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Discussions

Assessment of the effectiveness of participatory developed adaptation strategies for HCMC

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Abstract

Coastal cities are vulnerable to flooding, and flood risk to coastal cities will increase due to sea-level rise. Moreover, especially Asian cities are subject to considerable population growth and associated urban developments, increasing this risk even more. Empirical data on vulnerability and the cost and benefits of flood risk reducing measures are therefore paramount for sustainable development of these cities. This paper presents an approach to explore the impacts of sea level rise and socio-economic developments on flood risk for the flood prone District 4 in Ho Chi Minh City, Vietnam, and to develop and evaluate the effects of different adaptation strategies (new levees, dry- and wet flood proofing of buildings).

A flood damage model was developed to simulate current and future flood risk using the results from a household survey to establish stage-damage curves for residential buildings. the model has been used to assess the effects of several participatory developed adaptation strategies to reduce flood risk, expressed in Expected Annual Damage (EAD). Adaptation strategies were evaluated assuming combinations of both sea level scenarios and land use scenarios. Together with information on costs of these strategies, we calculated the benefit-cost ratio and net present value for the adaptation strategies until 2100, taking into account depreciation rates of 2.5 % and 5 %.

The results of this modeling study indicate that the current flood risk in District 4 is 0.31 million USD yr^{-1}, increasing up to 0.78 million USD yr^{-1} in 2100. The net present value and benefit-cost ratios using a discount rate of 5 % range from USD −107 to −1.5 million, and from 0.086 to 0.796 for the different strategies. Using a discount rate of 2.5 % leads to an increase in both net present value and benefit cost ratio. The adaptation strategies wet proofing and dry proofing generate the best results using these economic indicators. The information on different strategies will be used by the government of Ho Chi Minh City for selecting a new flood protection strategy. Future research should focus on gathering empirical data right after a flood on the occurring damage, as this appears to be the most uncertain factor in the risk assessment.

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1 Introduction

Coastal cities are vulnerable to flood risk as shown by the recent floods in New York City, USA (2012), Manila, Philippines (2012, 2013), and Brisbane, Australia (2011). These floods vividly illustrate that coastal mega-cities have increasing vulnerability to storm-surge flooding (Nicholls et al., 2008; UN, 2012). By the middle of this century, the majority of the world's population will live in cities in or near deltas, estuaries, or coastal zones, resulting in even more people located in highly exposed areas (Jongman et al., 2012). Such socio-economic trends further amplify the possible consequences of future floods, as more people move toward urban delta areas, and capital is continuously invested in ports, industrial centres, and financial businesses in these flood-prone areas. Moreover, climate change and sea level rise may further amplify the frequency, intensity, and duration of flood events (IPCC, 2007). Ho Chi Minh City (HCMC) in Vietnam is a typical example of a vulnerable coastal city, which is frequently hit by floods. In fact, the low-lying parts of the city are flooded each spring tide. However, while recent research has focussed on vulnerable coastal cities in Europe and the US, relatively little is known on the flood risk of coastal cities in Asia, including HCMC (Huq et al., 2007; ADB, 2010). In a global assessment by Hanson et al. (2011), HCMC is ranked in the top-20 most risky cities, when considering the size of the population exposed to coastal flooding (e.g. flooding by the sea).

A challenge in planning for flood adaptation is to the quantify trends in risks, and calculate the costs and benefits of different adaptation strategies to reduce those risks (Dawson et al., 2011; Ranger et al., 2011). This requires input from different disciplines, varying from coupled hydrodynamic flood modelling (e.g. Winsemius et al., 2013), catastrophe risk models of the city's exposed assets (Grossi and Kunreuther, 2005) to economic evaluation of risk management strategies, including policy, insurance, and engineering measures, in order to calculate the cost and expected benefits of different strategies over a given period of time (e.g. Hallegate, 2006). There are many studies that quantify flood hazard and expected changes in the hazard due to sea level rise (Nicholls and Cazenave, 2010). Other studies use flood risk assessment models, focussing both on the flood hazard, and on flood exposure and vulnerability (Apel et al., 2008; Merz and Thieken, 2009; de Moel and Aerts, 2011; Ward et al., 2013). Some of these studies use catastrophe risk models to calculate risk reduction for different flood adaptation measures on local to regional scales (e.g. Veerbeek and Zevenbergen, 2009; Bouwer et al., 2010; Koks et al., 2013; de Moel et al., 2014; Aerts et al., 2013), and for others on the river basin scale (e.g. te Linde et al., 2011; Poussin et al., 2012). Few studies, however, have assessed the effectiveness of those flood adaptation measures in terms of costs and benefits (e.g. Dawson et al., 2011), and only some make use of specific depth–damage relations of the studied area.

Storch and Downes (2011) recently assessed the exposure of HCMC to flooding by coupling data on urban development with projected maps of sea level rise scenarios. Their conclusion is that socio-economic development and urban expansion are the main drivers for the increased exposure with flooding compared to the influence of sea level rise. This conclusion is supported by Adikari et al. (2010). The Asian Development Bank (ADB) assessed the effect of a flood control plan as an adaptation to reduce the vulnerability of Ho Chi Minh City to increased flooding as a result of climate change and sea level rise. However, they only assessed the reduced exposure of assets (ADB, 2010). Hence, existing studies have not assessed the risk (often expressed as Expected Annual Damage, EAD) defined as a function of the flood hazard and its probability, and the consequences (the exposed assets and their vulnerability) (Kron, 2002). Partly this is because stage-damage curves are not available for South East Asian cities. As the EAD for flooding has not yet been established, it was also not possible to assess the cost-effectiveness of different flood adaptation measures for HCMC.

Different types of flood adaptation strategies are available to reduce flood risk. These consist of strategies to reduce the probability of flooding, for example dikes and levees (Merz et al., 2010; Poussin, 2012). And strategies to reduce the consequences of flooding, for example wet- and dry-proofing of houses, and elevating an area or individual houses (Kreibich and Thieken, 2009; Aerts and Botzen, 2011), as well as measures on evacuation and early warning (Merz et al., 2010; de Moel et al., 2014).

The main goal of this study is to conduct a benefit-cost analyses of alternative flood adaptation options for HCMC, assuming different scenarios of changes in land-use and climate. To achieve this assessment, we combined a participatory approach to identify adaptation options and vulnerability, with a model-based assessment of benefits and costs, in which stage-damage curves based on a survey in HCMC are used. This method is applied to District 4 in Ho Chi Minh City, one of the most exposed parts of the city. Section 2 describes the method and data, including the case study area. Sections 3, 4, and 5 provide, respectively, the results, discussion and conclusions.

2 Method and data

Figure 1 is an overview of the methodology of this paper. We applied a participatory approach (Sect. 2.4), for developing several key parts of the method, such as novel stage-damage curves and adaptation strategies, both tailored to HCMC. We used a flood damage model to calculate flood risk and expected annual damage, with and without a proposed flood management strategy. The damage model used synthetic flood hazard scenarios as input, which were produced by a coupled hydrological–hydrodynamic model. Future scenarios include sea level rise due to climate change, and projected urban growth. The effectiveness (risk reduction) of each strategy and its costs were then evaluated in a benefit-cost analysis (BCA) under the various future scenarios.

2.1 Case study: Ho Chi Minh City focussing on district 4

Ho Chi Minh City is located in the south of Vietnam in the floodplain of the Dong-Nai and the Sai-Gon river systems (Fig. 2), an area enclosed by the Mekong river system in the Western part and the East Sea on the eastern side (Vo, 2009). 40–45 % of the city's land cover has an elevation between 0 and 1 m a.s.l., while 15–20 % of the land is located at 1–2 m and only the northern area is located at higher levels (> 4 m a.s.l.) (World Bank, 2010). The city consists of 24 administrative districts (subdivided into 322 wards and communes and 5 townships), which vary in size, population density, and land-use (World Bank, 2010; ADB, 2010).

Ho Chi Minh City is a fast growing city. The mean annual GDP growth was 7.3 % yr^{-1} over the period 2001–2010 (CVCP, 2011) and the number of inhabitants rose from 3.8 million to 7.1 million between 1986 and 2010, excluding an additional 2 million unregistered migrants (Storch and Downes, 2011). By 2025, the city is expected to grow further to at least 10 million people (MPI, 2011), and economic growth is projected at 7–8 % yr^{-1} (CVCP, 2011; IMF, 2013). The HCMC region is an economic hub for the whole of Vietnam and generates one-third of the national GDP (Eckert et al., 2009).

The city is exposed to flooding from the sea and rivers, and this hazard is expected to increase in the future as a result of sea level rise (SLR) and soil subsidence (ADB, 2010; World Bank, 2010; Storch and Downes, 2011). Storch and Downes (2011) show that, currently, 160 km^2, or 32 % of the built-up area is exposed to flooding. This will increase up to 360 km^2, or 48 % when only taking into account urban development until 2025. They also identify District 4 as one of the most exposed areas in HCMC, and this is the subject of our analysis (see Fig. 1). We focus on District 4 because the spatial flood adaptation plans and data are available for this part of the City, enabling a detailed analysis of risk, including exposed population and assets. The district covers an area of 3 km^2 and is a typical example of the densely populated urban centre of HCMC.

2.2 Hydrological and hydrodynamic simulations

Inundation depths used in this research are modelled with the Mike 11 hydraulic software package. Mike 11 is a modeling program for the one-dimensional simulation of water quantity, quality and sediment transport in different types of water bodies (DHI, 2002). Impacts and effects of floods can be visualized using Mike 11 in combination with a GIS interface (DHI, 2002; CDWR, 2006). The resulting flood inundation maps can be used as input for flood damage assessment studies.

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The inundation maps have a spatial resolution of $20 \times 20\,m^2$, and are composed for five different return periods (1/10, 1/25, 1/50, 1/100, 1/1000) under the current sea level, and for five return periods including a sea level rise scenario of +30 cm (SLR+30) in the year 2050 (FIM, 2013).

2.3 Calculating the Expected Annual Damage

In order to calculate the Expected Annual Damage (EAD), we used a typical approach using damage curves (similar to Klijn et al., 2007; de Moel and Aerts, 2011). It requires two inputs: a land-use map for determining exposed assets, and an inundation map. These inputs are combined using the stage-damage curves, which per class of exposed assets yields the damage to the asset as a function of inundation depth. The EAD is calculated by aggregating damage estimates of different probabilities by taking the integral under the exceedance probability-damage curve (risk curve) (Grossi and Kunreuther, 2005; Meyer et al., 2009). Ward et al. (2011) have shown that flood damage related to five return periods (as available in this study: see Sect. 2.2) with a sufficient spread (low and high probabilities) are sufficient to estimate the EAD.

The exposed assets are classified in 6 classes (see Table 1), and are derived from an existing land-use map for HCMC, representing the situation in 2005 (ADB, 2010). This map has a resolution of $20 \times 20\,m^2$, and was updated and refined on the basis of presence of two types of residential buildings in sectors in District 4. For assessing the change in EAD due to socio-economic developments, we have used the land-use map 2025, developed by the government of HCMC as part of the socio-economic Master Plan 2025 (DPA, 2010). We assume land-use for 2050 to be the same as the land-use in 2025, since projections of land-use in 2050 are not available. When using the future land-use scenario in the analysis, we divide the change in exposed assets equally over the 12 yr period between 2013 and 2025.

Hence, as input for calculating the change in EAD, we use two land-use scenarios and two sea-level scenarios (Sect. 2.2). One represents the baseline situation, and the other represents the situation in 2050. Using different combinations of land-use and sea-level scenarios allows for comparing the relative importance of land-use change and sea level rise on the EAD.

2.3.1 Household survey: deriving stage damage functions

For calculating damage, we combine information on land-use and inundation depth using stage-damage functions. A damage curve provides the expected damage for a given inundation depth (as a proportion of the maximum damage), for each land-use type. Stage-damage functions for HCMC were not available prior to this research. In order to establish the relation between flood depth and damage for HCMC, a household survey was carried out. In total 659 households were interviewed using a structured questionnaire. The questionnaire covered the following topics: general information of households; past flood inundation; inundation damage; measures for inundation control; willingness-to-pay for flood protection; and, the potential damage caused by higher inundation levels. The households were located in districts exposed to the flooding of 2011, which was used as a reference flood. This recent flood enabled the interviewed households to better recollect the impacts and damage. A household selection was made, using an inundation map of the flood of 2011, and with additional information on the specifications of each ward from the local people's committee. The questionnaire was pre-tested on 100 households before the survey was executed.

Of the respondents, 54 % were female, the per capita income for 24 % of the respondents was below 1 million VND per month (USD 48), corresponding with the threshold for poor families according to the HCMC government. 86 % of the respondents were the owners of their house, and the average value of the houses was 2.5 billion VND (USD 117 000). 52 % of the houses were older than 15 yr and 11 % were less than 5 yr old. Out of the 659 household interviews, 644 had information on flood depth, damage to the house, damage to the furniture, value of the property, size of the ground floor, number of floors, and expected damage if the flood depth were to increase by 20, 40, and 100 cm.

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On the basis of the damage data for four flood depths, we developed stage-damage curves. The maximum flood depth reported by the respondents was 120 cm. For damage occurring at higher flood levels up to 5 m, we have extrapolated the data, assuming a slope that is half of the slope between the reported damages of 60 cm and 120 cm, in line with the flattening off found in many residential damage curves (see e.g. de Moel et al., 2014). We distinguished two types of houses: up to 2 floors (e.g. ground floor and first floor), and houses with more than 2 floors, representing, respectively, cheaper and more expensive houses. The stage-damage curves are similar (Fig. 3), but, the maximum damage costs are USD 7.46 and 22.40 m^{-2}, respectively (Table 1). The stage-damage curve for furniture was developed in a similar way. There is no difference in the shape of the curve, but the maximum damage is again different; USD 2.78 for houses up to 2 floors, and USD 5.91 for 2+ floor houses, respectively.

For other land-use classes, we have estimated the maximum damage values, using the ratio of maximum damage to the residential land-use to that of other land-uses, as used by FIM (2013). The maximum damage values, expressed in 2012 USD m^{-2}, and the damage factor proportions for all the land-use classes and inundation depths are shown in Table 1. Examples of the spatial distribution of damage caused by floods with different return periods for two land-use scenarios are shown in Fig. 6.

2.4 Participatory approach: developing flood management strategies

Seven design workshops (referred to as "Charettes") were organised in the context of the VCAPS project (VCAPS, 2013) to develop flood-adaptation strategies. The first set of workshops focussed on the current situation and the vulnerabilities in HCMC. The other workshops then focussed on: climate and socio-economic change; how to assess impacts of climate change; different types of adaptive measures that are available; and other issues and characteristics of importance for the evaluation of an adaptation strategy by the Vietnamese government. The participants of the workshops were the staff of governmental departments, selected on the basis of their expertise on relevant topics. For each workshop additional experts (universities, NGOs, etc.) were invited. An interactive approach was applied using a Touch Table (Arciniegas et al., 2011), drawing on large maps, and other tools. Five flood management strategies were developed: (S1) a strategy protecting the district with levees, hence aiming at reducing flood probability; strategies aiming to reduce flood exposure and sensitivity by (S2) wet-, and (S3) dry-proofing buildings; and (S4) elevating buildings and roads, aiming to reduce flood exposure; and (S5) a combination of several measures (referred to as "CAS") to reduce flood risk with adjusted land-use, which additionally would increase the spatial quality of District 4.

2.4.1 (S1) Ring dike strategy

This strategy consists of a series of levees with a height of two metres above average water level, or 3.37 m a.s.l. forming a ring around District 4. This dike height is used by the Vietnames government (FIM, 2013a). This ring dike protects District 4 on all sides from floods by the Rach Bên Nghé river in the North, the Te Channel in the South (Kên Té), and the Saigon river on the east side. The waterways of the district, which are in contact with the main water bodies, can be closed by sluices and floodgates. We assume there will be no damage when flood levels are below 3.37 m a.s.l. If water levels are higher, the levee will be overtopped and we assume the water level in the district will reach the same level as in the main water bodies.

2.4.2 (S2) Wet-proofing

Wet-proofing reduces the damage to the house and furniture, but water can still enter the house. Measures include, for example, putting expensive appliances at a higher elevation in the house, and having the power sockets higher above the ground. Existing studies (some using empirical data) show a reduction in damage of 35 % to 40 % when wet flood-proofing is applied (DEFRA, 2008; Poussin et al., 2012; De Moel et al., 2014). However, this district is regularly flooded, and, hence the inhabitants have already taken several measures to reduce the impact on their houses and belongings.

On the basis of discussions with local experts during the workshops and field visits, we assume damage will be reduced by 20 % compared with households that do not take wet-proofing measures. As wet-proofing involves moving assets to higher floors or raising them to a certain elevation, we assume the measure is no longer effective when the inundation depth is more than 3 m. At this point, the second floor will also be flooded. Hence, for wet-proofed land use the damage factor curve is reduced by 20 % up to two metres, and rises to the normal damage curve in the following metre. Figure 3 shows the adjusted stage-damage curve for wet-proofing, compared with the original curves.

2.4.3 (S3) Dry-proofing

Dry-proofing aims to seal the house to prevent water from entering (FEMA, 2009). It accounts for both water entering via the doors, windows and walls, and for water entering via the sewage system. It is roughly effective up to a water depth of 1 m, because the pressure of the water becomes too large for the walls of a building (Bubeck and de Moel, 2010; De Moel et al., 2014). If the flood depth is more than 1 m, the damage will quickly rise to be equal to the non-dry-proofed damage curve (Fig. 3). In the damage model we have included dry-proofing by reducing damage to the house by 85 %, and damage to the furniture by 100 % compared with the standard stage-damage curves. Between 1 m and 1.5 m, the curve rises toward the standard curve. Above that level, the curve is similar to the standard curve.

2.4.4 (S4) Elevating roads and buildings

District 4 will undergo major restructuring in the coming decades, and most buildings will be replaced by new ones (VCAPS, 2013). This process provides the opportunity to raise the ground level on which the buildings are built. Recently-built commercial and residential buildings are already at higher elevations as compared with the (older-) surrounding buildings. In order to assess the damage-reducing effect of elevating new

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buildings, we included three elevation levels where the whole district is elevated. The three elevation levels are:

- *Elevation of 2.11 m a.s.l. (S4 + 2.11)* This is based on the existing building code, which states that residential buildings in flood prone areas should be at least higher than the maximum water (H_{max}) level with a return period of 10 yr (Ministry of Construction, 2008). In this study, we take the H_{max} for a 1/10 flood, assuming the SLR+30 scenario.

- *Elevation of 2.53 m a.s.l. (S4 + 2.53)* This is based on the higher protection level for residential areas in the existing building code, which takes the flood level with a return period of 100 yr, assuming the SLR+30 scenario, and an additional 30 cm specifically for public buildings.

- *Elevation of 3.37 m a.s.l. (S4 + 3.37)* This is based on the height of the levees in S1. This strategy is included to enable a comparison of strategy S4 with the strategies S1 and S5, which both protect the district for a flood up to 3.37 m a.s.l.

In the model we have applied this measure by subtracting the elevations from the flood levels, and calculating the damage, which occurs in areas that are then still flooded, using the water levels with return periods as described in Sect. 2.2.

2.4.5 (S5) CAS

The climate adaptation strategy (CAS) consists of multiple measures to cope with the impacts of climate change, and to improve the living conditions in District 4. Measures include the construction of levees around the district, where the levee at the Saigon river is a designed as a wide "super levee". This wide levee includes a tunnel for a highway, and high rise buildings on top, and has room for multiple functions along the water shore. The plan aims at improving future living conditions, taking into account the urban heat island effect, flood risk, an improved public subway system, while maintaining the character of different parts of the district. This led to a design with more intense land-use and high-rise buildings on the super levee and close to the public transport stations. Lower densities and smaller buildings are located close to the creeks, and in parts of the district further away from the subway stations (Fig. 5). In these areas, space is created for storing excess rainwater. In the analysis we focus on measures to reduce flood risk.

2.5 Cost estimates for flood management strategies

We calculated direct tangible costs for all five flood management strategies, and assume indirect costs to be equal to direct tangible costs (Toyoda, 2008). Other costs are excluded from the analysis as data were not available. These are: intangible costs; damage to vehicles; damage to infrastructure; costs related to recovery after a flood (for example cleaning costs); and the effects on living conditions. No inflation figures are used, so maintenance costs remain the same over the whole period of analysis. We apply an exchange rate of USD 48 to 1 million Vietnamese Dong (VND). The investment costs as reported in literature for the elements of the five different strategies are summarized in Table 2.

S1: for the *Ring dike*, we used data on construction and maintenance costs per kilometre for levees, which were studied in detail by FIM (2013a). We assume it will take 5 yr to finish the construction of the levees around the district, that the investments are equal over those 5 yr, and that the EAD will be reduced after completion of the whole levee.

S2: for *Wet-proofing*, we assume all buildings in District 4 are wet-proofed, as the whole district is exposed to flooding. District 4 has circa 29 000 residential houses. The costs consist of taking measures to put household belongings on a higher level in the house, and move the power sockets to above flood level. The costs for moving furniture and cleaning after the flood are excluded from the analysis. The data originates from our survey, with added input from local experts. As wet-proofing is relatively simple, we assume the measures are in place after 1 yr.

S3: for *Dry-proofing,* we use the cost ratio between wet- and dry-proofing provided by Botzen et al. (2014). In their study, dry-proofing is 2.5 times more expensive per house than wet-proofing. In this Strategy 3, all buildings in the district are dry-proofed. As dry-proofing is more complex than wet-proofing, we assume it will take 3 yr for all buildings in the district to be dry-proofed and that every year one-third of the buildings will be dry-proofed. Hence, the EAD will be reduced by even steps over these 3 yr.

S4: for *Elevation* (elevating the whole district), we used the total amount of sand necessary to increase the height of the whole district to the different elevations. The total m^3 of sand is multiplied by the price of sand of 14.60 USD m^{-3}, which includes transport (FIM, 2013b), and we apply a factor of 1.5 to account for subsidence of the soil. For comparison, the cubic-metre price of sand in the Netherlands is also shown too in Table 2, which is 67.63 USD m^{-3} including transport (van Hussen, 2013). We assume the elevation takes place until 2025, and then the whole district will be elevated to the different heights of this strategy. The investment costs are equal for the 12 yr it is implemented, and the damage is reduced by 1/12th per year, until 2025.

S5: for the *CAS*, we have to differentiate between normal levees and the super levee next to the Saigon river. Cost data for the levee is calculated in the same way as for Strategy 1. For the construction and maintenance costs of the super levee we have used the ratio between investment costs for a normal levee and those for a super levee, which was calculated on the basis of Aerts et al. (2014). A factor of 2.72 was used to multiply cost estimates of a normal levee, which was established by FIM (2013b).

2.6 Benefit cost analyses (BCA)

The effect of the strategies described in Sect. 2.4 is calculated for combinations of the two sea-level scenarios and the two land-use scenarios. The reduced flood risk (EAD) is the benefit of the strategy, and is used in the Benefit-Cost Analysis (BCA). In particular, for each strategy the Benefit/Cost Ratio (B/C ratio) and the Net Present

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Value (NPV) are estimated, using:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{(B_t - C_t)}{(1+r)^t},$$

where B_t is the benefit of a flood risk management strategy in year t, C_t its cost, r is the social discount rate, and the investment horizon is T years. The benefit in year t in this context is the avoided flood damage in year t, and the cost includes the initial investments or construction costs and yearly maintenance costs. A positive NPV, thus, indicates that the sum of the discounted benefits exceeds the sum of the discounted costs over time, which implies that a strategy is beneficial in economic terms. A related indicator of economic efficiency of a flood risk management strategy is the B/C ratio:

$$B/C \text{ ratio} = \sum_{t=1}^{T} \frac{(B_t)}{(1+r)^t} \Bigg/ \sum_{t=1}^{T} \frac{(C_t)}{(1+r)^t},$$

If the NPV > 0, then the B/C ratio > 1. Both indicators are provided here since while the B/C ratio shows the economic efficiency in terms of relative benefits per dollar invested in a strategy, the NPV provides the amount of net economic benefits that a strategy generates.

Several of the studied adaptation strategies are designed to protect the city from flooding far into the future, and the corresponding investments thus are also made for the long term. We take this long term into account in the B/C analysis by calculating cost and benefits with a time horizon until 2100. All BCAs are conducted over an investment horizon which starts in year 2013 ($t = 0$), and ends in 2100 after 87 yr ($T = 87$).

An important variable is the social discount rate r, which reflects the opportunity costs of public investments, and is especially important in BCAs of projects with a long time horizon. It is an uncertain exogenously determined parameter. A broad range of discount rate values has been used in BCAs of investments by the public sector. We use the discount rate of 5 % ($r = 0.5$), as prescribed by the National Bank of Vietnam. However, the discount rates used in evaluating flood risk management strategies with a very long time horizon are debated. Relatively high rates have the effect that monetary values far in the future receive a very small weight in estimating their present value (and the NPV). The international discussion moves towards the use of a lower discount rate between 2 % and 4 % for these types of projects (Ministerie van Financiën, 2011; EPA, 2010). Hence, we also include an analysis using a discount rate of 2.5 %.

3 Results and discussion

3.1 Current and future flood risk

Inundation depths for three return periods for District 4 are shown in Fig. 5. These are based on two sea-level scenarios; baseline, and SLR. The figure shows that the South-East part of the case-study area has the highest inundation depths, and the Northern part has the lowest. The inundated area increases when looking at the baseline floods with return periods of 1/10, 1/100 and 1/1000. For floods with these return periods using the SLR+30 scenario, we see that the inundation depth increases, as already at the 1/10 flood return period the whole district is flooded. The 1/10 flood, using the SLR+30 scenario is higher than the 1/1000 flood using the baseline scenario. The maximum depth for the 1/1000 flood using the SLR+30 scenario is 1.14 m.

Figure 6 shows the distribution of damage over the case-study area. This map is a combination of inundation depths, and the sensitivity and value of the land-use type. The damage shows a high correlation with inundation depths. In the South-East part of the case-study area, different land-uses can be distinguished in Fig. 6, as there is a difference in damage in cells which are close to each other, and hence have comparable inundation depths. The area directly bordering the Saigon river shows lower damage. This is due to the land-use, which is industrial (harbour) and less sensitive to flooding, and has a lower value than that of residential land-use.

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Figure 7 shows for District 4 the change in flood damage for floods with different annual probabilities, and for future land-use (LU2025) due to increasing population growth, a sea level rise of 30 cm (SLR+30), and the combination of both developments. The EAD for the current ("baseline") land-use (LU2005) and sea level is 0.315 million USD yr^{-1}, increasing to 0.368 million USD yr^{-1} for the land-use of 2025. This increases to 0.675 million USD yr^{-1} when taking into account SLR, and up to 0.780 million USD yr^{-1} when taking into account both future scenarios of land-use and SLR. The rising sea level has a larger effect on EAD than the socio-economic developments, with an increase of 112 % and 115 %, compared with 15.5 % and 17.1 %.

3.2 Effect of damage reducing strategies

Table 3 shows the results of various calculations for the five flood management strategies, in combination with the land-use scenarios and sea-level scenarios. The strategies wet-proofing (S2) and dry-proofing (S3) show a reduction in EAD from 20 % to 100 % compared with the baseline for all combinations of scenarios. S2 has the smallest reducing effect of 20 % on the EAD, while S3 reduces the EAD on average by 95 %. Increasing the elevation (S4) to 2.11 m a.s.l. reduces damage by 100 % for the current sea level, and by 78 % when including SLR, with an EAD of only USD 0.155 million. The other strategies (S1, S4, and CAS) reduce EAD by 100 % for all scenarios.

3.3 Benefits and costs of different types of strategies

The benefits and costs of the different strategies in combination with land-use and sea-level scenarios, and for the two discount rates of 5 % and 2.5 % are listed also in Table 3. The outcomes of all strategies have the same trend when varying land-use and sea level scenarios. The LU2025 represents socio-economic development, which leads to an increase in assets exposed to flooding, compared with the LU2005, leading to higher EADs. The reduction in the EAD as a result of the adaptation strategies is considered to be a benefit, hence leading to a higher NPV, and a higher B/C ratio for

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the LU2025 calculations compared with the LU2005. For example the strategy S2 in combination with LU2005, the current sea level, and a discount rate of 5 % results in an EAD of USD 0.252 million, with an NPV of USD −5.01 million, and a B/C ratio of 0.330. When the land-use scenario 2025 is used the EAD increases to USD 0.295 million, with an NPV of USD −4.68 million, and a B/C ratio of 0.375. When SLR is included, the extent of the flood and flooding depths increase (Fig. 5) compared with the calculations without SLR. The EAD of a calculation with SLR is higher than a calculation without SLR, also improving the NPV and B/C ratio for the damage-reducing strategies. When combining LU2005 with SLR for the strategy S2 for example, the EAD increases further to USD 0.541 million, with an NPV of USD −2.18 million, and a B/C ratio of 0.709. When considering the combination LU2025 and SLR the EAD increases further to USD 0.624 million, with an NPV of USD −1.53 million, and a B/C ratio of 0.796. Table 3 and Fig. 7 show that sea-level rise has a larger effect on the EAD than land-use change.

The discount rate has an even higher influence on the cost-effectiveness, with the NPV and B/C ratio increasing substantially when using the lower discount rate of 2.5 %. For most strategies the costs are made in the first years, and the benefits will continue to occur until 2100. Due to the lower discount rate, these benefits are valued higher, even when they occur in the more distant future. For the strategies which need yearly maintenance, Ring dike (S1) and CAS (S5), the effect of varying the discount rate is less, as the maintenance costs occurring in the future also change in the same way as the benefits.

Comparing the strategies we see that S1, S4 + 2.53, S4 + 3.37, and S5 have a negative NPV for all combinations of scenarios and discount rates. This means that given the costs (implementation and maintenance) and benefits (reduced direct damage of flooding) considered in this study, it is not economically efficient to implement these measures. The strategies S2, S3, and S4 + 2.11 m have a positive NPV, and a B/C ratio of above 1 for the SLR scenarios in combination with a 2.5 % discount rate.

As mentioned, under current climate, none of the strategies is cost effective. When comparing the strategies, S2 (wet-proofing) is the cheapest strategy and has the best NPV values under the baseline circumstances, though still negative (−3.05 using a 2.5 % discount rate). However, under baseline circumstances S4 + 2.11 m has a better B/C ratio as it reduces EAD more than S2, apparently compensating for the higher investment costs. The other strategies perform even less than these two strategies. The same applies for the combination of the base line sea level and LU2025, or the combined SLR+30 and LU2025 while using a 5 % discount rate.

Only for the combination SLR+30, LU2025, and discount rate 2.5 % some strategies become cost effective. Strategy S3 (dry proofing), has the best result in terms of NPV (USD 13.26 million) and B/C ratio (1.376). Compared to the two other strategies with positive NPVs, S2, and S4 + 2.11 m, S3 results in a higher reduction in damage. Our results indicate that elevating to a level of 2.11 m a.s.l. is economically more efficient than elevating to 2.53 m, even though the latter reduces the EAD to zero. This means that the costs of the extra elevation outweigh the risk reduction as flood levels above 2.11 m a.s.l. only happen rarely.

For the adaptation strategy S1, Ring dike, we also explored the effect of delayed implementation, assuming start of work in 2025 and finalisation in 2030 as opposed to 2013–2018. This would result in an increase in cost effectiveness (i.e. higher NPV and B/C ratio), though they will remain smaller than zero. For the scenario LU2025 and SLR+30 in combination with a discount rate of 5 % this leads to a NPV of USD −31.14 million and a B/C ratio of 0.308, compared to a NPV of USD −57.46 million and B/C of 0.292 for the original calculation. Using a discount rate of 2.5 % the NPV is USD −28.17 million and the B/C ratio is 0.552, compared to a NPV of USD 37.89 million and B/C ratio of 0.556.

To explore the effect of a very high discount rate on the economic performance, we calculated the outcomes for the S1 strategy in combination with SLR+30 and LU2025 using a discount rate of 9 %. This is the percentage the Vietnamese government currently pays on its 10 yr bonds. The resulting NPV is USD −64.44 million and the B/C ratio is 0.147, these values are well below the results of 5 %. This is mainly because the investments are made in the near future, and the benefits occur over a longer period into the future.

4 Discussion of results

4.1 Comparison of results

The results of this study indicate that flood damage will increase as a result of socio-economic change (15.5–17.1 %) in the shorter term (see also Bouwer, 2011). However, in the longer term, the major increase in flood damage is caused by rising sea levels (112–115 %). This is in line with de Moel et al. (2014) who found a doubling of flood risk due to climate change for the case of Rotterdam in the Netherlands, and with Poussin et al. (2012) who report an increase in flood risk between 97 % and 185 %, for a similar projection year 2050. Note, however, that the projection years for climate change and sea level rise (2050) are different from socio-economic change (2025), and Storch and Downes (2011) have concluded that spatial developments for the whole of HCMC (including new urban areas) until 2025 have a larger impact on flood damage than projected SLR. Our study, however, focussed on an existing urban area, for which apparently socio-economic developments are less important than SLR. Additional analysis with land-use scenarios for 2050 would allow for an improved analysis of the relative influence of future projections on flood risk.

The EAD for District 4 for the baseline situation is 0.315 million USD yr^{-1}, or 1146 USD ha^{-1} yr^{-1}. The FIM (2013a) study, which evaluated the impacts of flooding on HCMC and the wider region around it, reported an EAD of 1144 million USD yr^{-1}, or 17 595 USD ha^{-1} yr^{-1}. One reason for the higher EAD estimate by FIM (2013a) is that they assume a maximum damage for urban houses of 1377 USD m^{-2}, which is much higher than the 28.30 USD m^{-2} applied in this study for damage to houses including funiture. Empirical data from the Thailand flood of 2011 show our estimate is quite realistic. A study by the World Bank (2012) indicates that the maximum damage for a house in Bangkok is 27.10 USD m^{-2}, which is comparable to our estimate for buildings in HCMC. When comparing the maximum damage with existing European studies (e.g. de Moel et al., 2014; te Linde et al., 2011; Kreibich et al., 2005), we see that the absolute numbers are obviously much lower in HCMC. For example, the maximum damage for houses in the Netherlands is 1600 € m^{-2} (2176 USD m^{-2}) (de Moel et al., 2014). However, when taking the different gross domestic products of Vietnam and the Netherlands into account, we see that the maximum damage per house for the Netherlands becomes 182 USD m^{-2}.

The adaptation strategies achieve a reduction in EAD between 20 % and 100 %, compared with the baseline. Wet-proofing has the smallest effect of 20 %, the other measures reduce the EAD by between 75 % and 100 %. These are larger reductions than for instance the measures studied by Poussin et al. (2012), who found a reduction of dry-proofing of 40 %. This is confirmed by Kreibich et al. (2005), who surveyed 1248 vulnerable households in the Elbe basin in Germany, and found that wet-proofing (flood-adapted interior fitting and the installation of heating and electrical utilities in higher storeys) reduced the mean damage ratio for buildings by 53 % and 36 %, respectively. These studies, however, concerned areas where high water depths can occur, in which case flood proofing of houses seizes to be effective. In our case, inundation levels are generally between 2 cm and 115 cm for the entire area. This is more comparable to a similar case in the "outer dikes" areas of Rotterdam, the Netherlands, where de Moel et al. (2014) found a reduction of 29 % for wet-proofing, 61 % for dry-proofing, and 50 % for increasing the elevation by 50 cm.

Regarding the results of the evaluation of the strategies on economic criteria, the NPV and the B/C ratio, we see that most strategies have a negative NPV under the different combinations of scenarios. Only S2, S3, S4 + 2.11 have positive values when using the combination of the SLR scenario and the socio-economic scenario for 2025. It should be noted, however, that the costs for damage to goods outside the house, the cleaning of the house and property, and nuisance were not included in these analyses. A sensitivity analysis was carried out for the strategy S1, Ring dike using a discount rate of 2.5 %, SLR30+, and socio-economic scenario 2025. When doubling, and tripling the damage cost, the corresponding NPVs changed from USD −37.89 million, to USD 7.06 million, and USD 55.89 million, respectively. The B/C ratios, similarly, appear to be quite sensitive, changing from 0.556 to 1.083, and 1.655, respectively. When applying a varying discount rate of 2.5 %, 5 %, and 9 % on S1, the corresponding NPVs were USD −37.89 million, USD −57.46 million, and USD −64.44 million. The B/C ratios, similarly, appear to be quite sensitive, with values of 0.556, 0.292, and 0.147, respectively (e.g. Hallegatte, 2006).

The outcomes of the EAD of this study are probably underestimations, as socio-economic change only until 2025 is included, and sea level rise until 2050. Both trends probably will continue toward 2100. The sea level rise projections for HCMC are 65 to 100 cm in 2100 (MONRE 2009), adding another 35 to 70 cm to the sea level rise scenario we used in this study. Unfortunately, these flood maps were not available for this study. We also did not account for change in storminess, which is expected to increase for HCMC according to experts. The expected changes between 2050 and 2100 will lead to an increase in the EAD, as there will be an increase in exposed assets and an increase the flood depth. If the EAD increases, this will lead to increased benefits in the B/C analysis, as prevented damage is a benefit for the strategies. In a future evaluation these longer-term effects should be included.

4.2 Strengths and limits of applied methods

The approach of the research included different steps, from hydrologic modelling, via participatory development of adaptation strategies, to a benefit-cost analysis. The inclusion of stakeholders and local participants in this process is relatively novel in flood risk management in HCMC, and has resulted in improved access to local information, and the development of adaptation strategies tailored to local circumstances. This stakeholder approach was also chosen to increase flood awareness, and the Vietnamese participants did indeed report that they have gained knowledge on these topics. How-

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ever, we have not systematically measured the learning effect, as has been done by Arciniegas et al. (2011).

By means of the survey, we gathered household level data on the occurrence of flood damage in relation to water depths: this is the first survey which has gathered this data in HCMC. However, the survey data showed quite a large variation in damage per square metre. For houses of more than 2 stories high, the average maximum damage is USD 22.40, and, for houses up to two stories, the average maximum damage is USD 7.46. And other studies show self- reporting on, for example, damage or time spent on certain activities is difficult for respondents (e.g. Lasage et al., 2013; Poussin et al., 2012). Unfortunately, other reports on occurred damage are, to our knowledge, not available. Such information could be used to validate survey results. Future research would benefit if flood damage were to be registered by, for instance, the government.

Cities such as Tokio, Shanghai, Bangkok, and Jakarta are confronted with land subsidence, which increases flood risk substantially (Nicholls and Cazenave, 2010; Ward et al., 2010). This is also a major issue for HCMC (ADB, 2010; FIM, 2013a). Unfortunately, data on subsidence was not available, hence it is not included in the analysis. However, the strategies Ring dike, CAS, and Elevating all areas to a level of 3.37 m a.s.l., are relatively robust, since the maximum simulated water levels are lower than the protection standards of those strategies. Hence, the proposed strategies can be considered robust options to cope with additional SLR and subsidence of circa 0.84 m. It is recommended, however, to address the issue of subsidence in future studies (Nicholls and Cazenave, 2010).

4.3 Policy implications

This study has provided relevant information on vulnerable people and assets at risk to policy makers in a participatory approach. It also has shown the effectiveness of several adaptation strategies to reduce risk. Bubeck et al. (2011) conclude these are the first steps to raise awareness, which is needed, in order to take effective action against the changing flood risk. For instance, the information can be used in the implementation of the Vietnamese governments National target programme to respond to climate change (DONRE, 2007). It appears that including long-term projections in policy planning is difficult, and this study serves as an example of the net benefits of addressing long-term changes to short-term investments. We show that most of the proposed strategies have a negative NPV, and these NPVs are improving over the longer term when risks are increasing. We also show that NPVs are dependent on the benefits, which are related to prevented damage. If the damage is twice as high as we have used in our analysis, most strategies will have a positive NPV. Also if other benefits occur with the strategies, like for example improved spatial quality, these could lead to more positive NPVs. HCMC will be confronted with flooding more often as a result of sea level rise, which, together with its economic growth (and hence a growing exposure), will increase the sense of urgency to act (VCAPS, 2013). This trend will lead to a reduced acceptance of the nuisance and damage occurring during flood events by the population, as has been shown to occur in, for example, European cities and regions (Becker et al., 2012). Households are already taking measures to reduce their exposure and sensitivity to flooding. Especially those households with enough means are investing in elevating the level of the ground floor. Moreover, almost every household has taken measures to wet-proof their property. In addition, the elevation of roads is being implemented in several locations of District 4, despite its costs (personal observations). For the final decision by the government of HCMC which strategy is the best to implement other information besides NPV and B/C ratio will or should be used, like technical, social and governance availability and capacity. For instance the impact and disturbance a strategy has on the residents, or the need for coordination by the government. The public consensus might vary between the strategies, influencing their chance of successful implementation.

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5 Conclusions

On the basis of the results of this study, we conclude that the current flood risk of district 4 in Ho Chi Minh City, and expressed as Estimated Annual Damage (EAD) is 0.315 million USD yr^{-1}. This risk is projected to increase over the coming years up to 0.780 million USD yr^{-1}. Sea level rise has a larger effect on the expected annual damage than socio-economic developments, with increases in EAD of a maximum of 115 % and 17 %, respectively. The damage mainly concerns residential buildings, which cover most of the case-study area. Residential buildings are divided into two classes, buildings with less than 2 floors, and those of 2 floors and more. For residential buildings, we have established new stage-damage curves based on household survey data. In future research in densely populated urban areas, it would be advisable to validate the self-reported damage with actual damage data. This would improve the reliability of the survey results. The adaptation strategies resulting from the participatory process are not very different from other studies. However, the approach we followed has improved access to local information and documentation, and the capacity to deal with climate change and adaptation of the people involved has increased. Most of the adaptation strategies evaluated in this study have a negative NPV under all scenarios. The strategies Wet-proofing, Dry-proofing, and Elevating to 2.11 m a.s.l., are effective for the sea level rise scenario in combination with the high socio-economic scenario and a discount rate of 2.5 %. It should be noted that the strategies Ring dike, Elevating to 3.37 m a.s.l., and CAS prevent flooding up to a relative sea level rise of 1.14 m compared with the baseline situation, indicating their even longer time horizon. Future research should assess whether a positive NPV is reached when flood depths increase. We believe that our approach is suitable for assessing changing flood risks in urban areas, which are exposed to coastal flooding. In Asia alone 24 % of the cities with more than 1 million inhabitants are located in low-elevation coastal zones (IIED, 2009), indicating a high vulnerability to flooding. In these cities this approach could be used to assess the risk, and evaluate adaptive measures.

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Table 1. Maximum damage and damage factors per cm inundation depth.

LU class	Max dam	Damage factor per cm inundation depth												
	(USD m^{-2})	10	15	20	25	30	50	75	80	100	150	200	300	500
Residential < 2 floors	7.46	0.268	0.403	0.537	0.565	0.593	0.655	0.683	0.689	0.716	0.764	0.797	0.865	1.00
Residential ≥ 2 floors	28.30	0.268	0.403	0.537	0.565	0.593	0.655	0.683	0.689	0.716	0.764	0.797	0.865	1.00
Furniture < 2 floors	2.78	0.285	0.427	0.569	0.599	0.628	0.689	0.709	0.715	0.740	0.783	0.814	0.876	1.00
Furniture ≥ 2 floors	5.91	0.285	0.427	0.569	0.599	0.628	0.689	0.709	0.715	0.740	0.783	0.814	0.876	1.00
Small Business	36.20	0.050	0.080	0.110	0.140	0.170	0.250	0.350	0.366	0.430	0.530	0.580	0.680	1.00
Large Business	36.20	0.030	0.040	0.050	0.060	0.067	0.095	0.135	0.140	0.160	0.200	0.222	0.265	0.352
Road	0.40	0.030	0.045	0.060	0.075	0.090	0.150	0.232	0.240	0.300	0.400	0.473	0.620	1.00
Public Building	26.10	0.040	0.060	0.080	0.100	0.120	0.200	0.250	0.260	0.300	0.450	0.500	0.600	0.750

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Table 2. Costs for different adaptive measures per unit.

Measure	Construction[a]	Yearly maintenance	Source
Levee	9.9–27 MUSD km^{-1}	2400–100 000 USD km^{-1}	FIM (2013b), Aerts et al. (2013)
Super levee	29.4 MUSD km^{-1}	4800 USD km^{-1}	Aerts et al. (2013)
Sand	14.60–67.63 USD m^{-3}		FIM (2013b), van Hussen (2013)
Wet-proofing, 3 m	200–9271 USD/house	0	Survey this study, Aerts et al. (2013), Zevenbergen et al. (2007)
Dry-proofing, 1 m	500–9361 USD/house	0	Survey this study, Aerts al. (2013)

[a] Prices in USD 2013.

Table 3. Total costs, EADs, and Net Present Values in million USD and BCA ratio's for different flood management strategies.

	Adaptation strategies 2013–2100							
	S1: Ring dike (2 m) Implementation 2025–2030	S1: Ring dike (2 m) Implementation 2013–2018	S2: Wet-proofing (3 m)	S3: Dry-proofing (1 m)	S4: Elevating (2.11 m)	S4: Elevating (2.53 m)	S4: Elevating (3.37 m)	S:5 CAS (2 m)
Investment costs (mln USD)	89	89	7.5	19	31	65		129
Yearly maintenance costs (mln USD)	0.021	0.021	0	0	0	0	0	0.026
Current sea level								
EAD LU05 (mln USD)[a]	0	0	0.252	0.010	0	0	0	0
NPV (mln USD) using high (5 %) and low (2.5 %) discount rate and corresponding B/C ratio, LU05	−39.40 (0.124) −48.91 (0.233)	−70.96 (0.125) −65.44 (0.233)	−5.01 (0.33) −3.05 (0.592)	−23.67 (0.326) −15.30 (0.578)	−13.79 (0.41) −7.56 (0.717)	−39.80 (0.194) −37.24 (0.354)	−78.59 (0.109) −81.52 (0.190)	−107.47 (0.086) −103.76 (0.161)
EAD LU25 (USD)[a]	0	0	0.295	0.017	0	0	0	0
NPV (mln USD) using high (5 %) and low (2.5 %) discount rate and corresponding B/C ratio, LU25	−38.45 (0.145) −46.51 (0.261)	−69.40 (0.145) −62.25 (0.270)	−4.68 (0.375) −2.39 (0.681)	−22.24 (0.366) −12.44 (0.657)	−12.31 (0.473) −4.47 (0.832)	−38.21 (0.224) −34.16 (0.394)	−77.11 (0.125) −78.44 (0.221)	−105.92 (0.100) −100.58 (0.186)
Sea level + 30 cm								
EAD LU05 (mln USD)[a]	0	0	0.541	0.031	0.155	0	0	0
NPV (mln USD) using high (5 %) and low (2.5 %) discount rate and corresponding B/C ratio, LU05	−33.00 (0.266) −32.84 (0.478)	−59.30 (0.269) −42.67 (0.500)	−2.18 (0.709) **2.02 (1.270)**	−10.91 (0.689) **8.04 (1.222)**	−7.55 (0.677) **4.91 (1.184)**	−33.55 (0.321) −24.78 (0.560)	−72.34 (0.179) −69.05 (0.314)	−105.75 (0.101) −92.00 (0.256)
EAD LU25 (mln USD)[a]	0	0	0.624	0.044	0.170	0	0	0
NPV (mln USD) using high (5 %) and low (2.5 %) discount rate and corresponding B/C ratio, LU25	−31.14 (0.308) −28.17 (0.552)	−57.46 (0.292) −37.89 (0.556)	−1.53 (0.796) **3.24 (1.444)**	−8.13 (0.768) **13.26 (1.376)**	−5.68 (0.757) **9.38 (1.352)**	−31.67 (0.358) −20.31 (0.640)	−70.48 (0.201) −64.58 (0.358)	−93.88 (0.201) −76.21 (0.384)

[a] The lifetime of the measures is assumed to be 87 yr.

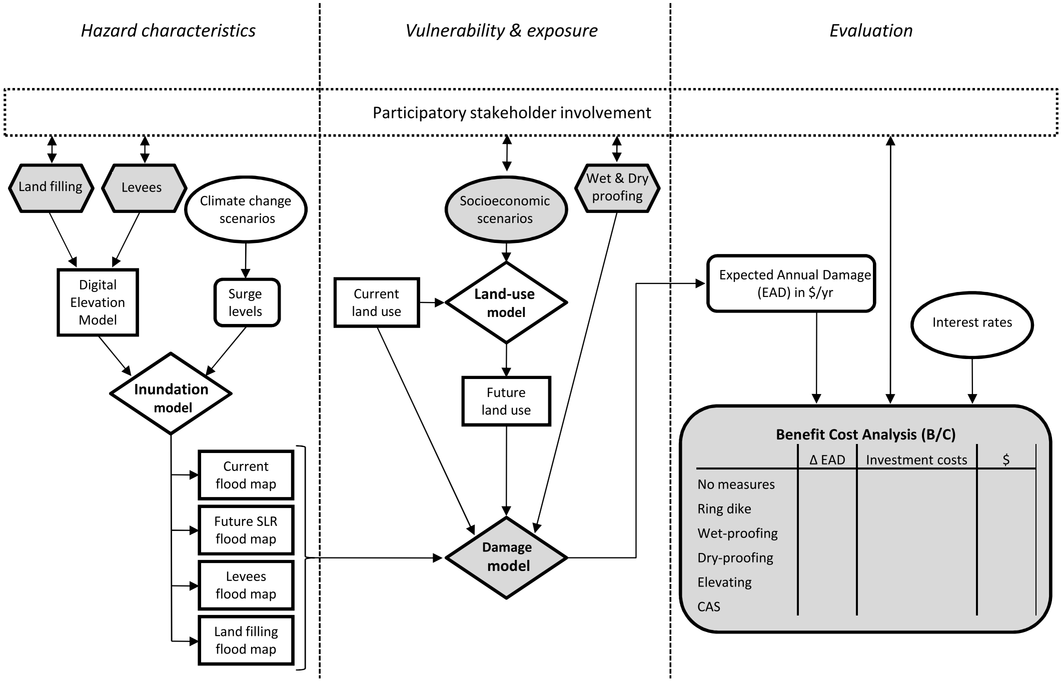

Fig. 1. Overview of methods applied in this paper (Filled shape indicate use of participatory developed information, *ovals* are external scenarios, *diamonds* are models, *squared boxes* are maps, *polygons* are adaptation strategies, and *rounded squared boxes* are evaluation criteria).

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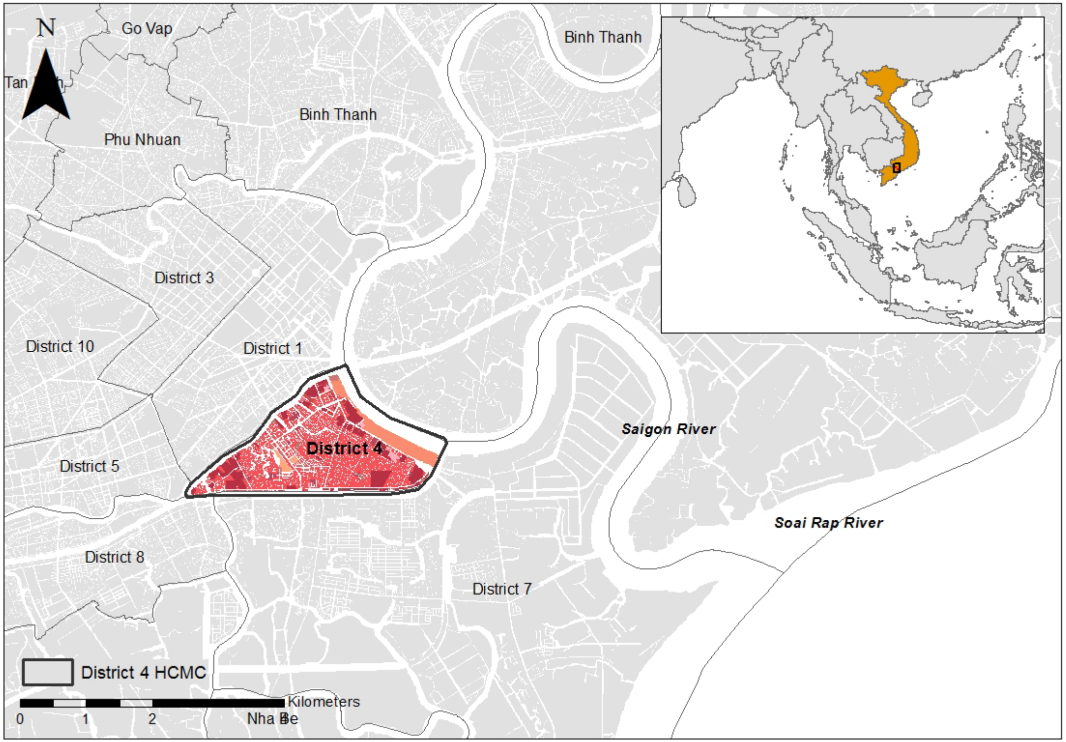

Fig. 2. Map of the study area in Ho Chi Minh City.

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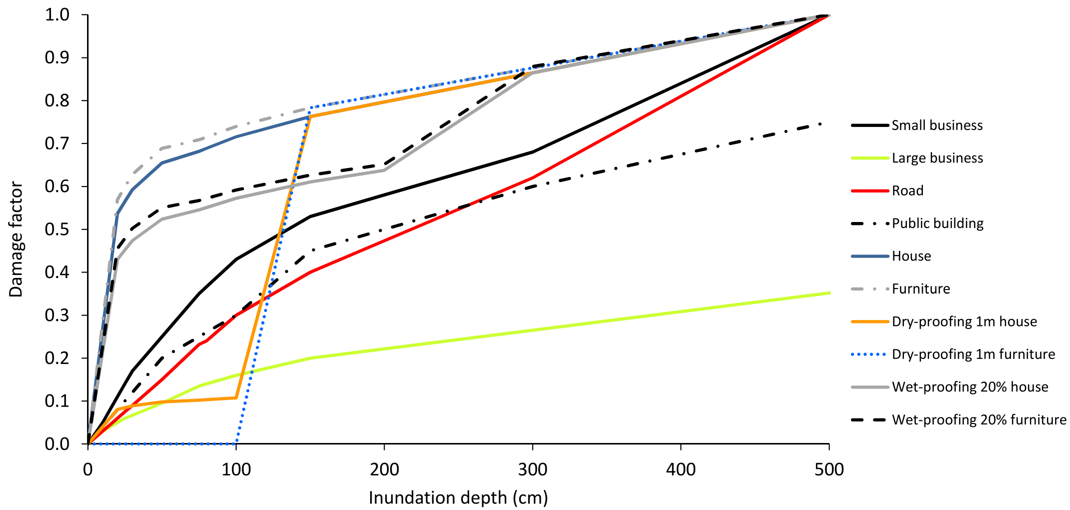

Fig. 3. Stage-damage curves as used in this study, including examples of dry and wet-proofing.

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Fig. 4. Spatial plan resulting from the participatory developed climate adaptation strategy for Ho Chi Minh City (Adopted from: VCAPS, 2013).

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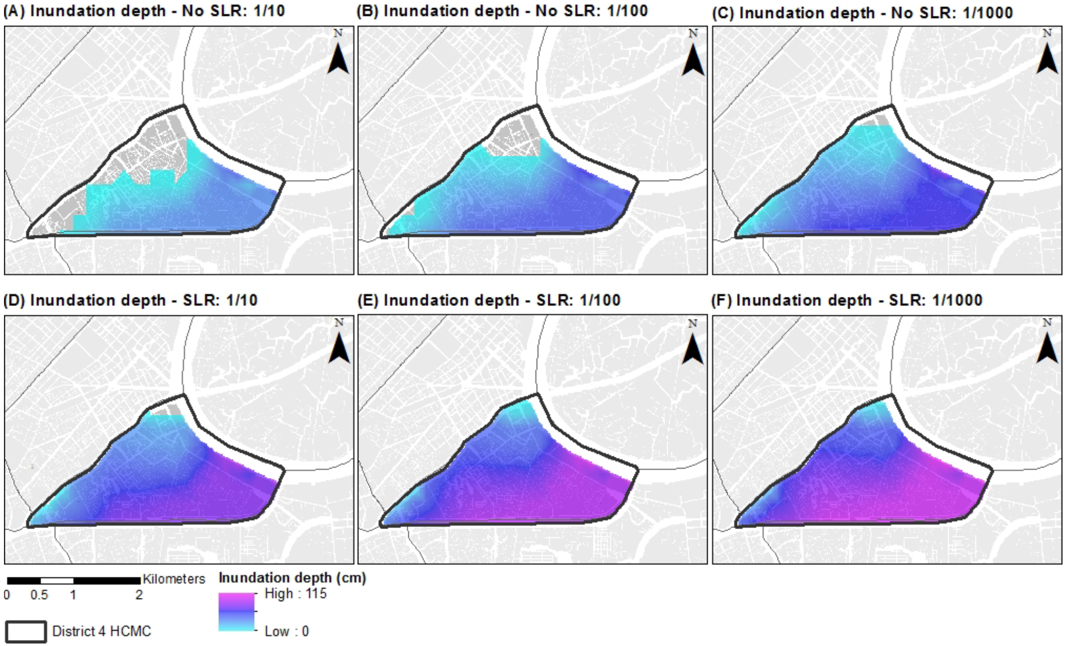

Fig. 5. Modelled inundation depths for different return periods for two sea level scenarios, the top figures **(A–C)** result from using the baseline sea-level scenario, and the bottom figures **(D–F)** result from using the sea-level rise scenario.

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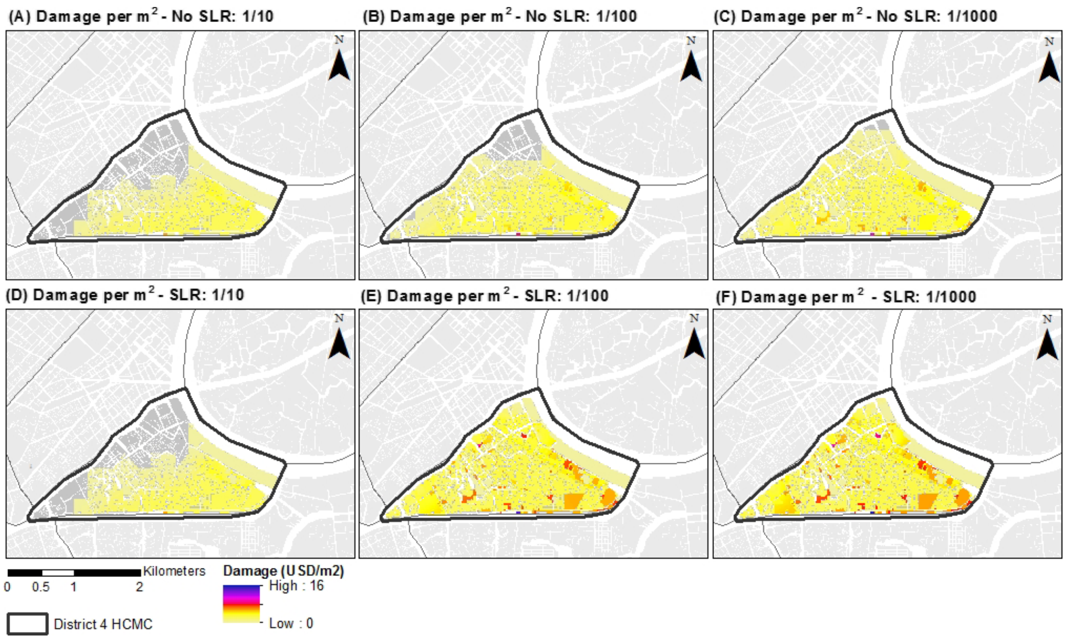

Fig. 6. Damage occurring for floods with different return periods, the top figures **(A–C)** are baseline sea level, and the bottom figures **(D–F)** result from using the sea-level rise scenario.

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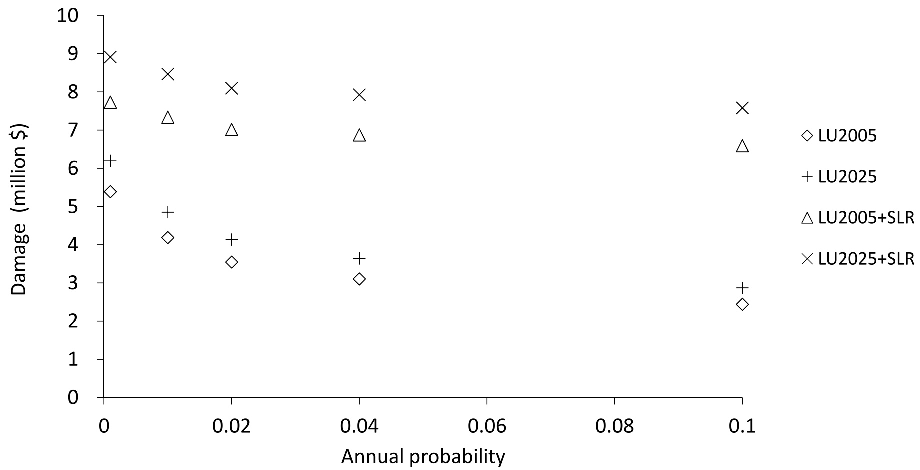

Fig. 7. Annual probability and damage curves for different combinations of land-use and sea-level scenarios.

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