated in Table 28.

Table 28: *Overview List of Flood and Heat Wave Adaptation Measures for Can Tho City. 'Grey' measures refer to technological and engineering solutions. 'NbS' measures refer to ecosystem-based (or nature-based) solutions and make use of multiple services provided by ecosystems. 'Hybrid' solutions indicate a combination of NbS and Grey types of measures. 'Insurance' solutions cover residual risks, which occur when adaptation measures are not cost-efficient. 'Systemic' measures relate to behaviour change or policy planning.*

#	Name of Measure	Type of Measure	Hazard
1	Retention reservoirs	NbS	Flood
2	Detention swales along roads	NbS	Flood
3	Improved solid waste management	Systemic	Flood
4	Rehabilitation of existing drainage canals	Grey	Flood
5	Flood awareness campaign	Systemic	Flood
6	Road spillways as bio-retention systems	NbS	Flood
7	Rain collection tanks for existing buildings	Grey	Flood

8	Mobile flood embankments	Grey	Flood
9	Flood wall	Grey	Flood
10	Flood protection storage facilities (incl. sandbags)	Systemic	Flood
11	Index Insurance	Insurance	Flood & Heat Wave
12	Green roofs	Hybrid	Flood & Heat Wave
13	Green spaces (Urban forestry)	NbS	Flood & Heat Wave
14	White roofs	Grey	Heat Wave
15	Cooling centres	Systemic	Heat Wave
16	Climate smart agriculture	Hybrid	Heat Wave
17	Climate proofed road design	Grey	Heat Wave

Multi-Criteria Analysis Decision Matrix

	Measures	Criteria: Weight	Cost-Effectiveness	No-Regret Options	Social Acceptance	Nature-based Solutions (NbS)	Potential of Mal-adaptation	Institutional Support	Up-scaling Potential	Co-Benefits (for SDGs)	Total Score	Short List
			17,5	15,1	13,9	11,	10,9	10,7	10,5	10,3	100	
18	Green Spaces (Urban Forestry)		1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	**1**	X
12	Retention reservoirs		1,0	1,0	1,0	1,0	1,0	0,5	1,0	1,0	**0,94645**	X
15	Constructed wetlands		1,0	1,0	1,0	1,0	1,0	0,5	1,0	1,0	**0,94645**	
13	Detention swales along roads		1,0	1,0	1,0	1,0	1,0	0,5	1,0	0,5	**0,89485**	X
27	Improved soild waste management		1,0	1,0	1,0	0,0	1,0	1,0	1,0	1,0	**0,8889**	X
19	Recharge parks with bio-filtration		0,5	1,0	1,0	1,0	1,0	0,5	1,0	0,5	**0,80755**	
9	Rehabilitation of existing drainage canals		1,0	1,0	1,0	0,0	1,0	0,5	1,0	0,5	**0,78375**	X
22	Flood awareness campaign		1,0	1,0	1,0	0,0	1,0	0,5	1,0	0,5	**0,78375**	X
20	Infiltration trenches		1,0	1,0	1,0	0,0	1,0	0,5	1,0	0,0	**0,73215**	
11	Road spillways as bio-retention systems		1,0	1,0	1,0	0,0	1,0	0,0	1,0	0,5	**0,7302**	X
23	Smart-City Data Hub Development		0,5	1,0	1,0	0,0	1,0	0,0	1,0	1,0	**0,6945**	
24	Improving the hydrological and meteorological monitoring		0,5	1,0	1,0	0,0	1,0	0,0	1,0	1,0	**0,6945**	
8	Improved drainage system		0,5	1,0	1,0	0,0	0,5	0,0	1,0	0,5	**0,58835**	X
2	Mobile Embankements		1,0	0,0	1,0	0,0	1,0	0,5	1,0	0,0	**0,58135**	X
25	Flood protection storage facilities		1,0	1,0	1,0	0,0	0,0	0,0	1,0	0,0	**0,5695**	X
14	Rain collection tanks for existing buildings		1,0	0,0	0,5	0,0	0,5	1,0	1,0	0,0	**0,5109**	X
1	Flood Wall		0,5	0,0	1,0	0,0	0,5	0,0	1,0	0,0	**0,38595**	X
16	Permeable pavements		0,5	0,0	1,0	0,0	0,5	0,0	1,0	0,0	**0,38595**	
17	Modular water retention systems under sealed areas		0,5	0,0	1,0	0,0	0,5	0,0	1,0	0,0	**0,38595**	
7	Reinforced electricity poles		0,5	0,0	0,5	0,0	1,0	0,0	1,0	0,0	**0,37105**	
26	Flood index insurance		0,5	0,0	0,5	0,0	0,5	0,0	1,0	0,5	**0,3681**	X
5	Elevation of electricity substations		0,5	0,0	1,0	0,0	0,0	0,0	1,0	0,0	**0,3314**	
6	Dry flood proofing		0,5	0,0	0,5	0,0	0,5	0,0	1,0	0,0	**0,3165**	
21	Wet flood proofing (public buildings)		1,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0	**0,2837**	
3	Sluice gates		0,5	0,0	0,5	0,0	0,5	0,0	0,0	0,0	**0,2113**	
4	Ground (Building) elevation		0,5	0,0	0,5	0,0	0,5	0,0	0,0	0,0	**0,2113**	
10	Pump Stations		0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	**0,15675**	

Figure 80: *Results of the MCA for flood adaptation measures. The selection criteria have been applied to the remaining measures of the long list. The following values were applied to the criteria: Stakeholder acceptance [High = 1, Medium = 0.5, Low = 0], Cost-Effectiveness [High = 1, Medium = 0.5, Low = 0], Upscaling Potential [Yes = 1, No = 0], Institutional support [High = 0, Medium = 0.5, Low = 1], Mal-adaptation [High = 0, Medium = 0.5, Low = 1], Cost-Benefits [High = 1, Medium = 0.5, Low = 0], No Regret Options [Yes = 1, No = 0], EbA [Yes = 1, No = 0]. Measures indicated in 'red' are considered to be merged with other measures marked in 'green' to further reduce the short list. Measures indicated in 'green' representing the 'Short List' of identified measures.*

Multi-Criteria Analysis Decision Matrix											
		Criteria:	Cost-Effectiveness	No-Regret Options	Social Acceptance	Nature-based Solutions (NbS)	Potential of Mal-adaptation	Institutional Support	Up-scaling Potential	Co-Benefits (for SDGs)	Total Score	Short List
	Measures	Weight	17,5	15,1	13,9	11,1	10,9	10,7	10,5	10,3	100	
6	Urban gardening (farming)		1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	**1**	
8	Urban Forestry		1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	**1**	
4	Urban green spaces and corridors		1,0	1,0	1,0	1,0	1,0	0,5	1,0	1,0	**0,94645**	
5	Green Roofs		0,5	1,0	1,0	1,0	1,0	0,5	1,0	1,0	**0,85915**	X
1	White Roofs		1,0	1,0	1,0	0,0	1,0	1,0	1,0	0,0	**0,7857**	X
3	Cooling centres		1,0	1,0	1,0	0,0	1,0	0,5	1,0	0,0	**0,73215**	X
9	Climate smart agriculture		0,0	0,0	1,0	0,0	0,5	0,0	1,0	1,0	**0,40185**	X
7	Shaded walkways		0,5	0,0	0,5	0,0	1,0	0,0	0,0	0,0	**0,26585**	
10	Cooling by water spray (fountains/spray parks)		0,5	0,0	1,0	0,0	0,0	0,0	0,0	0,0	**0,2262**	
2	Climate proofed standards for road design (cool pavements)		0,5	0,0	0,5	0,0	0,5	0,0	0,0	0,0	**0,2113**	X

Figure 81: *Results of the MCA for heat wave adaptation measures. The selection criteria have been applied to the remaining measures of the long list. The following values were applied to the criteria: Stakeholder acceptance [High = 1, Medium = 0.5, Low = 0], Cost-Effectiveness [High = 1, Medium = 0.5, Low = 0], Upscaling Potential [Yes = 1, No = 0], Institutional support [High = 0, Medium = 0.5, Low = 1], Mal-adaptation [High = 0, Medium = 0.5, Low = 1], Cost-Benefits [High = 1, Medium = 0.5, Low = 0], No Regret Options [Yes = 1, No = 0], EbA [Yes = 1, No = 0]. Measures indicated in 'red' are considered to be merged with other measures marked in 'green' to further reduce the short list. Measures indicated in 'green' representing the 'Short List' of identified measures.*

ANNEX 3: Description of Adaptation Measures

Introduction

This chapter presents the list of flood and heat wave adaptation measures identified for the three urban districts, Binh Thuy, Ninh Kieu, and Cai Rang of Can Tho City (see Figure 82). These measures will serve to reduce the vulnerability of the key assets and population groups selected during the Inception Workshop, by reducing either the number of assets expected to be affected, the intensity of the impact, or in some cases both. The benefit of each measure was linked to the potential averted damage. The adaptation measures were selected based on a comprehensive literature review, and a consultation process with key experts, partner organisations and government representatives. In total 27 flood adaptation measures and 10 heat wave adaptation measures were initially identified (referred to as a 'long list') and reduced to 17 (referred to as a 'short list'), which have been introduced to CLIMADA.

Table 29: *Overview List of Flood and Heat Wave Adaptation Measures for Can Tho City. 'Grey' measures refer to technological and engineering solutions. 'NbS' measures refer to ecosystem-based (or nature-based) solutions and make use of multiple services provided by ecosystems. 'Hybrid' solutions indicate a combination of NbS and Grey types of measures. 'Insurance' solutions cover residual risks, which occur when adaptation measures are not cost-efficient. 'Systemic' measures relate to behaviour change or policy planning.*

#	Name of Measure	Type of Measure	Hazard
1	Retention reservoirs	NbS	Flood
2	Detention swales along roads	NbS	Flood
3	Improved solid waste management	Systemic	Flood
4	Rehabilitation of existing drainage canals	Grey	Flood
5	Flood awareness campaign	Systemic	Flood
6	Road spillways as bio-retention systems	NbS	Flood
7	Rain collection tanks for existing buildings	Grey	Flood
8	Mobile flood embankments	Grey	Flood
9	Flood wall	Grey	Flood
10	Flood protection storage facilities (incl. sandbags)	Systemic	Flood
11	Index Insurance	Insurance	Flood & Heat Wave
12	Green roofs	Hybrid	Flood & Heat Wave
13	Green spaces (Urban forestry)	NbS	Flood & Heat Wave
14	White roofs	Grey	Heat Wave
15	Cooling centres	Systemic	Heat Wave
16	Climate smart agriculture	Hybrid	Heat Wave
17	Climate proofed road design	Grey	Heat Wave

To better define the location of each measure, a zonation of the study area has been introduced. The identified flood and heat wave adaptation measures have been allocated to the three urban districts of

Can Tho, representing Zone 1, 2, and 3. A map of the different zones, which correspond to the study area of the three urban districts is shown in Figure 82.

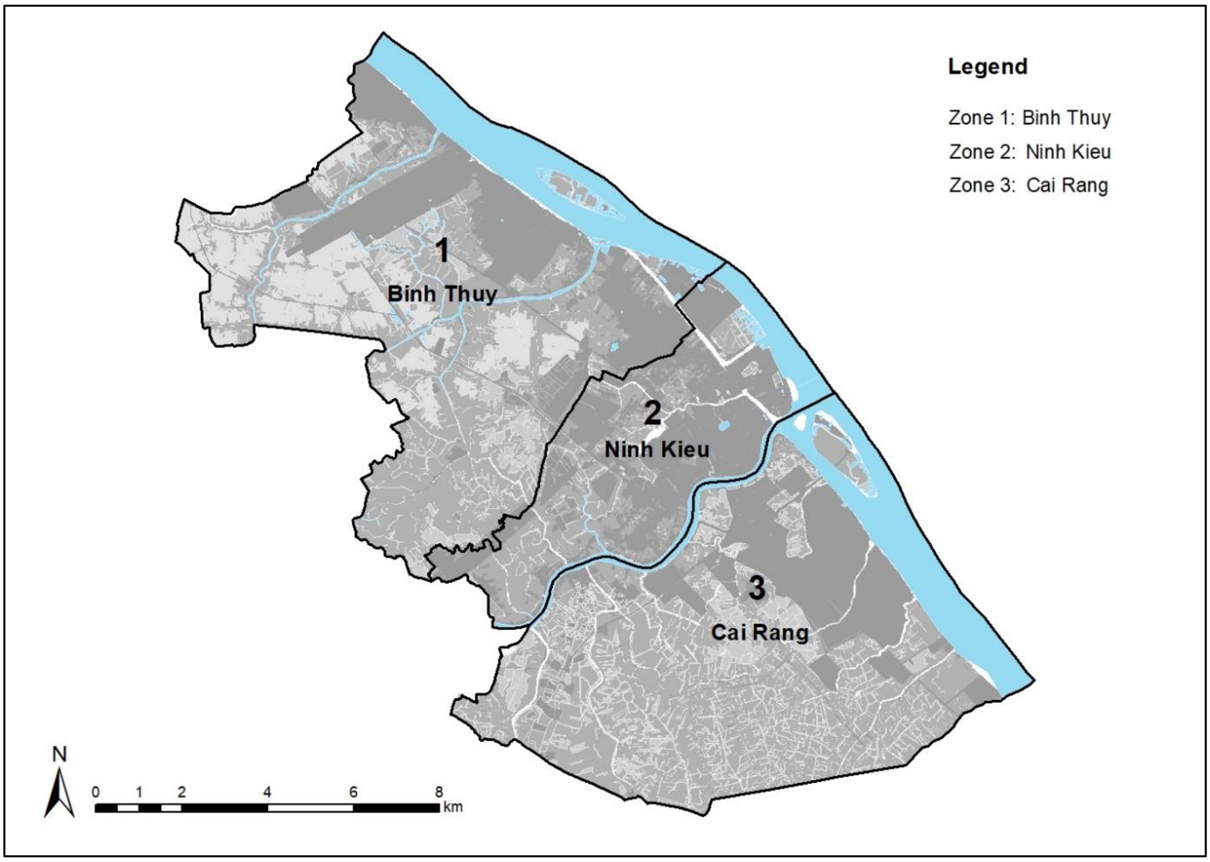

Figure 82: *Overview of zoning. Zones correspond to the study areas' district boundaries. Source: UNU-EHS.*

1. Retention reservoirs

Retention reservoirs are artificial ponds with vegetation around the perimeter and include a permanent pool of water in their design. They are usually designed to provide short-term storage of water. Retention reservoirs can retain flood events, reducing peak flows and limiting the risk of flooding. A permanent pool of water that fluctuates in response to precipitation and runoff from the contributing areas, keeps deposited sediments at the bottom of the holding area and is able to treat contaminated stormwater runoff. Retention ponds naturally improve water quality and remove pollutants. Impervious surfaces (i.e. paved surfaces, buildings, etc.) increase the volume of surface runoff in a watershed because they prevent rainwater from infiltrating into the soil. Also, pollutants that collect on impervious surfaces are not filtered by the soil or plants and are conveyed directly to rivers without treatment. Retention ponds naturally process pollutants through sedimentation and without additional equipment. In most cases, ponds are surrounded by natural vegetation which helps prevent erosion and improves aesthetic benefits. Retention ponds also referred to as recharge parks, can serve as multi-purpose areas and could be used for recreational purposes or public gathering spaces, etc. From a health standpoint, there is always a concern with standing water. This can be a drowning hazard, particularly with children, if ponds are not properly designed or maintained. Ponds can also draw mosquitoes, which may contribute to the transmission of some diseases.

From a design perspective, stormwater is conveyed from roads, parking areas, rooftops, and lawns through pipes and swales into the pond. The inlets are where stormwater runoff is discharged into the pond. In areas around inlets, the heaviest sediments settle. Small outlets allow some water to flow out so that the pond does not overflow. The retention ponds are designed to permanently retain water in the basin. This volume of water is known as the permanent pool or treatment pool. The treatment pool is designed to slow the water down and hold it long enough to allow gravity to pull sediments out of the water column and allow sunlight and biochemical processes to break down pollutants before they are released to rivers and beaches. In most cases, the treatment pool has an average depth of 1 to 2 meters, which has been shown to limit submerged vegetation and provide the necessary treatment and sediment capture. Ponds should usually be designed to be large enough to accommodate at least a 25-year flood event.

Stormwater ponds should be dredged when the permanent pool volume is half-filled with sediment because the pond is no longer effectively removing sediment and pollutants once filled to that level. For instance, if a stormwater pond was constructed to have an average depth of 2 meters, it will need to be dredged when the average depth reaches 1 meter. The permanent pool volume must be maintained to ensure proper water quality treatment and control of submerged aquatic vegetation.[114] It is also important that all inlets and outlets be inspected regularly to prevent blockages and to check for structural failures. Sinkholes and erosion around inlets should be repaired as soon as they are found because they can grow exponentially once started. Large trees and shrubs should not be allowed to grow around inlets and outlets and should be minimized within the basin to allow for maintenance access. Retention ponds, regardless of size, should be added to an annual inspection schedule, since unexpected events such as large or frequent storms result in heavier than normal sediment deposition and reducing pond capacity sooner than anticipated.[115]

Retention pond capital costs are typically USD 1.08[116] on average per cubic meter of volume provided for storage.[117] Requirements for pond lining, or construction on steeper slopes or less stable land may increase construction costs to ensure the integrity of the pond. Annual maintenance costs vary between USD 0.08 and USD 0.25 per square meter of the retention pond area, including vegetation management along the pond's perimeters.[118] The lower value of USD 0.08 has been selected for maintenance costs.

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[114] Stormwater Pond Design, Construction and Sedimentation, Clemson University Cooperative Extension Service, 2021 Clemson University. Retrieved from: https://bit.ly/3olZkpr (09.03.2021).

[115] Gulliver, J.S., A.J. Erickson, and P.T. Weiss. 2010. *Stormwater Treatment: Assessment and Maintenance*. University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN. http://stormwaterbook.safl.umn.edu/

[116] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP US (2019: 65287.5 USD) were compared. Between both, the difference is 1:24.

[117] U.S. Environmental Protection Agency (EPA), Costs and Benefits of Storm Water Best Management Practices. Retrieved from: https://www3.epa.gov/npdes/pubs/usw_d.pdf (07.10.2020).

[118] EU Directorate General Environment, Natural Water Retention Measures, *Individual NWRM Retention Ponds*. Retrieved from http://nwrm.eu/sites/default/files/nwrm_ressources/u11_-_retention_ponds.pdf (11.03.2021).

Each reservoir will be designed with a depth of 2 meters to allow the multifunctional purpose of the basins. Table 2 below shows the intended amount and dimensions of planned retention reservoirs, mainly located in Binh Thuy and Cai Rang district.

***Table 30:** Location and planned size of retention reservoirs in Can Tho.*

#	District	Area in square meter (m^2)	Depth (m)	Storage in cubic meter (m^3)
1	Binh Thuy	36 204	2	72 408
2	Binh Thuy	43 159	2	86 318
3	Binh Thuy	18 618	2	37 236
4	Binh Thuy	14 973	2	29 946
5	Binh Thuy	7 648	2	15 296
6	Binh Thuy	7 749	2	15 498
7	Binh Thuy	11 614	2	23 228
8	Binh Thuy	14 785	2	29 570
9	Binh Thuy	7 156	2	14 312
10	Binh Thuy	4 172	2	8 344
11	Cai Rang	48 568	2	97 136
12	Cai Rang	36 440	2	72 880
TOTAL		251 092		502 172

In total, 12 retention reservoirs are planned with a combined water storage capacity of 502 172 m^3. Based on a construction cost of USD 1.08 per cubic meter of storage, the initial construction cost amounts to USD 544 019 with annual maintenance costs of USD 20 924, and USD 606 805 for 29 years until 2050 (see Table 31). Hence, total costs until 2050 amount to USD 1 150 825.

***Table 31:** Overview of design features for retention reservoirs, incl. the overall costs.*

Feature	*Unit*	*Quantity*
Height (depth)	meters	2
Volume (all basins)	m^3	502 172
Area	m^2	251 092
Units	pieces	12
Cost/unit	USD	1.08 (per m^3)
Lifetime	years	>30
Total construction cost	**USD**	**544 019**
Maintenance cost per annum	USD	20 924
Maintenance cost (for 29 years)	USD	606 805
TOTAL (2050)	USD	1 150 825


Figure 83: *Examples of retention reservoirs/ponds. Source: https://bit.ly/3ojjMaw (17.02.2021).*

2. Detention swales along roads

Detention swales are broad shallow channels topped with vegetation, also referred to as 'bioswales'. Swales are designed to slow runoff, promote infiltration, and filter out pollutants and sediments. Detention swales are a 'green' alternative to conventional piping or drainage canal systems. Vegetated detention swales are linear grass-covered depressions that lead surface water overland from the drained surface to a storage or discharge system, typically using road verges. They are frequently used to convey runoff and disconnect impervious areas. A detention swale is a broad, shallow, trapezoidal, or parabolic channel, densely planted with shrubs and grasses or with trees. It is designed to attenuate and in some cases infiltrate runoff volume from adjacent impervious surfaces, allowing some pollutants to settle out in the process. In steeper slope situations, check dams are used to further enhance attenuation and infiltration opportunities. A vegetated swale can enhance the aesthetic value of a site through the selection of appropriate native vegetation. Swales may also discreetly blend in with landscaping features, especially when adjacent to roads.[119] Swales avoid the need for expensive roadside curbs, gullies, and related maintenance. Some regular maintenance is required to keep a grass swale operating correctly, e.g. mowing during the growing season. The optimum grass length is around 150 mm.[120] When properly designed, grassed swales result in a significant improvement over the traditional drainage ditch in both slowing and cleaning of water. Two types of vegetated swales exist, dry and wet swales. Wet swales mainly function as linear wetlands but also require more intense maintenance compared to dry swales, which are recommended for this measure. Dry swales are generally favoured for treating highway and residential road runoff because of their linear structure and inexpensive maintenance.

This measure proposes the establishment of dry grass swales of parabolic form to reduce runoff from roadways and/or sidewalks by allowing water to infiltrate. It is planned to establish swales of 1.5 meters depth and 2.5 meters width, representing 3.75 m^3 per linear meter. Total construction costs for 1 square

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[119] U.S. Environmental Protection Agency (EPA), Sustainable Drainage Systems, Tennessee Stormwater Manual, Chapter 5.4.3 Vegetated Swale. Retrieved from: https://tnpermanentstormwater.org/manual/11%20Chapter%205.4.3%20Vegetated%20Swales.pdf (24.02.2021).

[120] SuDS Techniques - Permeable Conveyance Systems. SuDS Wales, Sustainable Drainage Systems. Retrieved from https://www.sudswales.com/types/permeable-conveyance-systems/swales/ (02.03.2021).

meter grass swales consist of USD 17.55[121,122] and include components of site preparation (clearing, excavation, grubbing) and site development (salvaged topsoil, seeds, and mulch).[123]

It is important that swale depths and side slopes be shallow for safety and maintenance reasons. Annual operation and maintenance costs include debris removal, grass mowing, spot reseeding and sodding, weed control, swale inspection, and administration for inspections. Hence, annual maintenance costs amount to be USD 0.125[124] per square meter swale per year.[125] It should be noted that swales are not practicable in areas with too steep grades or wet or poorly drained soils.[126]

It is intended to establish grass swales along roads with up to 4 lanes and a maximum width of 12 meters. Table 32 provides an overview of the planned swales in Can Tho, stating their total length, water conveyance, and storage volume. Total costs until 2050 including construction and maintenance of ca 64 km swales amount to USD 859 470. Figure 85 shows the locations of planned swales per district.

Table 32: *Overview of location, length, and costs of vegetated swales in Can Tho.*

Feature / Districts	*Binh Thuy*	*Ninh Kieu*	*Cai Rang*
Depth (m)	1.5	1.5	1.5
Width (m)	2.5	2.5	2.5
Total length (m)	27 700	9 000	27 500
Total area (m²)	69 250	22 500	68 750
Total Volume (m³)	103 875	33 750	103 125
Total construction cost (USD)	794 643	258 187	788 906
Ann. maintenance cost (USD)	23 839	7 745	23 667
Ann. maintenance cost for all districts until 2050 (USD)	1 712 786	-	-
TOTAL (all districts, until 2050)	3 554 522	-	-

[121] Cost adjustment ratio: Costs were derived from Australian sources and stated in AUD. A cost adjustment ratio of 1:20 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP US (2019: 53378 USD) were compared. Between both, the difference is 1:20.
[122] Consisting of construction cost of swales of USD 13.5 per meter and site preparation (incl. street works and excavations) of USD 4.05 per cubic meter. Sources: Arcadis Construction Handbook Vietnam (https://bit.ly/3D38pdW and https://bit.ly/3sxI0Qo).
[123] U.S. Environmental Protection Agency (EPA), Costs and Benefits of Storm Water Best Management Practices. Retrieved from: https://www3.epa.gov/npdes/pubs/usw_d.pdf (07.10.2020).
[124] Cost adjustment ratio: Costs were derived from Australian sources and stated in AUD. A cost adjustment ratio of 1:20 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP US (2019: 53378 USD) were compared. Between both, the difference is 1:20.
[125] Department of Water and Environmental Regulation, Western Australia. Conveyance Systems. Swales and Buffer Strips. Retrieved from https://bit.ly/33Gdvwb (08.03.2021).
[126] Ibid.

Figure 84: *Examples of vegetated swales along roads and parking areas. Source: https://dottarchitecture.com (18.02.2021).*

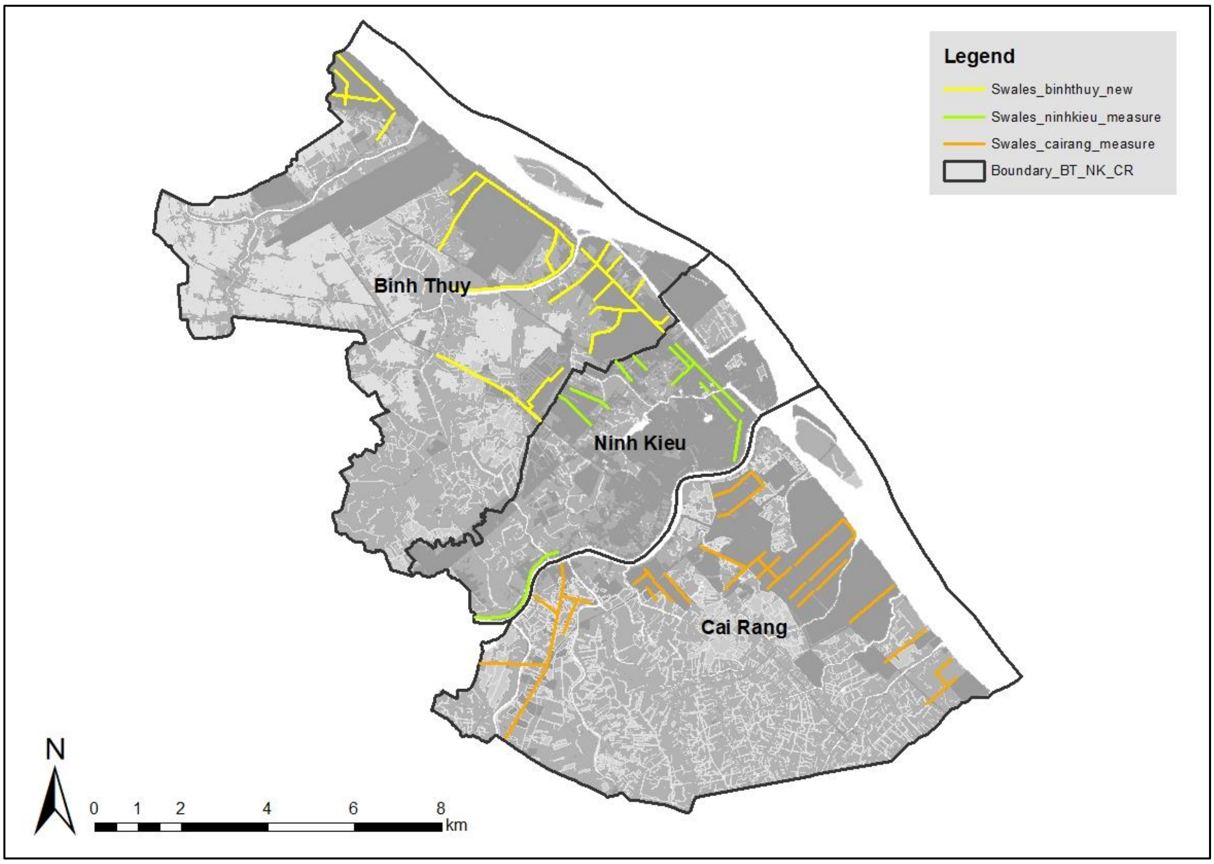

Figure 85: *Map of planned grass swales along roads (width up to 12 meters). Source: UNU-EHS.*

3. Improved solid waste management

Solid waste collection schemes should be organized and scheduled among communities living close to riverbeds and canal systems. The primary goal is to remove accumulating trash within the riverbeds and canals and respective slopes. Attention is given to areas with a high risk of trash accumulation, such as bridges or street culverts. These areas should remain garbage-free on an annual basis. Such a community waste management and collection scheme for watercourses will also reduce the vulnerability of people who live in the immediate proximity of rivers or water canals. Such a program will raise social awareness for solid waste management and its relation to urban flood risk.

Unmanaged disposal of waste frequently leads to blockages in drainage and watercourses, this reduces their capacity of storage and conveyance and leads to flooding and increased inundation areas. During a flood, waste and other debris collected by floodwaters can cause increased damage to property and lead to higher flood losses. Debris accumulates on bridge piers and various places with embankments and generates pressure on structures and causes water impoundment.[127] Also, deposition of waste can block access and be a source of toxins and breeding ground for diseases. The management of solid waste along watercourses and canal systems is considered to be a low-regret option for reducing flood risk as well as contributing to the quality of life, health, and development, while also lowering the impact of flood events.[128]

The negative impacts and causes of waste disposal are often derived from communities where waste management services may not be comprehensive and where drainage systems are inadequate or absent, or where informal housing has been built in flood-prone areas. In addition, informal settlements are partly not considered by waste disposal systems or solid waste collection programs.

For this reason, the engagement of communities in risk reduction helps increase resources and generates the necessary awareness and motivation to reduce dumping. Waste management measures implemented without community participation are often undermined by poor waste disposal habits. Inhabitants along rivers and streams often do not have access to timely garbage collection services and therefore deposit their garbage on the slopes and in the riverbeds, which strongly accumulates over time and affects the flow or contaminates the water. This measure proposes a community-based solid waste management program for areas along the riverbeds, streams, and relevant canal systems. Solid waste collection schemes should be organized and scheduled among the communities. The primary goal is to remove accumulating trash within the riverbeds and among the slopes. These areas must remain garbage-free regularly. These activities will take place in close liaison with local authorities, social service departments, and existing community leadership structures. Effective operation of waste collection schemes is guaranteed through enhanced awareness and capacities that encompass various trainings, especially with a focus on health and hygienic aspects during collection activities.[129]

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[127] Vanninen, A., & Nissinen, T. (2012). Initiating a Community-Based Solid Waste Management System in a Rural Community in Ghana: A Practical Framework: Case: Akrofu-Xeviwofe.

[128] United Nations Economic and Social Council (ESOC). Programme Planning and Evaluation: Monitoring and Evaluation: Review of Selected Projects in the Thematic Area of Poverty Reduction. *Community-Based Solid Waste Management*. 2006. Bangkok. Retrieved from: https://www.unescap.org/sites/default/files/2006-Waste-Management-Proj-Eval.pdf (31.03.2021).

[129] Rigasa, Y. A., Badamasi, A. G., Galadimawa, N., & Abubakar, G. U. (2017). Community based solid waste management strategy: A case study of Kaduna metropolis. *WIT Transactions on Ecology and the Environment*, 210, 761-772.

A solid waste management program should involve the following activities: [130]

1. Residents become more involved in maintaining their immediate surroundings.
    a. Encouraging residents to maintain a clean environment or organizing clean-up events
    b. Building a sense of common purpose and educating residents can build a sense of agency.
    c. Establish means of communication and set common goals/slogans
    d. Organize Public/Stakeholder Meetings
    e. Over the long term, residents need to become more aware of the role waste management plays in their everyday lives and communities

2. Clean riverbanks and canal systems and maintain drainage capacity
    a. Organize and schedule yearly clean-up events and make its positive impacts public
    b. Perform ad-hoc local drain cleanings before rain events
    c. Provision of alternative waste dumping facilities

In comparison with local and regional community-based waste management schemes (Vietnam, Indonesia & the Philippines), an initial budget of USD 109 000 has been defined to build a foundation.[131,132,133] Further project management and capacity development costs amount to USD 50248 per annum. A community-based waste management system, with a running time until 2050, would therefore cost USD 1 566 192.

Figure 86: *Examples of community-based waste management programs. Source: https://vietnamnet.vn/en/sci-tech-environment/waste-management-projects-line-up-to-address-vietnam-s-white-pollution-647336.html (12.03.2021)*

[130] Ibid.
[131] UNDP Vietnam / Global Environmental Facility. Article: *Waste management projects line up to address Việt Nam's white pollution.* Retrieved from: https://bit.ly/33Jd4RE (31.03.2021).
[132] UNESCO-IHE. Institute for Water Education. Performance of Community-Based Solid Waste Management for Integrated and Sustainable Solid Waste Management. The Case of Bogor City, Indonesia. April 2017. Retrieved from: https://bit.ly/3btI4cl (31.03.2021).
[133] UN-Habitat. The Community-based Solid Waste Management Project in Sitio San Nicolas, Philippines. Retrieved from: https://bit.ly/3yfujrF (31.03.2021).

4. Rehabilitation of existing drainage canals

Stormwater drainage systems in urban areas are a deterministic flood management system, especially in light of the current climate changes and intensified risks of severe floods. Irregular maintenance of urban drainage systems and canals may cause problems that reduce the efficient conveyance of water, especially the blockage or sedimentation of network pipes, which affects the efficiency of the network.[134] To guarantee the efficient conveyance of canal systems, dredging can be a suitable rehabilitation method. The term dredging is routinely used to refer to the systematic removal of accumulated material from watercourses, canals, or drainage systems. In its most extreme form dredging may be used to re-align canalized watercourses. The term dredging covers a range of activities from the removal of sedimentation in open drainage canals or pipes, or the wholesale straightening (canalization) and/or deepening of watercourses. The main objective of this drainage rehabilitation method is to increase the cross-sectional area (and hence its volume), as well as a reduction in the roughness of the channel. These effects can increase the efficiency of the canal in moving water. Hence increasing the conveyance. [135]

Generally, urban drainage systems are crucial to collect high quantities of water which accumulate in large amounts on the streets and passages. Many systems consist of reinforced concrete channels, mainly of trapezoidal shape or pipes of diameters with a diameter up to 120 cm. Sediment build-up in the drainage channels reduces their capacity and increases the potential for flooding. It also results in higher pollutant concentrations flushed out during large flood events. Other problems that could reduce the conveyance capacity of the channels could be root intrusion from vegetation or simple debris and other blockages.

Generally, it is assumed that pipes of 1 m diameter are blocked by sediment up to 0.3 m. This is equivalent to a reduction of the flow cross-section of the pipes of 25% (calculated by circle segment formulas). Therefore the sewer system capacity was reduced to 45*0.75 = 33.75 mm/h ~ 34 mm/h effective capacity, which was used in the simulations.[136,137] The following collector systems are targeted to be improved and cleaned to ensure the drainage capacities (see Table 33 below).

[134] Fathy, I., Abdel-Aal, G. M., Fahmy, M. R., Fathy, A., & Zeleňáková, M. (2020). The Negative Impact of Blockage on Storm Water Drainage Network. *Water*, *12*(7), 1974.
[135] Bailey, A D and Bree, T. (1981). The effect of improved land drainage on river flood flows, in The Flood Studies Report, Five Years On, pp. 131-42.
[136] Conley, G., Beck, N., Riihimaki, C. A., & Tanner, M. (2020). Quantifying clogging patterns of infiltration systems to improve urban stormwater pollution reduction estimates. *Water Research X*, *7*, 100049.
[137] Gonzalez-Merchan, C., Barraud, S., Le Coustumer, S., & Fletcher, T. (2012). Monitoring of clogging evolution in the stormwater infiltration system and determinant factors. *European Journal of Environmental and Civil Engineering*, *16*, p.34-p.47.

__Table 33:__ Overview of drainage systems in Ninh Kieu, Binh Thuy, and Cai Rang district. Source: Can Tho University.

Ninh Kieu			***Binh Thuy***			***Cai Rang***		
Diameter (m)	*Length (m)*	*Capacity (m^3)*	*Diameter (m)*	*Length (m)*	*Capacity (m^3)*	*Diameter (m)*	*Length (m)*	*Capacity (m^3)*
0.2	*595*	*18.69*	-	-	-	-	-	-
0.3	*1 304*	*92.17*	-	-	-	-	-	-
0.4	*21 307*	*2 677.51*	*0.4*	*28 917*	*3 633.81*	-	-	-
0.5	*712*	*139.80*	-	-	-	-	-	-
0.6	*17 374*	*4 912.38*	*0.6*	*4 143*	*1 171.40*	-	-	-
0.8	*20 413*	*10 260.69*	*0.8*	*2 348*	*1 180.23*	*0.8**	*64 754*	*32 548.91*
1.0	*4 569*	*3 588.48*	*1.0*	*1 202*	*944.04*	-	-	-
1.2	*1 866*	*2 110.39*	*1.2*	*157*	*177.56*	-	-	-
TOTAL	***68 145***	23 800.11	***TOTAL***	***55 737***	***7 107.04***	***TOTAL***	***64 754***	***32 548.91***
***TOTAL** (all districts)*		188 636 m^2 63 456 m^3						

**no data on diameter available, hence assumption made with 800 mm (0.8 m) pipe diameter.*

The total cost of rehabilitation measures, including the necessary repair, replacement, and cleaning of drainage pipes and canals amounts to USD 3 185 343. This corresponds to USD 12.41 per meter pipe/canal for refurbishment. It is recommended that all drainage systems be subject to annual inspection, with costs representing 1% of the total rehabilitation cost. This amounts to annual inspection costs of USD 23 409.[138] Figure 87 shows the locations of drainage systems per district.

[138] Cost adjustment ratio: from Honduran sources and stated in Lempira. A cost adjustment ratio of 1:1.05 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP Honduras (2019: 2574 USD) were compared. Between both, the difference is 1:1.05.

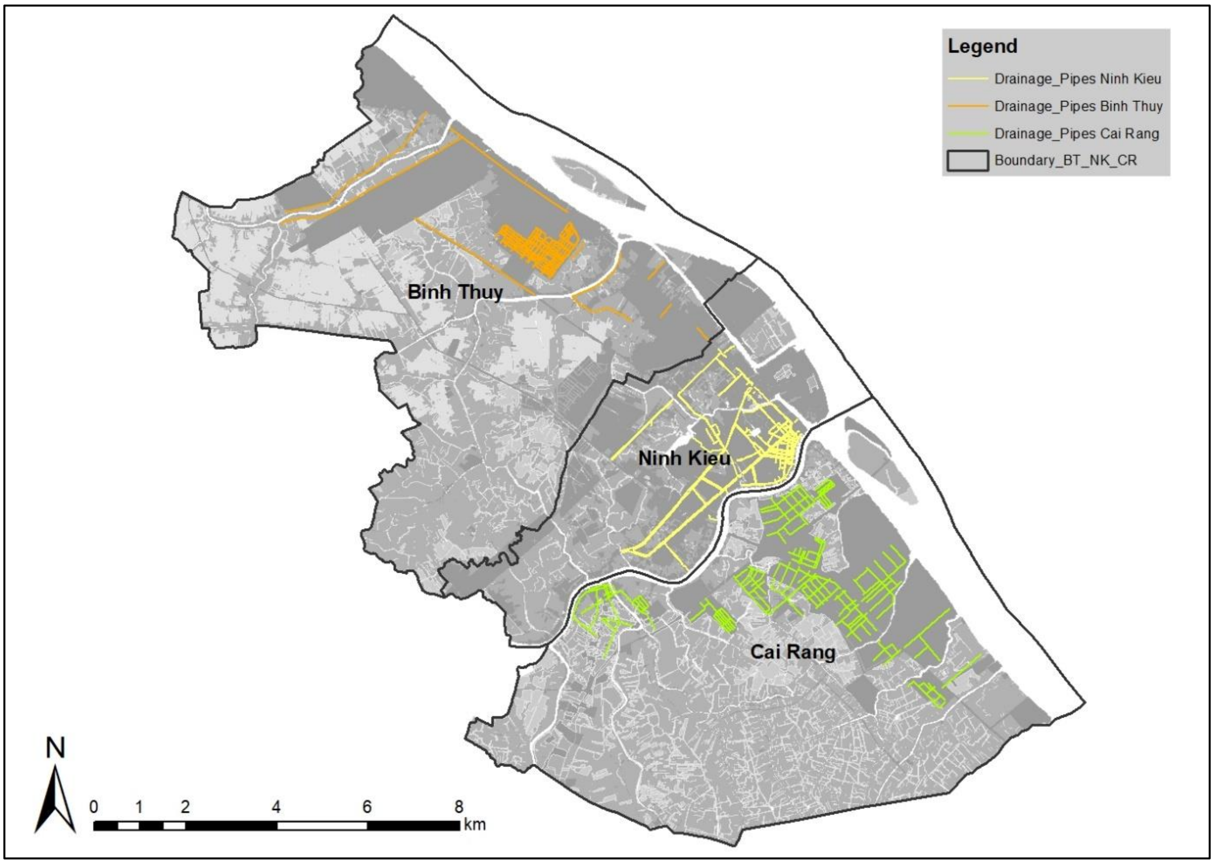

Figure 87: *Map of drainage systems in Can Tho which are subject to rehabilitation. Source: Can Tho University.*

5. Flood awareness campaign

Flood preparedness refers to 'the ability to predict, respond to and cope with the effect of floods'.[139] Flood awareness programmes should inform individuals about the risks as well as flood preparedness measures. Activities to prepare against flood should be planned in advance. Through flood preparedness programmes, understanding and awareness regarding the flood events is strengthened among the local community. Community members are focal point of preparedness programmes, therefore, informing the public and providing training for flood preparedness is vital. Some of the activities could include dissemination of the latest information and updates about the flood from local radio, TV stations, or any other communication portal; dissemination of information about local emergency shelter, etc. Awareness and preparedness campaigns should also include information on what should be done during and after a flood event. Awareness programmes should be designed community and context-specific.[140]

[139] Raising Flood Awareness and Self-Efficacy, Framework to Develop and Implement a Successful Social Marketing Program. May 2013. Retrieved from: http://www.flood-aware.com/topics/final_report_activity_2.pdf (04.11.2020).
[140] Mekong River Commission. (2016). Manual on Flood Preparedness Program for Provincial and District level Authorities in the Lower Mekong Basin Countries. Retrieved from: https://www.preventionweb.net/files/13076_Flood09.pdf (04.11.2020).

The framework for raising awareness comprises seven steps: (1) identify awareness level, (2) find need of the target groups, (3) find best ways for information dissemination, (4) start the campaign, and (5) evaluation. If planned appropriately, an awareness and preparedness campaign should include social aspects as well, such as using a (6) participatory approach (involvement of all community members), in which vulnerable people are identified and prioritised, and (7) taking a gender-based approach.[141]

In Can Tho, the flood awareness and preparedness campaign will focus on the most vulnerable group exposed to flood. For this reason, it is intended to target the campaign on households living in the areas along the urban watercourses or areas with frequent flooding. These campaigns should be carried out by municipal authorities in collaboration with respective community associations, NGOs and/or partners from academia. It is estimated that each flood awareness and preparedness campaign will kick off in a larger outreach strategy every 10 years with costs of each USD 323 822. Every 5 years an updated outreach will be initiated with evaluation elements targeting the same vulnerable groups from kick off. This returning and updated campaign will cost USD 64 764. In total, expected costs until 2050 for flood awareness campaigns amount to USD 1 165 785.[142]

Figure 88: *Examples of disseminated flood awareness and preparedness materials. Source: FloodRe Insurance London. Retrieved from: https://bit.ly/3waHyrQ (02.04.2021).*

[141] Raising Flood Awareness and Self-Efficacy, Framework to Develop and Implement a Successful Social Marketing Program. May 2013. Retrieved from: http://www.flood-aware.com/topics/final_report_activity_2.pdf (04.11.2020).
[142] Ibis.

6. Road spillways as bio-retention systems

To deal with increasingly regular flooding, a network of spillways as bio-retention systems will be created for roads with 6 to 8 lanes (width 22.5 meters). The primary purpose of a spillway is to discharge flows that cannot either be used immediately or stored in a reservoir for future use. Spillways act as a linear greenway, bringing life and activity to city streets. When the seasonal flooding arrive and the tide rises, the spillways absorb water which would normally flood the surrounding streets. This will allow for water to more easily move through the city and rain water to be held and released. At a neighbourhood scale local residents and businesses become stewards of the system. The expected lifetime of a vegetated swale is 50 years. It is intended that this network of canal-like spillways will be cut through existing overbuilt roads, reviving a 'lost' system of tandem road and canal based development. To allow for safer interaction with the urban waterways, reflow will also completely remove the sewage discharge from the canals through a distributed system of constructed retention reservoirs, built on existing green spaces, which will treat the wastewater and use the treated water to recharge groundwater. Besides the flood regulation, spillways' pollutant removal includes physical, chemical, and biological processes. Removal mechanisms include filtration and sedimentation (physical), adsorption (chemical) by the soil media, and absorption (biological) through plant uptake and microbial activity.[143] It is also advised to ground the spillways with a specific filter media. A filter media with an organic or clay content, high cation exchange capacity, and a neutral to alkaline pH, has the highest adsorption potential, as well as, storage capacity.[144] Generally, it is recommended that clay content do not exceed 5 percent because not only does excessive clay decrease the infiltration rate, but it also creates preferential paths for runoff.[145] The role of grass, shrub and tree vegetation within spillways systems is to enhance the water interception and pollutant removal performances by root systems. Vegetation also provides shade and dissipates heat by increasing evapotranspiration and, therefore, decreases effluent temperature.[146] When designing spillways' ponding volume the corresponding catchment area and the design's rainfall depth should be considered. Bio-retention outlets are prone to clogging and maintenance operation should be introduced carefully. It is imperative that outlets are checked on a monthly basis to ensure they are free of litter and debris. This is particularly important if a grate is used on the high flow bypass structure.

For Can Tho, it is intended to establish spillways as bio-retention systems on roads with 6 to 9 lanes that have a width of minimal 22.5 meters. The planning foresees to use and transform one lane (ca. 3.75 meters) of the roads into a bio-retention spillway. The spillways will replace and become a new median strip on the roads. The spillways will have a width of ca. 4 meters and an excavated depth of 2 meters. All districts combined, the total length of planned spillways counts to 53.43 km (see Figure 90). The exact spillways dimensions per district can be found in Table 6. The total cost of spillways construction in all districts combined amounts to USD 1 469 435. Necessary excavation works and potential road asphalt removal is calculated to be USD 3 295 808. Annual maintenance is calculated with USD 3 per meter spillway and includes activities such as weed control, litter removal, replanting, scour control, filter/drainage systems control and sediment control and/or removal. Hence, annual maintenance cost

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143 Marsh, W. M. (2005). *Landscape Planning Environmental Applications* (4th ed.). John Wiley & Sons, Inc.
144 North Carolina Department of Environment and Natural Resources (NCDENR). (2005). Stormwater BMP *"Updated Draft Manual of Stormwater Best Management Practices"*. North Carolina Division of Water Quality.
145 Hsieh, C.-H. and A. P. Davis (2005). Evaluation and Optimization of Bioretention Media for Treatment of Urban Storm Water Runoff. *Journal of Environmental Engineering*, 131, pp. 1521–1531.
146 Jones, M. P., W. F. Hunt, and J. T. Smith (2007). T*he Effect of Urban Stormwater BMPs on Runoff Temperature in Trout Sensitive Waters*. Paper presented at the ASABE Annual International Meeting, Minneapolis, MN.

until 2050 can be estimated to be USD 4 648 758. In total, all costs combined until 2050, the establishment of bio-retention spillways amounts to USD 9 414 001 (Table 34).

Table 34: *Locations, length, and costs of planned spillways along larger roads between 6 to 8 lanes (width ca. 22.5 meters).*

Features	*Binh Thuy*	*Ninh Kieu*	*Cai Rang*
Depth (m)	2	2	2
Width (m)	4	4	4
Total length (m)	9 997	27 143	16 294
Total area (m²)	39 988	108 572	65 176
Total Volume (m³)	79 976	217 144	130 352
Cost of spillway construction (USD)[147]	274 917	746 432	448 085
Ann. Maintenance cost (USD)	29 991	81 429	48 882
Excavation works for spillways (incl. removal of excavation) all districts (USD) [148]	3 295 808		
Total construction of spillways, all districts (USD)	1 469 435		
Ann. maintenance all districts (USD)	160 302 (per year);	4 648 758 (until 2050)	
TOTAL (USD) *incl. construction & maintenance until 2050*	**9 414 001**		

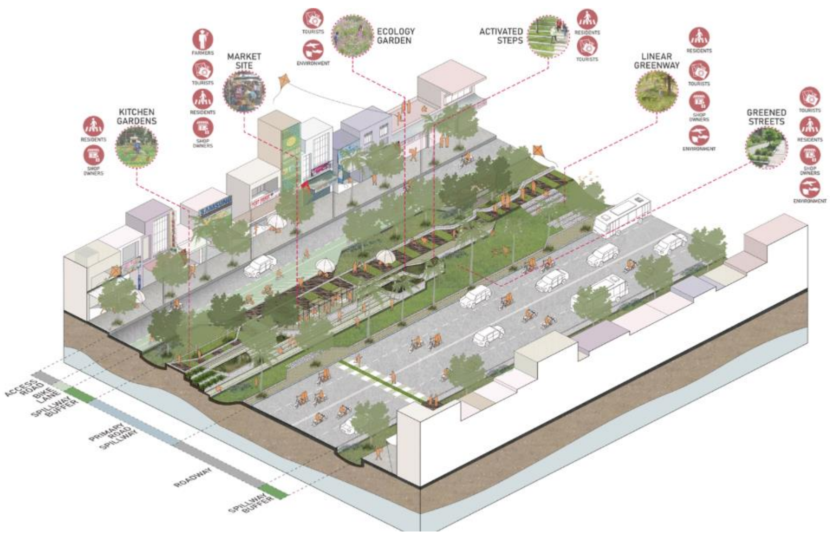

Figure 89: *Illustration of road spillways for roads with more than 8 lanes. Source: Columbia University: Water Urbanism, GSAPP (2019), https://bit.ly/2Rplawj (17.03.2021)*

[147] Cost of spillway construction: USD 125-150 (mean USD 137.5) per square meter. Since the source has been located in Australia and costs referred to Australian currency value, a cost adjustment rate of 1:20 has been applied. This resulted in spillways construction cost of USD 6.875, and represent the currency value in Vietnam. Source: Taylor, A. (2005). Structural stormwater quality BMP cost/size relationship information from the literature. *Cooperative Research Centre for Catchment Hydrology*, Melbourne, 53-64. Retrieved from: https://bit.ly/3ye2ksp (08.03.2021).

[148] Excavation cost: USD 4.02 per cubic meter. Source: *Construction Cost Handbook Vietnam*. 2020. Arcadis Vietnam Co., Ltd. Retrieved from: https://bit.ly/2QIH9Uf (08.03.2021).

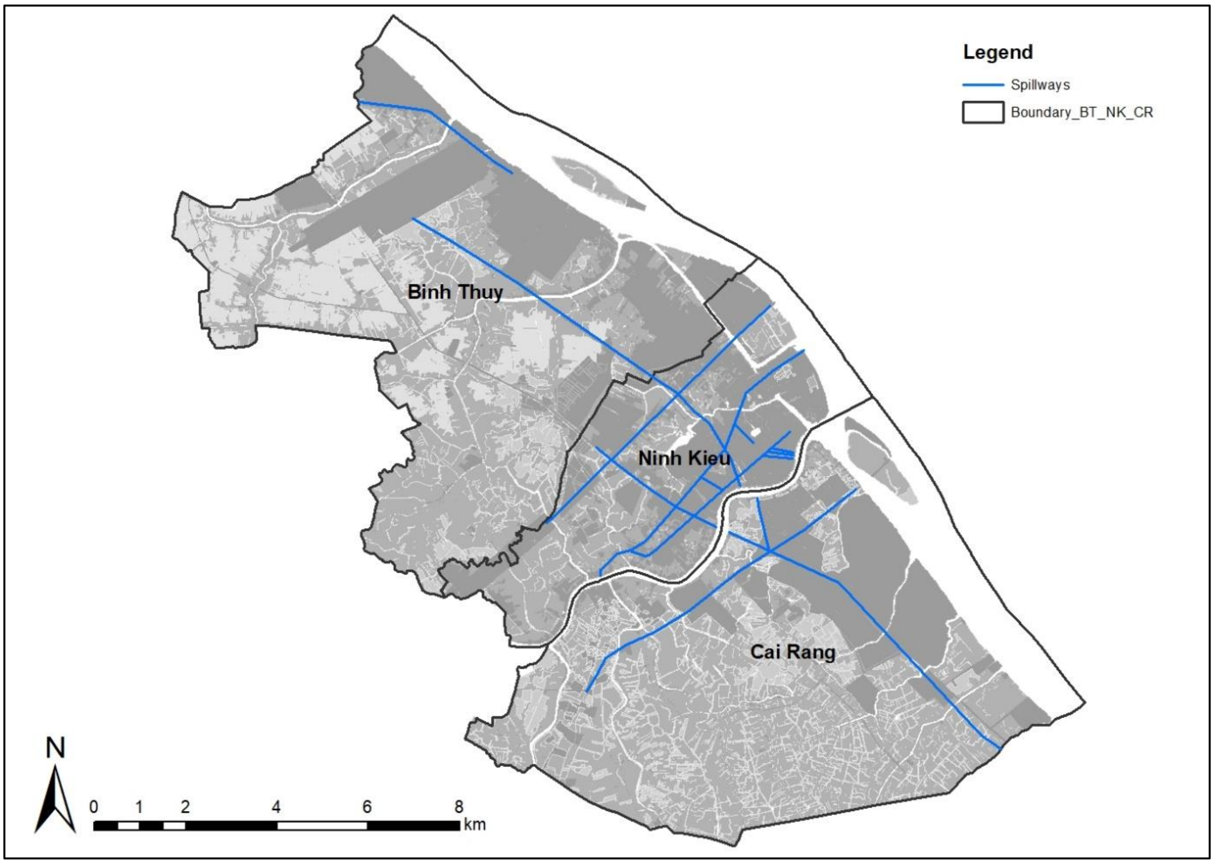

Figure 90: *Map of planned road spillways as bio-retention systems. Spillways are built on roads with more than six lanes with a width of at least 22.5 meters. Source: UNU-EHS.*

7. Rain collection tanks for existing buildings

This measure aims to collect rainwater in public and private buildings that have the capacity to accommodate one or more rainwater collection tanks with a specified capacity ca. 3500 litres. These collection tanks will be connected to public storm drainage systems or other waterways for discharge. Its effective use depends on the acceptance and uptake of potential users, who can be companies and commercial buildings, public buildings or private residential buildings and households who want to contribute to reducing the effects of flooding. This measure aims to lower runoff peak by collecting volumes of water in tanks.

The cost per unit is USD 33, including material and labour for construction of the cistern, filters, roof connections and the spill line.[149,150] Annual maintenance amounts to 1.5% of total construction cost and

[149] Lukes, R., & Kloss, C. (2010). *Managing wet weather with green infrastructure, Municipal handbook, Green streets, Low impact development center*. EPA-833-F-08-009. https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_harvesting.pdf (16.10.2020).
[150] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnam's currency value.

includes tank membrane inspections and drain pipe inspections. In Can Tho, circa 10% of all existing buildings that are affected by pluvial and fluvial flooding should be considered to be equipped with water collection tanks. This amounts to 4662 buildings that are subject to the installation of tanks with a water storage capacity of each 3534 cubic meters (Table 35).

Table 35: *Overview of dimensions for water collection tank installation in Can Tho.*

Feature	Unit	Quantity
Height	meters	2
Diameter	meters	1.5
Volume/unit	litre	3534 (3.53m³)
Units	pieces	4 662
Total Capacity	m³	16 475
Cost/unit	USD	33
Lifetime	years	20-30
Total construction cost	USD	153 846
Maintenance cost	USD/annually	2 307
TOTAL cost incl. construction and maintenance until 2050	**USD**	**222 999**

Figure 91: *Example of water collection tanks for buildings (e.g. residential buildings or public buildings). Source: https://www.rainfilltanks.com.au (26.03.2021).*

8. Mobile flood embankments

This measures introduces mobile flood embankment systems, consisting of inflatable tube (hose) segments that are used to insulate/dam flood water. These robust flood protection segments are first inflated with air by a compressor, brought into position and then filled with water. While filling the segments with water, it is possible to take water from the raising water (flood) body for this purpose. Compared so sand-based dams (e.g. made of sandbags), the construction time and complexity is much lower. It requires significantly fewer labour and there is no disposal of contaminated dam protection material, such as contaminated sandbags after their use. After protection from the flood, the hose dams are dismantled, cleaned and stored again. The advantage of mobile flood embankment systems is their immediate use and protection. There is no need for (time-intensive) planning, approval and construction phases that often take years, as is the case with stationary flood protection measures (e.g. construction dikes, etc.). The mobile systems can protect roads, buildings and critical infrastructure from flood waters. The barriers are reusable, which make them a more sustainable and effective solution. Normally the hose dam segments can be combined to reach dam heights varying from 50 cm to 250 cm, if necessary. Also, based on a sleeve system, different segments can be combined to any length or height and suited to any topographical conditions or surface composition. The hose system adapts to changing substrates and bank shapes, whether concave, convex, linear or U-shaped. Kerb stones, height differences of up to 1 m, embedded rocks and curves pose no problem for rolling out, for stability and for sealing. In addition, the mobile dike can not only be built in the water, but can even be overflowed without losing its stability. Hose dam embankment systems can be build up for 40 -150 meters per hour.[151] However, since the hose dam embankment systems are mainly used as mobile barriers against rising water levels in exposed areas, it also can be used as a temporary or permanent reservoir to store large amounts of water or contaminated liquids, e.g. during construction.

It is intended to introduce mobile flood embankment systems for a length of 3 km. For this, 30 hose modules with a diameter of 1.1 meter and length of 100 meters are needed. A 100 meter (and 110 cm diameter) segment costs USD 56 460. In total, the purchasing costs amount to USD 1 693 800, excluding maintenance. Depending on storage and maintenance, such an embankment system has a lifetime of around 30 years. Annual maintenance (storage and care) would amount to USD 2 920 (see Table 36).

Table 36: *Overview of dimensions for mobile flood embankments.*

Feature	Unit	Quantity
Length/unit	meters	100
Diameter/unit	meters	1.1
Amount of units (segments)	pieces	30
Total dam height	meters	0.5 – 2.5
Cost/unit	USD	56 460
Lifetime	years	>30
Total construction cost	USD	1 693 800
Maintenance cost	USD/annually	2 920
TOTAL cost incl. construction and maintenance until 2050	**USD**	1 719 204

[151] Beaver Portect. Beaver Schutzsysteme AG. Retrieved from: https://www.flexdamm.de/docs/Beaver-Prospekt2016.pdf (19.03.2021).

Figure 92: *Example of hose dam embankment systems. Protection of water along rivers and exposed residential buildings. Source: https://www.xh020.com (02.03.2021).*

Figure 93: *Example of the installation process of the hose dam segments. Lay out and position, inflate with air and fill with water. Source: https://www.flexdamm.de/docs/Beaver-Prospekt2016.pdf (02.03.2021).*

Figure 94: *Example of an applied system in Vietnam. Source: Innovative flood prevention Vietnam. NOPEF. Retrieved from: https://nopef.com/cases/innovative-flood-prevention-in-vietnam/ (02.03.2021).*

9. Flood wall

A floodwall is a freestanding, permanent, engineered structure designed to prevent encroachment of floodwaters. Floodwalls, which are typically constructed of reinforced concrete or masonry, provide a barrier against inundation, protect structures from hydrostatic and hydrodynamic loads, and may deflect flood-borne debris from buildings or any other exposed objects. Depending on the site topography, floodwalls may protect only the low side of the site (and must tie into the high ground), or they may surround the site. Floodwalls that surround a site have openings that provide access to the site. The option of establishing flood walls is of particular interest in locations where space is limited, for example, densely populated or built-up river banks. For this measure, it is intended to establish a reinforced flood wall embankment along the Can Tho River on the shore side of the Cai Rang district. Hence, this flood wall embankment shall protect Cai Rang district against pluvial/fluvial and tidal floods.

A flood wall, made of concrete or masonry is established on an earth-filled elevation. A so-called gravity flood wall with a T-shape will be placed on an earth-filled elevation. A gravity flood wall resists overturning primarily because of the dead weight of the construction material (concrete or masonry) and is simply too heavy to be overturned by a lateral flood load.[152] It is planned to establish this levee with a flood wall over a length of 6 kilometers.

The construction cost of a levee flood wall in Vietnam is estimated to be USD 0.9 -1.5 million (mean USD 1.2 million) per kilometer, with an effective flood protection height of three meters.[153] Based on this assumption a total construction cost of USD 7 200 000 for 6 kilometers is defined. Maintenance works, such as wall inspection and maintenance of earth-filled embankment elements of the levee are checked every 5 years. Annual maintenance cost is defined to be 0.5% of construction cost and amount to USD 36 000 (Table 37). The total construction cost incl. maintenance until 2050 is, therefore, USD 7 380 000.

Table 37: *Overview of flood wall dimensions and costs.*

Feature	*Unit*	*Quantity*
Length	meters	6000
Wall Height	meters	3
Construction cost/km	USD	1 200 000
Lifetime	years	>30
Total construction cost	USD	7 200 000
Maintenance cost	USD/5 years	36 000
TOTAL cost incl. construction and maintenance until 2050	**USD**	7 380 000

[152] FU Berlin. Floodwalls. Retrieved from: https://bit.ly/3omvLEr (02.03.2021).
[153] Aerts, J. C. (2018). A review of cost estimates for flood adaptation. *Water*, *10*(11), 1646.

Figure 95: *Examples of flood walls along riverbeds. Source: Waterways Journal. https://bit.ly/3fkd14h (02.03.2021).*

10. Flood protection storage facilities (incl. sandbags)

This measure intends to establish a storage facility for mobile flood protection elements such as sandbags. These storage facilities are very common buildings or warehouses, located in municipalities and are often managed by local authorities and respective fire or disaster risk management departments. These storage facilities often keep sandbags in stock, in the event of a rapid deployment against flood. Sandbags are easily stored ahead of time because they can lay flat and do not take up much space. Once there is a flood risk reported, they can be quickly put into action. Nonetheless, bulks of sandbags need to be stored in a safe, clean, dry place to protect them from the sun's UV rays and inclement weather. UV rays and moisture can significantly weaken the strength of the bag over time. Additionally, moisture may damage the contents of the bags if you are trying to store material that is needed for future use. It is therefore highly recommended not to store bags outside but in extra-built warehouses.[154]

In the event of a flood emergency, the use of sandbags from municipal stocks is regulated and prioritized. The sandbag use will be used primarily for repairs to existing flood defences such as flood walls or other embankment systems. This accounts especially for protected assets such as hospitals, schools, communication centers, and or operational emergency centers but also critical transportation routes. Local authorities will be also responsible for the pre-position of sandbag stocks in those areas for distribution in the event of a flood.

In Can Tho, it is planned to establish one storage (warehouse) facility with a capacity to store 564 500 filled polypropylene sandbags (40 cm x 60 cm). The number of sandbags was calculated based on the assumption that they would provide (in theory) protection for a flood depth of 50 cm for a length of 10,000 meters. The following assumptions regarding the number of sandbags and the storage facility itself are made below.

[154] Queensland Government. Disaster Management. Using sandbags to protect your home and business. Retrieved from: https://www.disaster.qld.gov.au/dmp/sandbagging/Pages/default.aspx (02.03.2021).

Dimensions of sandbags[155]

- *Intended potential length of dam protection 10.000 meters with an dam height of, 0.5 meters = 564 481 polypropylene bags (40 x 60 cm)*
- *Volume: 4 480 m³, Weight: 7 056 tons*
- *Pallets (for storage): 6 969 (e.g. 1 EU pallet is 0.96 m²)*
- *Sand needed to fill bags: ca. 7 000 tons.*

Costs:

- *100 PP bags*[156] *= circa USD 20.*
- *564 500 PP bags (*20) = 112.900 USD*
- *The average price of sand per metric ton in USD in 2020: 9.59 USD*[157]
- *Price for ca. 7000 tons sand: 41.300 USD*

Storage facility for sandbags

- *The building should have a storage capacity of ca. 650 000 bags (filled)*
- *Area needed for storage: 8000 m² on 5 stories*
- *Surface area needed for warehouse/storage facility: 1600 m²*

Costs:

- *Costs*[158] *for an industrial unit (storey framed units) = 305-380 USD/m²*
- *1600 m² *305 USD = 488 000 USD*
- *Annual operation cost for storage facility, 1.5%) = 9.633 USD*

In total, the costs for a flood protection storage facility for circa 564 500 filled sandbags amounts to USD 921 557. This cost includes the procurement of bags, sand as filling material, and a newly built storage facility incl. operation cost. Table 10 below summarizes the costs of this measure.

Table 38: *Summary of cost dimensions for establishing a flood protection storage facility with sandbags.*

Feature	Unit	Quantity
Sandbags (PP bags only)	USD	112 900
Filling for bags (sand)	USD	41 300
Storage facility	USD	488 000
Ann. operation cost for storage facility	USD	9 633
TOTAL cost incl. construction and maintenance until 2050	**USD**	921 557

155 Sandbag calculator. Operated by the Federal Agency for Technical Relief. Retrieved from: https://thwms.de/_v2/content/sandsackrechner/index.php (02.03.2021).
156 Polypropylene bags (40 x 60 cm). Retrieved from: https://bit.ly/3bwWYil (02.03.2021).
157 Average price of sand and gravel. Statista Platform. Retreived from: https://bit.ly/33UqQ3P (02.03.2021).
158 *Construction Cost Handbook Vietnam*. 2020. Arcadis Vietnam Co., Ltd. Retrieved from: https://bit.ly/2QIH9Uf (02.03.2021).

Figure 96: *Example of a flood protection storage/warehouse. Bulks of sandbags can be stored until use against floods. Source: https://bit.ly/33Lkvb9 (02.03.2021).*

Figure 97: *Example of a flood protection storage facility for sandbags (left). Example of polypropylene (PP) sandbags. Source: https://www.feuerwehr-neuhaus.bayern/kat-lager/ (02.03.2021).*

11. Index Insurance

Index-based flood and heat wave insurance is an innovative approach to developing effective payout schemes for low-income, flood and heat wave prone communities. Index insurance schemes make use of modelling and satellite imagery with other data to predetermine flood thresholds, which could trigger rapid compensation payouts. Effective end-to-end solutions will be developed in collaboration with a range of organizations and experts from central and state government bodies, private insurance firms, community-based organizations (CBOs) and nongovernmental organizations (NGOs).

12. Green Roofs

Green roofs consist of a growing material placed over a waterproofing membrane on a relatively flat roof. Green roofs not only provide an attractive roofing option but also use evapotranspiration to reduce runoff volume, and provides some detention storage. Green roofs may reduce some pollutants from the rainwater as well, they usually are significant sources of phosphorus due to leaching from the growing media. In addition, they can create habitats for wildlife and help to lower urban air temperatures, and also positively influence the temperature of the building itself. There are two types of green roofs, extensive and intensive. An extensive green roof has low-lying plants designed to provide maximum ground cover, water retention, erosion resistance, and transpiration of moisture. Extensive green roofs usually use plants with foliage from 5 to 15 cm in height and from 5 to 10 cm of soil. An intensive green roof is intended to be more of a natural landscape, installed on a rooftop. Intensive green roofs may use plants with foliage from 30 cm to 4.5 meters in height and may require several meters of soil depth and are therefore not common. A green roof can have a life expectancy of 40 years, under good maintenance conditions.[159,160]

Besides multifaceted benefits, this measure aims to address flooding and heat waves. Green roofs can act as a water retention system during rainfall and can lead to delayed runoffs, therefore relive other flood protection or drainage systems. The amount of rainfall retained by a green roof depends primarily on the depth of the growing medium and the roof slope. Studies have shown that green roofs will typically capture between 50 and nearly 100 percent of incoming rain (mean 75 percent), depending on the amount of growing medium used, the density of vegetation, the intensity of an individual rainfall, and the frequency of local rain events.[161,162] In urban areas that have combined sewer systems, green roofs help prevent heavy rain from overwhelming the systems and causing untreated human waste to be discharged into waterways.[163] The comparison of green and simulated conventional roofs indicated that the green roofs were able to mitigate the peak of runoff and could delay the start of runoff. The results show that green roofs can reduce the frequency and magnitude of such problems depending on the covered roof area.[164] Also, combining a storage layer into a green roof can enhance the runoff reduction performance and reduce the need for irrigation.[165]

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[159] Keating, K., Keeble, H., Pettit, A., & Stark, D. (2015). *Delivering Benefits through Evidence: Cost Estimation for SUDS*. Environment Agency, Bristol, UK.
[160] Shin, E., & Kim, H. (2015). *Analysing Green Roof Effects in an Urban Environment: A Case of Bangbae-dong, Seoul.* Journal of Asian Architecture and Building Engineering, 14(2), 315-322.
[161] VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh, R.T. Fernandez, and L. Xiao. 2005. Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth. Journal of Envi-ronmental Quality 34:1036-1044.
[162] Ctrs. for Disease Control & Prevention (CDC), Extreme Heat: *A Prevention Guide to Promote Your Personal Health and Safety*, http://www.bt.cdc.gov/disasters/extremeheat/heat_guide.asp
[163] Greater London Authority, London's Urban Heat Island: A Summary for Decision Makers (2006), available at http://static.london.gov.uk/mayor/environment/climate-change/docs/UHI_summary_report.pdf
[164] Razzaghmanesh, M., & Beecham, S. (2014). The hydrological behaviour of extensive and intensive green roofs in a dry climate. *Science of the Total Environment*, *499*, 284-296.
[165] Guo, Y., Zhang, S., & Liu, S. (2014). Runoff reduction capabilities and irrigation requirements of green roofs. *Water resources management*, *28*(5), 1363-1378.

The cooling potential of green roofs was often considered inconsistent and was found to be much lower than that of trees. Some studies have highlighted the benefits of green roofs, such as reducing the temperature, which in turn reduces the cooling demand of buildings in periods of extreme heat, contributing to air quality improvement, and enhancing the energy performance of buildings.[166,167] Studies concluded that the maximum air temperature reduction in a green roof was between 0.1 °C and 1.7 °C, with the median value of reduction being close to 0.3 °C.[168] It was found that the indoor average temperature data for vegetative roofs could be reduced by 2.4°C from the outdoor average temperature and 0.8°C for a non-vegetative roof.[169]

Also, vegetation evapotranspiration has a great potential to reduce urban temperatures. Literature review suggests that vegetation and urban agricultural evapotranspiration can reduce urban temperatures by 0.5 to 4.0°C. [170] Green roofs (including urban agriculture) and water bodies have also been shown to be effective ways of reducing urban temperatures. In addition, green roofs act as sound buffers, reducing sound levels by as much as 50 decibels, depending on the roof depth. In urban environments where residences are located near noisy airports, bars, or industrial parks, this reduction in outside sound is particularly beneficial. Another positive side effect is, that green roofs improve air quality and reduce greenhouse gas emissions, which in turn improve public health. Green roofs filter air pollutants and capture greenhouse gases.[171]

For this measure being introduced in Can Tho, the following design considerations are foreseen. A green roof typically consists of the following layers (from top to bottom): 1) Vegetation, 2) Growing medium, 3) Filter membrane, 4) Drainage layer, 5) Root barrier, 6) Waterproof membrane, 7) Cover board, 8) Thermal insulation, 9) Vapor barrier.[172]

Proposed configuration of green roofs in Can Tho:

- Type: Semi-intensive
- System maximum height: 30 cm
- System volume per m^2: 0.3m^3
- Slope: 10°
- Vegetation: Semi-dense flora
- Vegetation height: 150 mm
- Substrate: organic clay
- Substrate max. thickness: 130mm
- Draining mat thickness: 40 mm

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166 Razzaghmanesh, M.; Beecham, S.; Salemi, T. The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia. *Urban For. Urban Green.* 2016, 15, 89–102.
167 Perini, K.; Magliocco, A. Effects of vegetation, urban density, building height, and atmospheric conditions on local temperatures and thermal comfort. *Urban For. Urban Green.* 2014, 13, 495–506.
168 Tsoka, S.; Tsikaloudaki, A.; Theodosiou, T. Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. *Sustain. Cities Soc.* 2018, 43, 55–76.
169 Odli, Z. S. M., Zakarya, I. A., Mohd, F. N., Izhar, T. N. T., Ibrahim, N. M., & Mohamad, N. (2016). Green roof technology-mitigate urban heat island (UHI) effect. *In MATEC Web of Conferences* (Vol. 78, p. 01100). EDP Sciences.
170 Qiu, G. Y., LI, H. Y., Zhang, Q. T., Wan, C. H. E. N., Liang, X. J., & Li, X. Z. (2013). Effects of evapotranspiration on mitigation of urban temperature by vegetation and urban agriculture. *Journal of Integrative Agriculture*, *12*(8), 1307-1315.
171 U.S. Global Change Research Program (USGCRP), Global Climate Change Impacts in the United States 101 (Thomas R. Karl, Jerry M. Melillo & Thomas C. Peterson eds., 2009), available at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf
172 Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, 57(10), 823-833.

- Water-saturated weight: 195 kg/m²

In general, green roof installation costs per square meter decrease as size increases. For a semi-intensive roof, USD 8.85[173] per square meter can be calculated. Annual maintenance cost lies on average at USD 0.80[174] per square meter.[175,176,177] The costs of maintaining a roof decrease after the plants cover the entire roof. In Can Tho, 46619 buildings are affected by pluvial and fluvial flooding. It is intended to establish green roofing on at least 5% of these buildings, which represents 2 330 buildings that are subject to harvest rainwater and to mitigate urban heat island effects through evapotranspiration. The average rooftop surface area of these buildings is 46.2 square meters. The total cost including construction and maintenance amounts to USD 1 183 445 (see Table 39)

Table 39: *Overview of cost dimensions for green roofs.*

Feature	*Unit*	*Quantity*
Area	m²/unit	46
Total area (2330 buildings)	m²	107 180
Height/depth	m/unit	0,3
Units	pieces	2330
Total Volume of Green Roofs	m³	32 154
Cost/unit	USD	230
An. Maintenance cost/unit	USD	9.5
Lifetime	years	40
Total construction cost	USD	948 543
Ann. maintenance cost	USD	85 744
Cumulated maintenance cost (until2050)	USD	2 486 576
TOTAL cost (incl. construction & maintenance) until 2050	**USD**	**3 435 119**

[173] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnam's currency value.
[174] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnam's currency value.
[175] Keating, K., Keeble, H., Pettit, A., & Stark, D. (2015). Delivering Benefits through Evidence: Cost Estimation for SUDS. *Environment Agency, Bristol, UK*.
[176] U.S. General Services Administration, Cost Benefit Analysis for Green Roofs. Retrieved from: https://bit.ly/3w6PRVC (16.02.2021).
[177] U.S. Environmental Protection Agency. 2008. "Green Roofs." In: Reducing Urban Heat Islands: Compendium of Strategies. Draft. Retrieved from: https://bit.ly/2Ris3j4 (02.03.2021).

Figure 98: *Examples of green roofs. Source: Bloomberg, https://www.bloomberg.com/news/articles/2018-04-13/improving-the-biodiversity-of-green-roofs (02.03.2021).*

13. Green Spaces (Urban Forestry)

Urban forestry can be described as the science and art of managing trees, forests and natural ecosystems in and around urban communities to maximise the physiological, sociological, economic and aesthetic benefits that trees provide society. It is distinct from arboriculture and horticulture, and considers the cumulative benefits of an entire tree population across a town or city.[178]Urban forests provide critical ecosystem services such as air and water filtration, shade, habitat, oxygen, carbon sequestration, and nutrient cycling. Urban forests also provide a connection to nature that is often perceived to be missing in urban areas.

This measure, the introduction of urban forestry, will contribute to both, flood and heat wave mitigation. Tree canopies and root systems reduce stormwater flows and nutrient loads that end up in waterways. Tree canopies intercept and mitigate the impact of heavy rainfalls. Healthy tree roots help reduce the nitrogen, phosphorus, and heavy metal content in stormwater. A healthy forest for urban and semi-urban areas can reduce the amount of runoff and pollutant loading in receiving waters in four primary ways: (1) through evapotranspiration, trees draw moisture from the soil ground surface, thereby increasing soil water storage potential, (2) leaves, branch surfaces, and trunk bark intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows, (3) root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow, and (4) tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces. Rainfall interception works best during small rain events, which account for most precipitation. With large rainfalls that continue beyond a certain threshold, vegetation begins to lose its ability to intercept water. With trees in full leaf, evergreens and conifers were found to intercept over 35 percent of the rainfall.[179]

In addition, trees and other vegetation provide great benefits to the built environment in mitigating urban heat island effects. Through the process of transpiration and the provision of shade, trees help reduce day and night-time temperatures. During transpiration, plants/trees draw water from the soil and release

[178] Helms, 1998, Dictionary of Forestry. Quoted in JC Schwab (Ed.), 2009, Planning the Urban Forest

[179] Xiao, Q., E.G. McPherson, J.R. Simpson, and S.L. Ustin. 1998. Rainfall Interception by Sacramen-to's Urban Forest. Journal of Arboriculture. 24(4):235-244.

moisture through their leaves into the air. A study investigated the thermal performance of ten urban parks in Singapore. They found that the air temperature in the parks was 7.7 – 12°C lower than that of the surrounding areas. Factors influencing this cooling effect of parks included parameters such as tree canopy and the spatial arrangement of the parks.[180] Another study in urban areas found that increasing 5% of mature deciduous trees can reduce the temperature by 1°C.[181] Some studies suggested tree coverage for at least 1/3 of the total area, which is needed to reduce by 1°C temperature.[182] Generally, studies reported, that the addition of trees reduced air temperature by varying between 0.35 - 1.87°C.[183,184] These results are consistent with the conclusion from previous literature reviews which showed that the addition of trees and hedges in an urban area may reduce the peak ambient temperature ranging between 0.2 and 5.0°C, with the median reduction being close to 1°C.[185,186] Human thermal comfort is also enhanced by increasing tree quantity. A study in Dar es Salaam, Tanzania, showed that the physiological equivalent temperature can be reduced by up to 14°C in the spots where the trees are added and it is reduced by an average of 4°C in the overall area.[187]

Most studies found that the ability of trees to reduce the temperature as well as improve human thermal comfort is consistent. Trees canopies provide shade and thus reduce the direct solar radiation. Through evapotranspiration, trees release vapour to the atmosphere and thus increase relative humidity, decreasing temperature and eventually improve the thermal comfort condition. The number of trees planted influences the level of temperature reduction, although more trees do not necessarily lead to a lower thermal comfort level.[188]

Besides the positive effects of urban trees on storm water and heat, healthy urban forests also contribute to biodiversity and habitat provision. By planting and managing different age strata, biodiversity and

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[180] Hwang, Y.H.; Lum, Q.J.G.; Chan, Y.K.D. Micro-scale thermal performance of tropical urban parks in Singapore. *Build. Environ.* 2015, 94, 467–476.
[181] Skelhorn, C.; Lindley, S.; Levermore, G. The impact of vegetation types on air and surface temperatures in a temperate city: A fine scale assessment in Manchester, UK. *Landsc. Urban Plan*. 2014, 121, 129–140.
[182] Imran, H.; Kala, J.; Ng, A.; Muthukumaran, S. *Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia*. J. Clean. Prod. 2018, 197, 393–405.
[183] Salata, F.; Golasi, I.; Petitti, D.; Vollaro, E.D.L.; Coppi, M.; Vollaro, A.D.L. Relating microclimate, human thermal comfort and health during heat waves: *An analysis of heat island mitigation strategies through a case study in an urban outdoor environment*. Sustain. Cities Soc. 2017, 30, 79–96.
[184] Herath, H.; Halwatura, R.; Jayasinghe, G. *Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy*. Urban For. Urban Green. 2018, 29, 212–222.
[185] Santamouris, M.; Ding, L.; Fiorito, F.; Oldfield, P.; Osmond, P.; Paolini, R.; Prasad, D.; Synnefa, A. Passive and active cooling for the outdoor built environment – *Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects*. Sol. Energy 2017, 154, 14–33.
[186] Tsoka, S.; Tsikaloudaki, A.; Theodosiou, T. *Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review*. Sustain. Cities Soc. 2018, 43, 55–76.
[187] Yahia, M.W.; Johansson, E.; Thorsson, S.; Lindberg, F.; Rasmussen, M.I. Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam, Tanzania. *Int. J. Biometeorol*. 2018, 62, 373–385.
[188] Balany, F., Ng, A. W., Muttil, N., Muthukumaran, S., & Wong, M. S. (2020). Green Infrastructure as an Urban Heat Island Mitigation Strategy—A Review. *Water*, *12*(12), 3577.

wildlife habitat values can be enhanced. Apart from the environmental benefits, urban forests (green spaces) can provide places for events, festivals and celebrations throughout the city can bring diverse groups of people together while having positive effects on people's wellbeing. Green spaces also play a role in defining the culture and image of a city. Tourism is of increasing importance to many cities, and green spaces can help to promote tourism, as main attractions or locations for various types of events and activities that could boost the local economy.

Since urban forests are public spaces and provide a safe and clean environment, the cost for urban forests are mainly maintenance costs and therefore quickly exceed the actual construction/planting costs. Vegetation doesn't need to be replanted but is well managed either for ecological or aesthetical reasons. A survey among multiple cities with urban forests concluded that cities spent about USD 0.62 - 2.83[189] (mean USD 1.73) annually per tree, including planting and especially any activity related to maintenance, such as pruning or watering.[190] For further calculations, the mean value of USD 1.73 has been chosen.

In Can Tho, 416 hectares of green spaces have been identified in the ECA study. The selected green spaces consist mainly of parks, conservation landscapes, such as natural green spaces along riverbanks or natural conservation zones, areas of natural reservoirs, or water retention. Ninh Kieu, Binh Thuy and Cai Rang districts are the most urbanized districts in Can Tho. Therefore some spaces in the districts can be considered as spaces with a multipurpose function between recreation and aesthetic purposes such as flower gardens, green pedestrian trenches along streets, rivers and canals. These areas are subject to further re- or afforestation, by increasing the vegetation density with newly planted trees.

The long-term goal is to create an urban forest heritage, in which every tree element that is located in public areas will be considered as heritage, so its protection, care and maintenance is important for GHG mitigation and the reduction of the effects of climate change, among other benefits to the city. This measure considers reforestation with native species in urban green spaces. This could include e.g. Pine (*Pinus spp*), Dipterocarpus[191] (*Hopea odorata, D. alatus,)*, Fabaceae (e.g. *Pterocarpus macrocarpus),* Combretaceae (*Terminalia spp*.), Cedar and Mahogany (*Swietenia macrophylla*). Since all identified urban green spaces have a different purpose (recreation, parks, etc.) and available space, planting trees is limited and in competition with other land use. For this reason, we assume that 45% of the total area is suitable for re- and afforestation purposes. This means, out of 416 hectares of green spaces, 187.2 hectares will be used for reforestation purposes. The amount of planted trees and cost calculation can be found in Table 40. In total, the costs to manage 187.2 ha of urban forest amounts to USD 1.525.431.

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[189] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnams currency value.
[190] U.S. Environmental Protection Agency. 2008. "Trees and Vegetation." In: Reducing Urban Heat Islands: Compendium of Strategies. https://www.epa.gov/heat-islands/heat-island-compendium. (03.02.2021).
[191] Many Dipterocarpaceae species are endangered and ex-situ conservation in urbanized areas is needed since there are not enough lowland forest reserves left for their long term protection.

Table 40: *Overview of cost dimensions to implement urban forests in Can Tho.*

Feature	*Unit*	*Quantity*
Area for planting	ha	187.2
No. of planted trees	trees	29 390 (157 trees/ha with 8 x 8 meter spacing)
Ann. interception of trees (9.5m³/tree)	m³	279.205
Lifetime	years	>50
Total Cost (incl. planting & maintenance) annualy	USD/annually	50 845
Total Cost (until 2050)	**USD**	**1 525 341**

Figure 99: *Example of urban green spaces with dense tree vegetation. Source: https://treesource.org (02.03.2021).*

14. White Roofs

In dense urban areas, temperatures are commonly observed to be higher than those in surrounding peri-urban or rural areas. In periods of extreme temperatures, these urban areas can be subject to a city-specific phenomenon called Urban Heat Island (UHI) effect. The increase of periods with heat waves of extreme temperatures and dense urbanization means that future populations are likely to be at increased risk of overheating in cities. A potential measure to mitigate overheating and to decrease urban temperatures are so-called 'White Roofs' also referred to as 'Cool Roofs'. The basic principle of this measure is based on the reflection of sunlight. The materials that comprise most city buildings and especially their roofs reflect much less solar radiation than the vegetation they have replaced. Reflective 'white' roofs have a higher albedo (i.e. sunlight reflectivity) compared with ordinary roofs, which increases the amount of reflected solar radiation. They reflect incoming solar radiation more efficiently than darker roofs, reducing the amount of heat that is absorbed by the rooftop and the building itself and ultimately transferred to the atmosphere. This potentially reduces urban daytime temperatures, and building energy consumption for cooling demand.[192]

Changing the albedo of rooftops is seen as a pragmatic strategy to implement, as rooftops constitute an estimated 20% of urban surfaces around the world, and ca. 4% (7 km^2 out of 169 km^2) in Can Tho for Ninh Kieu, Binh Thuy and Cai Rang district together.[193] Typically, the mean albedo of urban surfaces is taken to be around 0.2 (i.e. 20% of the incoming radiation is reflected, with the rest being absorbed), but can range from 0.1 to 0.3.[194] White roofs themselves have a range of albedos depending on the type of coating or roofing material, and typically have albedos in the range of 0.65 to 0.8 (and a few newer technologies can reach 0.85 or even higher).[195]

For heat wave periods, modelling from diverse studies suggests that 'white' roofs could reduce urban daytime air temperature by 0.5°C on average, and up to a maximum of 3°C.[196,197,198] Another study assessed globally installed white roofs in 33 regions across the globe and found, averaged over all urban areas, the annual mean heat island phenomenon has been decreased by 33%.[199] Heat waves can also exacerbate health conditions such as cardiovascular and respiratory diseases, and lead to heatstroke and death, especially for elderly populations. A study focusing on European cities concluded that white roofs may offset 25% of heat-related mortality during heat waves.[200] For US cities it was found that a 20% increase in surface reflectance could reduce heat-related mortality by between 5% and 21% depending on the city over 10 years.[201]

Besides the direct impacts of 'white' roofing strategies, there are also some indirect benefits. For residential buildings without air conditioning, 'white' roofs can provide an important public health benefit during heat waves. The annual decrease in cooling electricity consumption can cause cost savings from downsizing cooling equipment. At building scale, the application of cool materials results in the reduction of cooling energy use and peak energy demand for cooling, as less heat is transferred from the cooler roof into the building. A large number of experimental studies have been performed in residential and non-residential buildings documenting energy savings between 3% and 35%, depending on ceiling insulation

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192 Macintyre, H. L., & Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment international*, *127*, 430-441.
193 Zinzi, M., and S. Agnoli, 2012: Cool and green roofs. *An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. Energy Build*, 55, 66–76, https://doi.org/10.1016/j.enbuild.2011.09.024.
194 Wang, Y., Berardi, U., & Akbari, H. (2016). Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. *Energy and Buildings*, *114*, 2-19.
195 Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, *85*(12), 3085-3102.
196 Macintyre, H. L., & Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment international*, *127*, 430-441.
197 Georgescu, M., Morefield, P. E., Bierwagen, B. G., & Weaver, C. P. (2014). Urban adaptation can roll back warming of emerging megapolitan regions. *Proceedings of the National Academy of Sciences*, *111*(8), 2909-2914.
198 Synnefa, A., Karlessi, T., Gaitani, N., Santamouris, M., Assimakopoulos, D. N., & Papakatsikas, C. (2011). Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate. *Building and Environment*, *46*(1), 38-44.
199 Oleson, K. W., Bonan, G. B., & Feddema, J. (2010). Effects of white roofs on urban temperature in a global climate model. *Geophysical Research Letters*, *37*(3).
200 Macintyre, H. L., & Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment international*, *127*, 430-441.
201 Vanos, J., Shickman, K., Alliance, G. C. C., & Sheridan, S. (2014). Assessing the health impacts of urban heat island reduction strategies in the cities of Baltimore, Los Angeles, and New York.

levels, duct placement, and attic configuration.[202,203] This reduced demand for cooling energy will also moderate peak energy demand during heat waves, and thereby decreasing the risk of power outages.

In addition, the city-scale application of high-reflecting roof materials can potentially reduce air pollution both directly and indirectly. Direct reduction of air pollution is due to the fact, that less cooling energy is used, and therefore fewer emissions are produced (e.g. CO_2, NO_x, and PM10 particles). Indirect air pollution reductions reflect the fact that the reaction of ozone formation (that produces smog) accelerates at higher temperatures, therefore at lower urban air temperatures the probability of smog formation is decreased.[204]

High reflecting coatings for rooftops are best applied to low-sloped or ideally flat roofs in good condition. The majority of 'white' coatings have a consistency of thick paint and contain additives that improve their adhesion, durability, suppression of algae and fungal growth, and ability to self-wash or shed dirt under normal rainfall. Generally, there are two main types of 'white' roof coatings: cementitious and elastomeric. Cementitious coatings contain cement particles. Elastomeric coatings include polymers to reduce brittleness and improve adhesion. Some coatings contain both cement particles and polymers. Both types have a solar reflectance of 65% or higher when new and have a thermal emittance of 80% to 90%. The important distinction is that elastomeric coatings provide a waterproofing membrane, while cementitious coatings are pervious and rely on the underlying roofing material for waterproofing.[205] In some cases, white single-ply membranes can be used as well. This roofing material consists of one layer of membrane material rather than multiple layers. It is rolled onto the roof and attached with mechanical fasteners, adhered with chemical adhesives, or held in place with ballast (gravel, stones, or pavers).

Incorporating goals for increasing the number of white roofs into a comprehensive or general plan can be an important prerequisite step to later changes to building or zoning codes.[206] In some studies, commercial and industrial type buildings contributed more than half of the reduction for heat wave periods. Modifying half of all industrial/commercial urban buildings could have the same impact as modifying all high-intensity residential buildings.[207]

'White' roofs consisting of cementitious and elastomeric coatings may cost between USD 0.31 and USD 0.625[208] per square meter.[209] Single-ply membrane solutions vary from USD 0.625 to USD 1.25[210] per square meter, including materials, installation, and reasonable preparation work. When applied properly, 'white' coatings can last more than 20 years. A key concern for 'white' roofs is maintaining their high solar

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[202] Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, *85*(12), 3085-3102.
[203] Haberl, J., & Cho, S. (2004). Literature review of uncertainty of analysis methods: Cool roofs. *Energy Systems Laboratory Report, No. ESL-TR-04-10-04 (October)*.
[204] Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, *85*(12), 3085-3102.
[205] Ferguson, B., Fisher, K., Golden, J., Hair, L., Haselbach, L., Hitchcock, D., & Waye, D. (2008). Reducing urban heat islands: compendium of strategies-cool pavements.
[206] Hoverter, S. P. (2012). Adapting to urban heat: a tool kit for local governments. *Georgetown Climate Center*.
[207] Macintyre, H. L., & Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment international*, *127*, 430-441.
[208] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnam's currency value.
[209] EPA (2008). Reducing Urban Heat Islands: Compendium of Strategies. United States Environmental Protection Agency
[210] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied to the stated amount in order to reflect Vietnam's currency value.

reflectance over time. If a building's roof tends to collect large amounts of dirt or particulate matter, washing the roof can help retain solar reflectance. Other maintenance work includes regular roof inspections, repairs, or roof material disposal, and replacement costs.

It is intended to introduce 'white' roofing to at least 20% of all available roof surfaces with *elastomeric coatings with a square meter cost of USD 0.47*. For Can Tho, this would mean a potential of 1.4 km² (1 417 847 m²) roof surfaces. This measure will be applied in all three districts, Ninh Kieu, Binh Thuy and Cai Rang. It is advised to introduce 'white' roofing on industrial/commercial buildings first, followed by public buildings such as hospitals, schools, and administrative buildings. For districts, such as Ninh Kieu, with a high building (roof) density and a high likelihood of occurring urban heat island effect, roof adjustments should be prioritized as well. Regarding coating types, it is advised to use cementitious and elastomeric coatings, due to their lifetime, resistance and cost-efficiency compared to single-ply membranes. Resulting from this, cost estimations for 20% of available roof surfaces (ca. 30 684 buildings) lie at USD 664 615.[211] Since the lifetime of white roofs lies with 5-10 years, hence it is advised that roofs need to be renewed at least 4 four times until 2050. This would result in a total cost until 2050 of USD 2 658 460. High temperatures are a risk factor for hospitalisation or diseases for children (0-14 years, 22.61%) and elderly people (>65 years, 7.91%) in Can Tho. Hence, this measure has the largest impact on these two age groups in the population of Can Tho.[212]

Table 41: *Overview of cost dimensions for white roofs in Can Tho.*

Feature	*Unit*	*Quantity*
Area for white roofs	m²	1 417 847
No. of affected buildings	buildings	30 684
Cost per square meter (m²)	USD	0.47
Lifetime	years	20
Total Cost (until 2050)	**USD**	**2 658 460**

[211] 1 417 847 m² * USD 11.25 (mean) = USD 15 950 778 (before cost adjustment ratio has been applied)
[212] Age structure projected from national scale. https://www.indexmundi.com/vietnam/demographics_profile.html (16.03.2021)

Figure 100: *Example of white ("cool") roofs in urban areas. Source: YaleEnvironment360, https://bit.ly/3xRS35k (29.03.2021)*

15. Cooling centres

During heat waves, vulnerable population groups are most at risk. Heat-related illness is one health impact that will be directly affected by climate change. Health effects include heat cramps, heat exhaustion, heatstroke, and death.[213] An individual's heat vulnerability depends on their exposure and sensitivity to extreme heat, and their ability to adapt. Typically these population groups are most vulnerable to extreme heat: (1) Elderly, young children, and people with underlying medical conditions, as they are more sensitive to extreme heat. This includes pregnant women, (2) Low-income people and those living in poor quality housing, who may have less access to water, green spaces, information, and air-conditioning, (3) Outdoor construction workers, who have high exposure to heat and may have jobs requiring physical exertion, (4) Marginalized groups including homeless people, migrants, and/or refugees, as they may have less access to and awareness of cooling options.

To protect these vulnerable groups, so-called Cooling Centres being established in periods of extreme urban heat. Cooling centers (or 'cooling shelters') are typically air-conditioned or cooled buildings that have been designated as a site to provide respite and safety during extreme heat. This may be a government-owned (public) building such as a library or school, an existing community center, religious center, recreation center, or a private business such as a coffee shop, shopping mall, or movie theatre. Cities must promote awareness of the locations of these centers ahead of, and during, a heat wave, for example by using billboards, phone applications, or text messages. Cities can also map these using online platforms.[214] During power outages, centers can be opened to provide public information, charging stations for electronic devices, and power for medical equipment. Cooling centers may be operated by a

[213] Giford, W., *Customer Impact Evaluation for the 2009 Southern California Edison Participating Load Pilot*. Lawrence Berkeley National Laboratory, 2010.
[214] C40 Knowledge Hub. How to adapt your city to extreme heat. August 2019. Accessed here: https://bit.ly/2RuMTeG (10.03.2021).

health department, city government, non-profit groups, or a combination of agencies and/or partners.[215] Generally, cooling centers are a relatively low-cost strategy that can utilize existing infrastructure and personnel and are relatively easily implemented.

While there is a lack of research directly assessing the use of cooling centers to health outcomes, there is strong evidence that extreme heat is harmful to health and staying in a cool environment can help to maintain a safe core body temperature and reduce mortality.[216] Studies indicate that spending even a few hours in a cool environment, or with a working air conditioner or cooling unit, reduces vulnerable populations' risk to heat exposure. Those who adjust their behaviour to include spending time in a cool place during a heat wave are less likely to suffer from heat wave mortality.[217]Some studies even indicate that access to air conditioning can prevent and reduce heat-related morbidity and mortality.[218,219] A study from Chicago in 1999 showed that heat wave mortality has been reduced by 80% compared to events a decade before. The reason for this was that shopping malls, and movie theatre's had above-average attendance as people tried to escape the heat in air-conditioned facilities.[220] Another study from 2009 found, that nearly 30% of urban inhabitants would leave their homes during heat wave periods and visit cooler places.[221] Although, studies found evidence that cooling centres are used by more low risk individuals compared to high risk individuals.[222]

Besides the benefits of cooling centres, there are some challenges worth mentioning. Some studies indicate, that people in areas of extreme heat didn't know about cooling centres at all.[223] Some respondents in respective studies indicated that they did not see themselves as vulnerable to heat. Others were hesitant to go to cooling centres because they are unsure of what they provide and don't want to sit in a room with nothing to do.[224] Other studies found that it was difficult for homeless population groups to utilize a public cooling space due to short opening hours and respective homeless services.[225] When establishing cooling centres, sufficient outreach and communication are needed, especially in those districts or communities of residing individuals with low adaptation capacity to extreme heat. To better promote cooling centres information on the location and other specifications should be published in various forms. Efficient communication is key since some studies indicate challenges with peoples'

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[215] Mannuci, P. J., Brown, C. L., Hess, J. J., & Luber, G. (2011*). Climate and Health Technical Report Series: Climate Health Program. Centres for Disease control and Prevention*, Atlanta, USA, National Centre for Environmental Health.

[216] Luber, G. and M. McGeehin, *Climate change and extreme heat events*. American Journal of PreventiveMedicine, 2008. 35(5): p. 429-35.

[217] Vandentorren, S., et al., *August 2003 heat wave in France: risk factors for death of elderly people living at home*. Eur J Public Health, 2006. 16(6): p. 583-91.

[218] O'Neill, M.S., A. Zanobetti, and J. Schwartz, *Disparities by race in heat-related mortality in four US cities: The role of air conditioning prevalence*. Journal of Urban Health, 2005. 82(2): p. 191-197

[219] Bouchama, A., et al., Prognostic factors in heat wave related deaths: a meta-analysis. Arch Intern Med,2007. 167(20): p. 2170-6.

[220] Palecki, M.A., S.A. Changnon, and K.E. Kunkel*, The nature and impacts of the July 1999 heat wave in the midwestern United States: learning from the lessons of 1995*. Bull. Amer. Meteor. Soc., 2001. 82(7): p.1353-1367.

[221] Giford, W., *Customer Impact Evaluation for the 2009 Southern California Edison Participating Load Pilot*. Lawrence Berkeley National Laboratory, 2010

[222] Kovats, R.S. and L.E. Kristie*, Heatwaves and public health in Europe*. The European Journal of PublicHealth, 2006. 16(6): p. 592-599.

[223] Alberini, A., W. Gans, and M. Alhassan, *Individual and public-program adaptation: coping with heat waves in five cities in Canada.* International Journal of Environmental Research and Public Health, 2011. 8(12): p. 4679-4701.

[224] Sampson, N.R., et al., *Staying cool in a changing climate: Reaching vulnerable populations during heat events.* Global Environmental Change, 2013. 23(2): p. 475-484.

[225] Cusack, L., et al., *Extreme weather-related health needs of people who are homeless*. Australian Journalof Primary Health, 2013. 19(3): p. 250-255.

perception of cooling centres being 'just for old people', therefore limiting other vulnerable groups from using them.[226]

Suggested steps and considerations for implementing a cooling centre:[227]

	1. Scoping
a)	Are cooling centres a feasible, appropriate, and cost-effective strategy for your jurisdiction?
b)	Do cooling centres already exist in your jurisdiction? Who runs them?
	2. Existing landscape and identification of partners
a)	What is the role of the health department in cooling centre implementation?
b)	Do existing groups provide cooling centres?
c)	Are there other government agencies and non-profit partners that should be involved?
d)	What other key stakeholders should be involved?
e)	Is there available budget and staff?
	3. Assessment of vulnerable populations and geographic scale
a)	Which populations should cooling centres target?
b)	Are there particularly vulnerable neighbourhoods?
c)	Which stakeholders can help identify populations of concern?
	4. Planning
a)	Check agency policies, local laws, and ordinances
b)	Identify relevant materials and utilize existing guidance
c)	Identify staff and responsibilities
d)	Finalize locations
e)	Identify transportation options
f)	Determine thresholds for triggering cooling centres
g)	Create timeframe and budget
	5. Implementation
a)	Communicate and provide information
	6. Evaluation and publication
a)	If resources are available, the intervention should be monitored and evaluated
b)	Publication in the grey literature or peer-reviewed literature will aid other health departments

It is intended to establish at least 10 cooling centres in the study area. With respect to the population count per district, this would mean for Ninh Kieu five centres, for Binh Thuy three centres and for Cai Rang two centres. The centres should be accessible to a vulnerable population with an age above 65 (ca. 8%, 44 152 people). It is advised to involve 'local emergency managers' who will manage the lists of identified official cooling centres. These lists will be a result of a conducted screening of potential locations and consider cost constraints and optimal public buildings that would be the most economically feasible in areas with high amounts of vulnerable populations. In each cooling centre, two basic supplies need to be ensured, free water and air conditioning as well as medical assistance.

[226] White-Newsome, J.L., et al., *Strategies to Reduce the Harmful Effects of Extreme Heat Events: A Four-City Study*. International Journal of Environmental Research and Public Health, 2014. 11(2): p. 1960-88.
[227] Mannuci, P. J., Brown, C. L., Hess, J. J., & Luber, G. (2011). *Climate and Health Technical Report Series: Climate Health Program*. Centres for Disease control and Prevention, Atlanta, USA, National Centre for Environmental Health. Accessed here: https://bit.ly/3usxfPB (17.03.2021)

It is crucial to assist the implementation and utilization of cooling centres with sufficient communication strategies. Some studies indicated that the public often did not know about their existence. A potential outreach strategy can include the provision of real-time information on websites or using messages in prominent places such as bus stops or pharmacies. In communities of highly vulnerable and elderly people, pamphlets and brochures can be distributed to inform about location, opening hours and medical services. Clear signs and boards should be installed in front of every cooling centres to guide people accordingly.

The costs of these measures therefore largely relate to advertising costs, supply of bottled drinking water (ca. 2000 bottles a day), and personnel for the management of these centres (e.g. managers, volunteers, etc.) and temporary medical personnel. The identified cooling centres are already in public hands. However, their use in periods of extreme heat could be temporarily diverted from their intended purpose, and thus higher operating costs (e.g. energy costs), due to extended opening hours, could arise. It is assumed that approximately 1500 - 2000 individuals use cooling centres each day, typically for periods of less than one hour for heat relief and other services. In total, the operation of 10 cooling centres will cost USD 4 439 100 (see Table 42).

Table 42: *Overview of costs for operating 10 cooling centers in Can Tho. Costs reflect the use of centers for one heat wave period of three weeks per year.*

Item	*Costs (USD)*
Additional personnel costs[228] (for 3 weeks)	
▪ *Facility managers (10)*	13 650 (13 550*10)
▪ *Volunteers (50)*	67 750 (13 550*50)
▪ *Medical staff (10)*	36 000 (36 000*10)
Additional operating costs	
▪ *Utility costs (electricity + water +air condition)[229]*	15 500
Bottled Water	
▪ *ca. 2000 units per day[230]*	5000 (0,25*20000)
Communication/Outreach strategy	
▪ *Maintenance of websites*	250
▪ *Information boards/signs*	6100
▪ *Printed materials (brochures)*	3700
TOTAL (annually)	**147 950**
per district	7 398 (Ninh Kieu), 4 439 (Binh Thuy), 2 959 (Cai Rang)
TOTAL (until 2050)[231]	**4 439 100** (14 795 * 30 years)
per district	2 219 550 (Ninh Kieu), 1 331 730 (Binh Thuy), 887 820 (Cai Rang)

[228] Average labor costs for a month VND 40.181.000 in 2019. Source: Ministry of Labour-Invalids and Social Affairs of Vietnam (http://english.molisa.gov.vn/Pages/home.aspx)
[229] Average utility cost (electricity and water) per square meter per annum = 3.9 USD. Assuming an area of 1000 m² cooling centre = 3900 USD for 21 days (three weeks). From this 40% is 1550 USD. For 10 cooling centres: 1550 USD * 10 = 15500 USD. Source: http://www.facilityservicespartners.com/facility-costs/
[230] Bottled water (1,5 liter) = VND 5000 (USD 0,25)
[231] USD 147 950 * 30 years

Figure 101: *Example of a cooling center in Toronto, Canada. Public spaces, e.g. community halls, sports centers were opened to the public. Source: C40 Knowledge Hub, https://bit.ly/3eXPhmo (25.03.2021).*

16. Climate smart agriculture

Orchards

Fruit tree plantations (orchards) are the most abundant agricultural land use in the study area, especially in Cai Rang district with 3444 hectares, followed by Binh Thuy district with 2847 hectares and Ninh Kieu with 756 hectares. The most commonly grown species are coconut, orange, mango, pomelo and longan. It is intended to introduce climate smart practices to the orchard systems to further strengthen existing fruit tree and rice cultivation against hazards, such as heat waves and droughts. Two climate smart strategies have been identified.

Intercropping. Intercropping in fruit orchards allows improved heat stress management and aims to regulate microclimate and soil moisture content. The development of intensive fruit tree production systems with intercropped vegetable crops (preferably legumes such as peanut, *Arachis pintoi*, etc., due to N-fixation) is recommended, as well as the development of sub-urban vegetables or flower and fruit tree farming areas for domestic consumption and agro-eco-tourism attraction. This sub-urban farming model can be expanded further into solid supply chains since Can Tho is becoming a major tourist site in the Mekong Delta.

Smart water and irrigation management. The need to improve the efficiency of agricultural water use has become a necessity in addressing periods of extreme heat and droughts, especially in the Mekong Delta and specifically in Can Tho, with crucial agricultural export markets. Hence, this intervention proposes piped irrigation systems such as drip or sprinkler irrigation systems that support traditional open canal flood irrigation systems and aim to use water supply more efficiently and precisely for high-value fruit crops. Piped systems provide more efficient in-service delivery, support farmers to adopt on-farm water efficiently, require less maintenance, are more resilient to extreme weather conditions (e.g. drought or heat waves), and do not require water user groups to handle significant responsibilities to operate the distribution networks.[232] As such, they are more cost-effective in the long term. In addition to piped irrigation systems, it is advised to establish water storage reservoirs with a total extend of 100 hectares (3 000 000 m³)[233] distributed over three districts. These reservoirs will supply irrigation water during dry periods.

Rice

Rice farming is facing a dual challenge of delivering sufficient and nutritious food to meet the projected demands of population growth and markets, and overcoming issues such as climate change, soil fertility depletion and water scarcity during periods of extreme heat and droughts.[234] In this study, Binh Thuy is the only district that hosts rice cultivation (triple rice system) with an area of about 966 hectares. It is intended to introduce climate smart rice cropping systems to further strengthen existing rice cultivation against hazards, such as heat waves and droughts. Two climate smart strategies have been identified.

Alternate wetting and drying (AWD). More efficient water management practices are needed so that rice production levels can still be maintained or increased even with the use of less irrigation water. One form of a water-saving technique is alternate wetting drying. AWD has been promoted in Asia, with the most widespread adoption in Bangladesh, the Philippines and Vietnam. AWD is an irrigation technique where intermittent periods of submergence occurred during the growing stages of rice. This is in contrast to the traditional irrigation practice of continuous flooding. This means that the rice fields are not kept continuously submerged but are allowed to dry intermittently during the rice-growing stage. This approach, reducing the water amount with drying periods, reduces CH4 emission and thus contributes positively to the mitigation of climate change. Except for 'System of Rice Intensification' (SRI) which is based on transplanting, most of the AWD approaches are based on rice sowing on relatively dry soil reducing about 2 to 3 weeks the field submergence.[235] The practice involves draining the field until the water level reaches 15 cm below the soil surface after which the field is re-flooded to a depth of around 5 cm. The threshold of water at a 15 cm level below the soil surface will not cause any yield decline because the roots will still be able to capture water from the saturated soils.[236] In Vietnam, farmers in the Mekong Delta adopting AWD reported lower labor costs than non-AWD adopters. The irrigation frequency was also lower for the AWD adopters. The increase in net income (by 26%) was attributed to increased rice yield that was partly due to reduced lodging. AWD of rice paddy has been promoted as a strategy to decrease irrigation water use and reduce GHG emissions from rice cultivation while maintaining or improving yields.[237] Because periodic aeration of the soil inhibits CH4-producing bacteria, AWD can reduce CH4 emissions and, thus, has a proven potential to mitigate methane emission.

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[232] Toan, T. Q. (2014). Climate change and sea level rise in the Mekong Delta: flood, tidal inundation, salinity intrusion, and irrigation adaptation methods. In *Coastal disasters and climate change in Vietnam* (pp. 199-218). Elsevier.
[233] Assuming water storage reservoirs with a maximum depth of 3 meters, hence 1 000 000 m² (100 hectare) * 3 meters = 3 000 000 m³.
[234] Tivet, F., & Boulakia, S. (2017). Climate smart rice cropping systems in Vietnam. *State of knowledge and prospects. CIRAD, Montpellier, France*, 1-41.
[235] Tivet, F., & Boulakia, S. (2017). Climate smart rice cropping systems in Vietnam. *State of knowledge and prospects. CIRAD, Montpellier, France*, 1-41.
[236] Lampayan, R.M., Rejesus, R.M., Singleton, G.R., Bouman, B.A.M., 2015. *Adoption and economics of alternate wetting and drying water management for irrigated lowland rice*. Field Crops Research 170: 95–108
[237] Richards, M., Sander, B.O., 2014. *Alternate Wetting and Drying in Irrigated Rice: Implementation Guidance for Policymakers and Investors*. Internet Resource. https://cgspace.cgiar.org/bitstream/handle/10568/35402/info-note_CCAFS_AWD_final_A4.pdf. (25.03.2021)

Note: The AWD approach can be implemented only if the irrigation can be fully managed and water is available when needed. It will also depend on the efficiency of the drainage system during the wet season as water should be drained out in time. Promoting water-saving technologies implies that the characteristics of the irrigation system allow changes in water distribution rules and that the drainage capacity is efficient. Thus, and before targeting the AWD approach, it is essential to identify within the irrigation scheme where these conditions are available during the dry and rainy seasons based on the results of the analysis of the operation of the hydraulic frame.

Diversification of rice cropping systems with non-rice crops. This climate smart intervention generally consists of replacing one or two rice cycles in the annual succession by other types of production. These alternatives could consist of other crops, for example, upland annual and/or perennial species, or could include the integration with aquaculture or other breeding activities. Most of the rice cropping systems of the Mekong River Delta and the coastal plains are driven by the extent and occurrence of flood in the autumn (from September to early December). Diversification with cover crops and particularly legumes should be tested after rice harvesting at the end of August and early September. The use of productive cover crops are threefold: (1) it increases the diversification of rice with high-quality fodder sources, (2) it improves the soil fertility through the biomass inputs (above and belowground) with N-fixing legumes, and (3) it decreasing, weeds and diseases pressure and regulates the soil moisture content and makes fields more resistant against drought or periods of extreme heat.[238] Another form of diversification can be the introduction of a rice-aquaculture structure (e.g. summer-autumn rice with brackish shrimp culture) or the conversion of inefficient parts of paddy fields into orchards.

This climate smart agriculture project will initiate a transformation to address increasing periods of extreme heat in the urban and peri-urban agricultural systems of Can Tho. Based on previous agriculture transformation projects in the Mekong Delta, it is proposed to set up a phased investment programme until 2050 with costs of USD 1 600 000 for every 5 years. [239,240]

Figure 102: *Example of the alternate wetting and drying (AWD) system (picture left) and a smart irrigation system on a papaya orchard (picture right). Source: http://www.knowledgebank.irri.org (25.03.2021)*

[238] Tivet, F., & Boulakia, S. (2017). Climate smart rice cropping systems in Vietnam. *State of knowledge and prospects. CIRAD, Montpellier, France*, 1-41.
[239] https://www.ifad.org/en/web/operations/-/project/2000002335
[240] https://reliefweb.int/report/viet-nam/portfolio-climate-smart-agriculture-practices-scaling

17. Climate proofed road design ('Cool' pavements)

Most pavements made of conventional materials, such as asphalt, absorb sunlight almost completely. Because of its dark color, low reflectance, and high heat retention, asphalt pavements reach temperatures up to 65°C on days with direct sun radiation and in turn raise surrounding air temperatures.[241] Not only during daytime sunlight but also at night, pavements release trapped heat and keep urban built-up environments warmer compared to peri-urban or rural environments. Studies indicate, that increased night-time temperatures have a major impact on urban residents' health. [242] Basically, cities have two options to mitigate these heat absorptions of pavements. First, through the minimization of paved surfaces, or secondly, through the use/application of so-called 'cool' pavements. These surfaces aim to reduce both surface and air temperatures, hence mitigating the heat island effect in periods of extreme heat.

Generally, 'cool' pavements can be classified into two categories: 1) permeable or porous pavements and 2) light-coloured pavements. Porous pavements have voids for air and water to pass through. These voids allow evaporation and therefore cooling the pavement and the air above it.[243] Asphalt and concrete can both be made porous by omitting the smaller aggregates that are usual components. More specialized forms of porous pavements include interlocking concrete pavers, in which water drains through the gaps between precast blocks, and grass or gravel pavers, in which fill materials are laid on top of a plastic grid. The second category is light-coloured pavements, which have high solar reflectance (also called albedo). They reflect the sun's radiation rather than storing it. Albedo is expressed on a scale from 0 (complete solar absorption) to 1 (complete solar reflectance). Usually, to be considered a cool pavement, a material must have an albedo over 0.3 while the most reflective pavements have albedos over 0.75. In contrast, new black asphalt has a low albedo, between 0.05 and 0.12, green grass has 0.25 and for example, desert sand has 0.40.[244] Using a light-coloured aggregate in asphalt or adding a light-coloured overlay to an existing pavement will also produce lighter, cooler pavements than traditional asphalt. Studies have shown that every 10 percent increase in solar reflectance could decrease surface temperatures by 4°C. Further, they predicted that if pavement reflectance throughout a city were increased from 10 percent to 35 percent, the air temperature could potentially be reduced by 0.6°C.[245]

In general, 'cool' pavements show a number of benefits worth considering during planning. First, they mitigate heat island effects in densely built-up areas, leading to reduced surface and air temperatures. 'Cool' pavements can lead to lower car or motorcycle temperatures and therefore less fuel evaporation and fewer NOx tailpipe emissions when starting engines.[246] Another (unknown) benefit is the reduction in temperature of stormwater runoff into local water bodies. Minimizing overheated runoff can preserve

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[241] David A. Taylor, *Growing Green Roofs*, City by City, 115 Environmental Health Perspectives (2007), available at http://ehp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info:doi/10.1289/ehp.115-a306. (22.03.2021)
[242] Geater London Authority, *London's Urban Heat Island: A Summary for Decision Makers* (2006), available at http://static.london.gov.uk/mayor/environment/climate-change/docs/UHI_summary_report.pdf (22.03.2021).
[243]Joyce Klein Rosenthal et al., Sustainable South Bronx, *Urban Heat Island Mitigation Can Improve New York City's Environment*: Research on the Impacts of Mitigation Strategies on the Urban Environment 12 (2008)
[244] Hoverter, S. P. (2012). Adapting to urban heat: a tool kit for local governments. *Georgetown Climate Center*.
[245] Pomerantz, M., B. Pon, H. Akbari, and S.-C. Chang. 2000. *The Effect of Pavements' Temperatures on Air Temperatures in Large Cities*. Paper LBNL-43442. Lawrence Berkeley National Laboratory, Berkeley, CA.
[246] Eco-Friendly Parking Lot in Fair Oaks Village, Heat Island Reduction Initiative (HIRI) News, Apr. 19, 2001, at 2, available at http://www.epa.gov/heatisld/resources/pdf/apr_01.pdf

aquatic ecosystems and especially protect wildlife vulnerable to temperature increases.[247] If surface applications are implemented, this could also lead to reduced tire noise of traffic vehicles. It should be mentioned that requirements to apply 'cool' pavements are more effective in areas with a lot of new development, e.g. residential areas.

In this study, it is advised to apply strategies for existing pavements, hence using so-called surface applications that can be applied to existing conventional asphalt or concrete surfaces. The district of Ninh Kieu has been chosen as a target district for this measure, due to its high potential of a possible heat island effect. In locations of the district where the existing pavement is in relatively good condition, a surface treatment to change the reflectivity of the pavement surface should be applied. Doing this can also extend the life and improve the performance of the pavement due to reduced thermal and environmental stresses.[248] Surface treatments can also help to extend the road's service life by reducing the rate of deterioration. Two different surface applications should be applied. The first one is 'Chip seals with light aggregate' for roads with relatively low traffic volumes, and secondly, the surface application called 'Whitetopping', preferably for roads with high traffic volumes, such as street intersections, bus lanes, highways where rutting and shoving of asphalt surfaces is a predominant problem.

Chip seals with light aggregate. This application should be applied on roads with low traffic volume and pavements in good structural condition. A chip seal is constructed by first placing a thin layer of asphalt emulsion on the existing pavement surface and then broadcasting and embedding graded aggregates using a pneumatic roller. This results in a surface that initially takes on the appearance of the aggregate used in the seal. The use of light-coloured aggregates in the chip seal would result in a surface with much greater reflectivity than a typical existing asphalt pavement, although this reflectivity will diminish with time as the aggregates continue to be embedded into the asphalt under the action of traffic. Chip seals add little to no structural capacity to the existing pavement. At most a chip seal may be used to repair minor cracks. Chip sealing results in an impervious surface with increased surface friction. As result, the surface is rough and noise from the pavement is increased. It is therefore recommended to apply this measure on roads with low traffic volumes away from residential areas, such as industrial parks or near airports, large parking areas, or areas of agricultural production. This surface application has a life duration of approximately 8 years and installation costs varying between USD 0.042 to USD 0.0625 (mean USD 0.052)[249] per square meter.[250] In Ninh Kieu, 16.6 km of 'low traffic' and non-residential road[251] has been identified for chip seals. Using a mean price of USD 0.052 per square meter, costs represent USD 10 375 for ca. 199 200 square meters[252] of road. Considering a lifetime of 8 years for the material, the chip seal's

[247] Lance Frazer, Paving Paradise: The Peril of Impervious Surfaces, 113 Environmental Health Perspectives A456, A459 (2005), available at http://ehp03.niehs.nih.gov/article/fetchObjectAttachment.action?uri=info%3Adoi%2F10.1289%2Fehp.113-a456&representation=PDF.

[248] Levine, K. K. Cool Pavements Research and Technology. Institute of Transportation Studies Library at UC Berkeley, Sep. 2011.

[249] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP US (2019: 65287.5 USD) were compared. Between both, the difference is 1:24.

[250] Ferguson, B., Fisher, K., Golden, J., Hair, L., Haselbach, L., Hitchcock, D., & Waye, D. (2008). Reducing urban heat islands: compendium of strategies-cool pavements.

[251] Class 3 roads, with a width of 12 meters.

[252] 16600 meter * 12 meter = 199 200 m²

surface needs to be renewed three times until 2050. This would result in a total cost of USD 41 500 (Table 15).

Whitetopping. Whitetopping is recommended for roads with high traffic volumes and dense urban areas that are used as well so residential purposes. Whitetopping is a bonded concrete overlay of existing asphalt pavement with a layer of concrete of around 10 cm thickness, often containing fibers for added strength. Adding these light cement concrete layers with slag, greyish cement, can increase solar reflectance up to 50%. Whitetopping layers have an estimated life duration of 15 years and installation costs lie between USD 0.625 to 2.71 (mean USD 1.66)[253] per square meter.[254] In Ninh Kieu, 25.85 km of primary and 'high traffic' road[255] has been identified for whitetopping. Using a mean price of USD 1.66 per square meter, estimated costs are USD 969 375 for ca. 581 625 square meters[256] of road. Considering a lifetime of 15 years for the material, the chip seals surface needs to be renewed one more time until 2050. This would result in a total cost of USD 1 938 750 (Table 43).

Both surface applications combined, the total costs amount to USD 1 980 250 until 2050 (Table 43).

***Table 43:** Overview and summary of cost dimensions for 'cool' roads.*

Feature	Unit	Quantity
Chip seals with light aggregate		
Length of road (12.5 m width)	km	16.6
Area for chip seals	m²	199 200
Cost per square meter (m²)	USD	0.052
Lifetime	years	8
Total cost (for 8 years)	USD	10 375
Total cost (until 2050)	USD	41 500
Whitetopping		
Length of road (12.5 m width)	km	25.85
Area for chip seals	m²	581 625
Cost per square meter (m²)	USD	1.66
Lifetime	years	15
Total cost (for 15 years)	USD	969 375
Total cost (until 2050)	**USD**	**1 938 750**
TOTAL (until 2050)	**USD**	**1 980 250**

[253] Cost adjustment ratio: Costs were derived from U.S sources and stated in USD. A cost adjustment ratio of 1:24 has been applied. The ratio here is based on the GDPP (GDP per capita) to represent the difference of the buying rate differential (purchasing power of individual currencies). GDPP Vietnam (2019: 2715.3 USD) and GDPP US (2019: 65287.5 USD) were compared. Between both, the difference is 1:24.
[254] Ferguson, B., Fisher, K., Golden, J., Hair, L., Haselbach, L., Hitchcock, D., & Waye, D. (2008). *Reducing urban heat islands: compendium of strategies-cool pavements.*
[255] Class 1 roads, with a width of 22.5 meters.
[256] 25 850 meter * 22.5 meter = 581 625 m²

Figure 103: *Example of whitetopping (left) road design, as well as applied chip seals with light-colored aggregates. Source: Intra Construction & Equipment Magazine, https://bit.ly/3hhw9Cj (12.03.2021).*

Overview

Table 44: *Overview of all measures applied in Can Tho incl. location. The total cost until the year 2050 (incl. construction & maintenance) and the targeted hazard (pluvial-fluvial and/or tidal or heat wave) are listed.*

Can Tho			
Measure	Zone 1, 2, 3 (Districts)	Total Cost in USD (for 30 years, incl. construction & maintenance)	Hazard
1. Retention Reservoirs	1 and 3	1 150 825	pluvial-fluvial, tidal
2. Detention swales along roads	1, 2, and 3	3 554 522	pluvial-fluvial, tidal
3. Improved solid waste management	1, 2, and 3	1 566 192	pluvial-fluvial, tidal
4. Rehabilitation of existing drainage canals	1, 2, and 3	3 185 343	pluvial-fluvial, tidal
5. Flood awareness campaign	1, 2, and 3	1 165 758	pluvial-fluvial, tidal
6. Road spillways as bio-retention systems	1, 2, and 3	9 414 001	pluvial-fluvial, tidal
7. Rain collection tanks for existing buildings	1, 2, and 3	222 999	pluvial-fluvial
8. Mobile flood embankments	1, 2, and 3	1 719 204	pluvial-fluvial, tidal
9. Flood wall	3	7 380 000	pluvial-fluvial, tidal
10. Flood protection storage facility (incl. sandbags)	1, 2, and 3	921 557	pluvial-fluvial, tidal
11. Green Roofs	1, 2, and 3	3 435 565	pluvial-fluvial, heat wave

12. Green spaces (Urban Forestry)	1, 2, and 3	1 525 341	pluvial-fluvial, tidal, heat waves
13. White Roofs	1, 2, and 3	2 658 463	heat wave
14. Cooling centers	1, 2, and 3	4 439 100	heat wave
15. Climate smart agriculture	1, 2, and 3	9 600 000	heat wave
16. Climate proofed standards for road design ('Cool' pavements)	1, 2, and 3	1 980 250	heat wave
17. Index Insurance	1, 2, and 3	(2 200 00 per year/flood) (500 000 per year/heat waves)	pluvial-fluvial, tidal, heat waves
TOTAL[257]		53 919 120	all

District (Zone)	Total Cost in USD (for 30 years, incl. construction & maintenance)
Binh Thuy (1)	13 479 780
Ninh Kieu (2)	16 714 927
Cai Rang (3)	23 724 413
TOTAL	53 919 120

[257] Excluding costs for Index Insurance

ANNEX 4: Recommendation for a Flood Monitoring Network

Flood Management processes are driven by natural processes causing possible loss of lives and property. They have the aim to reduce and to avoid the negative effects of flood hazards to the human sphere by assessing the development of specific flood situation.

The UN Office for Disaster Risk Reduction (UNDRR) "advocates the use of Flood early warning systems (FEWSs) as one of the most common flood-impact mitigation measures. […] Comprehensive FEWS consists of four components, which includes (1) risk knowledge, (2) monitoring and forecasting, (3) warning, dissemination, and communication, and (4) response capabilities."[258]

The occurrence and the progress of specific flood situation itself has to be estimated as good as possible by describing the natural processes with measurements and model simulations to provide a basis for decision makers and emergency relief. Establishing flood warning systems along relevant waterways or water bodies helps to provide critical information for the protection of property and lives. Effective flood warning approaches are composed out of the installation of gages and telemetry equipment and carefully designed procedures to provide early warning about whether a flood is to be expected, when it will occur, and how severe it will be.

Facing this point, measurements of the natural processes as precipitation and discharge are central for an increased preparedness to floods of a city like Can Tho at the confluence of several rivers.

In addition to the possible flood warning aspect, continuous measurements and statistical analysis of precipitation, climate data (e.g. temperature, humidity) and discharge will help to understand hydrological behaviour of the catchments better and to monitor undergoing climate change processes within the catchments.

[258] Perera, D., Seidou, O., Agnihotri, J., Rasmy, M., Smakhtin, V., Coulibaly, P., & Mehmood, H. (2019). *Flood Early Warning Systems: A Review Of Benefits, Challenges And Prospects*. Hamilton, Canada: United Nations University Institute for Water, Environment and Health (UNU-INWEH).

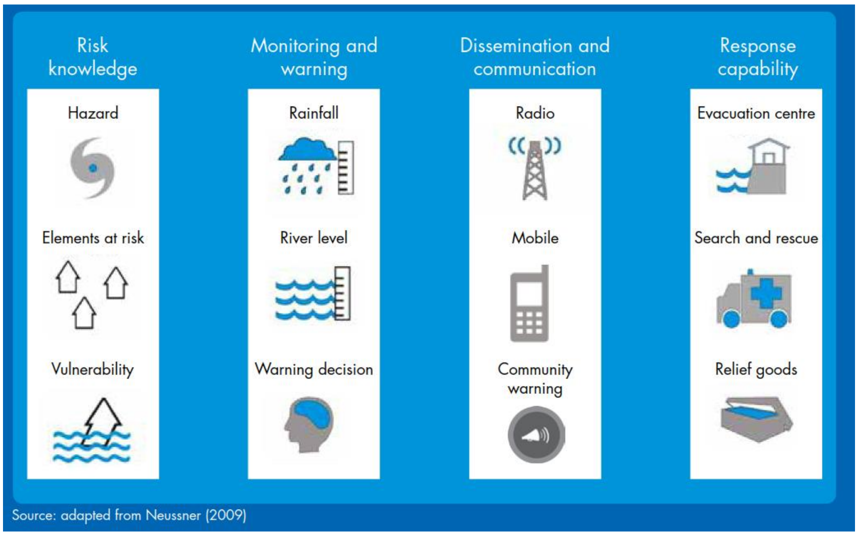

Figure 1: *Components of a flood early warning system.*[259]

Figure 1 presents hydrometric and meteorological monitoring networks which usually include the following components:

1. (Automated) weather station monitoring network / climate data

   Monitoring

   - precipitation (high temporal resolution < 1 h or continuous)
   - additional climate data as temperature, humidity, radiation

   Potential benefits for the river catchment

   - monitoring of time series and statistical analysis (e.g. annual mean, storm duration and pattern, return period/precipitation)
   - monitoring of climate change effects
   - improvement of (sub)catchment behaviour (e.g. discharge volume of sub-catchment and superposition to relevant hydrograph)
   - improvement of Rainfall-Runoff-Calculation and calculation of discharge values for hydrodynamic calculations
   - implementation of early warning systems by alert stations and/or Rainfall-Runoff-Calculation
   - useful for downscaling of (regional) climate model data

2. Stream discharge measurements / gauges

   Monitoring

   - discharge

[259] Shrestha, M., Kafle, S., Gurung, M., Nibanupudi, H., Khadg, V., & Rajkarnikar, G. (2014). *Flood Early Warning Systems in Nepal - A Gendered Perspective.* Kathmandu, Nepal: International Centre for Integrated Mountain Development.

- developing discharge rating curve

Potential benefits for the river catchment

- monitoring of time series and statistical analysis (Return Periods etc.)
- study of Rainfall/Runoff aspects (e.g. develop ideas about the general effective precipitation in connection to measured precipitation)
- Modelling improvement and possibility to calibrate/validate models
- Installation of alert gauge for early flood warning (e.g. triggering E-Mail dispatch)

To allow the estimation of possible flood hazards and corresponding risks, often model-based simulations are used to create flood hazard maps and to calculate the flooded area and other relevant parameters as water depth, flow velocity, travel time of flood peak or critical water level indicating the need of evacuations e.g. of hospitals or other vulnerable objects. These models rely on data to describe the flow propagation through the river channel. Physical properties are for example cross sections taken from river channel survey to describe the capacity of the river channel to store and to guide the water downstream without flooding forelands. Nevertheless, also hydraulic and hydrological parameters as effective precipitation and discharge volume are important.

One observation out of this ECA study is that the precipitation and discharge measurement network is not dense enough to allow a calibration and validation of hydrological and hydrodynamic models. Generally, the installation of a measurement network would allow to improve the hydrological simulation e.g. in terms of more reliable precipitation depth applied to the models for the calculation of relevant discharge volumes as well as the more reliable calculation of the hydrodynamic process transforming the discharge volume into a water level. These discharge measurements will ideally be accompanied by a survey of river cross sections (e.g. water body, bridges).

To determine the location and number of monitoring station a more detailed analysis would be needed. Major patterns, should be analysed including:

1. main wind directions/storm tracks
2. similar reacting sub-catchments,
3. topography/exposition
4. travel time of flood peak from discharge gauges to Can Tho for localisation of gauge stationing
5. needed time for emergency services and protective measures
6. first idea about operating warning system
7. Reachability / accessibility / connectivity to authorities

Furthermore, sensor technique has to be chosen according to the local condition and determines the corresponding cost. For stream gauge example simple non-contact water-level sensors (Ultrasonic/RADAR) USD 500; Radar can be around USD 3 000. The choice of the technique depends on local conditions that have to be evaluated. Low cost climate station could start from USD 500 for the sensor itself.

Sensors have to be extended with a data collection platform and a system for data transmission (e.g. GSM) and collected within databases and provided to the user via Graphical User Interfaces. These possibilities also have to be evaluated in addition to the above-mentioned location search, Figure 2 shows the principle elements of a FEWS. Within a first study possibilities and costs had to be evaluated according to the requirement for the corresponding station.[260]

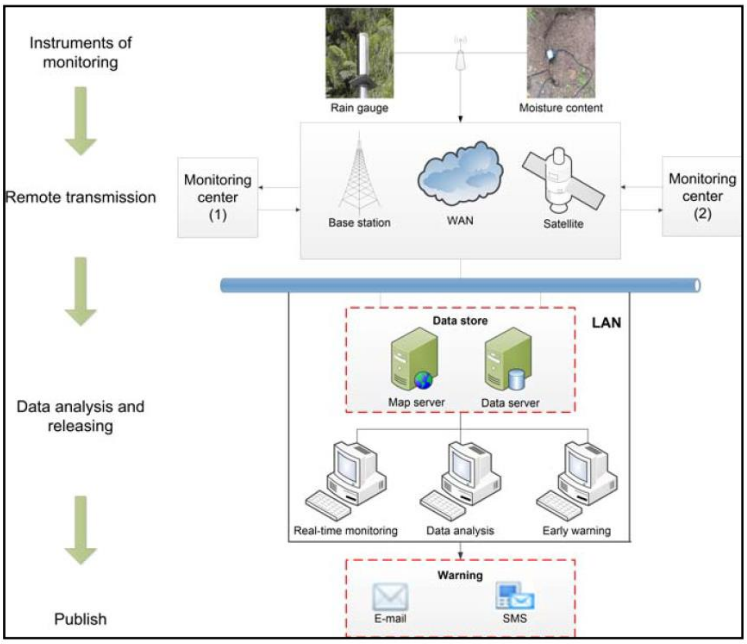

Figure 2: *Architecture of the early warning system (modified).*[261]

[260] Further reading: Challenges and Technical Advances in Flood Early Warning Systems (FEWSs) DOI: http://dx.doi.org/10.5772/intechopen.93069

[261] Ju, N.-p., Huang, J., Huang, R.-q., He, C., & Li, Y. (2015). A Real-time monitoring and early warning system for landslides in Southwest China. *Journal of Mountain Science*, 1219-1228.

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