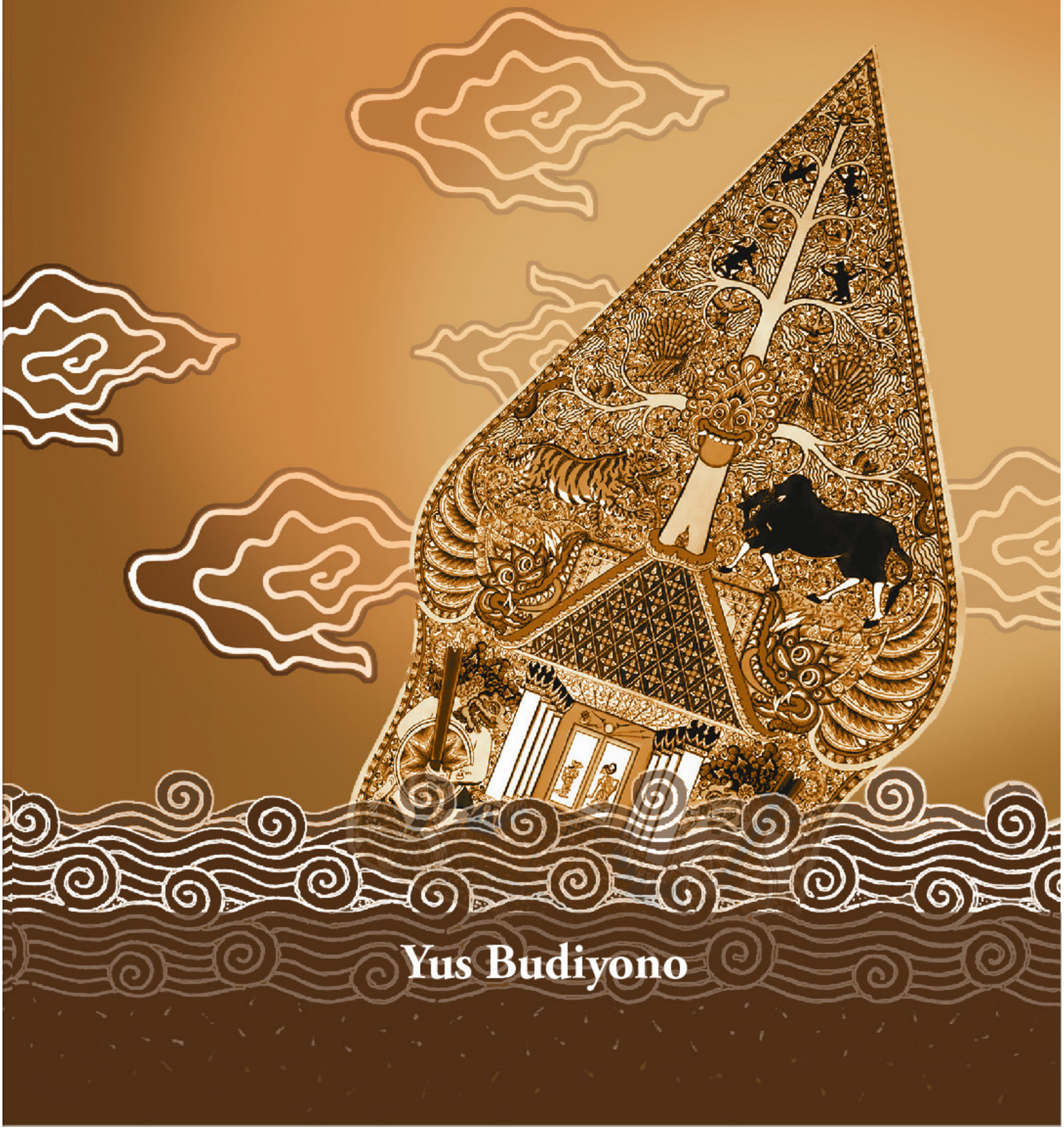
Flood Risk Modelling in Jakarta

development and usefulness in a time of climate change



Yus Budiyono

Flood risk modeling in Jakarta

development and usefulness in a time of climate change

Yus Budiyono

to my mom who sent me to school
and my dad who taught me to survive

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development and usefulness in a time of climate change

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SUMMARY

Flooding is a huge problem in Jakarta. Each time torrential rains pour, flood events appear in the media. Most of these river floods occur during the wet months of December, January and February; these are the months in which the city prepares for flood damages. The most recent large flood occurred in January 2013, causing economic damages estimated at US$ 3 billion, with 47 fatalities, and over 100,000 houses destroyed or damaged. Other major floods in the 21st century occurred in 2002 and 2007, with estimated direct damages of ca. US$ 1.5 billion and US$ 890 million respectively.

Flood damages may increase in the future as a result of various physical and socioeconomic drivers, such as land use change, climate change, subsidence, urbanisation, and an increase in the number of people living in flood-prone areas. Therefore, it is important that the city takes measures to reduce the damages and other negative impacts caused by flooding. This can be achieved through flood risk management, whereby flood risk refers to the probability of a flood multiplied by its consequences. Flood risk is composed of three elements (UNISDR, 2013): hazard, which refers to "...dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage"; exposure, which refers to "...people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses"; and vulnerability, which refers to "...characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". In order to reduce risk, measures can be taken to reduce either of these elements, or a combination of different elements. In order to design effective flood risk management, methods are needed to assess both current and future flood risk, and the risk that can be avoided by taking flood risk reduction measures.

To respond to these issues, the main objectives of this Thesis are: (a) to develop a model for assessing river flood risk in Jakarta; (b) to use the model to assess the impacts of changes in physical and socioeconomic drivers on flood risk; and (c) to use the model to assess the impacts of various adaptation measures on flood risk. In order to address these objectives, the Thesis addresses the following research questions:

- Can we develop a model to rapidly assess river flood risk in Jakarta, and how well does it simulate reported flood damage?
- How sensitive is the flood risk model to the use of different vulnerability curves?
- What are the possible future changes in river flood risk in Jakarta as a result of climate change, land subsidence, and land use change?
- How much could flood risk in Jakarta be reduced under current and future conditions by upgrading and installing polder systems, and what are the costs and benefits?
- What is the potential reduction in flood risk that could be achieved in Jakarta through the implementation of an SMS-based Flood Early Warning System?

In this Thesis, a flood risk model for rapidly assessing flood risk in Jakarta has been set up using information on hazard, exposure and vulnerability, namely Damagescanner-Jakarta. In the model, hazard is represented by inundation maps showing the flood extent and depth for floods with different probabilities and of different severity. Exposure is represented by land use maps, whereby each land

use class is assigned a maximum damage value in US Dollars (US$). This value reflects the potential damage that could occur for each land use type if a flood occurs. Vulnerability is represented by depth-damage curves, which show for each land use class the percentage of the maximum damage value that would actually occur for floods of different depths.

The initial development, setup, and validation of Damagescanner-Jakarta are described in Chapter 2. Here, hazard maps were developed using the 1D/2D SOBEK Hydrology model; the model schematization represents the hydrological situation of Jakarta in 2007. Exposure is represented using an official land use map of the situation in 2002. For each land use class, the maximum potential damage due to flooding was estimated based on a workshop and series of expert meetings held in 2012. During the same workshop and expert meetings, depth-damage curves were also developed for each land use class, based on expert knowledge from practitioners in Jakarta. Using these model settings, the expected annual damage (EAD) due to river flooding in Jakarta is estimated at US$ 321 million per year (Chapter 2). The simulated damages are of the same order of magnitude as the reported damages in 2002 and 2007. We also show that the spread of the damages across different land use classes is similar to those reported. These findings give confidence in the use of the model for flood risk assessment in later chapters.

One of the key challenges faced in developing Damagescanner-Jakarta was deriving the depth-damage curves to represent vulnerability. Given the lack of local information on vulnerability, many flood risk studies simply use depth-damage curves developed for other cities. Therefore, depth-damage curve from five existing studies carried out in south-east Asia are applied. The results show that the implementation is highly sensitivity to the selected curve; there is a factor 8 difference in simulated EAD when using the different curves. Hence, for this Thesis locally tailored curves were developed through a series of expert meetings and a workshop with local stakeholders. The simulated damages based on these curves were closer to reported damages than when using the curves transferred from other studies. This finding has important implications for flood risk assessments around the world, and demonstrates that flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves.

In Chapter 3, several improvements are made to Damagescanner-Jakarta. Firstly, hazard maps are used from an updated schematization of the 1D/2D SOBEK Hydrology model. In this version, the hydraulic schematisation was updated to include flood protection measures implemented between 2007 and 2013, including flood gates and weirs, and most importantly the newly completed Eastern Flood Canal. Secondly, a more recent land use map was used to represent exposure, namely the official land use map 2009. The updated version in Chapter 3 estimates an EAD of US$ 186 million. This seems reasonable given the changes in the hydrological and hydraulic situation during the intervening period. Therefore, the updated model setup was used as the baseline for making projections of future flood risk in 2030 and 2050 in Chapter 3, and for assessing the effectiveness of flood risk reduction measures in Chapters 4 and 5.

In detail Chapter 3 described the use of Damagescanner-Jakarta to assess flood risk in Jakarta in 2030 under several scenarios of climate change (both changes in precipitation and sea level rise), land subsidence, land use change, and economic development. Combining all of these scenarios, the median projected increase in flood risk between baseline and 2030 is 180% (+111% to +262% for the 5th to 95th percentiles). The single driver with the largest contribution to overall increase in risk is land subsidence; alone it leads to an increase by +126%. The influence of changes in precipitation only is highly uncertain (-94% to +104% for the 5th to 95th percentiles). However, the signal of change on sea level resulting from climate change is clear. Using two scenarios of sea level rise (high and low), the results suggest an increase in risk due to sea level rise alone of between +7% and +20% by 2030. If land use change continues at the same rate as it did over the period 1980-2009, this could lead to an increase in risk of +45% by 2030. However, under an "idealized" land use change scenario, which assumes that the official Jakarta Spatial Plan 2030 is fully implemented, risk could be reduced by -12%. In summary, Chapter 3 concludes that whilst the influence of climate change on precipitation intensity in the region is uncertain, when combined with the other drivers of risk, the increase is always large, and hence adaptation and flood risk reduction measures are imperative, irrespective of the chosen climate scenario or projection.

Therefore, Damagescanner-Jakarta is applied in Chapter 4 and Chapter 5 to assess the potential decrease in risk that could be achieved through two risk reduction measures, namely a polder system in Chapter 4 and an SMS-based Flood Early Warning System in Chapter 5.

In 2012, plans were developed for a polder system that would divide the northern part of Jakarta into 66 polders. Using Damagescanner-Jakarta, the potential reduction in risk that could be achieved through this system was assessed, and the avoided risk (benefits) were compared with a first order estimation of the costs (Chapter 4). Such a benefit/cost analysis was carried out for each polder, using both current conditions and future scenarios of climate change, land use change, and land subsidence. Overall, it is shown that the implementation of the polder system could greatly reduce flood risk compared to the current risk. Benefit/cost ratios greater than 1.0 exist at 21 out of 66 polders under current conditions, and at 31 out of 66 polders under the future scenario (for a return period of 2 years). In the current condition, even if polders were designed for a 2 year return period flood, they could reduce risk by 25%. In the future scenario, the system could reduce risk by 52%. Much of this risk reduction could be achieved in just 3 polders in the onshore areas. The three polders contribute to 50% of the total risk reduction under current conditions and 31% of risk reduction under the future scenario. Adding 9 polders of importance could reduce risk by 56% under the current scenario and 81% under the future scenario. The study also shows the importance of considering future conditions when planning for such structural measures with a long lifetime, since the overall benefits of the projects are much higher when the potential future changes are included.

In Chapter 5, the potential risk reduction that could be achieved by implementing an SMS-based Flood Early Warning System (FEWS) is presented. If warnings are received in time, residents can take actions to reduce the potential damages, such as moving valuable items upwards and moving vehicles outside the potential flood zone. Using the results of a survey of inhabitants along the Pesanggrahan river in South and West Jakarta, the depth-damage curves were adjusted to reflect the damage that inhabitants could potentially avoid. Damagescanner-Jakarta was then run with the original and adjusted depth-damage curves to examine how much risk could be avoided. The analysis suggests that the FEWS could decrease flood risk by 1.9% in a realistic scenario and 12% in an optimistic scenario. In the realistic scenario, it was assumed that risk reduction measures would be taken only by the percentage of households that currently take adaptation measures according to the survey. In the optimistic scenario, it was assumed that all households would take measures to avoid damage based on the warning. Limiting the calculation to the residential areas only, which is the land use class that the proposed system targets, the potential decrease is 13% in the realistic scenario and 84% in the optimistic scenario. The Chapter acknowledge that the FEWS is still hypothetical and the approach makes many simplifications. However, it does demonstrate that risk reduction may be possible at relatively low costs.

Next to the model development, the Thesis discusses the possible use of the results in practice for the government, private sector, and citizens. An important product is the Damagescanner-Jakarta model itself and the resulting flood risk maps. This model can now be used by stakeholders in Jakarta to carry out flood risk assessments. Indeed, Damagescanner-Jakarta and the resulting maps are already being used in practice in Jakarta. For example, the use of the model for assessing the risk in several polders was sponsored by CTC-N/UNEP (Project Number 65800016), carried out jointly by DHI and the Jakarta Research Council, resulting in risk-based policy recommendations on flood management at polder scale. Recently, a risk study approach passed the second assessment by the Korea International Cooperation Agency, which aims to assess polder-based flood management. Our results can provide valuable information to citizens in flood prone areas on how individual actions that they take can reduce damage to their own assets. For example, in Chapter 5 it was shown that taking actions based on an SMS-based Flood Early Warning System (FEWS) can reduce damage to an individual's property and/or assets. The application of the model to assess the potential reduction of risk that could be achieved by implementing the polder system and an SMS-based Flood Early Warning System are two examples of concrete assessments that can be carried out to assess the potential effectiveness of flood risk reduction measures. In future studies, the effectiveness of further measures could be assessed.

Finally, the Thesis reflects on the main limitations and provides recommendations for future research. First, due to a lack of officially mandated scenarios of climate and environmental change for Jakarta, the scenarios used to carry out the future projections in this Thesis were selected on an ad hoc basis. We recommend that the future development of official tailored scenarios for Jakarta (or indeed Indonesia) should be a research priority. Second, whilst this Thesis assesses the sensitivity of flood risk to different variables, no formal uncertainty assessment has been carried out. For future studies it would be beneficial to attempt to capture the uncertainty of the risk estimates to a large range of model parameters, for example using Monte Carlo modelling techniques. Third, in this Thesis flood risk has only been assessed from river flooding. Coastal and pluvial flooding are also important processes in Jakarta, and future research would benefit from examining the risks from all of these kinds of flooding, both separately and where they occur simultaneously (i.e. compound flooding). Fourth, the representation of vulnerability in this Thesis using static depth-damage functions is a large simplification, and does not include social vulnerability or changes in vulnerability over time. The development of future projections of (social) vulnerability is a research priority for the flood risk community as a whole, as well as in Jakarta. Fifth, simplifications have been made in the simulation of the effectiveness of the polder systems and SMS-based Flood Early Warning System, and therefore these should be considered as first order estimates. More generally, the flood risk assessment has been carried out a spatial resolution of 50m x 50m; future studies would benefit from using a finer modelling resolution.

Despite these limitations, the Thesis has shown the ability of Damagescanner-Jakarta to assess current and future flood risk, and the effectiveness of several risk reduction measures. We recommend the use of Damagescanner-Jakarta to assess other risk reduction measures in Jakarta. For example, Jakarta is planning and implementing a giant sea wall to prevent coastal flooding, as part of the National Capital Integrated Development (NCICD); river normalization works are planned or being carried out under the Jakarta Urgent Flood Mitigation Project/Jakarta Emergency Dredging Initiatives (JUFMP/JEDI); canals are planned to divert excessive water from the Ciliwung to Eastern Flood Canal; and upland retention lakes are planned at Ciawi. These measures could be parameterized in Damagescanner-Jakarta to assess their potential contribution to flood risk reduction.

SAMENVATTING

Overstromingen van rivieren vormen een groot probleem in Jakarta: zodra de stortregens naar beneden komen, verschijnen de hartverscheurende verhalen over de gevolgen hiervan in de media. Het merendeel van deze overstromingen doet zich voor tijdens de natte maanden december, januari en februari. De meest recente grote overstroming vond plaars in januari 2013 en veroorzaakte een economische schade die wordt geschat op US$ 3 miljard, met bovendien 47 dodelijke slachtoffers en meer dan 100.000 verwoeste of beschadigde huizen. Andere grote overstromingen in de 21e eeuw deden zich voor in 2002 en 2007, met een geschatte directe schade van respectievelijk US$ 1,5 miljard en US$ 890 miljoen.

De kans is groot dat de schade door rivieroverstromingen in de toekomst zal toenemen. Verschillende omgevings- en sociaaleconomische factoren zijn hierop van invloed, zoals veranderingen in landgebruik, klimaatverandering, bodemdaling, verstedelijking en een toename van het aantal mensen dat in overstromingsgevoelige gebieden leeft. Het is daarom erg belangrijk en noodzakelijk dat Jakarta maatregelen neemt om schade en andere negatieve gevolgen van overstromingen in te perken. Dit kan worden bereikt door goed overstromingsrisicobeheer, waarbij overstromingsrisico verwijst naar de kans op een overstroming vermenigvuldigd met de gevolgen ervan. Drie elementen spelen een rol bij overstromingsrisico (UNISDR, 2013): gevaar, dat verwijst naar een "...dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage"; blootstelling, dat verwijst naar "...people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses"; en kwetsbaarheid, die verwijst naar "...characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". Voor elk van deze elementen of een combinatie ervan kunnen verschillende maatregelen worden genomen om het overstromingsrisico in te perken. Voor het ontwikkelen van een effectief overstromingsrisicobeheer zijn methoden nodig waarmee we zowel het huidige als het toekomstige overstromingsrisico kunnen inschatten, inclusief het risico dat kan worden vermeden door maatregelen te nemen die overstromingsrisico's beperken.

De drie doelstellingen van dit proefschrift zijn: (a) het ontwikkelen van een model om het overstromingsrisico van rivieren in Jakarta te kunnen bepalen; (b) het gebruik van dit model om de impact van fysische en sociaaleconomische factoren op overstromingsrisico's te kunnen bepalen; en (c) het gebruik van het model om de impact van verschillende aanpassingsmaatregelen op overstromingsrisico's te kunnen bepalen. Om deze doelstellingen te kunnen bereiken, wordt in dit dit proefschrift antwoord gegeven op de volgende onderzoeksvragen:

- Kunnen we een model ontwikkelen waarmee we het overstromingsrisico van rivieren in Jakarta snel kunnen bepalen, en hoe goed is dit model in staat de daadwerkelijk ontstane schade te simuleren?
- Hoe gevoelig is het overstromingsrisicomodel voor het gebruik van verschillende kwetsbaarheidscurven?
- Wat zijn de mogelijke toekomstige veranderingen met betrekking tot het overstromingsrisico van rivieren in Jakarta als gevolg van klimaatverandering, bodemdaling en verandering van landgebruik?
- In hoeverre kan het overstromingsrisico in Jakarta onder huidige en toekomstige omstandigheden worden verminderd door het upgraden en installeren van poldersystemen, en wat zijn de kosten en baten hiervan?
- In hoeverre kunnen we het potentiële overstromingsrisico in Jakarta verminderen door de

implementatie van het op sms gebaseerde Flood Early Warning System (FEWS) voor de vroegtijdige waarschuwing van burgers voor overstromingen?

Damagescanner-Jakarta is een model waarmee een snelle inschatting kan worden gemaakt van overstromingsrisico's in Jakarta, op basis van gegevens over gevaar, blootstelling en kwetsbaarheid. In dit model wordt de mate van gevaar bepaald met behulp van kaarten die de omvang en diepte van overstromingen met een verschillende kans en uiteenlopende ernst laten zien. Blootstelling wordt bepaald op basis van kaarten over landgebruik, waarbij aan elke categorie landgebruik een maximale waarde van de schade in US Dollars (US$) is toegekend. Deze waarde is de potentiële schade die in het geval van een overstroming kan optreden voor elk type landgebruik. Kwetsbaarheid wordt bepaald op basis van kwetsbaarheidscurven, die de relatie tussen overstromingsdiepte en schade vastleggen.

Hoofdstuk 2 beschrijft de ontwikkeling, het gebruik en de validatie van Damagescanner-Jakarta. Hiervoor zijn overstromingskaarten, die ontwikkeld zijn met behulp van het 1D/2D SOBEK hydrologische model, dat de hydrologische situatie van Jakarta in 2017 voorstelt. Blootstelling wordt weergegeven door de officiële landgebruikskaart van Jakarta in 2002. In 2012 is in een workshop en een aantal expertmeetings de geschatte maximale potentiële schade door overstromingen voor elk type landgebruik bepaald. Tijdens dezelfde workshop en expertmeetings zijn ook kwetsbaarheidscurven voor elk type landgebruik ontwikkeld, gebaseerd op de kennis en expertise van lokale professionals. Op basis hiervan wordt de verwachte jaarlijkse schade (EAD) door rivieroverstromingen in Jakarta geschat op US$ 321 miljoen per jaar (Hoofdstuk 2). De gesimuleerde schade is daarmee vergelijkbaar met de daadwerkelijk gerapporteerde schade in 2002 en 2007. Ook de spreiding van schade wat betreft verschillende typen landgebruik is vergelijkbaar met de gerapporteerde schade. Deze bevindingen geven vertrouwen voor het gebruik van Damagescanner-Jakarta in de latere Hoofdstukken.

In Hoofdstuk 3 wordt Damagescanner-Jakarta op enkele onderdelen verbeterd. In de eerste plaats worden overstromingskaarten uit een geactualiseerde schematisering van het 1D/2D SOBEK hydrologische model gebruikt. Deze versie bevat ook de beschermingsmaatregelen tegen overstromingen die tussen 2007 en 2013 zijn geïmplementeerd, inclusief sluizen en waterkeringen en het recent voltooide Eastern Flood Canal. Ten tweede is een recentere kaart gebruikt voor het bepalen van blootstelling, namelijk de officiële kaart van landgebruik uit 2009. Met de geupdate versie van het model wordt de verwachte jaarlijkse schade (EAD) geschat op US$ 186 miljoen. Een redelijke schatting, gezien de veranderingen in de hydrologische en hydraulische omstandigheden in de tussenliggende periode. Om die reden is het geupdate model in Hoofdstuk 3 gebruikt als baseline voor het voorspellen van toekomstige overstromingsrisico's in 2030 en 2050, en voor het bepalen van de effectiviteit van maatregelen om overstromingsrisico's te verminderen in Hoofdstukken 4 en 5.

Eén van de voornaamste uitdagingen in de ontwikkeling van Damagescanner-Jakarta was het bepalen van de kwetsbaarheidscurven. Vanwege het gebrek aan lokale gegevens over kwetsbaarheid, maken veel studies naar overstromingsrisico's gebruik van kwetsbaarheidscurven die zijn ontwikkeld voor andere steden. Om die reden is in deze studie gebruik gemaakt van de kwetsbaarheidscurven van vijf bestaande studies, uitgevoerd in Zuid-Oost Azië. Uit de resultaten blijkt dat de geselecteerde curve van grote invloed is op de implementatie; er is een factor 8 verschil in gesimuleerde EAD bij het gebruik van verschillende curves. In het kader van deze studie zijn daarom op maat gemaakte curves ontwikkeld tijdens een workshop en expertmeetings met lokale stakeholders. De gesimuleerde schade op basis van deze curves bleken dichter bij de daadwerkelijk gerapporteerde schade te liggen dan het geval was bij gebruik van curves uit andere studies. Deze bevinding heeft belangrijke gevolgen voor het bepalen van overstromingsrisico's wereldwijd, omdat hieruit blijkt dat de selectie, het ontwikkelen en het testen van kwetsbaarheidscurven om grote nauwkeurigheid vraagt.

In Hoofdstuk 3 wordt Damagescanner-Jakarta gebruikt om overstromingsrisico's in Jakarta in 2030 te bepalen, onder verschillende scenario's van klimaatverandering (zowel veranderingen in neerslag als stijging van de zeespiegel), bodemdaling, verandering van landgebruik en economische ontwikkeling. Als we al deze scenario's combineren, is de mediane verwachte stijging van het overstromingsrisico tussen baseline en 2030 180% (+111% tot +262% voor de 5e tot 95e percentielen). De factor die de grootste bijdrage levert aan de toename van het algehele risico is bodemdaling; bodemdaling alleen leidt tot een toename van +126%. De invloed van veranderingen in neerslag alleen is erg onzeker (-94% tot +104% voor de 5e to 95e percentielen). Het signaal van zeespiegelverandering door klimaatverandering is helder: in de analyse van twee scenario's van zeespiegelstijging (hoog en laag), laten de resultaten zien dat er door stijging van de zeespiegel alleen een toename van overstromingsrisico's is van +7% en +20% in 2030. En als de verandering van landgebruik doorgaat in hetzelfde tempo als in de periode 1980-2009, kan dit leiden tot een stijging van het risico van +45% in 2030. Echter, bij een "ideaal" scenario voor verandering van landgebruik, dat ervan uitgaat dat het officiële Jakarta Spatial Plan 2030 volledig wordt geïmplementeerd, kan het risico worden teruggebracht met -12%. De conclusie van Hoofdstuk 3: terwijl de invloed van klimaatverandering op neerslagintensiteit in de regio onzeker is, is de toename van overstromingsrisico's altijd groot wanneer dit wordt gecombineerd met andere risicofactoren. Daarom zijn maatregelen om overstromingsrisico's te verminderen absoluut noodzakelijk, ongeacht klimaatscenario.

In Hoofdstuk 4 en 5 wordt Damagescanner-Jakarta gebruikt voor het onderzoeken van de potentiële risicoreductie door twee maatregelen, namelijk een poldersysteem in Hoofdstuk 4 en een op sms gebaseerd Flood Early Warning System (FEWS) in Hoofdstuk 5.

In 2012 zijn plannen ontwikkeld voor het implementeren van een poldersysteem. Dit zou betekenen dat het noordelijke deel van Jakarta wordt opgedeeld in 66 polders. Met behulp van Damagescanner-Jakarta is de potentiële risicoreductie door dit systeem onderzocht, en is het vermeden risico (baten) vergeleken met een globale inschatting van de kosten (Hoofdstuk 4). Een dergelijke kosten-batenanalyse is uitgevoerd voor elke polder, zowel onder de huidige omstandigheden als onder toekomstscenario's voor klimaatverandering, verandering in landgebruik en bodemdaling. Uit de resultaten blijkt dat de implementatie van het poldersysteem het overstromingsrisico aanzienlijk zou kunnen verminderen, in vergelijking met het huidige risico. De baten-kostenratio is groter dan 1,0 bij 21 van de 66 polders onder de huidige omstandigheden en bij 31 van de 66 polders onder het toekomstscenario (met een herhalingstijd van 2 jaar). In de huidige situatie, zelfs als de polders zijn ontworpen voor een herhalingstijd van 2 jaar, zouden ze het risico met 25% kunnen verminderen. In het toekomstscenario zou het systeem het risico met 52% kunnen verminderen. Veel van deze risicoreductie kan worden bereikt door slechts 3 polders aan te leggen in gebieden landinwaarts. Deze 3 polders dragen bij tot 50% van de totale risicovermindering onder de huidige omstandigheden en 31% van de risicoreductie in het toekomstscenario. Het aanleggen van 9 van de polders kan het risico verminderen met 56% onder de huidige omstandigheden en met 81% onder het toekomstscenario. De studie toont ook aan hoe belangrijk het is om toekomstige omstandigheden in overweging te nemen bij het plannen van dergelijke structurele maatregelen met een lange levensduur, aangezien de algehele voordelen van de projecten veel groter zijn wanneer de mogelijke toekomstige veranderingen worden opgenomen.

Hoofdstuk 5 gaat over de potentiële risicoreductie door de implementatie van het op sms gebaseerde Flood Early Warning System (FEWS). Als bewoners op tijd waarschuwingen ontvangen, kunnen zij maatregelen nemen om de potentiële schade te verminderen. Denk aan het verplaatsen van waardevolle spullen naar hoger gelegen plekken of het verplaatsen van motorvoertuigen naar een gebied dat buiten het potentiële overstromingsgebied ligt. Door gebruik van resultaten van een enquête onder inwoners langs de Pesanggrahan rivier in zuid en west Jakarta, zijn de kwetsbaarheidscurven aangepast om te laten zien hoeveel schade er voorkomen kan worden door de inwoners zelf. Die curves werden vervolgens gebruikt in Damagescanner-Jakarta. Uit de analyse komt naar voren dat het FEWS het overstromingsrisico kan verminderen met 1.9% in een realistisch scenario en 12% in een optimistisch scenario. Het realistische scenario gaat uit van het percentage huishoudens dat volgens de enquête momenteel al risicoverminderende maatregelen neemt. Het optimistische scenario gaat ervan uit dat alle huishoudens risicoverminderende maatregelen nemen naar aanleiding van de waarschuwing. Als we de berekeningen beperken tot woonwijken, dan is de potentiële reductie 13% in het realistische scenario en 84% in het optimistische scenario. Daar moet wel bij worden gezegd dat het FEWS nog steeds een hypothetisch systeem is en dat de aanpak in dit Hoofdstuk sterk vereenvoudigd is. Het laat echter wel zien dat risicoreductie mogelijk is tegen relatief lage kosten.

Naast de ontwikkeling van het model, gaat dit proefschrift in op de mogelijke toepassing van de resultaten in de praktijk door de overheid, private sector en burgers. Stakeholders in Jakarta kunnen Damagescanner-Jakarta zelf en de kaarten voor overstromingsrisico's die daaruit voortvloeien gebruiken om meer inzicht te krijgen in overstromingsrisico's in bepaalde gebieden. Om precies te zijn wordt het model momenteel al gebruikt in Jakarta: CTC-N/UNEP (Project Number 65800016) maakte mogelijk dat DHI en het Jakarta Research Council het model en de kaarten kunnen gebruiken om overstromingsrisico's in verschillende polders inzichtelijk te maken. Dit leidde tot aanbevelingen voor beleid op het gebied van overstromingsbeheer op het niveau van de polders. De resultaten kunnen ook waardevolle informatie verstrekken aan burgers in overstromingsgevoelige gebieden, bijvoorbeeld over hoe zij door zelf in te grijpen schade aan hun eigendommen kunnen verminderen of voorkomen. Zo is in Hoofdstuk 5 aangetoond dat het nemen van maatregelen naar aanleiding van het Flood Early Warning System (FEWS) de schade aan iemands eigendommen kan verminderen. Wat klimaatverandering betreft, is de invloed daarvan op de neerslagintensiteit in de regio erg onzeker. Maar in combinatie met de andere factoren is de toename van het risico tot 2030 altijd groot. Daarom is het nemen van aanpassingsmaatregelen noodzakelijk, ongeacht klimaatscenario. De toepassing van het model om de potentiële risicoreductie te bepalen die zou kunnen worden bereikt door de implementatie van het polderstelsel en een op sms gebaseerd Flood Early Warning System, zijn twee concrete voorbeelden van maatregelen die kunnen worden genomen om overstromingsrisico's te verminderen. De effectiviteit van andere maatregelen zou onderwerp kunnen zijn van toekomstige studies.

Tenslotte beschrijft dit proefschrift de belangrijkste beperkingen en geeft het aanbevelingen voor toekomstig onderzoek. Ten eerste zijn de scenario's voor het uitvoeren van voorspellingen voor de toekomst ad hoc geselecteerd, omdat officiële scenario's voor veranderingen op het gebied van klimaat en milieu in Jakarta ontbreken. Onze aanbeveling is dat de ontwikkeling van officiële scenario's voor Jakarta (of zelfs Indonesië) een prioriteit voor toekomstig onderzoek zou moeten zijn. In de tweede plaats beoordeelt dit proefschrift de gevoeligheid van overstromingsrisico's voor verschillende variabelen, maar is er geen formele onzekerheidsanalyse uitgevoerd. In toekomstige studies zou zou het nuttig zijn om een poging te doen om de onzekerheid van de risicoschattingen vast te leggen in een groot aantal modelparameters, bijvoorbeeld met behulp van Monte Carlo-modelleringstechnieken. In de derde plaats focust dit proefschrift zich alleen op het overstromingsrisico van rivieren. In Jakarta is daarnaast ook sprake van kustoverstromingen en wateroverlast door toename van neerslag. In toekomstige studies zou het risico van al deze verschillende soorten overstromingen moeten worden onderzocht, zowel afzonderlijk als wanneer ze gelijktijdig optreden (zogeheten compound flooding). Ten vierde is de weergave van de kwetsbaarheid met behulp van static kwetsbaarheidscurven in dit proefschrift een grote vereenvoudiging en omvat het geen sociale kwetsbaarheid of veranderingen in kwetsbaarheid in de loop van de tijd. De ontwikkeling van toekomstige voorspellingen van (sociale) kwetsbaarheid is een onderzoeksprioriteit voor overstromingsrisico's als geheel, niet alleen in Jakarta. En als laatste zijn enkele vereenvoudigingen doorgevoerd in de simulatie van de effectiviteit van de polderstelsels en het op sms gebaseerde Flood Early Warning System. Daarom moeten deze resultaten worden beschouwd als een eerste, globale inschatting. Meer in het algemeen is de overstromingsrisicobeoordeling uitgevoerd met een ruimtelijke resolutie van 50m x 50m; toekomstige studies zouden baat hebben bij het gebruik van een meer gedetailleerde modelleringsresolutie.

Ondanks deze beperkingen blijkt uit dit proefschrift dat Damagescanner-Jakarta in staat is om een goede inschatring te maken van huidige en toekomstige overstromingsrisico's en de effectiviteit van verschillende risicoverminderende maatregelen. Het wordt dan ook aangeraden om Damagescanner-Jakarta te gebruiken voor het onderzoeken van de effectiviteit van andere risicoverminderende maatregelen in Jakarta. Als onderdeel van de National Capital Integrated Development (NCICD) ontwikkelt en implementeert Jakarta bijvoorbeeld een gigantische zeewering om overstromingen aan de kust te voorkomen; werkzaamheden aan de rivier worden ingepland of uitgevoerd in het kader van het Jakarta Urgent Flood Mitigation Project / Jakarta Emergency Dredging Initiatives (JUFMP / JEDI); kanalen moeten het overtollige water afvoeren van de Ciliwung naar het Eastern Flood Canal; en hooggelegen retentiemeren zijn gepland in Ciawi. Deze maatregelen zouden met Damagescanner-Jakarta kunnen worden onderzocht, om te bepalen in hoeverre zij zouden kunnen bijdragen aan het verminderen van overstromingsrisico's.

RINGKASAN

Banjir adalah permasalahan utama bagi Jakarta. Setiap terjadi hujan besar di Jakarta dan daerah hulunya, kejadian banjir muncul di media. Sebagian besar kejadian banjir terjadi pada bulan basah, yakni Desember, Januari, dan Februari sehingga ketiganya menjadi bulan yang membutuhkan persiapan besar bagi Jakarta. Banjir terbesar dalam sejarah Jakarta masa kini adalah pada Januari 2013. Kerugian yang timbul saat itu diperkirakan USD 3 milyar dolar, dengan korban meninggal 47 orang dan 100.000 rumah rusak ringan dan berat. Banjir besar lain yang terjadi sebelumnya adalah pada tahun 2002 dan 2007, yang menyebabkan kerugian berturut-turut USD 1.5 milyar dan USD 890 juta.

Kerugian banjir kemungkinan akan naik di masa yang akan datang oleh sebab perubahan fisik dan sosial ekonomi wilayah oleh sebab misalnya perubahan tata guna lahan, perubahan klimat global, penurunan tanah, urbanisasi, dan pertambahan penduduk di daerah banjir. Oleh sebab itu, Jakarta perlu langkah strategis untuk menurunkan kerugian banjir dan dampak negatifnya. Hal ini bisa dicapai dengan menggunakan pendekatan manajemen risiko banjir. Pendekatan risiko banjir merupakan perkalian antara statistik kemungkinan terjadinya banjir dikalikan dengan konsekuensi ekonomi atas kejadian tersebut. Dari prinsip ini, risiko banjir mempunyai tiga elemen (UNISDR, 2013) yakni: hazard yang didefinisikan sebagai "kejadian berbahaya, material, aktifitas manusia, atau kondisi yang mengakibatkan kehilangan jiwa, kecelakaan atau dampak kesehatan lain, kerusakan properti, hilangnya pekerjaan dan pelayanan, kerugian sosial dan ekonomi, atau kerusakan lingkungan"; exposure yang didefinisikan sebagai "perorangan, properti, sistem, atau elemen lain yang ada di wilayah hazard yang oleh sebab itu menjadi subyek kerugian"; dan vulnerability yang didefinisikan sebagai "karekteristik dan situasi sebuah masyarakat, sistem, atau aset yang rentan terhadap dampak kerusakan yang ditimbulkan oleh hazard". Berdasar hal ini, besarnya risiko bisa diturunkan dengan cara merubah salah satu dari tiga elemen risiko atau kombinasi diantara ketiganya. Untuk itu dibutuhkan metodologi untuk menghitung risiko banjir pada masa kini dan masa yang akan datang beserta contoh penggunaannya atas langkah-langkah penurunan risiko yang ada untuk menghasilkan desain manajemen risiko yang efektif.

Sebagai respon permasalahan tersebut, tesis ini bertujuan untuk: (a) mengembangkan model untuk menghitung risiko banjir dari luapan sungai di Jakarta; (b) menerapkan model tersebut untuk menghitung risiko banjir karena perubahan sosial dan ekonomi; dan (c) menerapkan model untuk menghitung efektifitas beberapa pilihan adaptasi terhadap banjir. Untuk mencapai tujuan tersebut digunakan research questions berikut:

- Bagaimana mengembangkan model untuk dengan cepat menghitung risiko banjir Jakarta dan seberapa akurat hasil model tersebut dibandingkan laporan yang sudah ada?
- Bagaimana sensitivitas model terhadap perubahan elemen vulnerability?
- Bagaimana model memprediksi perubahan risiko pada masa yang akan datang sebagai hasil perubahan klimat global, penurunan tanah, dan perubahan tata guna lahan?
- Seberapa besar penurunan risiko banjir Jakarta pada masa kini dan masa depan bila banjir dikelola dengan sistem polder? Seberapa besar hasil perhitungan cost and benefit-nya?
- Seberapa besar penurunan risiko banjir Jakarta bila diterapkan sistem peringatan dini banjir berbasis SMS?

Dalam tesis ini, telah dikembangkan model risiko banjir Jakarta bernama Damagescanner-Jakarta yang berguna untuk bisa menghitung risiko banjir secara cepat dengan menggunakan informasi hazard, exposure, dan vulnerability. Dalam model ini, hazard diwakili oleh peta genangan yang

merepresentasikan distribusi spasial beserta kedalaman genangan dan pada banyak periode ulang beserta kondisi khusus yang menyertainya. Exposure diwakili oleh peta tata guna lahan di masa lalu dan masa yang akan datang. Dalam peta tata guna lahan ini terdapat banyak sistem lahan yang masing-masing mempunyai nilai kerugian maksimum (dalam US$) bila terjadi banjir. Vulnerability direpresentasikan oleh kurva kedalaman vs kerugian, yang mana kedalaman genangan mengubah prosentase kerugian dan berbeda-beda untuk tiap sistem lahan.

Proses pengembangan, persiapan perhitungan, dan validasi Damagescanner-Jakarta diuraikan di Bab 2. Dalam bab ini, hazard dikonstruksi menggunakan model hidrodinamika SOBEK hydrology suite dengan pendekatan 1D/2D. Skematisasi model hidrodinamika ini mempertimbangkan situasi banjir 2007. Exposure diwakili oleh peta tata guna lahan 2002 yang ada di lingkungan pemerintak DKI Jakarta. Untuk tiap sistem lahan, disintesa kerugian maksimum akibat genangan melalui serangkaian pertemuan para ahli dan diakhiri dengan workshop bersama-sama dengan praktisi dari berbagai disiplin. Dengan cara yang sama juga dibuat kurva vulnerability. Proses ini dilakukan pada tahun 2012 di Jakarta. Sintesa Damagescanner-Jakarta atas masing-masing elemen risiko tersebut, diketahui potensi kerugian tahunan (expected annual damage, EAD) oleh sebab banjir luapan sungai sebesar US$ 321 juta per tahun. Hasil perhitungan ini serasi dengan laporan kerugian banjir 2002 dan 2007. Distribusi spasial banjir juga sesuai dengan laporan yang ada. Hasil ini menyediakan kepercayaan terhadap implementasi model di bab-bab berikutnya.

Hal utama yang menjadi tantangan pengembangan Damagescanner-Jakarta adalah pembuatan kurva vulnerability. Kenyataan bahwa informasi tentang vulnerability tidak tersedia di suatu lokasi menyebabkan banyak studi risiko banjir menggunakan kurva kedalaman vs kerugian yang dikembangkan di kota lain. Hal yang sama digunakan pada awal studi menggunakan kurva yang tersedia untuk wilayah Asia Tenggara. Dari tes tersebut diketahui bahwa studi risiko sangat sensitif terhadap penggunaan kurva vulnerability. Misalnya, EAD dari seluruh tes mendapati perbedaan hingga kelipatan 8. Sehubungan dengan itu, tesis ini mengembangkan kurva sendiri yang dikembangkan melalui pertemuan para pakar dan diakhiri sengan sebuah workshop bersama dengan pengampu kepentingan di Jakarta. Menggunakan hasil sintesis seperti ini, risiko yang dihasilkan serasi dengan laporan kerugian sebelumnya. Metode ini menjadi pesan penting bagi studi risiko di tempat lain di seluruh dunia, dan memberi petunjuk bahwa studi risiko perlu memperhatikan pemilihan, pengembangan, dan pengetesan kurva vulnerability.

Di Bab 3, dilakukan beberapa perbaikan pada model Damagescanner-Jakarta. Pertama, peta hazard direvisi mulai dari skematisasi model disesuaikan dengan kondisi setelah tahun 2007 hingga tahun 2013. Termasuk didalam revisi adalah adanya pintu air pengontrol banjir, bendungan banjir, dan yang terbesar adalah beroperasinya Kanal Banjir Timur. Kedua, digunakan peta tata guna lahan 2009 atau terbaru yang ada. Versi baru Damagescanner-Jakarta ini menghasilkan EAD US$ 186 juta per tahun. Nilai baru ini ini serasi dengan perubahan infrastruktur banjir dan situasi hidrologi dan hidrolika yang disebabkannya. Revisi ini menjadi basis bagi proyeksi risiko banjir pada 2030 dan 2050 yang diuraikan pada Bab 3 dan digunakan pada bab-bab berikutnya yang menelisik efektifitas pendekatan struktural dan non-struktural dalam menurunkan risiko banjir.

Bab 3 menguraikan penggunaan Damagescanner-Jakarta untuk mengnelaah risiko banjir Jakarta pada 2030. Menggunakan beberapa skenario yakni perubahan klimat global (baik dari presipitasi dan kenaikan muka air laut), penurunan tanah, perubahan tata guna lahan, dan perkembangan ekonomi. Integrasi dari semua perubahan tersebut menghasilkan kenaikan risiko dengan median +180% (+111% hingga +262% pada percentil 5 dan 95) dibanding baseline. Faktur tunggal utama dalam perubahan adalah penurunan tanah dengan perubahan sebesar +126%. Presipitasi sebagai faktor tunggal menunjukkan perubahan yang sangat tidak pasti, yakni -94% hingga +104% pada persentil 5 dan persentil 95. Di lain pihak, dampak kenaikan muka air laut lebih jelas. Dengan menggunakan skenario rendah dan tinggi, risiko banjir naik antara +7% hingga +20% pada 2030. Kenaikan risiko banjir atas perubahan tata guna lahan menunjukkan penambahan +45% pada 2030. Nilai tetap ini adalah hasil proyeksi kenaikan pada kurun perhitungan 1980-2009 menggunakan peta tata guna lahan yang tersedia di pemerintah Jakarta. Sedangkan bila digunakan peta rencana tata ruang wilayah 2030 yang tampak ideal, risiko turun -12%. Secara ringkas, Bab 3 menyimpulkan bahwa dampak perubahan iklim terhadap ketidakpastian risiko banjir sangat lebar. Meskipun demikian, integrasi dari berbagai elemen perubahan di masa mendatang menunjukkan perubahan yang signifikan dan bisa diprediksi sehingga strategi adaptasi banjir untuk menurunkan risiko banjir sangat diperlukan tanpa harus melakukan pilihan tertentu atas skenario perubahan klimat.

Berikutnya, Damagescanner-Jakarta diterapkan di Bab 4 dan 5 untuk mengetahui potensi penurunan risiko atas adanya dua langkah struktural dan non-sturktural yakni penerapan sistem polder (Bab 4) dan penerapan sistem peringatan dini banjir (FEWS) berbasis SMS (Bab 5).

Pada tahun 2012, terdapat rencana untuk membagi Jakarta bagian Utara menjadi 66 sistem polder. Menggunakan Damagescanner-Jakarta, perhitungan potensi penurunan risiko atas rencana ini dilaksanakan disertai juga dengan membandingkan keuntungan atas turunnya risiko terhadap investasi untuk mengadakan masing-masing sistem polder. Benefit/cost alanysis (BCA) semacam ini diterapkan untuk kondisi saat ini dan masa yang akan datang dengan mempertimbangkan perubahan klimat global, perubahan tata guna lahan, dan penurunan tanah. Secara umum, hasil penelaahan menunjukkan bahwa sistem polder mampu menurunkan risiko banjir Jakarta dibanding risiko saat ini. BCA diatas 1.0 terdapat pada 21 dari keseluruhan 66 sistem polder untuk skenario banjir masa kini dan 31 dari 66 sistem polder untuk skenario masa depan untuk periode ulang banjir 2 tahunan. Pada skenario masa kini, bahkan polder untuk periode ulang 2 tahunan mampu menurunkan risiko sebesar 25%. Pada masa yang akan datang, penurunan menjadi lebih besar yakni 52%. Lebih penting lagi, penurunan sebagian besar risiko dikontribusukan oleh 3 sistem polder yang relatif berdekatan dengan pantai. Ketiga polder ini menurunkan risiko 50% pada skenario masa kini dan 31% pada masa mendatang. Bila ditambahkan 9 polder lainnya, penurunan bertambah menjadi 56% dan 81%. Perhitungan ini juga menunjukkan pentingnya mengikutsertakan skenario masa yang akan datang dalam perencanaan sistem polder, mengingat penurunan risiko pada masa mendatang lebih besar dibanding pada masa kini.

Pada Bab 5, Damagescanner-Jakarta digunakan untuk menghitung potensi penurunan risiko banjir bila diterapkan FEWS berbasis SMS. Bila peringatan dini disampaikan pada waktunya sehingga penduduk mempunyai waktu untuk bersiap-siaga terhadap banjir, misalnya untuk waktu yang cukup guna mengevakuasi aset ke lantai atas, FEWS akan mampu menurunkan risiko antara 1.9% pada skenario realistis hingga 12% pada skenario optimistis. Skenario realistis dihitung berdasar jumlah sampel yang telah mempunyai persiapan terhadap banjir, sedang skenario optimistis adalah bila langkah persiapan ini diselenggarakan oleh semua rumah. Perhitungan ini melibatkan hasil survey di Jakarta Selatan dan Jakarta Barat. Hasil survey ini menurunkan nilai risiko dengan cara mengubah kurva vulnerability. Survey juga menunjukkan bahwa langkah adaptasi ini hanya berlaku untuk daerah perumahan, sehingga bila perhitungan hanya dibatasi pada sistem lahan perumahan, penurunannya menjadi 13% pada skenario realistis dan 84% pada skenario optimistis. Meskipun pengujian atas efektivitas FEWS saat ini masih bersifat hipotekal karena mengandung banyak simplifikasi, Damagescanner-Jakarta terbukti mampu menunjukkan keandalannya untuk menjadi metode telaah penurunan risiko banjir.

Menindaklanjuti pengembangan model, tesis ini menguraikan kemungkinan penerapan hasil studi dalam dunia nyata oleh pemerintah, dunia usaha, dan masyarakat. Produk terpenting adalah Damagescanner-Jakarta itu sendiri beserta peta risiko bencana banjir. Model ini bisa digunakan oleh pengampu kepentingan di Jakarta untuk keperluan telaah risiko bencana banjir. Peta risiko yang dihasilkan menjadi contoh kongkrit atas amanah Undang-undang No. 24/2007 dan turunannya yakni Peraturan Pemerintah No. 21/2008 serta National Action Plan for Disaster Risk Reduction (NAP-DRR 2010-2012) yang mana dua lembaga negara yakni Badan Perencanaan Pembangunan Nasional (Bappenas) dan Badan Nasional Penanggulangan Bencana (BNPB) menjadi institusi utama. Dengan demikian, studi ini telah benar-benar menjadi perangkat implementatif di Jakarta. Sebagai tindak lanjut, model yang ada juga telah menjadi perangkat utama dalam kajian pengelolaan sistem polder contoh sebagaimana disponsori oleh CTC-N/UNEP (Project No. 65800016) yang pelaksananya adalah DHI dan Dewan Riset Daerah Jakarta dengan hasil utama rekomendasi kebijakan penanganan banjir dalam skala polder. Pada saat ringkasan ini ditulis, studi tersebut dikembangkan untuk lebih banyal polder dengan sponsor Korea International Cooperation Agency (Koica) bekerja sama dengan Green Climate Fund (GCF) sebagai bagian dari UNFCC. Dalam skala masyarakat, tesis juga menjadi informasi penting bagi penduduk di daerah rentan bencana banjir khususnya mengenai bagaimana penduduk melakukan respon untuk menurunkan kerugian terhadap aset yang dimiliki. Sebagai contoh, pada Bab 5 diuraikan bagaimana penduduk bisa merespon kejadian banjir menggunakan informasi SMS yang dikirimkan oleh FEWS untuk menurunkan kerusakan aset akibat banjir. Dari hasil survey diketahui bahwa sebagian penduduk telah melakukan adaptasi terhadap banjir yang mana langkah ini bisa diterapkan oleh penduduk lain dengan cara yang mudah dan murah. Implementasi dari model untuk menghitung potensi penurunan risiko atas penerapan sistem polder dan FEWS berbasis SMS diatas adalah dua contoh kongkrit bagaimana model bisa diterapkan untuk melihat efektivitas dari langkah adaptasi terhadap banjir. Pada masa yang akan datang, studi bisa dilanjutkan untuk langkah adaptasi lainnya.

Sebagai penutup, tesis mengungkapkan keterbatasan dan menyampaikan rekomendasi untuk riset berikutnya. Pertama, terkait dengan tidak adanya skenario perubahan iklim dan lingkungan yang menjadi mandat resmi pemerintah Jakarta, skenario proyeksi ke depan yang ditempuh dalam tesis ini masih berdasar pilihan terbuka. Sehubungan dengan hal itu, direkomendasikan agar pemerintah Jakarta (atau Indonesia secara umum) menjadikan pilihan skenario sebagai prioritas dalam merencanakan pembangunan pada masa yang akan datang. Kedua, sementara tesis ini mengkaji sensitivitas berbagai variabel yang berpengaruh terhadap risiko banjir, pada kenyataannya juga tidak terdapat langkah formal yang ditetapkan untuk mengkaji hal-hal yang menimbulkan ketidakpastian proyeksi risiko banjir. Oleh sebab itu, studi yang akan datang perlu mengembangkan cara untuk mengikutsertakan banyak variabel penyebab ketidakpastian kedalam satu model, misalnya dengan menggunakan pendekatan model Monte Carlo. Ketiga, tesis ini mengkaji risiko banjir yang berasal dari luapan sungai. Sementara itu, banjir dari laut dan banjir setempat oleh akibat hujan lokal juga merupakan hal yang penting di Jakarta. Oleh karena itu, direkomendasikan agar studi yang akan datang mengkaji kedua jenis banjir ini secara tersendiri atau terintegrasi (compound flooding). Keempat, representasi dari vulnerability curve dalam tesis ini masih tergolong statis dan mengandung banyak simplifikasi. Sementara itu, kurva ini bisa berubah menjadi dinamis misalnya karena adanya kerentanan sosial dan perubahan zaman. Untuk itu, perubahan vulnerability oleh akibat proyeksi sosial di Jakarta atau Indonesia menjadi penting untuk bisa memotret risiko banjir di masa yang akan datang secara utuh. Kelima, perhitungan efektivitas sistem polder dan SMS FEWS dalam menurunkan risiko banjir masih tergolong sederhana, sehingga kajian ini adalah langkah awal dalam peneraan risiko banjir. Perbaikan terhadap langkah ini lebih detil diuraikan dalam Bab 4 dan Bab 5. Terakhir, secara umum model dikerjakan dalam kedetilan spasial 50m x 50m; untuk itu diperlukan pengujian model pada skala spasial yang lebih detil sesuai situasi kebutuhan pengelolaan lahan di Jakarta.

Terlepas dari semua keterbatasan diatas, tesis terlihat mampu menunjukkan keandalan Damagescanner-Jakarta dalam menelaah risiko banjir pada masa kini dan pada masa yang akan datang termasuk efektivitas langkah-langkah penurunan risiko yang ada. Untuk itu, Damagescanner-Jakarta direkomendasikan penggunaannya untuk menelaah langkah penurunan banjir yang ada di Jakarta.

Sebagai contoh, saat ini Jakarta sedang merencanakan sekaligus menerapkan bendungan laut untuk mengatasi banjir yang berasal dari laut dalam proyek Program Pengembangan Terpadu Pesisir Ibukota Negara (PTPIN) atau National Capital Integrated Coastal Development (NCICD); normalisasi sungai dalam proyek Jakarta Urgent Flood Mitigation Project/Jakarta Emergency Dredging Initiatives (JUFMP/JEDI); pembangunan sodetan Ciliwung-Kanal Banjir Timur; dan waduk resapan Ciawi. Langkah-langkah struktural ini bisa diintegrasikan dalam model Damagescanner-Jakarta untuk dihitung efektivitasnya dalam menurunkan risiko bencana banjir.

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

B/C	benefit/cost (ratio)
Σ	Sigma, summation operator
i	Discount rate
n	Number of years
t	time

Abbreviations

1D/2D	The coupled one and two-dimensional (hydrodynamic model)
AAUI	General Insurance Association of Indonesia
AR4	IPCC Fourth Assessment Report
AR5	IPCC fifth Assessment Report
AWLR	automatic water level recorder
Bappenas	The National Development Planning Agency, Indonesia
BBWSCC	The Ciliwung Cisadane river management office
BMKG	the National Office for Climate, Indonesia
BNPB	The national office for disaster management, Indonesia
BPBD	Local office for disaster management
BPPT	Agency for the Assessment and Application of Technology, Indonesia
BPS	Central Agency on Statistics, Indonesia
Bulog	Bureau of logistics
CMIP5	Coupled Model Intercomparison Project Phase 5
DEM	Digital Elevation Model
DiDAH	Digitasi Data Historis project
DKI (Jakarta)	The Special Capital Region of Jakarta
DPU DKI	The office of Public Works, Jakarta
DTR DKI	The office of city planning in Jakarta
EAD	Expected Annual Damage
ECLAC	The United Nations Economic Commission for Latin America and Caribbean
ENSO	El Niño–Southern Oscillation
EU-WATCH	Integrated Project Water and Global Change
FCM	Fuzzy Cognitive Mapping
FEWS	Flood Early Warning System
FHM	Flood Hazard Mapping
FMIS	Flood Management Information System
GCM	Global Climate Models
GDP	Gross Domestic Product
GEV	Generalised Extreme Value
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory's global coupled climate-carbon Earth System Models Part II
HadGEM2-ES	Met Office Hadley Centre Global Environmental Model - Earth System model
HCMC	Ho Chi Minh City
HKTI	Association of Farmers, Indonesia
IDR	Indonesian Rupiah
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM5A-LR	Institut Pierre Simon Laplace Climate Model 5A, Low□ Resolution
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
Kepres	President's authority (regulation)

MIROC-ESM-CHEM	Model for interdisciplinary research on climate earth system model, atmospheric chemistry coupled version
NAP-DRR	National Action Plan for Disaster Risk Reduction
Nedeco	Netherlands Engineering Consultants
NGO	Non-governmental organizations
Nor-ESM1-M	Norwegian Earth System Model, Intermediate Resolution
PAM Jaya	Potable water industry of Jakarta
PBJR	Greater Jakarta Flood Control Project
PDAM	Local Potable water industry
PDF	Probability density function
Perda DKI	Provincial Government Regulation of Jakarta
Permen PU	Minister of Public Works Regulation
Permenkeu	Ministry of Treasury Regulation
Permenkominfo	Ministry of Communication and Informatics Regulation
PGRI	Association of teachers, Indonesia
Pusair	Research Center for Water Resources, Indonesia
RCP	Representative Concentration Pathways
RR	Rainfall run-off (model)
Rx1day	The annual maximum daily precipitation
SACA&D	Southeast Asian Climate Assessment & Dataset
SLR	Sea Level Rise
SMS	Short Message Service
STEI	University of Islamic Business and Economics
UNDP	the United Nations Development Programme
UNISDR	United Nations International Strategy for Disaster Reduction
US$	United States Dollar
VHF	Very high frequency

Chapter 1

1 INTRODUCTION

1.1 Background and problem definition

1.1.1 History of flood in Jakarta

Flooding has been a problem in Jakarta (Figure 1.1) for centuries. Since the era of kingdoms in Java, and during the history of colonization when the city was named Batavia, floods have caused huge losses to the city. The first record of floods and flood management in what is now Jakarta is inscribed on Prasasti Tugu (the Tugu Monument) from the 5th century. The Prasasti describes the digging of the Candrabaga River by Rajadirajaguru and the Gomati River by Purnawarman, during their administrations (Noorduyn and Verstappen, 1972). It is further described that the work aimed to avoid floods in the wet season and provide safe water resources during the dry season, by diverting the presently named Cakung river to the adjacent sea, crossing rice fields. Similar structures, namely waduk (presently recognized as retention lakes) were extensively used during the era of Cultivation Systems (Tanam Paksa,1830-1870) all around Java (van Oosterhout, 2008; Ravesteijn, 2007).

Records on the more recent flood history in Jakarta are available from the colonial government, including the years 1621, 1654, 1876 (Deltares, 2011), 1893, 1895, 1899, 1904, 1918 and 1932 (Gunawan, 2010). Important floods after the colonial period have been recorded in 1976 (Grijns and Nas, 2000), 1996, 2002, 2007 (Nugroho, 2008), and 2013. The last three flood events are better documented and provide good information for risk assessment purposes.

Whilst floods are not a new problem in Jakarta, their impacts have increased in recent decades, as a result of rapid changes in both physical and socioeconomic drivers (e.g. Budiyono et al., 2015); Ward et al., 2011a). A few examples of physical drivers include land subsidence due to groundwater extraction (Abidin et al., 2011), and a low drainage capacity of the waterways clogged with solid waste and sediments (Steinberg, 2007). Rapid increases in socioeconomic drivers, like population and wealth, have also led to extensive changes in the land use of the city and its surroundings (Verburg et al., 1999). These land use changes can affect flooding in Jakarta in two main ways: (a) increasing river discharge and sedimentation in Jakarta's rivers; and (b) increasing the value of assets and number of people potentially exposed to floods (Ward et al., 2011a).

The potential devastation of flooding was once again demonstrated by the flood in January 2013, which was one of the most severe on record (Sagala et al., 2013). The flood was caused by heavy seasonal

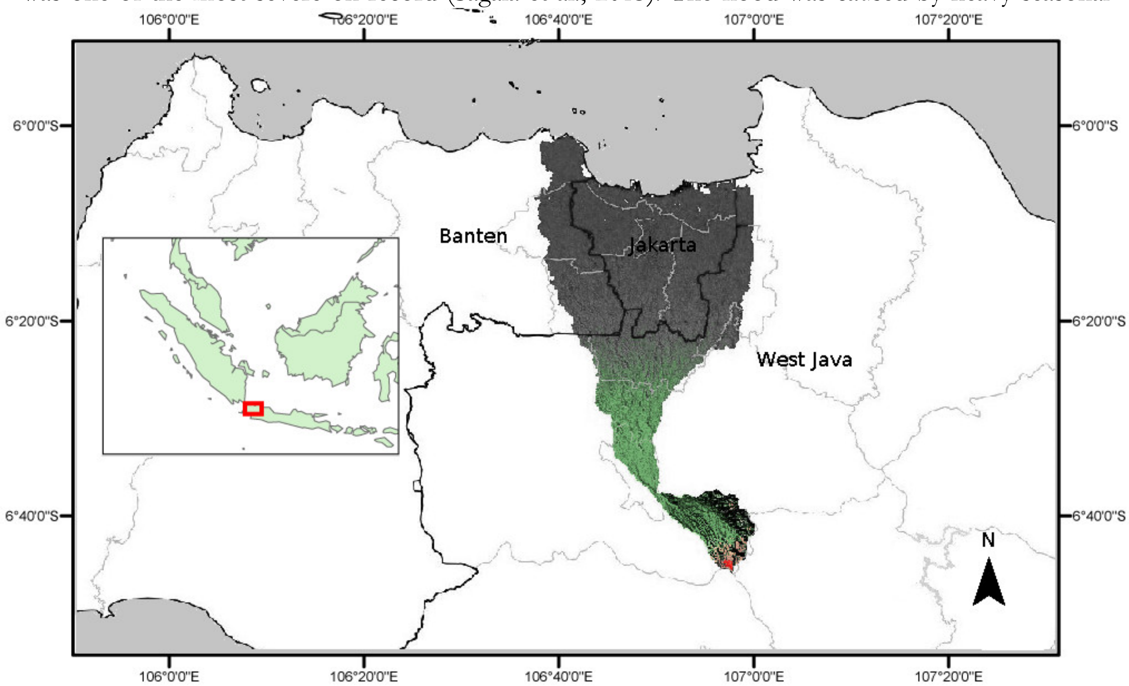

Figure 1.1 Jakarta map and its surrounding with digital elevation model boundary used in hazard model.

rainfall that led to flooding, and was worsened by the collapse of a dike. According to Munich Re (2013), the economic losses were around US$ 3 billion. In addition, there were 47 fatalities, and over 100,000 houses were destroyed or damaged. Other major floods in the 21st century include those of 2002 and 2007, which are estimated to have caused direct losses of ca. US$ 1.5 billion and US$ 890 million, respectively (Bappenas, 2007).

1.1.2 Traditional flood management in Jakarta

Given its long history of flood problems, Jakarta also has a long history in managing floods. Early examples have already been mentioned above, and over the last century Jakarta has conducted three main master plans on coping with flood. The first was in 1920 by Herman van Breen, known as the Van Breen Plan (Caljouw et al., 2005; Kooy and Bakker, 2008; Gunawan, 2010). The second was presented in 1973, known as the Master Plan for Drainage and Flood Control of Jakarta, and published by the Ministry of Public Works with the help of Netherlands Engineering Consultants, Nedeco, and lastly in 2007 the Megapolitan plan (Sutiyoso, 2007). The principle of the Van Breen Plan was building a canal in the south and diverting the water through a western flood canal to the sea. The implementation of the plan was started in 1922, i.e. 4 years after the large floods in 1918. The Master Plan for Drainage and Flood Control of Jakarta was a rewrite of the Van Breen Plan, which updated the original plan and added an eastern flood canal. The Megapolitan plan is a conceptual approach, which also includes the greater Jakarta area with satellite townships. Overall, the plans are summarized in the diagram shown in Figure 1.2 (Mirah Sakethi, 2010).

In more recent years, Jakarta has seen different flood management projects, such as: river normalization; river dredging; and resettlement through the Jakarta Urgent Flood Mitigation Project (JUFMP), financed jointly by World Bank (IBRD Loan Number 8121-ID) in a concerted effort of the

Government of Indonesia and DKI Jakarta. Another large structure that has partly been completed is the channeling of the Ciliwung at Bukit Duri into the Eastern Flood Canal (Joe, 2014). Currently in its planning stage, the Government of Jakarta has issued plans for the development of a system called 'polder system 2030', dividing the northern low lying part of Jakarta into 66 polders protected by levees. Finally, together with the national government, discussions have also been intensifying with regard to the implementation of the National Capital Integrated Coastal Development (NCICD) whose draft was funded by the Dutch Water Sector in 2012 (Witteveen+Bos, 2014). An important part of this plan

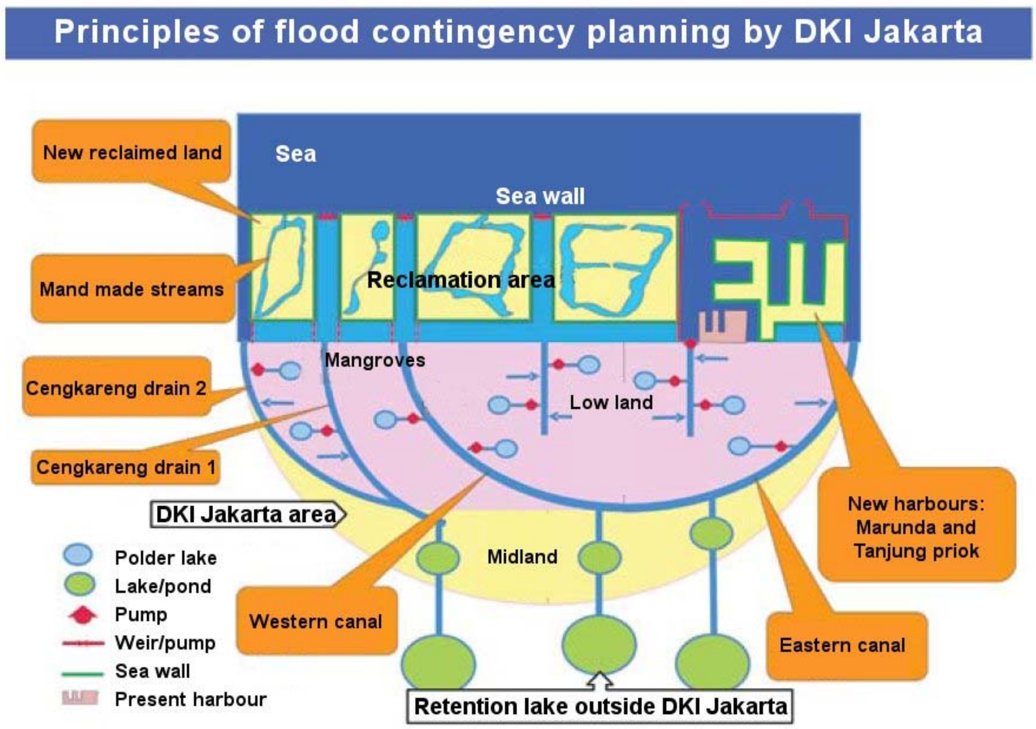

Figure 1.1.2 Infrastructure planning of flood control in Jakarta (translated from Mirah Sakethi, 2010).

is the building of a large seawall in the Jakarta Bay.

From the examples described above, it can be seen that flood management in Jakarta has mainly focused on the traditional approach of infrastructure development to keep the water away from humans.

1.1.3 Drivers of flood risk in Jakarta

Physical and socioeconomic drivers both contribute to changes in flood risk in Jakarta. For example, land subsidence is a serious problem (Abidin et al., 2011) due to groundwater extraction, construction loading, natural consolidation of alluvium soil, and geotectonic adjustments (Rismianto and Mak, 1993; Murdohardono and Sudarsono, 1998; Harsolumakso, 2001; Hutasoit, 2001). The first three, and especially groundwater extraction, are believed to be the most dominant drivers (Abidin et al., 2011).

Observed rates of subsidence in Jakarta are generally about 1-15 cm/year. Recent estimates of Abidin et al. (2011) suggest that the northern part of the city experiences an average subsidence rate of 4 cm/year. However, there are also cones of subsidence where subsidence is occurring more rapidly.

Future flood risk in Jakarta may also be influenced by climate change. During the 20th century, the mean annual temperature in Indonesia as a whole increased by ca. 0.3°C (Hulme and Sheard, 1999). Other research indicates that there has been a change in mean annual rainfall totals for Jakarta over the 20th century, even though the number of days with rainfall has decreased (Siswanto et al., 2016). Across the country as a whole, observations suggest that mean annual rainfall over the same period decreased by ca. 2-3%, mainly in the wet season from December to February (Cruz et al, 2007). Several climate models project a temperature increase of ca. 0.1° to 0.3°C per decade over the 21st century (Hulme and Sheard, 1999). The same projections suggest that mean annual rainfall may increase in the future across most of Indonesia, although in Java it may decrease.

Jakarta will also be affected by climate change due to projected sea-level rise. Sea-level rise is currently taking place at a rate of ca. 1-3 mm/year in most parts of coastal Asia (IPCC, 2007). In the Bay of Jakarta, observations based on altimetry satellite detection show mean sea-level rise of ca. 2-4 mm p.a. between 1992 and 2005 (Prijatna and Darmawan, 2005). Detailed projections of climate change's impacts of on sea-level rise specific to the Jakarta Bay are not yet available. Nevertheless, these observed changes over recent decades are within the range of global rise reported by IPCC (2007), i.e. a likely minimum and maximum global mean sea-level rise until 2100 of between 18 cm and 59cm.

In terms of global socioeconomic developments in Jakarta and the exposure of population and assets to flooding, Jakarta's population has risen rapidly from 2.7 to 9 million between 1960 and 2007 (BPS, 2010). This is projected to increase further in the future. At the same time, the GDP of Indonesia has also increased rapidly, and is projected to increase in the future, further increasing the exposure of assets and wealth to flooding hazards.

The rapid growth of population and economic developments have led to extensive changes in land use in Java (Verburg et al, 1999), and in Jakarta in particular (Firman, 2009). For example, over the last three decades, agricultural land has been converted into urbanised and industrialised areas (Rukmana, 2015, Yamashita, 2017). At the same time, many former residential areas have been converted to offices and business spaces, and green space has greatly decreased (from 28.8% of the total land area in 1984, to just 6.2% in 2007; Firman, 2009). These changes in land use affect flooding in Jakarta in two main ways: (a) by increasing river discharge and the delivery of sediment of Jakarta's rivers; and (b) by increasing the value of assets and number of people potentially exposed to floods if they do occur (Ward et al., 2011a).

These physical- and socioeconomic drivers also interact. The increased population and economic development have played a major role in lowering drainage capacity in drainage channels and waterways of the city. Moreover, socioeconomic developments continue to put pressure on the city's water supply system, and lead to increasing (ground-) water demands. Meanwhile, rapid urban development is being accompanied by increasing slum settlements, especially along river channels; this condition leads to an increased vulnerability of people living there to river flooding.

1.1.4 Flood risk assessment

As a result of the ongoing physical and socioeconomic changes outlined above, there is a growing recognition that flood risk in Jakarta will increase. Hence, adaptation measures are required to reduce both the chance of flooding and the consequences should a flood occur. This is facilitated by a flood risk approach, whereby flood risk is defined as a function of hazard, exposure, and vulnerability (e.g.

UNISDR, 2011).

The risk framework, and disaster risk reduction in general, are increasingly recognised as being key to international development and adaptation in a broader sense. Also, the last decades have seen the development of key institutions in the field of disaster risk management, such as the United Nations International Strategy for Disaster Reduction (UNISDR) and the World Bank's GFDRR (Global Facility for Disaster Reduction and Recovery). Key documents and activities of these organisations, such as the bi-annual Global Assessment Reports (GAR) of the UNISDR (UNISDR, 2009, 2011, 2013, 2015), and the Understanding Risk reports and forum (e.g. World Bank GFDRR, 2012, 2014a, 2014b, 2014c) provide a solid platform and sound scientific concepts in which to carry out flood risk analyses and research. Hence, this Thesis uses the terminology set out by UNISDR (http://www.unisdr.org/we/inform/terminology), whereby:

- Hazard refers to a "...dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage";

- Exposure refers to the: "...people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses"; and

- Vulnerability refers to the: "...characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard".

1.2 Objectives and research questions

The above flood risk challenges have lead to the implementation of new regulations related to risk assessment, such as Laws No. 24/2007 and No. 21/2008. Furthermore, recent advances in research have addressed flood risk management challenges in Jakarta (Bappenas 2010, Amri et al., 2016). For this process, more research is needed to further steer and prioritize flood risk management, and this Thesis provides an example at the scale of the greater Jakarta region to assess trends in flood risk and how to develop flood risk management approaches to reduce the negative impacts of flood.

In order to respond to the issues discussed in section 1.1, the main objectives of this Ph.D. study are: (a) to develop a model for assessing river flood risk in Jakarta; (b) to use the model to assess the impacts of changes in physical and socioeconomic drivers on flood risk; and (c) to use the model to assess the impacts of various adaptation measures for reducing flood risk.

In order to address these objectives, the following research questions have been formulated:

- Can we develop a model to rapidly assess river flood risk in Jakarta, and how well does it simulate reported flood damage?

- How sensitive is the flood risk model to the use of different vulnerability curves?

- What are the possible future changes in river flood risk in Jakarta as a result of climate change, land subsidence, and land use change?

- What is the potential reduction in flood risk that could be achieved in Jakarta through the implementation of an SMS-based Flood Early Warning System?

- How much could flood risk in Jakarta be reduced under current and future conditions by upgrading and installing polder systems, and what are the costs and benefits?

1.3 General research strategy

In this Thesis, a modeling approach is used to simulate risk, by integrating information on the hazard, exposure, and vulnerability (Figure 1.3). The overall framework follows the Damagescanner approach, originally developed by Klijn et al. (2007) to assess flood risk in the Netherlands. The original version of Damagescanner has been used to carry out many flood risk assessments in the Netherlands and several European basins (e.g. Aerts and Botzen, 2011; Aerts et al., 2008; Bouwer et al., 2010; De Moel and Aerts, 2011; Klijn et al., 2007; Te Linde et al., 2011).

In this Thesis, a new version of Damagescanner is developed, specifically for flood risk assessment in Jakarta, named Damagescanner-Jakarta. An overview of the framework is presented in Figure 1.3. Damagescanner-Jakarta combines information representing the three elements of risk, i.e. hazard, exposure and vulnerability. The hazard map is the output of a hydrodynamic model, which uses precipitation, sea level (as boundary of model), and surface data including land subsidence to simulate inundation extent and depth. The inundation map produced is verified against past inundation reports. Exposure is represented in the model with land use maps issued by the local government of Jakarta; and each land use category is assigned a maximum damage. Vulnerability is represented by flood depth-damage functions. The maximum damages and depth-damage functions were derived through a series of meetings and a workshop, using a fuzzy cognitive mapping (FCM) technique with experts from various disciplines.

Risk simulations produced by Damagescanner-Jakarta calculate direct damages for floods of different return periods (or exceedance probabilities). Expected annual damages are then calculated as the integral of the area under an exceedance probability-damage curve (risk curve); this is shown in Figure 1.4.

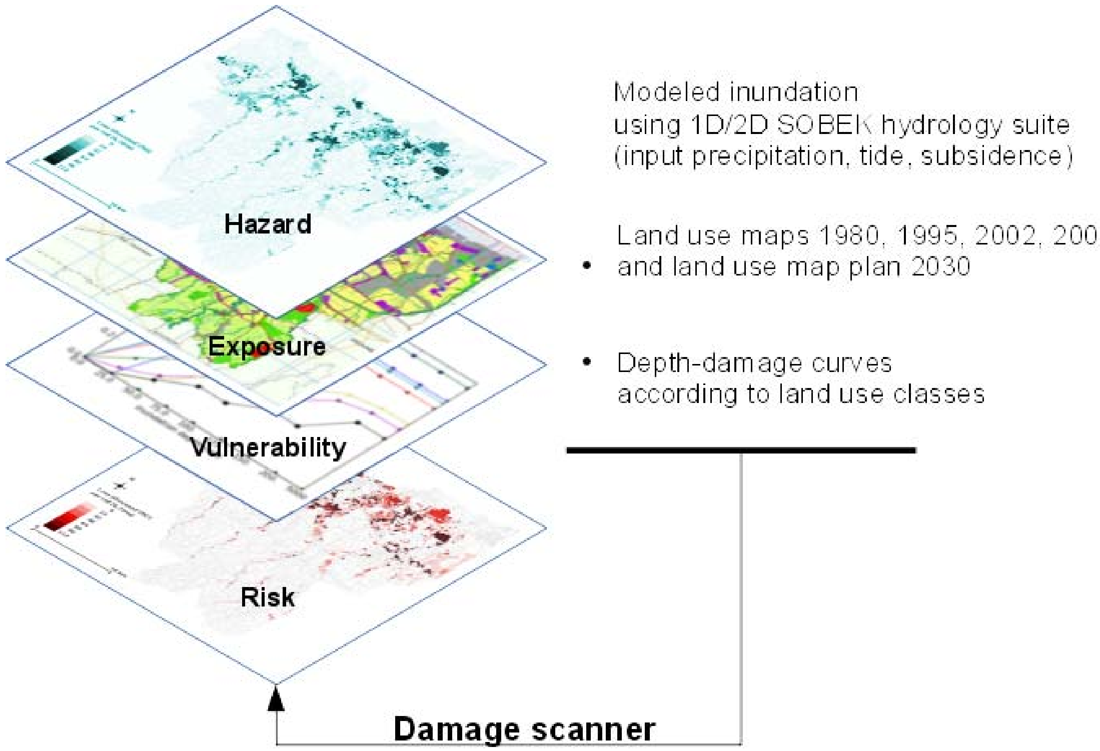

Figure 1.3 Flow diagram representation of Damagescanner-Jakarta.

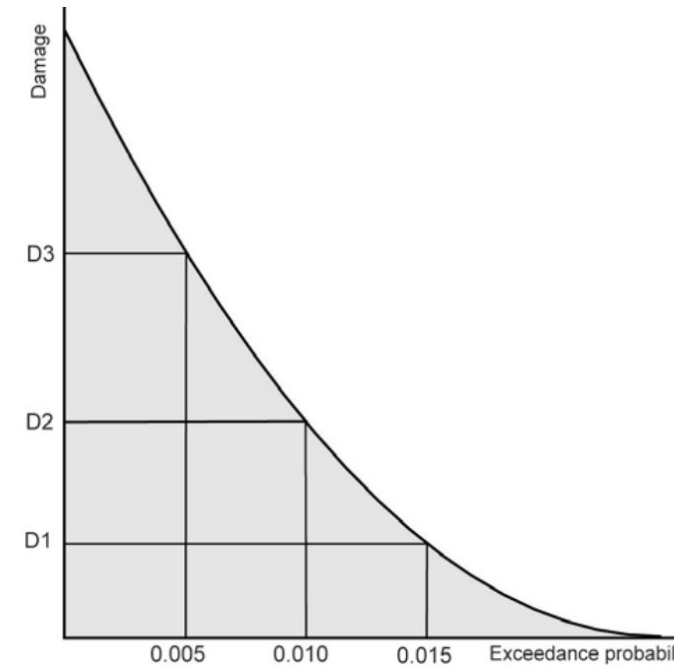

Figure 1.4 Theoretical risk curve; the area under the curve (in grey) represents the risk, expressed as the average

1.4 Framework of the research project

This Thesis was carried out in the framework of the research project Jakarta Climate Adaptation Tools (JCAT), which was funded by the Dutch National Research Programme Knowledge for Climate and the Delta Alliance. The JCAT consortium consists of Vrije Universiteit Amsterdam, Gadjah Mada University Yogyakarta, Wageningen UR, and Bogor Agricultural University. The project was carried out in close collaboration with LIPI (The Indonesian Institute of Sciences), and several stakeholders in Jakarta.

The overarching goal of JCAT is to contribute to the development of methods and tools to assess, compare, and optimise options for climate adaptation in Jakarta. Results of the broader JCAT study are summarised in the JCAT final report (Ward et al., 2014b).

1.5 Thesis outline

Chapter 2 contains a description of the set-up and validation of the flood risk model developed in this Thesis, Damagescanner-Jakarta. The model is based on the generic Damagescanner model, and is adapted for Jakarta using local information on hazard, exposure, and vulnerability. In this section, local datasets were used, and vulnerability curves for each exposure class were synthesized by means of workshops and meetings held in Jakarta. A validation of the model, which was carried out to assess how well the model simulates reported flood damage was also addressed. The model is run with different curves to represent vulnerability, and the sensitivity to the use of these different curves is investigated. Finally, using the model an estimate of current flood risk in Jakarta is presented. This chapter is based on Budiyono et al. (2015).

In Chapter 3, Damagescanner-Jakarta is used to assess how river flood risk could change in the future as a result of climate change, land subsidence, and land use change. This is achieved by forcing the model with scenarios of future changes in these physical and socioeconomic drivers in 2030 and 2050. The model itself is also further improved, by using more up to date land use data and an updated hydraulic schematization that includes a better representation of current flood protection measures than the original version of Damagescanner-Jakarta. This chapter is based on Budiyono et al. (2016).

In Chapters 4 and 5, the Damagescanner-Jakarta model is used to provide first order estimates of the potential reduction in flood risk that could be achieved in Jakarta by implementing two different risk reduction measures. In Chapter 4, the potential flood risk reduction that could be achieved by implementing new, and rehabilitating existing, polder systems in Jakarta is examined. In this chapter, the potential risk reduction in both current and future climate scenarios is addressed. A first order assessment of the costs and benefits of carrying out this risk reduction measure is presented. Finally, in Chapter 5 the potential reduction in risk is assessed under current conditions of implementing a non structural measure the SMS-based Flood Early Warning System.

Finally, in Chapter 6, synthesis of the research is addressed, and answers to the research questions posed in this Thesis are provided. The Chapter also provides a discussion of some of the implications of the research findings for flood risk management, as well as some of the examples in which the results of this Thesis have already been used. Finally, several recommendations are made for future research.

1.6 Publications related to this Thesis

1. Budiyono, Y., Aerts, J., Brinkman, J., Marfai, M. A., Ward, P. (2015). Flood risk assessment for delta mega-cities: a case study of Jakarta, Natural Hazards, 75(1), 389–413, doi:10.1007/s11069-014-1327-9, 2015.

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2 FLOOD RISK ASSESSMENT FOR DELTA MEGA-CITIES: A CASE STUDY OF JAKARTA

This chapter is based on:

Budiyono, Y., Aerts, J., Brinkman, J., Marfai, M.A., Ward, P., 2014. Flood risk assessment for delta mega-cities: a case study of Jakarta. Nat Hazards 75, 389–413. doi:10.1007/s11069-014-1327-9.

Abstract

Jakarta has suffered major floods in 2002, 2007, and 2013. To cope with and adapt to both the current and future flood problem, the city requires quantitative assessments of flood risk. In this study, we develop a flood risk assessment model for Jakarta. The model is based on the Damagescanner model, adapted for Jakarta using local information on hazard, exposure, and vulnerability. The model was first set up using existing estimates of economic exposure of different land use classes to represent exposure, and depth-damage functions (vulnerability curves) from several existing studies in Southeast Asia to represent vulnerability. Using these data to simulate damage led to an overestimation by several orders of magnitude. Hence, we held a series of expert meetings and workshops with local stakeholders to develop specific estimates of economic exposure per land use class, and to derive vulnerability curves specific for Jakarta. We compare the resulting simulated damages to reported damages, and found them to be in good agreement, giving confidence in the use of the model for flood risk assessment. Under current conditions we found the annual expected damage due to river flooding in Jakarta to be approximately US$ 321 million per year. We also examined the sensitivity of flood risk assessments to the use of different vulnerability curves. The sensitivity is high: using the six curves described in this study to simulate risk led to a factor eight difference between the lowest and highest values. Our findings demonstrate that flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves.

2.1 Introduction

Floods are the most commonly occurring natural disasters in Asia. Recent studies on flood risk at the global scale show many regions of Asia to be amongst the most high risk regions in terms of potential damages and affected population, both in terms of river flooding (e.g. Hirabayashi et al., 2013; UNISDR, 2011; Ward et al., 2013a), and coastal flooding (Hanson et al., 2011).

One of the countries in Asia with the highest impacts from flooding is Indonesia, and in particular its capital city Jakarta. Indeed, Jakarta has already suffered several devastating floods in the 21st century, with major floods in 2002, 2007, and 2013. For the 2002 and 2007 events, the government issued formal estimates and documentation on the flood damages, through The National Development Planning Agency (Bappenas). An overview of these findings is shown in Table 2.1. Moreover, the indirect impacts of the floods to the society and regional economy may have been even greater than those reported below, since these investigations do not include aspects such as transformational losses by individuals, and the period of investigation was only 10 days between 5-14 February 2007, whilst indirect losses may have been felt over a longer time span (Bappenas, 2007). The floods of 2007 caused the displacement of over half a million people, the closure of many roads and rail lines, including the main highway to the international airport, and telephone lines were cut off (Ward et al., 2011a, b). Whilst the social and economic impacts of the flood in January 2013 are still being assessed, initial reports suggest that the flood was one of the most severe on record, along with those of 2002 and 2007 (Sagala et al., 2013).

Table 2.1 Comparison of Jakarta flood damage during 2002 and 2007 flood (Bappenas, 2007).

Description	2002	2007
Precipitation	361,7 mm	327 mm
	(mean Jakarta in 10 days)	(mean Greater Jakarta in 6 days)
Inundated area	331 km2 in Jakarta	454,8 km2 in Jakarta
Loss of life	80 persons	79 persons
		(status of 12 February 2007)
Refugee	381 persons	590.407 persons (status of 6 February 2007)
Direct losses	IDR 5.4 trillion (2002 values) US$ 1,510 million (2012 values)*	IDR 5.2 trillion (2007 values) US$ 890 million(2012 values)*
Indirect losses	IDR 4.5 trillion (2002 values) US$ 1,260 million(2012 values)*	IDR 3.6 trillion (2007 values) US$ 620 million (2012 values)*

* Values in Rupiah (IDR) are original values in year of event. These were converted into US$ values for the year of the event using exchange rates from the World Bank (http://data.worldbank.org/data-catalog/world-development-indicators), and then adjusted to 2012 values using GDP deflators from the International Monetary Fund (http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/index.aspx).

Historical records show that flooding per se is not a new problem in Jakarta. Floods have occurred since the era of the Tarumanegara kingdom in the 5th century, as documented in the Prasasti Tugu (Noorduyn and Verstappen, 1972). However, the impacts of flooding have increased in recent decades as a result of a large number of drivers, both physical and socioeconomic in nature. Examples of physical drivers include land subsidence due to the extraction of groundwater (Abidin et al., 2011); and low drainage and/or storage capacity in the city's waterways, partly due to them being clogged up by solid waste and by sediments eroded from upstream (Steinberg, 2007). At the same time, socioeconomic development has caused rapid changes in Jakarta. Over the last half century, Jakarta's population has risen from 2.7 million in 1960 to 9 million in 2007 (BPS, 2012), accompanied by a rapid growth in GDP. These changes in population and wealth have also led to rapid changes in land use (Verburg et al., 1999), which can affect flood disasters in Jakarta in two main ways: (a) due to increased discharge and sediment delivery of the rivers running through Jakarta as a result of reduced soil water holding capacity and infiltration rates in the watersheds above Jakarta (Poerbandono et al., 2009); and (b) due to changes in the value of assets and number of people potentially exposed to floods if they do occur (Ward et al., 2011a, b).

Moreover, the flood problems in Jakarta may become more severe in the future as a result of climate change. For example, observations based on altimetry satellite detection for selected Indonesian coasts, including Jakarta, show a mean sea-level rise in the Bay of Jakarta of ca. 3-4 mm per year over the period 1993-2009 (Nurmaulia et al., 2010). Moreover, most climate studies in Southeast Asia suggest that extreme rainfall events may increase in severity and frequency within the 21st Century (e.g. IPCC, 2007), which could lead to increased extreme river discharges.

Hence, there is a clear need for coordinated efforts to reduce flood risk in the city, both under current and future conditions. Indeed, Jakarta has a long history of dealing with floods. To date, Jakarta has conducted three main master plans on coping with floods (Caljouw et al., 2005; Kooy and Bakker, 2008; Gunawan, 2010; Sutiyoso, 2007). A similar aspect of all of these past plans has been the traditional approach to flood management, i.e. using infrastructural measures to reduce the chance of flooding (Sagala et al, 2013).

However, there is a growing recognition amongst practitioners and researchers that due to the ongoing and large physical and socioeconomic changes outlined above, it will become increasingly expensive to defend against floods. Moreover, the chance of flooding can never be completely removed. Hence, long-term adaptation plans are required that both reduce the chance of flooding and the consequences should a flood occur. This is facilitated by a flood risk approach, whereby flood risk is the product of hazard, exposure, and vulnerability (e.g. UNISDR, 2011). Hazard refers to the physical flood event, including its characteristics and probability of occurrence; exposure refers to the location of economic assets or people in a hazard-prone area; and vulnerability refers to the susceptibility of those assets or people to suffer damage and loss. Throughout this Chapter, we have used the same terminology as UNISDR (2011). Whilst risk assessment and risk management are already encapsulated in several Indonesian regulations (such as the regulation related to risk assessment in Law No. 24/2007 and its descriptive in the Regulation of the Government of Indonesia No. 21/2008), no detailed flood risk assessment method is currently available for the city. Bappenas, together with the National Office for Disaster Management (BNPB) have produced a document called National Action Plan for Disaster Risk Reduction (NAP-DRR 2010-2012) that contains a rough risk map for the entire country, showing areas of low, medium, and high risk at the country scale.

City scale flood risk assessments are important since they allow planners to identify the most at risk areas, to assess how risk may change in the future, and to assess the effectiveness (in terms of reduced flood risk) of various adaptation measures (Ward et al., 2011a, b).

For coastal flooding, several efforts have already been carried out to assess both current and future flood exposure and risk in Jakarta. In a study of the exposure of people and assets to coastal flooding in 136 port cities worldwide, Hanson et al. (2011) projected that Jakarta will be ranked in 20th place by

2070, in terms of exposed population. Similarly, Hallegatte et al. (2013) projected that Jakarta will be the 11th ranked city worldwide by 2050 in terms of annual expected loss, considering socio-economic change, land subsidence, sea level rise, and adaptation to maintain flood probability. Ward et al. (2011a, b) also simulated the potential impacts of future sea-level rise and land subsidence on the exposure to flooding in northern Jakarta. They found that the economic exposure to flooding may increase by a factor of 4–5 between 2010 and 2100, predominantly as a result of land subsidence.

However, to date, there have been no studies of river flood risk in Jakarta, despite that fact that many of the recent major flood events have resulted from riverine flooding. In this Chapter, we develop a first river flood risk assessment tool for Jakarta, and use it to calculate risk under current conditions. To do this, data are needed on all of the components of risk, i.e. hazard, exposure, and vulnerability. Whilst in many cities information on flood hazard (i.e. inundation maps) and exposure (i.e. land use and/or population maps) may be available, data on vulnerability are limited. As a result, some studies attempt to only assess exposure to flood hazard, ignoring vulnerability. For example, Ward et al. (2011a, b) carried out an assessment of the economic exposure to coastal flooding for the northern part of Jakarta. Other studies often apply generic depth-damage functions, or curves from studies in other cities, to represent vulnerability (e.g. Beckers et al., 2013; Messner et al., 2007; Muto et al., 2010; Pillai et al., 2010; Te Linde et al., 2011; Ward et al., 2011a, b). Both of these approaches may be problematic for flood risk assessments, since vulnerability is known to be highly heterogeneous (Jongman et al., 2012; UNISDR, 2013). However, little is known on the sensitivity of flood risk assessments to the use of different vulnerability curves transferred from elsewhere.

To respond to these issues, the main aims of this Chapter are therefore to:

- develop a flood risk assessment model for the mega delta-city of Jakarta;
- use the model to estimate riverine flood risk under current conditions; and
- assess the sensitivity of flood risk assessments to the use of different vulnerability curves transferred from other cities.

This Chapter extends the work of Ward et al. (2011a), in which economic exposure to coastal flooding was carried out for northern Jakarta. The Chapter extends this work by investigating risk (rather than economic exposure), producing a coverage for the entire city, and focusing on riverine flooding rather than coastal flooding. Riverine flooding is examined due to the lack of existing studies.

2.2 Methods

In this study, we developed a damage model for Jakarta, based on the Damagescanner model (Klijn et al., 2007; Aerts et al., 2008). We used this model to estimate the direct economic damage as a result of floods of different return periods (2 to 100 years). We then calculated flood risk (in terms of expected annual damage) by plotting these damages and their associated exceedance probabilities on an exceedance probability-loss (risk) curve, whereby the risk is approximated by the area under the curve (Meyer et al., 2009a). In this section, we first describe the flood damage model (Damagescanner), and then describe the input data used to run the model in this study.

2.2.1 Damagescanner

We calculated the direct economic damage for floods of different return periods using an adapted version of the Damagescanner model (Aerts et al., 2008; Klijn et al., 2007). The model considers flood risk as a function of hazard, exposure, and vulnerability; the basic framework is presented in Figure 2.1. Damagescanner, and its application in several European basins, has been described in several studies (e.g. Aerts and Botzen, 2011; Aerts et al., 2008; Bouwer et al., 2010; de Moel and Aerts, 2011; Klijn et al., 2007 ; Te Linde et al., 2011 ; Ward et al., 2011a, b, 2013a, b, c), so we only provide a brief overview here.

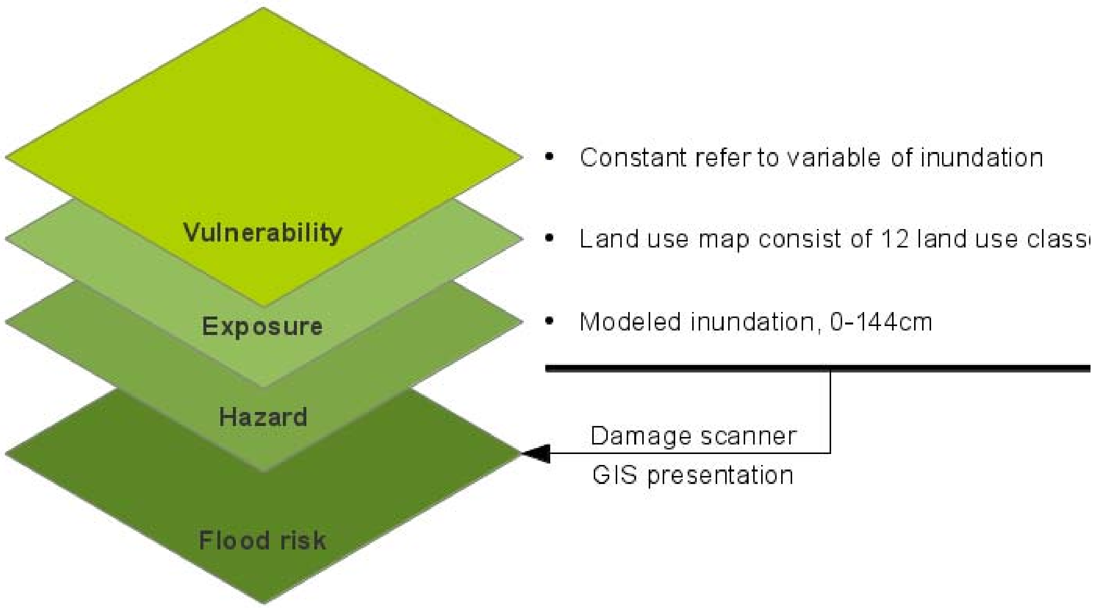

Figure 2.1 Flow diagram representation of Damagescanner

Damagescanner needs three inputs, namely: (a) a map showing inundation extent and depth to represent the hazard; (b) a land use map, with associated economic values of each land use class, to represent the exposure; and (c) depth-damage functions to represent the vulnerability. Depth-damage functions estimate the expected damage for a given inundation depth and a given land use for each grid-cell. In this study, a new version of Damagescanner was developed in Python. The resolution of the model used in this study is 50m x 50m. Hence, all input data were first resampled to this spatial resolution. In the following section, we describe the specific data used in this study to represent hazard, exposure, and vulnerability.

2.2.2 Input data

2.2.2.1 Hazard data

Flood hazard is represented by maps showing inundation depth and extent for several return periods (1, 2, 5, 10, 25, 50 and 100 years). These inundation maps for Jakarta were produced by the Flood Hazard Mapping (FHM) framework by Deltares in 2007 and 2009, as well as the Flood Management Information System (FMIS) projects by Deltares in 2012 together with the Research & Development Center for Water Resources (Pusair) and the National Office for Climate (BMKG) for the province of DKI Jakarta (Special Capital Region of Jakarta) administration and the national government of Indonesia (Deltares et al., 2012). The FHM framework includes a hydrological and hydraulic model of the Ciliwung River integrated with an overland flow model of DKI Jakarta. The framework is used by and updated in close communication with stakeholders in Jakarta [i.e. local office of Public Works (PU DKI) and the office for Ciliwung Cisadane river management (BBWSCC)].

The hydrological and hydraulic processes are computed using the SOBEK model; a full description of

SOBEK has been developed by Deltares (2014), and is accessible online. SOBEK is a modeling framework for flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, river morphology, salt intrusion and surface water quality. The components within the SOBEK modeling framework simulate the complex flows and the water related processes in almost any system. The coupled one and two dimensional (1D/2D) hydrodynamic system over horizontal plane engine operates with complete Saint-Venant equations including transient flow phenomena and backwater profiles (Stelling and Verwey, 2006). The hydrodynamic engine has an automatic drying and flooding procedure that is 100% mass-conservative. The engine can deal with steep canals with supercritical flows, moving hydraulic jumps and complex interloped water systems.

In the FHM framework (Tollenaar et al., 2013), all major rivers discharging to Jakarta Bay are included in a 1D network for the computation of water levels and discharges. A 2D grid is included for the computation of overland flow in case 1D embankments are overtopped. The overland flow model uses grid-cells of 50x50m at the Ciliwung floodplain and 100x100m for the rest of the Jakarta province. To force the 1D model, a library of Rainfall Runoff (RR) models is available in SOBEK. In the Ciliwung catchment the Sacramento model (Burnash, 1995) is used to generate runoff for 449 sub-catchments from rainfall and evaporation records. Sacramento discriminates an upper zone and lower zone for the computation of quick (e.g. surface runoff) and slow (e.g. base flow) runoff components. Incorporation of both quick and slow runoff components is important for a proper simulation of major flood events. Such events are characterised by days or weeks of wet conditions increasing baseflow and an extreme rainfall event at which river and canal embankments are overtopped.

As an example, the hazard map for a 50 year return period flood is shown in Figure 2.2. The spatial resolution of the original hazard map is 50m x 50m, and the depths are given for increments of 1cm.

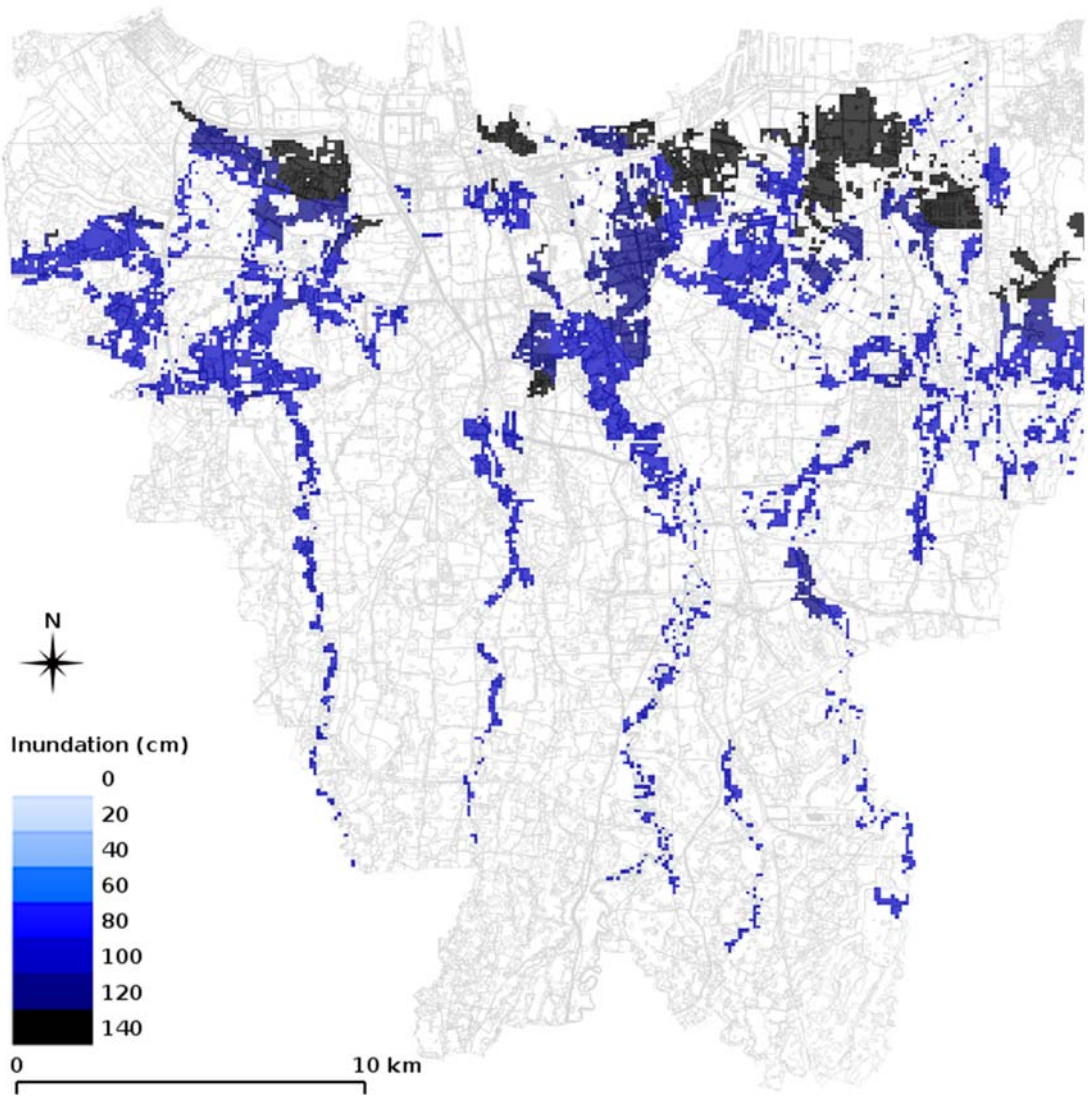

Figure 2.2 Map of Jakarta showing the modeled hazard for a 50 year flood return period using the SOBEK hydrology suite.

2.2.2.2 Exposure data

Exposure is represented by a map showing the economic exposure per grid-cell, which is in turn based on a land use map. In this study, we used the land use map available for the year 2002, supplied by the office of city planning in Jakarta (DTR DKI, 2007). The map shown in Figure 2.3 shows land use at a horizontal resolution of 50m x 50m, for 12 land use classes, namely: agriculture and open space; low density urban kampung (self-made houses or residential areas with no site plan); swamp, river and pond; industry and warehouse; commercial and business; planned house; education and public facility; government facility; high density urban kampung; transportation facility; and park and cemetery. The map is harmonious in terms of land use classes with land use maps for 1980 and 1995, thus allowing for extrapolations to the future in subsequent studies.

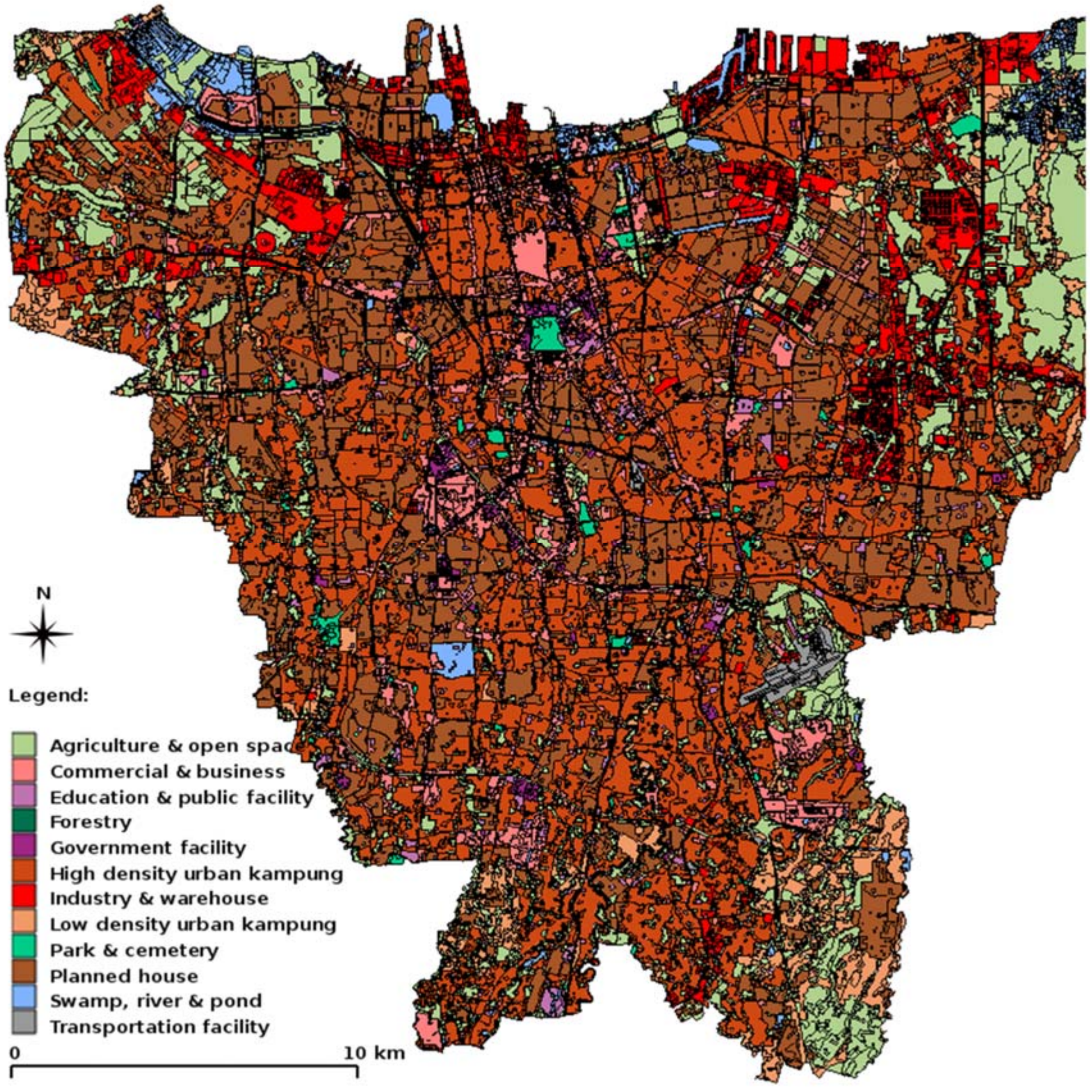

Figure 2.3 Jakarta land use map for 2002 from the office of city planning, showing twelve land use classes.

In the Damagescanner model, a value for economic exposure is applied to each land use class. In this study, we used two approaches to assign these values. Firstly, we carried out a literature review of past studies in Jakarta in which the economic value of different land use classes has been estimated. This review was based on available studies in Jakarta using different approaches. The first is a study of flood exposure in northern Jakarta (Ward et al., 2010), in which market valuations were assigned based on interviews (for two land use categories, namely uniform and non-uniform settlements) and on existing literature and statistics for the other land use types. The second is a study carried out in the Kampung Melayu are of East Jakarta (Marschiavelli, 2008), based on a limited number of household surveys. This resulted in the maximum value estimates shown in Table 2.2.

However, the aforementioned studies note that these values are very rough and uncertain. Hence, for this study we also developed new estimates of economic exposure values based on a series of expert meetings and workshops described in section 2.2.2.3.

Table 2.2 Economic exposure values per land use class according to literature review of past studies in Jakarta.

Land use name	Economic exposure (thousand US$ per hectare)
Industry and warehouse	2,500
Commercial and business	2,500
Government facility	2,500
Planned house	1,200
Transportation facility	Not available
Education and public facility	1,000
High density urban kampung	1,000
Low density urban kampung	1,000
Forestry	1.7
Swamp, river and pond	1.7
Park and cemetery	1.7
Agriculture and open space	80

2.2.2.3 Vulnerability data

In Damagescanner, vulnerability is represented by depth-damage functions, hereafter referred to as vulnerability curves. These curves show the percentage of the economic exposure values that would actually suffer damage for different flood depths per land use class (e.g. Merz et al., 2010b). For Jakarta, no officially recognised vulnerability curves are currently available. Hence, in this study we first calculated risk based on vulnerability curves derived from flood risk studies in large cities in the South-East Asia region. We then held a series of expert meetings and workshops to derive new vulnerability curves specific to the Jakarta region, and recalculated risk based on these curves. Finally, we compared the risk results obtained through using the different vulnerability curves, in order to assess the sensitivity of the final risk results to the choice of vulnerability curve.

For the existing vulnerability curves, we used the following: curves for specific localities in the Kampung Melayu village of East Jakarta (Marschiavelli, 2008); curves for Bangkok (World Bank, 2009); curves for Ho Chi Minh City (HCMC) (Dickens, 2011), and curves for Manila (Muto et al., 2010, Pillai, 2010). The methods used to derive these curves are only documented in summary, and therefore it is difficult to know the assumptions made in their development, and hence the impacts of those assumptions on the risk calculations. In brief, the curves for Kampung Melayu in Jakarta, Bangkok, and HCMC were based on surveys in those localities, whilst the curves for Manila are in fact simply the standard vulnerability curves for Japan.

In order to derive the new economic exposure values and synthetic vulnerability curves (Penning-Rowsell and Chatterton, 1977), specific to the case of Jakarta, a series of expert meetings and workshops was held in 2012 in Jakarta. Essentially, this process followed a Fuzzy Cognitive Mapping (FCM) approach (Groumpos, 2010; Stach et al., 2010), as previously employed by Murungweni et al. (2011) to estimate livelihood vulnerability. The process consisted of two main rounds. In the first round, a series of four expert meetings was held with nine stakeholders in order to derive preliminary economic exposure values and vulnerability curves. In a second round, a one-day workshop was held with a larger group of different stakeholders in order to validate, and where necessary improve, these initial values and curves. The two rounds are described briefly below.

In the first round, BPPT (Agency for the Assessment and Application of Technology) hosted a series of four one-day expert meetings, as part of the project 'SMS based flood early warning system to decrease flood risk in Jakarta'. This project was funded by Ministry of Research and Technology, Indonesia (PKPP fund F1.129/2012), and had the purpose of assessing the potential effectiveness of an early warning system to reduce flood risk in Jakarta. The meeting was attended by nine experts from different stakeholder groups involved in the project, namely stakeholders from the fields of: agriculture, education, infrastructure, machinery, ecosystem modeling, hydrology, forestry, environmental science, and administration. The meetings addressed three main aspects. Firstly, for each of the land use classes listed in Table 2.3, the meetings were used to identify 'fuzzy elements', i.e. the elements potentially exposed to flooding in each land use class, both in terms of fixed elements (e.g. houses, offices, and infrastructure) as well as their contained assets. For example, for the land use class "low density urban kampung", the experts identified the buildings that could be affected, as well as fixed elements of those buildings that could be affected (e.g. houses, being made of fixed elements such as walls, roofs, doors, windows, etc.), as well as the assets contained in a standard unit (e.g. furniture, books, television, motorcycles, etc.). Secondly, each of these fuzzy elements was assigned an economic exposure values equal to its market price. Finally, the experts were asked to estimate the percentage damage to each fuzzy element that would occur for inundation depths of the following increments: 25, 50, 75, 100, 125, 150, and 200 cm. All of these meetings were carried out in plenary sessions.

In the second round, a one-day workshop was held in Jakarta on 'Vulnerability synthesis for flood risk assessment', with representatives from outside the project from local governments, and private and public organizations, as listed in Table 2.3. In the first part of the workshop, the theory and practice of flood risk assessment was explained, so that the attendants understood the reason for developing the values and vulnerability curves. As part of this presentation, the flood risk that would occur in Jakarta assuming the existing economic exposure values and vulnerability curves was shown in the form of maps and tables. For each land use class, the representatives were then asked to discuss the economic exposure values and forms of the vulnerability curves in order to reach a consensus on each. Carrying out the analyses in two rounds aims to give a better focus to the workshop.

Table 2.3 List of experts attending workshop to develop economic exposure values and synthetic vulnerability curves specific for Jakarta

Land use class	Representatives		
	Government	Public	Private

Agriculture and open space	Office of Marine Issues and Agriculture	Association of Farmers (HKTI)	Bureau of Logistics (Bulog)
Low density urban kampung	The National Office for Disaster Management (BNPB)	STEI Tazkia University, PKPU Zakat charity	Takaful Micro Insurance
Swamp river and pond	Office of Marine Issues and Aquaculture	Ciliwung National Park, HKTI	Takaful Micro Insurance
Industry and warehouse	DKI Jakarta (Special Capital Region of Jakarta) Administration	AAUI	Axa Insurance
Commercial and business	DKI Jakarta (Special Capital Region of Jakarta) Administration	AAUI	Axa Insurance
Planned house	DKI Jakarta (Special Capital Region of Jakarta) Administration	Association of Building Developers	Bintaro Residence, Axa Insurance
Education and public facility	DKI Jakarta (Special Capital Region of Jakarta) Administration	Association of Teachers (PGRI)	Takaful Micro Insurance
Government facility	DKI Jakarta (Special Capital Region of Jakarta) Administration	Association of Building Developers	Takaful Micro Insurance
High density urban kampung	The National Office for Disaster Management (BNPB)	STEI Tazkia University, PKPU Zakat charity	Takaful Micro Insurance
Transportation facility	Jakarta office of Public Works	AAUI	Axa Insurance
Park and cemetery	DKI Jakarta (Special Capital Region of Jakarta) Administration	PKPU Zakat charity	Takaful Micro Insurance
Forestry	DKI Jakarta (Special Capital Region of Jakarta) Administration	PKPU Zakat charity	Takaful Micro Insurance

2.3 Results

We first show the new values for economic exposure values and the new vulnerability curves derived from our workshop. We then show the results of our damage modeling exercise when only the economic exposure values and vulnerability curves from the literature study are used, followed by the results based on the new economic exposure values and vulnerability curves. Next, we show how the economic risk (expressed as annual expected damages) is distributed over different land use classes, as well as a spatial representation of the risk.

2.3.1 Vulnerability curves and economic exposure values

2.3.1.1 Economic exposure values

In Table 2.4, we show the economic exposure values per hectare for each land use class. The values in the left-hand columns are derived from the literature on past studies in specific parts of Jakarta, as described in the Methodology section. For some of these past studies, it is not always clearly documented how these estimates were derived. Hence, we also derived economic exposure values specific for Jakarta during our workshops with stakeholders. These values are shown in the right-hand column. The first thing to note is that the values derived from the workshop are, in general, significantly lower than the values derived from the literature review. The only classes where this is not the case are 'swamp, river, and pond', 'park and cemetery', and 'forestry', all of which only contribute minimally to flood damage in Jakarta. For the main damage causing categories (i.e. 'industry and warehouse', 'commercial and business', 'planned house', and 'high density urban kampung'), the difference between the values from the past studies and our workshop is about a factor of four to six.

Table 2.4 Economic exposure values per land use class according to literature review of past studies in Jakarta, and according to results of our workshop.

Land use class	Economic exposure (thousand US$ per hectare)	
	Past studies	Workshop*
Industry and warehouse	2,500.0	517.9
Commercial and business	2,500.0	517.9
Government facility	2,500.0	517.9
Planned house	1,200.0	341.8
Transportation facility	Not available	331.5
Education and public facility	1,000.0	259.0
High density urban kampung	1,000.0	155.4
Low density urban kampung	1,000.0	129.5
Forestry	1.7	10.4
Swamp, river and pond	1.7	3.8
Park and cemetery	1.7	3.1
Agriculture and open space	80.0	2.0

* Original values were derived in the workshop in Indonesian Rupiah (IDR) and converted to US$ using exchange rate of 9,654 IDR to US$ 1.

2.3.1.2 Vulnerability curves

In Figure 2.4, we show the vulnerability curves for the four land use classes that generate the highest flood damages, namely: (a) 'industry and warehouse'; (b) 'commercial and business'; (c) 'planned house'; and (d) 'high density urban kampung'. Whilst the curves from different studies described in the literature are very different from each other, there are clear similarities in the curves of each individual study between the classes 'industry and warehouse' and 'commercial and business', and between the classes 'planned house' and 'high density urban kampung'.

For 'industry and warehouse' and 'commercial and business', the curves based on the studies on Bangkok and Manila clearly show much lower damages (as a percentage of economic exposure values) for a given inundation depth than those derived for HCMC, past studies focusing on specific parts of Jakarta, and those developed in our workshop. The curves developed during our workshop show the highest damages of all curves for these classes, though for inundation depths above 125 cm, they show the same fractional damage as those for HCMC and the other two studies in parts of Jakarta. For 'planned house' and 'high density urban kampung', again the curves from the Bangkok study show very low fractional damages at all inundation depths, though the curves for HCMC show even lower damages. The curves derived from our workshop appear to give damage fractions corresponding to around the average of the other curves.

Given the large spread of the vulnerability curves, we can expect that the flood risk estimates based on the different curves will also show a large range.

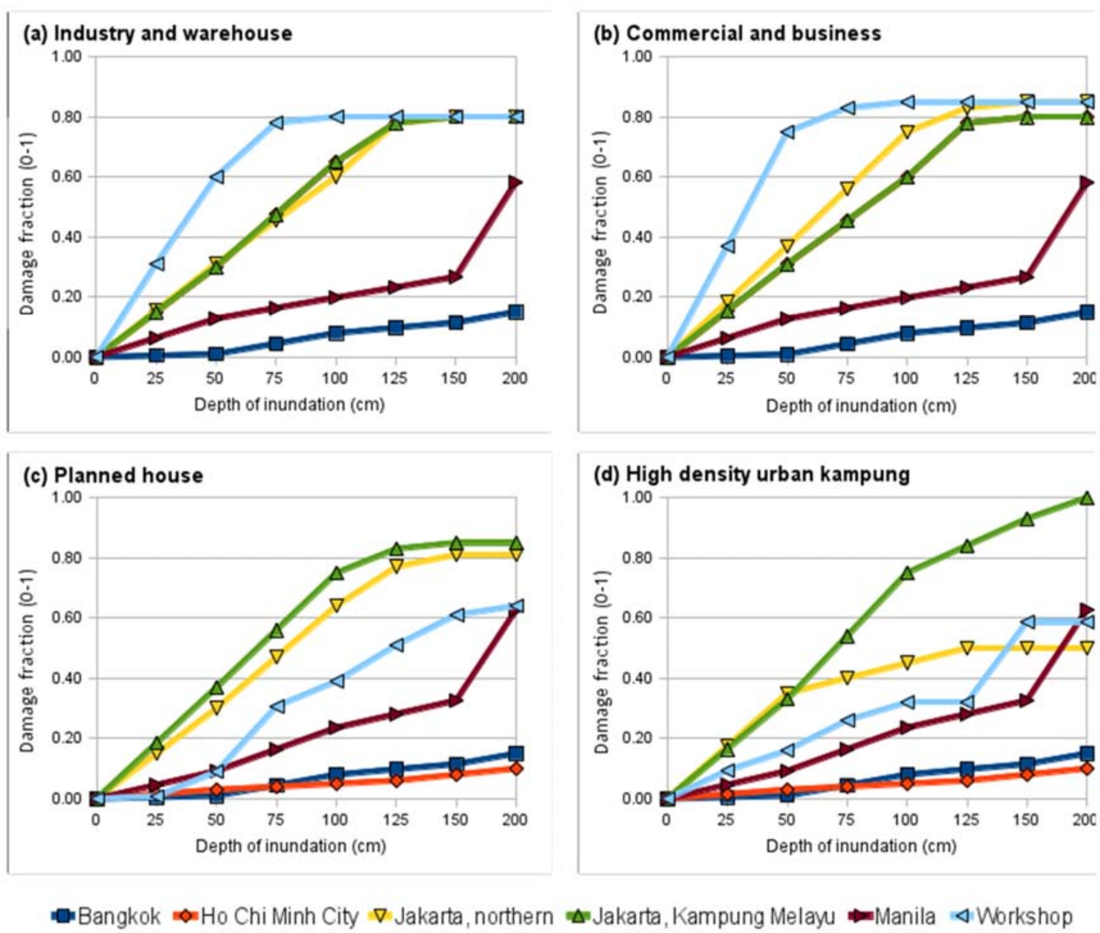

Figure 2.4 Vulnerability curves for the four land cover classes that cause the highest economic damage, namely: (a) 'Industry and warehouse'; (b) 'Commercial and Business'; (c) 'Planned house'; and (d) 'High density urban kampung'. For each land cover, the curves show the fraction of the economic exposure values that is damaged at given inundation depths

2.3.2 Economic damage and risk based on existing economic exposure values and

vulnerability curves

In Table 2.5, we show the damages for floods of different return periods, as well as the risk (expressed as annual expected damages), based on calculations carried out with the vulnerability curves and economic exposure values taken from the past literature. There is a large variation in the damage estimates depending on which vulnerability curve is used. This is to be expected, since the vulnerability curves vary significantly between each other, as shown in section 2.3.1. In terms of annual expected damages, there is a factor seven difference between the lowest value of US$ 250 million per year and the highest value of US$ 1,825 million per year.

A comparison of the modelled flood damages with reported damages based on past events is provided in section 2.4.1. However, here we already note that in general the modelled damages based on these existing economic exposure values and vulnerability curves appear to be significantly higher than the losses reported by Bappenas, and displayed in Table 2.1. The floods of 2002 and 2007 are estimated to have had a return period of somewhere between 25 and 50 years. Comparing the reported direct damages for 2002 and 2007 from Bappenas (US$ 1,510 million and US$ 890 million respectively) with the modelled values for 25- and 50-year flood return periods shows the modelled values to be much higher.

Table 2.5 Flood damage (US$ millions) and flood risk (US$ millions/year) based on vulnerability curves and maximum values from previous research in Southeast Asian countries. The damage values are show for different return periods (1-100 years), and the risk is shown in terms of annual expected damage.

Flood Return Period	Bangkok	Ho Chi Minh City	Jakarta, Northern	Jakarta, Kampung Melayu	Manila
Flood damage (US$ millions)					
1	0	0	0	0	0
2	165	616	1,032	1,213	390
5	399	1,531	2,509	2,904	930
10	592	2,334	3,718	4,289	1,373
25	875	3,522	5,603	6,408	2,039
50	1,078	4,228	6,877	7,898	2,503
100	1,297	5,014	8,287	9,495	3,008
Flood risk (US$ millions/year)					
	250	965	1,576	1,825	584

2.3.3 Economic damage and risk based on new economic exposure values and all vulnerability curves

Based on the results described in section 2.3.2, it appears that using the estimates of economic exposure values taken from existing literature in Jakarta may lead to an overestimation of damage. As explained earlier, given the large uncertainty in using these estimates, as part of our workshop with local stakeholders we also derived new estimates of economic exposure values for the different land use classes. The new values are shown in Table 2.4.

In Table 2.6, we show the damages for the different return periods, and the annual expected damages, based on these new estimates, and in combination with both the vulnerability curves from past literature, as well as the new curves derived from our workshop. The resulting values are about a factor 5 lower than those shown in Table 2.5, which is logical since the economic exposure values derived from the workshop are about 4-6 times lower (depending on the land use class) than those based on the literature review.

The results using the new vulnerability curves for Jakarta derived from our workshop are very similar to the results using the vulnerability curves based on past studies in specific parts of Jakarta. The results based on all three sets of vulnerability curves for Jakarta are significantly higher than the results based on the vulnerability curves derived from studies in Bangkok, Ho Chi Minh City, and Manila.

Table 2.6 Flood damage and risk (US$ millions) and flood risk (US$ millions/year) based on (1) economic exposure values plus new curves from the stakeholder workshop (column to the right), and based on vulnerability curves from previous research and economic exposure values from the workshop (column 2-6). The damage values are show for different return periods (1-100), and the risk is shown in terms of annual expected damage

	Flood damage (US$ millions)					
Flood Return Period	Bangkok	Ho Chi Minh City	Jakarta, Northern	Jakarta, Kampung Melayu	Manila	Workshop
1	0	0	0	0	0	0
2	29	121	218	247	76	208
5	71	302	530	592	181	511
10	106	461	785	874	267	764
25	160	698	1,190	1,318	401	1,151
50	197	838	1,465	1,629	494	1,415
100	237	994	1,768	1,963	595	1,702
	Flood risk (US$ millions/year)					
	45	191	333	373	114	321

2.3.4 Economic damage per land use class

In Figure 2.5, we show the percentage distribution of annual expected damage per land use class, based on the vulnerability curves taken from the literature as well as those derived from our workshop. The results are shown for the four most damaging land use classes (using the workshop vulnerability curves), with other land uses being classed as "others". The figure clearly shows that the majority of the damage occurs within these four land use classes. Broadly speaking, these four land use classes can be split into two categories: (a) commercial, represented by ‘Industry and warehouse’ and ‘Commercial and business’; and (b) residential, represented by ‘Planned house’ and ‘High density urban kampung’.

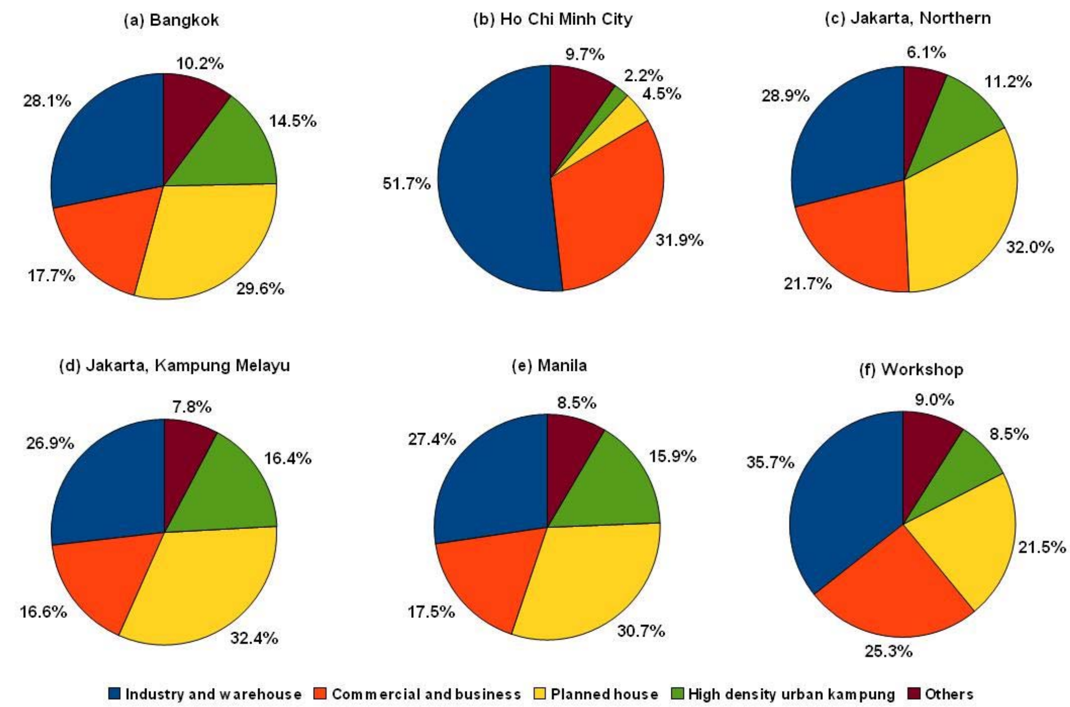

Figure 2.5 Pie-charts showing the percentage of total annual expected damage resulting from each land use class. The pie charts are shown for the new maximum damage based on the workshop, and for the vulnerability curves for: (a) Bangkok; (b) Ho Chi Minh City; (c) Northern Jakarta; (d) Kampung Melayu, Jakarta; (e) Manila; and (f) Workshop.

The figure also shows that the distribution of annual expected damages between these two broad categories (commercial and residential) is rather similar between the results based on the vulnerability curves for Bangkok, Jakarta (northern and Kampung Melayu, and Manila). In these cases, these categories account for ca. 90% of the total annual expected damages, with about half in the commercial category and half in the residential category. For the results based on the vulnerability curves from our workshop, damages in the commercial category account for a greater proportion of the overall damages (57%) than residential damages (29%). However, the most anomalous results (in terms of distribution of damages between land use categories) are for the Ho Chi Minh City vulnerability curves. In this case, commercial damages are by far the largest (83% of the total), with residential damages accounting for 7% of the total.

2.4 Discussion

2.4.1 Comparison with reported damages and past modeling studies

In this section, we compare the modelled flood damages with reported flood damages based on past events in Jakarta. The main estimate of the costs of the flood events in 2002 and 2007 have been carried out by Bappenas (see Table 2.1), who estimated the direct economic damages for these events at US$ 1,510 million and US$ 890 million respectively. Bappenas (2007) estimated these damages based on the quick damage and loss assessment approach described by the United Nations Economic Commission for Latin America and Caribbean (ECLAC) (ECLAC, 2003). The approach has previously been implemented following other large disasters in Indonesia, such as the Indian Ocean tsunami in 2004 and the Yogyakarta earthquake in 2006. Bappenas (2007) report the sum of damages for five categories, namely: housing, infrastructure, productive economy, social infrastructure, and other losses. Damage to housing is sub-divided into three damages categories, namely medium, heavy, and total loss. Each category is assigned a damage value (US$ 850 per house for medium loss, US$ 1,700 for heavy loss, and US$ 3,400 for total loss; all values in 2012 values). These values are then multiplied by the number of houses suffering from medium, heavy, and total loss. Note that these values are relatively low, since they are considered to occur on non-permanently constructed houses. In addition, the quick scan assessment for housing generally focuses mainly on places that require government recovery, such as in the high density urban kampung areas. Infrastructure damage covers transportation, energy, post and telecommunication, water supply, and agriculture. Damage in the productive economy covers industry and merchants, but does not include damage to modern supermarkets. Damage to social infrastructure covers schools, hospitals, worship houses, and other social infrastructure. Other damage covers government buildings, security infrastructure, and banking. The carrying out of the calculation is supported by government institutions under the administration of BNPB, as well NGOs (e.g. the Indonesia Employers Association; Apindo), the General Insurance Association of Indonesia (AAUI); and the United Nations Development Programme (UNDP). Since the approach mainly focuses on houses that require government recovery, not all damages are included, and therefore the approach may represent a lower total damage than that which actually occurs on the ground.

The flood event of 2007 is estimated to have had a return period of about 50 years (Van der Most et al., 2009); in terms of precipitation intensity the 2002 event was a little more severe, whilst in terms of inundated area it was a little less severe. Hence, we compare our modelled results for a 50 year return period with the reported losses of Bappenas (US$ 1,510 million and US$ 890 million for 2002 and 2007 respectively). Using the economic exposure values taken from the literature and used in past studies, the simulated damages are much higher than these reported values, except for when using the vulnerability curves for Bangkok, for which modelled damage is US$ 1,077 million. For all of the other vulnerability curves, the modelled damages are in excess of even the higher damages reported for 2002, by a factor ranging from 1.7 (Manila curves) to 5.2 (Jakarta Kampung Melayu curves). However, the economic exposure values from the former study are known to be very rough estimates. Hence, the series of expert meetings and workshops described in this Chapter was used to develop updated economic exposure values specific to Jakarta, based on local expert knowledge. Applying these values in Damagescanner led to the improved estimates of damages displayed in Table 2.6. Here, we see that the modeled damages for a 50 year return period flood are more similar to the reported values, and are of a similar order of magnitude to the reported losses either in 2002 or 2007 (except for the estimates using the vulnerability curves from Bangkok, for which the damages are a factor 4.5 lower than the reported value for the event of 2007).

The results based on all three sets of vulnerability curves for Jakarta (based on our workshop, and based on past surveys in Kampung Melayu and northern Jakarta) give damages for a 50 year return period flood slightly higher than the reported damages in 2002. The results are of the same order of magnitude, and as stated earlier it is to be expected that the reported losses based on the ECLAC approach are somewhat lower than observed damages on the ground, since in the category 'houses', this approach mainly focuses on those houses that require government recovery, and do not all include damages. The modelled damages using the curves from Ho Chi Minh City are also similar to the reported damages.

The reported damages of Bappenas for 2007 also give some information on the distribution of damage between different land use categories, which can also be use to further verify the model outputs.

Bappenas (2007) estimate that for the 2007 flood, approximately 56% of damages occurred in 'commercial' activities, whilst about 25% occurred in 'housing'. Reference to the pie-charts in Figure 2.5 shows that this distribution of damages is most similar to the modeled distribution of risk based on the vulnerability curves developed in our workshop. Using these curves, commercial activities accounted for ca. 57% of total damages, and residential for 29%. Whilst the overall modeled damage estimate for a 50 year return period flood using the vulnerability curves from Ho Chi Minh City fell between the reported damages for the 2002 and 2007 events, the distribution of the damage between categories is very different for the modeled data (83% commercial, and 7% residential). The same is true for the damage results using the vulnerability curves from northern Jakarta and Kampung Melayu, though the difference in the distribution between categories is less severe than for the Ho Chi Minh City curves.

In summary, the results based on the Jakarta-specific economic exposure values and vulnerability curves appear to produce the most reliable damage estimates, since they have both a similar order of magnitude to reported losses, and a similar distribution of those losses over the categories commercial and residential. None of the other combinations of economic exposure values and curves provide damage estimates satisfying both of these criteria.

2.4.2 Sensitivity of flood risk assessment to the use of different vulnerability curves transferred from elsewhere

As stated earlier, our results are highly sensitive to the vulnerability curves used in the calculation of damages and risk. The difference in annual expected damage between the curves with the lowest values (Bangkok) and highest values (Kampung Melayu) is a factor greater than eight. Moreover, whilst the total annual expected damages are very similar using all three sets of curves based on studies in Jakarta (US$ 321 million using the workshop curves; US$ 333 million using the northern Jakarta curves, and US$ 373 million using the Kampung Melayu curves), our analysis of the distribution of damages between different categories reveals that there is an equafinality problem here. Whilst they all produce similar estimates in this case, only the values based on the workshop curves show a distribution across damage categories similar to the reported damages. Whilst the validation of flood damage and flood risk models is notoriously difficult (e.g. Merz et al., 2010a) due to the lack of reported data, we show here the added value of also using information on the reported distribution of damages across damage categories (where available).

The findings above have important implications for flood risk assessments around the world. Flood risk assessments in various parts of the world are often carried out by transferring vulnerability curves from other countries (e.g. Beckers et al., 2013; Muto et al., 2010; Pillai et al., 2010; Te Linde et al., 2011; Ward et al., 2011a, b). Indeed, Messner et al. (2007) state that relative vulnerability functions (i.e. those in which the damage for different inundation depths is expressed as a percentage of the maximum potential damage, such as those used in this study) are easier to transfer to other regions than absolute damage functions. Whilst this is true, our results show that great care is still needed to assess whether the relative damage relationships are transferable from the region in which they are developed to the target region in which they are to be applied.

Until recently, few flood risk studies assessed the uncertainty in flood damage estimates resulting specifically from the use of vulnerability curves. In the last decade, however, several such studies have shown that they form a large source of uncertainty. For example, Merz et al. (2004) evaluated empirical relationships between inundation depths and reported flood damages to buildings in Germany, and found large uncertainty in the data used to derive damage functions. Other studies have examined uncertainty in flood damage assessment values based on different factors (e.g. inundation depth, elements at risk, and/or vulnerability curves) (e.g. Apel et al., 2008; Egorova et al., 2008; Merz and Thieken, 2009; Meyer et al., 2009b; De Moel and Aerts, 2011; Jongman et al., 2012). De Moel and Aerts (2011) systematically assessed the relative contribution of four components to overall uncertainty, namely: inundation depth, land use; the value of elements at risk; and depth-damage curves, for a case-study region in the Netherlands. For this region, they found that the elements at risk and the depth-damage curves were the most important sources of uncertainty. Jongman et al. (2012) assessed the sensitivity of modeled flood damage for two case study regions (in the UK and Germany) to the use of eight different vulnerability curves; the resulting damages differed from each other by a factor of 4 to 11. In this study, the use of different vulnerability curves leads to results differing by a factor ranging from 2.5 to 8.3. The previous research also found that the uncertainty associated with different vulnerability curves was greatest for floods with relatively low inundation depths (> 2m), since the vulnerability curves show the largest differences between each other at these depths. This finding is also relevant in the case of Jakarta, since the simulated inundation depths have a maximum depth of 1.44 m.

Clearly, flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves. Whilst much research tends to focus on the correct simulation of the flood hazard, the vulnerability assessment part has traditionally been rather simplified and neglected. By holding just one workshop with key local stakeholders who can provide expert knowledge on flood damage in Jakarta, and a series of meetings with experts, we were able to improve our overall damage estimates, highlighting the need to carry out such activities.

2.4.3 Implications

Given the serious nature of the flood problem in Jakarta, there is a clear need for risk-based information in order to adapt to both current and future climatic and socioeconomic conditions (Firman et al., 2011). Since quantitative risk-based assessments, especially in terms of flood damages, are relatively new in Indonesia, our study provides useful information for stakeholders involved in disaster risk reduction in Jakarta, such as BNPB and DKI Jakarta. We found that we were able to develop a flood risk model capable of producing flood damage estimates of a similar order of magnitude to reported events, by using a simple series of expert meetings and a workshop to develop synthetic vulnerability curves specific to the Jakarta situation based on local expert knowledge.

Examples of uses of such risk-based information can be for targeting areas for prioritising risk reduction measures, including spatial planning measures (e.g. not building in the most flood-prone areas and relocation of people in high-risk areas) and building codes (e.g. assigning building use dependent on the risk characteristics of the region, building houses with second storeys so that valuable items are not damage during regular inundation). The flood risk data and maps are also of interest for the insurance industry, since they could be used as a basis for developing a flood insurance market; at present flood insurance is merged with fire insurance in Jakarta. Moreover, flood risk mapping can be used as a tool for increasing awareness on flooding in communities, which may lead to increased interaction between communities and authorities in discussing and designing possible adaptation measures (Fuchs et al., 2009; Van Alphen et al., 2009).

For these purposes, flood risk mapping is particular useful, since it gives a clear idea of areas where flood risk is highest. For example, Figure 2.6 shows the geographical distribution of flood damage for a 50 year return period flood, as simulated using the Damagescanner approach. The digital version of this map, as well as the damage maps for the other return periods, can be found in the supplementary material. The figure clearly shows that most damage is concentrated in northern Jakarta. This part of the city includes the historical centre, which has become a commercial area over time. In turn, this has led to a shift in residential areas to more southern areas and to the northern reclamation area. This also explains why a large proportion (57%) of the simulated damages in Jakarta are in areas with a predominantly commercial land use type. Maps similar to those shown in Figure 2.6 can also be developed for each individual land use class. Compared to existing inundation maps available in Jakarta, maps such as the one displayed in Figure 2.6 provide a large step-forward in terms of their potential for both awareness-raising and adaptation planning. An example of an existing inundation map is shown in Figure 2.7. The map shows inundated areas (in blue) during the 2007 flood event, based on

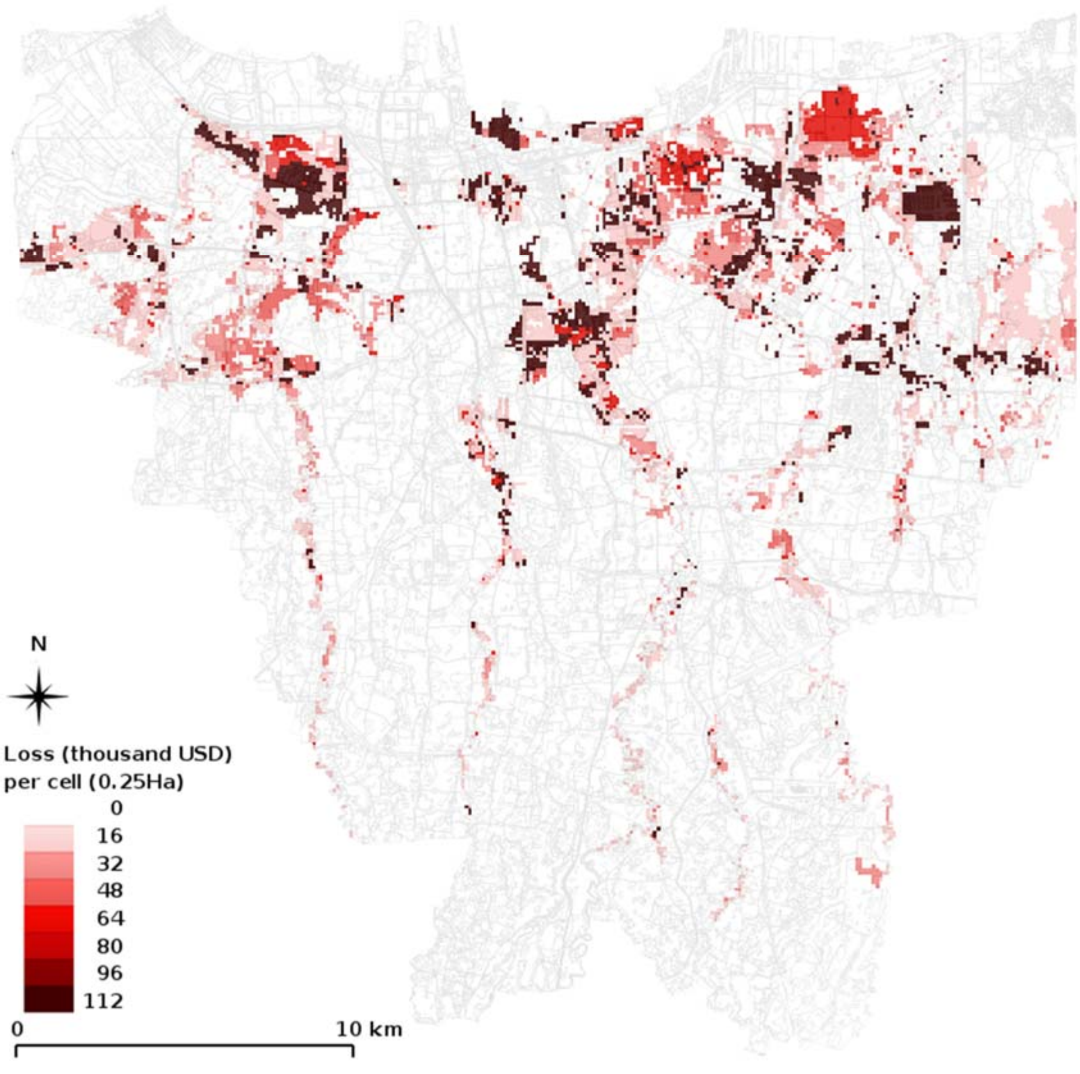

Figure 2.6 Maps of Jakarta showing damages in US$ (thousands) for a 50 year return period flood.

reports from village managers. The delineation of the inundated areas is based on district boundary information. Hence, if a flood was reported in any part of the district, it is displayed in the map as inundated. The flood hazard and risk maps produced in this study provide more geographically specific information, as well as a greater detail of data (for example flood depths instead of just inundated or not; flood extents and depths for different magnitude events; and expected damages related to different flood hazards).

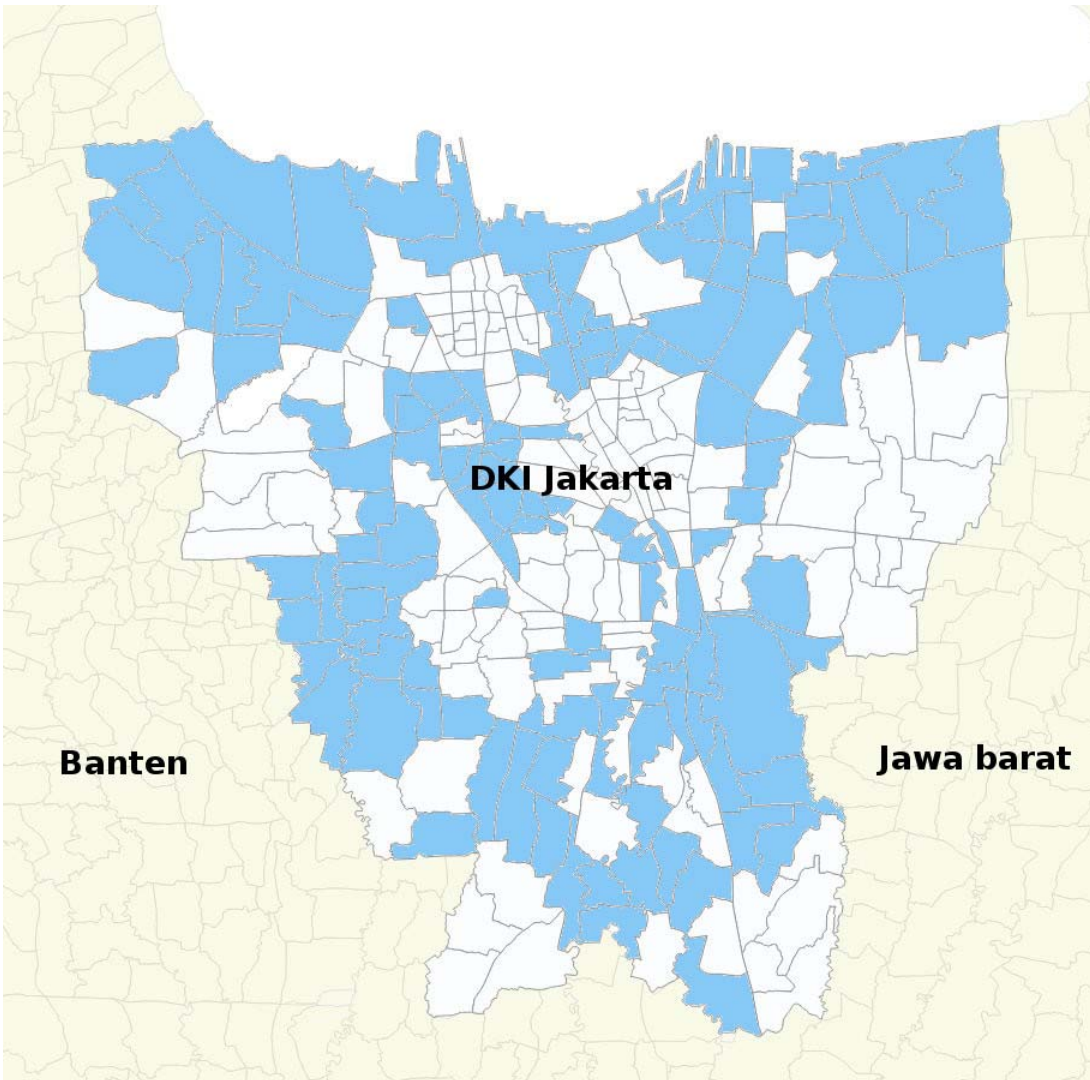

Figure 2.7 Map of Jakarta showing districts reported as being inundated (in blue) by village managers. Map translated from Bakornas PB-UNDP report, 14 February 2007 (Bappenas, 2007).

2.4.4 Limitations and future research

One of the main aims of this Chapter was to assess the sensitivity of river flood risk assessments in Jakarta to the used of different vulnerability curves transferred from other cities. Whilst we have done this, we have not carried out a full assessment of the uncertainty in the overall risk estimates to all input and model parameters. Generally, uncertainties in absolute flood risk estimates are large (Apel et al., 2008; Merz et al., 2010b; De Moel and Aerts, 2011). However, we have shown here that the results of the Damagescanner model do compare well with reported damages, both in terms of total damage and the distribution of that damage across different damage categories. This validation lends support to the use of the model in future studies on flood risk in Jakarta, in which more thorough uncertainty assessments would be useful.

One of the planned applications of the model is to assess the relative change in flood damages and risk in the future (compared to present) under scenarios of changes in both physical and socioeconomic conditions (for examples climate change, land subsidence, land use change, population increase, and increase in asset values). Bubeck et al. (2011) have shown that estimates of relative changes in risk under different scenarios are more robust than absolute flood risk estimates.

In the current work, we have not used the model to assess the effectiveness of adaptation measures in terms of reducing flood risk. However, this has been one of the main reasons for developing such a modelling framework, and this will be addressed, together with stakeholders, in our future research. The Damagescanner approach provides a useful tool in this regards, since it allows the user to assess the influence on risk of changes in any one (or combination) of the three elements contributing to risk, namely hazard, exposure, and vulnerability. For example, Poussin et al. (2012) used Damagescanner in the Netherlands to assess the effectiveness in terms of flood risk reduction of: (a) spatial zoning measures, by adapting the land use maps used to represent exposure; and (b) measures taken at the household level to prevent water from entering houses in the event of a flood, by adapting the shape of the vulnerability curves. Moreover, the model can be used to assess the potential reduction in risk due to changes in the probability of flooding, i.e. the hazard (e.g. Aerts and Botzen, 2012), for example due to a theoretical implementation of higher flood protection standards (such as dikes or water retention areas).

The vulnerability curves developed for this Chapter assume that individuals do not take private adaptation measures to deal with floods or reduce the damages associated with floods. However, it is known that such measures are in fact taken at the household level in many communities, such as building small concrete retaining walls in front of houses to prevent inundation from relatively shallow floods and moving valuable goods to the second storey of houses to avoid damages during floods (Ward et al., 2010; Marfai et al., 2013). Therefore, research is required to examine how such soft-measures taken at the individual and community level affect the relationship between flood depth and damage (and therefore the shape of the vulnerability curve). Once these relationships are known, surveys could be carried out within the communities to ascertain the percentage of households in which such measures are taken. Including this information in the risk modelling approach would further improve the representation of vulnerability. Also related to the vulnerability curves, whilst the validation performed in his study showed that the development of synthetic vulnerability curves for Jakarta led to simulated damages of the same order of magnitude as reported damages, we also plan to compare the vulnerability curves derived using this approach with new curves that are currently being developed in Jakarta based on extensive surveys in several areas.

The current Chapter only assesses flood risk due to river flooding. In practice, Jakarta is also subject to coastal flooding and flash flooding due to intense rainfall within the city. Ward et al. (2011a, b) have assessed the economic exposure due to coastal flooding in northern Jakarta. Future research would benefit from examining the risk from river and coastal flooding, both separately and where they occur simultaneously.

2.5 Conclusions

In response to the demand for risk-based information on flooding in Jakarta, we have developed a river flood risk assessment model, based on the principles of the Damagescanner model, but adapted with local information on hazard, exposure, and vulnerability.

The model was first used to assess flood damage and risk using economic exposure values and vulnerability curves taken from a literature review of past studies in Jakarta. We found that the use of these values to represent exposure led to simulated damage several orders of magnitude larger than reported damages during the 2002 and 2007 floods. Hence, workshop series of expert meetings and a workshop was held to derive new estimates of economic exposure values for different land use classes. For the land use classes that have the highest contribution to flood damage, these were between four to six times lower than the values taken from the past studies. Using these new estimates of economic exposure values in the risk model led to simulated damages of the same order of magnitude as reported damages.

We then assessed the sensitivity of flood risk estimates to the use of different vulnerability curves transferred from other cities. To do this, we took five sets of vulnerability curves from studies in cities in Southeast Asia, namely: Bangkok, Manila, Ho Chi Minh City, northern Jakarta, and Kampung Melayu (Jakarta). Next to these, we used our series of expert meetings and a workshop to derive a new set of synthetic vulnerability curves generic for the entire city of Jakarta. We found that flood risk is highly sensitivity to the choice of vulnerability curve. The difference in annual expected damage between the curves with the lowest values (Bangkok) and highest values (Kampung Melayu) is a factor greater than eight.

We found that the damage estimates based on the workshop-derived values of economic exposure values and vulnerability curves were closest to the damages reported during the floods of 2002 and 2007. Whilst the vulnerability curves for Ho Chi Minh City, northern Jakarta, and Kampung Melayu also led to total modelled damages similar to the reported values, only the modelled values using the new workshop-derived vulnerability curves led to a similar distribution of damages across different land uses, compared to the reported data.

These findings give confidence in the use of the model for flood risk assessment in Jakarta. Using the workshop-derived vulnerability curves and values for economic exposure values, we estimated the present day annual expected damage as a result of river flooding in Jakarta to be ca. US$ 321 million. In our future work, the model will be used to assess the relative change in risk in the future due to changes in physical and socioeconomic conditions (e.g. climate change, land subsidence, population growth), and to assess the effectiveness of different adaptation measures in terms of their potential to reduce, or limit the growth of, that risk.

Our findings demonstrate that flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves. Whilst much research tends to focus on the correct simulation of the flood hazard, the vulnerability assessment part has traditionally been rather simplified and neglected. Even the simple approach used here to develop synthetic vulnerability curves, led to improved estimates of flood damages (in terms of the agreement with reported damages) when compared to the simple adoption of vulnerability curves from other cities in south-east Asia.

3 RIVER FLOOD RISK IN JAKARTA UNDER SCENARIOS OF FUTURE CHANGE

This chapter is based on

Budiyono Y, Aerts JCJH, Tollenaar D, Ward PJ (2016) River flood risk in Jakarta under scenarios of future change. Nat Hazards Earth Syst Sci 16:757–774.

Abstract

Given the increasing impacts of flooding in Jakarta, methods for assessing current and future flood risk are required. In this Chapter, we use the DamagescannerJakarta risk model to project changes in future river flood risk under scenarios of climate change, land subsidence, and land use change. Damagescanner-Jakarta is a simple flood risk model that estimates flood risk in terms of annual expected damage, based on input maps of flood hazard, exposure, and vulnerability. We estimate baseline flood risk at US$ 186 million p.a. Combining all future scenarios, we simulate a median increase in risk of +180 % by 2030. The single driver with the largest contribution to that increase is land subsidence (+126 %). We simulated the impacts of climate change by combining two scenarios of sea level rise with simulations of changes in 1-day extreme precipitation totals from five global climate models (GCMs) forced by the four Representative Concentration Pathways (RCPs). The results are highly uncertain; the median change in risk due to climate change alone by 2030 is a decrease by −46 %, but we simulate an increase in risk under 12 of the 40 GCM–RCP–sea level rise combinations. Hence, we developed probabilistic risk scenarios to account for this uncertainty. If land use change by 2030 takes places according to the official Jakarta Spatial Plan 2030, risk could be reduced by 12 %. However, if land use change in the future continues at the same rate as the last 30 years, large increases in flood risk will take place. Finally, we discuss the relevance of the results for flood risk management in Jakarta.

3.1 Introduction

Jakarta, the capital city of Indonesia, suffers from regular floods that cause significant economic damage. For example, the major floods in 2002, 2007, 2013, and 2014 have caused billions of dollars of direct and indirect economic damage (Bappenas, 2007; Ward et al., 2013a; Sagala et al., 2013). Whilst flooding in Jakarta is not a new problem per se (Noorduyn and Verstappen, 1972), the scale of the flood impacts has increased greatly in the last few decades. This increase is related to a large number of drivers, both physical and socio-economic. Physical drivers include land subsidence, low drainage or storage capacity in Jakarta's rivers and canals as a result of being clogged by waste and sediments eroded from upstream, and possibly climate change. Socioeconomic drivers include a rapidly growing population, and land use change causing a growth in economic assets located in potentially flood-prone areas. Extensive overviews of the drivers of increasing flood risk can be found elsewhere (e.g. Budiyono et al., 2015; Caljouw et al., 2005; Steinberg, 2007; Ward et al., 2011a).

As in most parts of the world, flood management in Jakarta has traditionally focused on technical protection measures, in order to lower the probability of the flood hazard through dikes and levees (Texier, 2008). Given the increasing impacts of flooding, and the importance of both physical and socio-economic drivers on risk, recent years have seen a shift towards a more flood-risk-management-based approach in Jakarta (Ward et al., 2013b). Hereby risk is defined as a function of hazard, exposure, and vulnerability, as per the definitions in UNISDR (2011). In this approach, flood risk management measures that address the other elements of risk (exposure and vulnerability) are also considered next to, and indeed in combination with, traditional hazard-reducing measures. This can be seen in ongoing and planned flood risk management activities, such as the planned Garuda Project (Kementerian Koordinator Bidang Perekonomian, 2014), as part of the National Capital Integrated Coastal Development project, as well as the Jakarta Spatial Plan 2030 (Perda DKI Jakarta 1, 2012), which specifically mentions the integration of flood control and zoning with spatial planning measures. Flood risk is also identified in the Law No. 24/2007 as well as its description in Government Regulation No. 21/2008. The implementation of the latter is documented in the National Action Plan for Disaster Risk Reduction (NAP-DRR) 2010–2012 at country scale by the National Development Planning Agency (Bappenas, 2010) and the United Nations Development Programme.

The flood risk approach can also be seen in scientific developments related to flooding in Jakarta. For example, using global models, Hanson et al. (2011) examined the exposure of people and assets to coastal flooding in 136 port cities worldwide, including Jakarta, and using a similar approach, Hallegatte et al. (2013) estimated flood risk in terms of annual expected damages in those cities. More specifically for Jakarta, Ward et al. (2011a) assessed the potential exposure of assets to coastal flooding in Jakarta, but did not carry out a full flood risk analysis.

The first city-scale quantitative flood risk assessment in Jakarta was that of Budiyono et al. (2015), who developed a river flood risk assessment model (Damagescanner-Jakarta) to assess current river flood risk. However, when planning adaptation measures and strategies, it is also vital to know how risk will develop in the future. Future flood risk in Jakarta is complicated, since it will depend on the interplay of the myriad of physical and socio-economic drivers of risk. For coastal flooding, the global-scale studies of Hanson et al. (2011) and Hallegatte et al. (2013) examined the potential influence of changes in climate, land subsidence, and population growth on flood exposure and risk. However, they focus only on coastal flooding, using rough estimates from global models, and neither on river floods nor the projection in the future.

The aim of this Chapter, therefore, is to further apply and develop the Damagescanner-Jakarta risk model from Budiyono et al. (2015) to project possible future changes in river flood risk in Jakarta as a result of climate change, land subsidence, and land use change. Using these simulations, we can examine the individual influence of these risk drivers to overall changes in flood risk. Given the limited amount of input data for the future scenarios of subsidence and land use change, this Chapter is not intended to provide a full uncertainty assessment. For each driver of risk, we use the best available data to develop future scenarios, meaning that more scenarios are available for some drivers (e.g. climate change) than others (e.g. land subsidence and land use change). Therefore, the results should be interpreted as first-order estimates of the potential order of magnitude of the future changes in risk.

3.2 Method

In this study, we use Damagescanner-Jakarta, a flood risk model for Jakarta developed by Budiyono et al. (2015) in the Python programming language. Damagescanner-Jakarta estimates flood risk as a function of hazard, exposure, and vulnerability. The model is explained in detail in Budiyono et al. (2015). In brief, the model has a horizontal resolution of 50 m × 50 m, and works by combining maps of hazard and exposure with a depth–damage function to represent vulnerability. For each grid cell, the model identifies the depth of inundation found in the flood hazard map. For this grid cell, it then identifies the land use class and the associated value of maximum damage for this class. The model then uses the depth–damage function for the land use class in question, to identify what proportion of the maximum damage would occur for the inundation depth in that cell. By combining these three elements, the model estimates the direct economic damage. This procedure is carried out for floods of several return periods between 2 and 100 years. Finally the expected annual damage is calculated as the area under the exceedance probability-loss (risk) curve, whereby the area is estimated using a trapezoidal approximation (e.g. Meyer et al., 2009).

In Budiyono et al. (2015), the model was set up to simulate risk under current conditions. Here, we further improve the model to simulate future flood risk, by including projections of physical and socio-economic change. These are incorporated into the model by changing the input data representing the three elements of flood risk, as presented in the framework of analysis in Figure 3.1. In the following sections, the data used to represent hazard, exposure, and vulnerability are described.

3.2.1 Hazard

Flood hazard is represented by maps showing inundation depth and extent for several return periods (1, 2, 5, 10, 25, 50, and 100 years). To simulate flood hazard, we used the SOBEK Hydrology Suite, which is a model suite combining a Sacramento hydrological model and a 1-D/2-D hydraulics model (Deltares, 2014). More information on the model and its use in Damagescanner-Jakarta can be found in Budiyono et al. (2015). The model for Jakarta was developed during the flood hazard mapping project and the Flood Management Information System project (Deltares et al., 2012), by Deltares, National Bureau for Meteorology (BMKG), Research Center for Water Resources (Pusair) and Jakarta Office of Public Works (DPU-DKI). For baseline conditions, we used the hydraulic schematization resulting from field measurements in 2012.

In this study, we also simulated inundation maps (for each return period) for different future scenarios of climate change and land subsidence. To simulate impacts from climate change, we forced the model with changes in two factors: precipitation intensity and sea level rise.

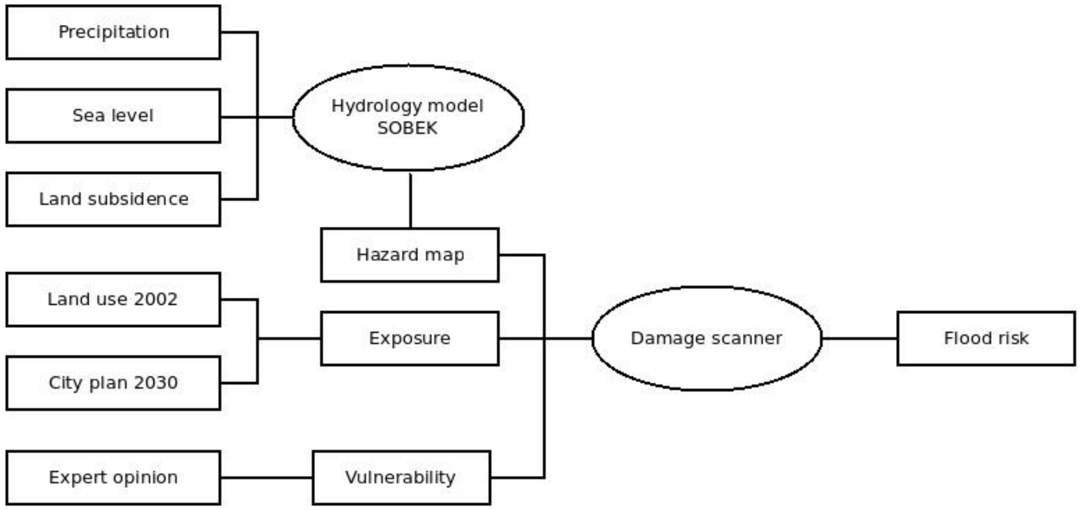

Figure 3.1 Framework of analysis.

Uncertainty in future changes in precipitation, and precipitation intensity, is known to be very high in the region, as discussed in Section 3.4.1. Hence, we estimated change in precipitation intensity using output data from a large range of global climate models (GCMs) and Representative Concentration Pathways (RCPs). To do this, we used bias-corrected daily data on precipitation from five GCMs, obtained from the ISI-MIP project (Inter-Sectoral Impact Model Intercomparison Project) (Hempel et al., 2013). These bias-corrected data are available at a horizontal resolution of 0.5° × 0.5°. The bias-correction method is described in detail by Hempel et al. (2013). In brief, they modified the daily variability of the simulated precipitation data around their monthly means, in order to match daily precipitation variability in the EUWATCH baseline reanalysis data set (Weedon et al., 2011) for the period 1960–1999. Monthly variability and mean were corrected using a constant multiplicative correction factor, which corrected for long-term differences between simulated monthly mean precipitation and mean monthly precipitation from the EU-WATCH baseline reanalysis data set.

These downscaled future climate data were used for five GCMs, namely GFDL-ESM2M, HadGEM2-ES, IPSLCM5A-LR, MIROC-ESM-CHEM, and NorESM1-M, and for the following Representative Concentration Pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Thus, we used 20 GCM–RCP combinations in total. We calculated change factors in daily precipitation between the baseline climate data set and each GCM–RCP combination, for each of the return periods used in this study. The extrapolation to the different return periods is carried out by fitting the Gumbel distribution to the time series of annual maximum precipitation, whereby the Langbein correction (Langbein, 1949) is applied for return periods lower than 10 years. We carried out this statistical process for each of the GCM– RCP combinations for two time periods, namely 2010–2049 and 2040–2079. These time periods are used in the Chapter to represent climate conditions in 2030 and 2050, respectively. Finally, these change factors were applied to the standard input of the SOBEK model under current conditions, which is based on gauged precipitation data at 29 stations.

In the SOBEK model, sea level is used as a boundary condition at the river–sea interface. Therefore, we used two simple scenarios of sea level rise between 2010–2030 and 2010– 2050, and added these to the SOBEK input baseline sea level for 2010. These low and high scenarios represent the likely range in global sea level rise projections of the IPCCs Fifth Assessment Report (AR5) (IPCC, 2013, Table

AII7.7) average across all four RCPs. The scenarios represent increases in sea level of 6 and 11 cm respectively for the period 2010– 2030, and 14 and 24 cm respectively for the period 2010– 2050.

Finally, we also produced hazard maps showing the magnitude of continued land subsidence. This was done by subtracting projections of future subsidence from the digital elevation model (DEM) used in SOBEK (Deltares et al., 2012; Tollenaar et al., 2013). The DEM has a horizontal resolution of 50 m × 50 m. In SOBEK, the original DEM is replaced by the new DEM (including future subsidence), and the hydrological–hydraulic simulations are repeated. This results in new flood hazard maps showing the flood inundation and extent under the land subsidence scenario, which are then used as input to the Damagescanner-Jakarta model. A map showing the spatial distribution of the projected land subsidence between 2012 and 2025 used in our model set-up is shown in Figure 3.2. We used a hypothetical scenario of land subsidence, in which the current rate of subsidence (Abidin et al., 2011) continues at the same rate, and ultimately stops in the year 2025. This current rate of subsidence ranges from 1 to 15 cm per year across different parts of the city; the resulting spatial distribution of land subsidence over our study period is shown in Figure 3.2. The linear trend in future subsidence was decided in close collaboration with the National Bureau of Meteorology (BMKG) and Jakarta Office of Public Works (DPU-DKI). The linear rate of subsidence is based on investigations in several other cities over longer time periods, for example Tokyo for 60 years (Endo et al., 2001), Tokyo lowlands for 20 years (Aichi, 2008), and Bangkok for 20 years (Phien-wej et al., 2006). In several cities, it has been shown that land subsidence can be reduced rather rapidly once groundwater extraction is reduced. For example, in Tokyo the government implemented a gradual groundwater extraction policy for 13 years by preventing the creation of new wells and regulating groundwater extraction in the central districts of Tokyo to an absolute minimum (Tokunaga, 2008). As a result, groundwater potential recovered quickly, particularly due to high recharge rates in the region, and the land subsidence stopped in several years. In March 2015, the Ministry of Public Works (PU) in Indonesia issued the "100-0-100" sanitation policy (Direktorat Jenderal Cipta Karya, 2015), which means that the government aims to provide 100 % of water supply needed by Jakarta by 2019. If the policy target is achieved in time, it is the expectation that land subsidence would reduce quickly after 2019, and hence, the assumption to continue land subsidence until 2025 in the model.

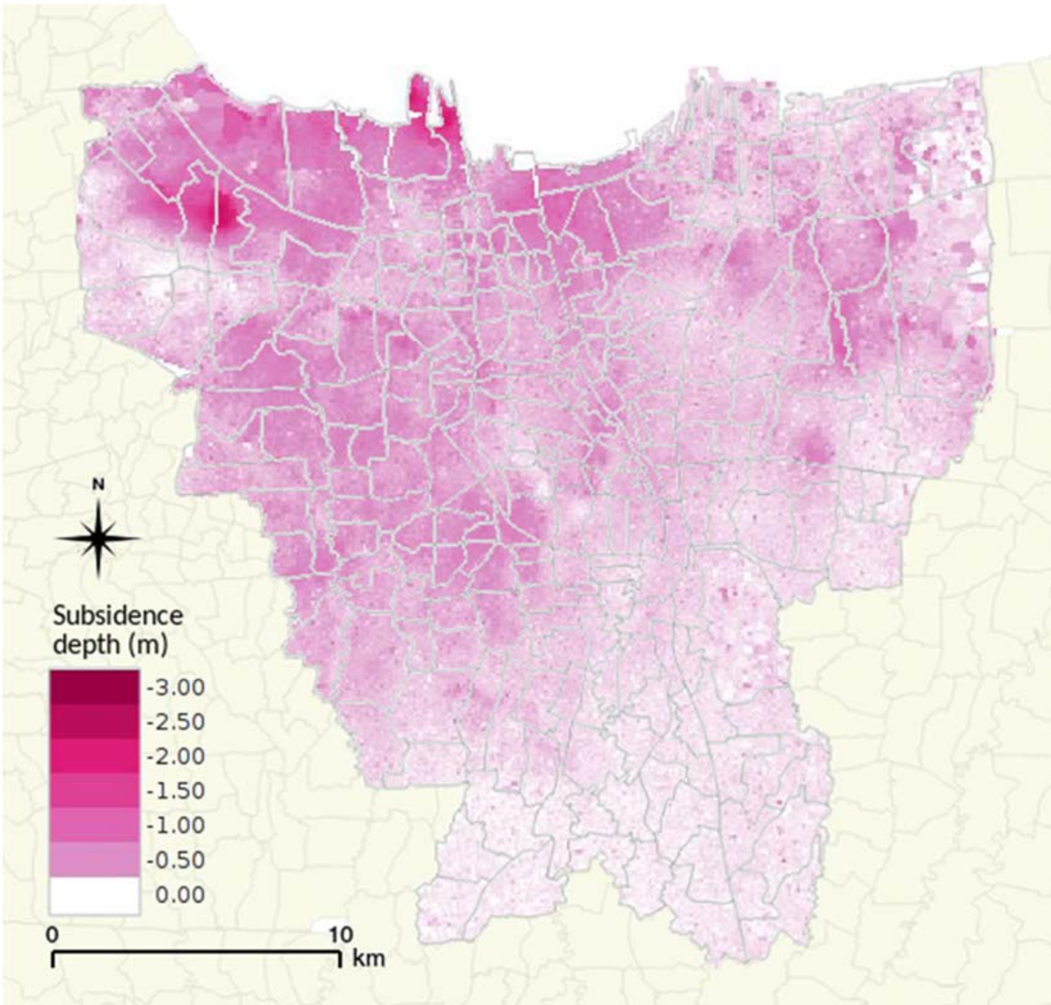

Figure 3.2 Spatial distribution of projected total land subsidence over the period 2012–2025.

As was the case in Budiyono et al. (2015), we assume that no flood damage occurs at a return period of 1 year. Hence, simulated flood depths at 1-year return period are subtracted from simulated flood depths for higher return periods. This was carried out in order to represent an assumption of zero damage at bankfull discharge (e.g. Ward et al., 2011b; Winsemius et al., 2013). The flood hazard maps generated by SOBEK represent a situation in which the flood management system in place is operating under normal conditions, and cannot account for system failures or those caused by a lack of maintenance.

3.2.2 Exposure

In Damagescanner-Jakarta, exposure is represented through land use maps, whereby each land use class has an associated maximum economic exposure value (in US$ per hectare). In our earlier study (Budiyono et al., 2015) we used the land use map 2002 (DTR DKI, 2007) to represent baseline conditions. However, we now have a more up-to-date land use map available, namely the land use map 2009, which was issued by the Office of City Planning, Jakarta (Perda DKI Jakarta 1, 2012). Hence, for this Chapter, we used this more up-to-date land use map 2009 to represent baseline land use.

The land use map 2009 contains a larger number of classes than the land use map 2002. Hence, the land use map 2009 was first reclassed to show the same land use classes as the land use map 2002; the reclassification was carried out as per Table 3.1. This reclassification was necessary because the estimates of maximum economic exposure value and the depth– damage function used in Damagescanner-Jakarta are based on the original land use classes from the land use map 2002.

Table 3.1 Reclass of 21 land use classes from land use map 2009 to the 12 land use classes of the land use map 2002.

	Landuse names	
No	2002	2009
1	Agriculture and open space	Wetland agriculture, Dryland agriculture, Open space, Unused land
2	Commercial and business	Health care, Others, Commercial , Market
3	Education and public facility	Education
4	Forestry	n/a
5	Government facility	Government facility
6	High density urban kampung	Urban kampung, Worship place
7	Industry and warehouse	Service station, Manufacture, Industrial place, Warehouse, Animal husbandry
8	Low density urban kampung	n/a
9	Park and cemetery	Cemetery
10	Planned house	Planned house
11	Swamp river and pond	Pond fishery
12	Transportation facility	Transportation facility

Table 3.2 Area per land use class compared to total area of Jakarta (%) for the land use map 2002 and the land use plan 2030. Several of the original land use classes were reclassed as per the notes under the table.

No	Land use class name	2002	2030
1	Agriculture and open space[a]	18.65	14.17

2	Residential[b]	57.85	57.61
3	Swamp river and pond	3.61	1.00
4	Industry and warehouse	7.06	8.87
5	Commercial and business	8.28	16.46
6	Government facility[c]	4.53	1.98
7	Forestry	0.01	0.33
	Total	100.00	100.00

[a] Merge of "Agriculture" and "Agriculture and open space" in both the baseline land use map and Spatial Plan 2030.

[b] Merge of "High density urban kampong", "Low density urban kampong" and "Planned house" in baseline land use map; and merge of "Residential" and "Residential with greenery" in Spatial Plan 2030.

[c] Merge of "Government facility", "Education and public facility", and "Transportation facility" in baseline land use map; merge of "Government facility", and "Transportation facility in Spatial Plan 2030, while land use class "Education and public facility" does not exist.

For future land use, we took two approaches to estimate the future influence of land use change in 2030. Firstly, we developed an idealized land use scenario for 2030, based on the official Jakarta Spatial Plan 2030 (Perda DKI Jakarta 1, 2012), which was recently approved by the lower House of Representatives, Jakarta. The Spatial Plan 2030 contains 12 land use classes, which is the same number of classes as the land use map 2002. However, three of the land use classes in the Spatial Plan 2030 pertain to the planned new reclamation islands, which should not be affected by river flooding. Hence, three of the land use classes present in the land use map 2002 are not used in the Spatial Plan 2030. Note also that the Spatial Plan represents an idealized situation, and as a result it shows much more homogenous patterns of land use than the land use map 2009 used for the baseline conditions. Therefore, we represented the future change in risk due to land use change as follows. Firstly, we reclassed several land use classes to derive similarities of land use between the current land use map and the Spatial Plan 2030 (see notes accompanying Table 3.2). Then, using GIS analysis we calculated the total area of each land use class in 2009 and 2030, as shown in Table 3.2. From this, we were able to derive factors showing the change in the area of each land use category. This was used in the damage calculations to estimate the change in risk per land use category between the baseline and future scenarios. For example, the total area of land use class "Industry and warehouse" increases from 7.06 to 8.87 % (an increase of ca. 26 %). Hence, the annual expected damage associated with this land use class was increased by 26 % in the future scenario compared to the baseline scenario. Whilst this map represents an idealized scenario, assuming that all of the plan is implemented, it is useful to use in this study since it is the map used in official studies in Jakarta. Each land use class is assigned a value of economic exposure per hectare (Table 3.3). These values were derived via a series of expert meetings and a workshop, as described in detail in Budiyono et al. (2015), and as described briefly in Section 3.2.3. For land use classes that are consistent for both land use maps, values are taken directly from Budiyono et al. (2015). For land use classes where reclassifications were required as described above, exposure values were derived by area-weighted averaging. For example, the maximum value of land use class "Residential" in the land use map 2030 results from the average of two classes, weighted by spatial percentage of land use classes "High density urban kampung" and "Low density urban kampung" in the baseline land use map (detail in Table 3.3).

Table 3.3 Maximum economic exposure values per land use class, using an exchange rate of US$ 1 = IDR 9,654.

No	Land use class name	New maximum economic exposure value (thousand US$ per hectare)*
1	Government facility[a]	301.0
2	Forestry	10.4
3	Industry and warehouse	517.9
4	Commercial and business	517.9
5	Residential[b]	150.6
6	Residential with greenery[c]	341.8
7	Agriculture	1.6
8	Swamp river and pond	3.8
9	Agriculture and open space	3.1

[a] Area-weighted average of land use classes "Education and public facility" and "Government facility" in land use map 2002.

[b] Area-weighted average of land use classes "High density urban kampung" and "Low density urban kampung" in land use map 2002.

[c] Land use class "Planned house" in land use map 2002.

Table 3.4 Median and standard deviation of precipitation multiplication between the 5 GCMs for each RCP scenario in 2030 and 2050

	Median	Standard deviation
2030		
RCP 2.6	0.79	0.33
RCP 4.5	0.76	0.47
RCP 6.0	0.79	0.51
RCP 8.5	0.85	0.49
2050		
RCP 2.6	0.79	0.32
RCP 4.5	0.82	0.48
RCP 6.0	0.79	0.56
RCP 8.5	0.96	0.58

Secondly, because the Spatial Plan 2030 represents an idealized situation, we also developed a simple method to assess how risk may change in the future if this idealized plan is not achieved. To do this we calculated flood risk using Damagescanner-Jakarta using the land use maps 1980, 1995, 2002, and 2009, all reclassed to the same land use classes as used in the land use map 2002. We then fit a second-order polynomial fit ($R^2 = 0.837$) to these flood risk calculations, and used the resulting regression equation to estimate risk in 2030. Hence, this gives a first-order estimate of how future risk may develop in the future if land use change continues at the same rate as over the period 1980–2009. Unfortunately, no land use simulation models are available to specifically simulate future land use in Jakarta.

3.2.3 Vulnerability

The third element of the risk framework is vulnerability. In this Chapter, we adopt the definition of UNISDR (2011), that vulnerability is "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". In DamagescannerJakarta, vulnerability is represented by depth–damage functions (Merz et al., 2010b), which show the fraction of the maximum economic exposure value per land use type that would actually result in damage for different inundation depths (see Figure 3.4). In reality, these functions only represent physical vulnerability, but not social vulnerability, i.e. the sensitivity of populations to natural hazards and their ability to respond to and recover from their impacts (e.g. Cutter and Finch, 2008; Cutter et al., 2013; Gain et al., 2015). We therefore use the term depth–damage functions throughout the rest of this Chapter, to avoid confusion.

The depth–damage functions for Jakarta were derived in a previous study (Budiyono et al., 2015), for each of the land use classes in the land use map 2002. These synthetic depth– damage functions were developed through a series of expert meetings and a workshop, following the fuzzy cognitive mapping method (Groumpos, 2010; Stach et al., 2010). The process consisted of two rounds. First, a series of four expert meetings was held employing nine stakeholders in order to derive preliminary maximum economic exposure values and depth–damage functions. Secondly, a 1-day workshop was held with a larger group of different stakeholders in order to validate, and where necessary to improve the initial values and functions. The resulting depth–damage functions are shown in Figure 3.4. For further details on the method used to derive the depth–damage functions, including the participants of the expert meetings and workshop, we refer the reader to Budiyono et al. (2015). The same depth–damage functions were used for the baseline scenario and 2030, since no data were available on potential changes in the curves over that time (see Section 3.4.3).

3.3 Results

This section is split into three subsections. Firstly, we describe the flood risk results under baseline conditions in comparison to past results reported in Budiyono et al. (2015) to show the change resulting from the new model schematization and the newly operational flood protection measures. Secondly, we show the potential impacts of climate change on extreme precipitation, one of the drivers of risk change discussed in this Chapter. Thirdly, we show the potential changes in flood risk between the baseline situation and the future, based on the various future scenarios. We examine both the individual and combined influence of the different drivers on flood risk.

3.3.1 Flood risk under baseline conditions

In this study, we ran Damagescanner as described in section 3.2. The resulting flood risk under baseline conditions is US$ 186 million p.a. Figure 3.3 shows the distribution of flood risk compared to a modelled flood hazard map for a return period of 100 years. This number is significantly lower than our past result as presented in Budiyono et al. (2015), in which flood risk was estimated to be US$ 321 million p.a. There are several reasons for this. Firstly, as explained in section 3.2.2, in the current study we use a more up-to-date land use map to represent baseline exposure. If we use the same land use map as was used in Budiyono et al. (2015), the estimate of baseline risk using the new model set-up is US$ 143 million p.a. The lower flood risk estimate in the current Chapter compared to our previous estimate is due to changes that have been carried out in the hydraulic system in Jakarta, which have been included in the revised schematization of the hydrological and hydraulic model used for this

Chapter. The version of the hazard model used in Budiyono et al. (2015) used a hydraulic schematization based on the situation in 2007. In the current Chapter, we used an updated version of the model in which the hydraulic schematization has been updated to include flood protection measures, including flood gates and weirs that have been implemented between 2007 and 2013. Moreover, the revised version of the model has a more accurate representation of those flood protection measures that were already in place in 2007. The most important single change in the hydrological and hydraulic situation since 2007 has been the completion of the East Flood Canal (Banjir Kanal Timur). This canal diverts flood waters away from the eastern side of the city. It was not included in the former schematization of SOBEK, but is included in the new schematization used in this Chapter. Comparing the flood hazard maps for a given return period based on the 2007 and 2013 schematizations shows that the simulated flood extent in the eastern half of the city has indeed decreased. For example, in Figure 3.5 we show the differences in inundation depth between 2007 and 2013; in the eastern half of the city, the flood extent has decreased by 27 % in terms of width or by 34 % in terms of volume.

As a result of the major changes in the hydrological and hydraulic situation since 2007, it is difficult to directly compare our modelled flood damages directly with reported damages for floods that occurred before that time. Reported damages for the 2007 flood are available from Bappenas, namely US$ 890 million. This flood had a return period of ca. 50 years. Our simulated damages for a 50-year return period flood using the new model schematization and land use map 2009 are US$ 579 million, i.e. 35 % lower than the reported losses in 2007. This seems reasonable given the afore mentioned changes in the hydrological and hydraulic situation since that time.

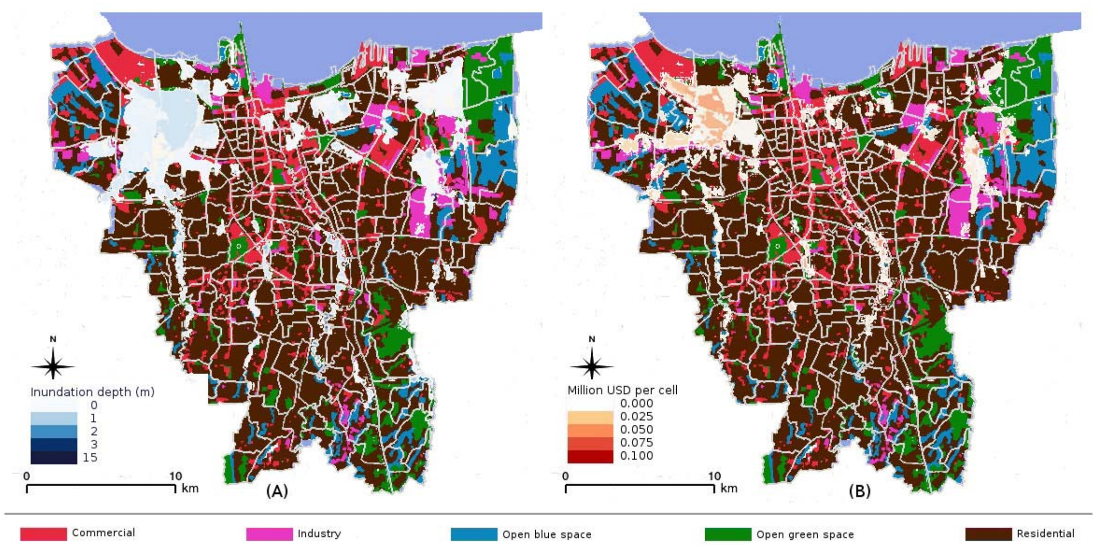

Figure 3.3 Flood hazard map for a return period of 100 years in current conditions (a); and annual expected damage (b). The background is land use map 2009, reclassed into five land use classes found in the three previous land use maps.

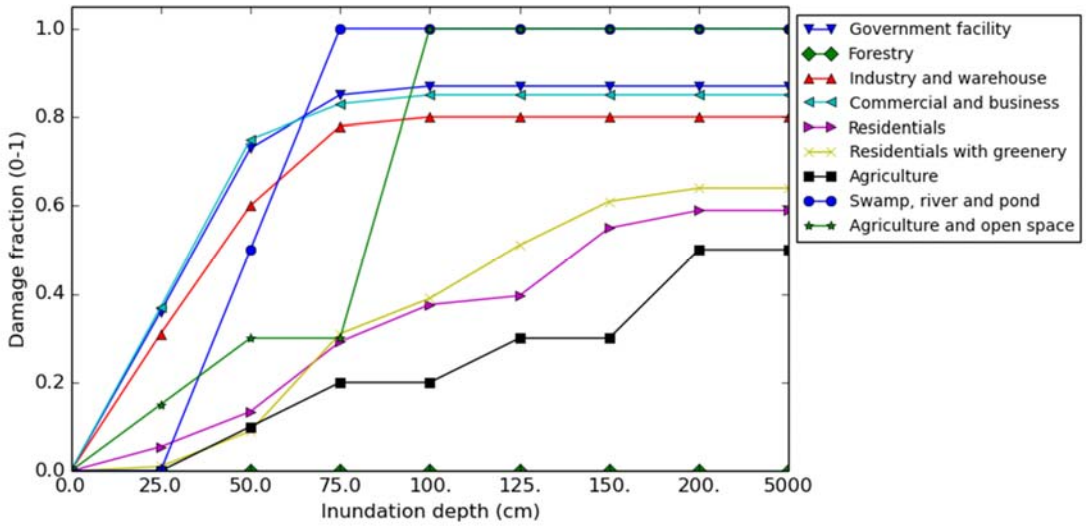

Figure 3.4 Depth–damage functions used in this study for each land use class.

The reliability of the new 2013 flood maps has also been compared with empirical flood maps produced by the National Disaster Management Office (BNPB). These maps show which village administration units (Kelurahan) in Jakarta actually suffered from inundation during the 2007 and 2013 flood events (Figure 3.6). We can see that the spatial pattern in the western half remains fairly similar, whilst far fewer Kelurahan were reported as suffering from inundation during the 2013 flood in the eastern part. It should be noted that the return periods of the floods in 2007 and 2013 are not exactly the same; the former is estimated to have a return period of ca. 50 years, compared to 30 years in the latter. Hence, the figure is only intended to demonstrate the fact that there appears to be an overall agreement between the 2013 modelling results and the government flooding maps showing smaller inundation areas in the eastern parts as compared to previous research. This explains our lower risk estimates compared to Budiyono et al. (2015).

Finally, the changes in the inundation depths are also partly due to further modifications of the SOBEK schematization in terms of its hydraulics. Namely, the Saint–Venant equations have been implemented on more detailed dimensions of stream fractions, which produces finer 1-D overtopping and a more disperse but shallower 2-D floodplain.

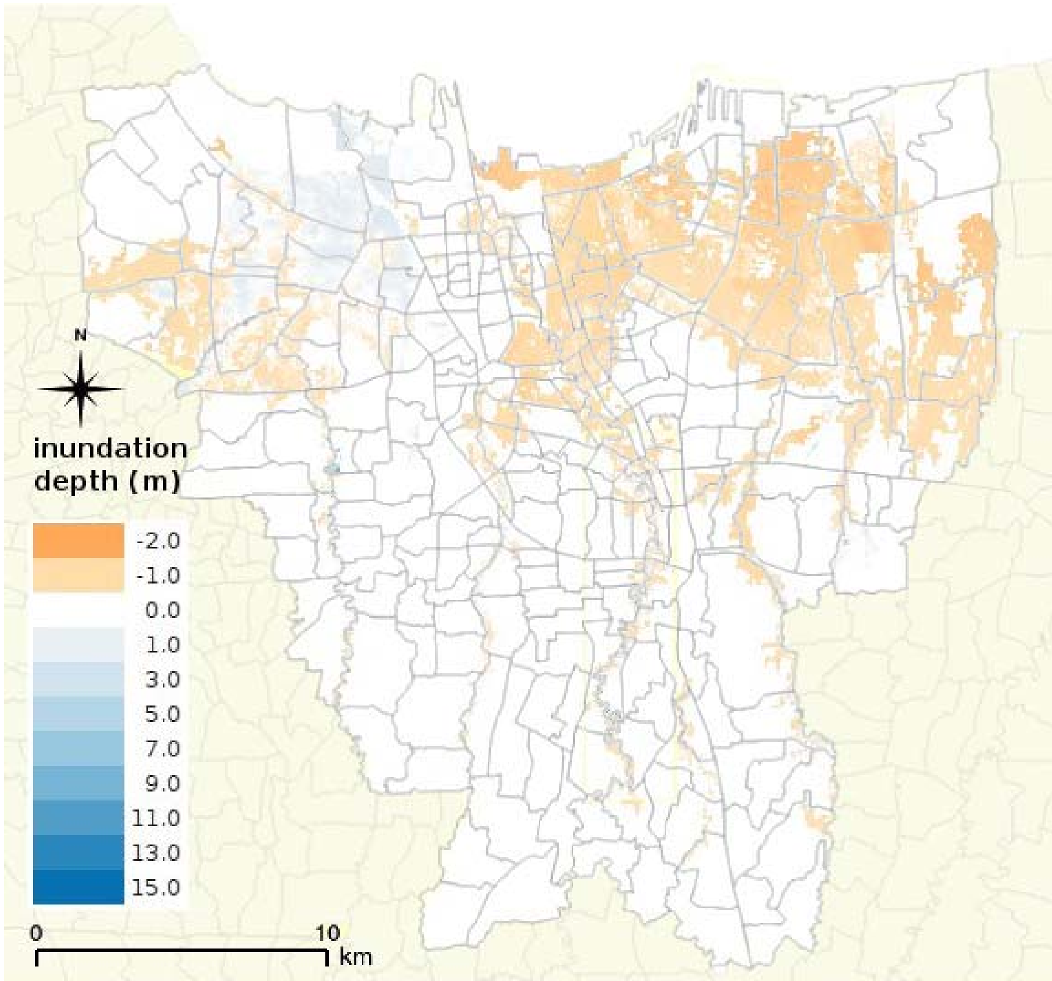

Figure 3.5 Change in inundation depth for a return period of 100 years in the flood hazard maps based on the SOBEK schematization of 2013 compared to that of 2007.

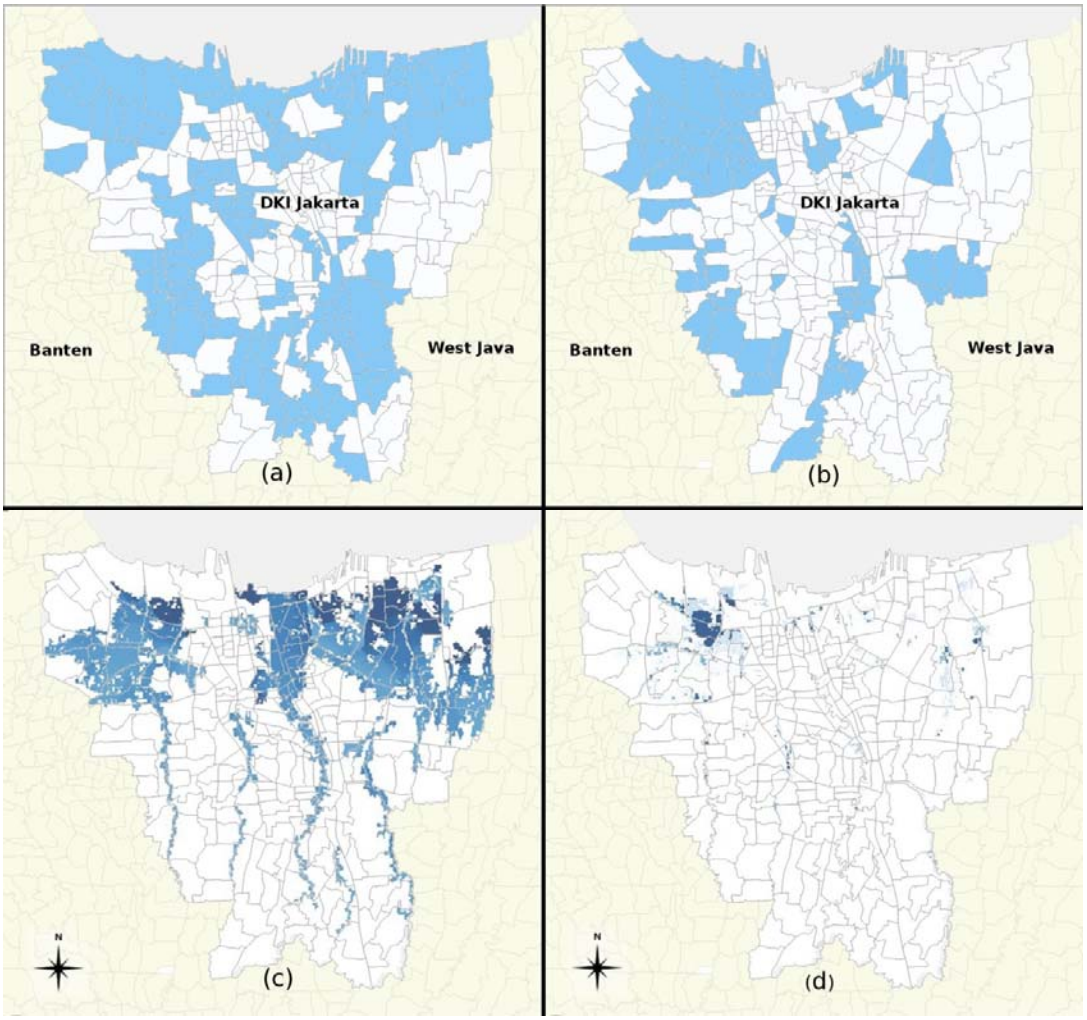

Figure 3.6 Maps showing Kelurahan (village administration units) in which part of the village administration unit was reported to be inundated in the (a) 2007 and (b) 2013 floods. These maps were reported to the National Disaster Management Office (BNPB) by the village administrator. The estimated return periods of the flood events in 2007 and 2013 are 50 and 30 respectively. Below, the inundation maps from the SOBEK model are shown, based on (c) 2007 schematization and a return period of 50 years, and (d) 2013 schematization and a return period of 25 years.

3.3.2 Potential impacts of climate change on extreme precipitation

As described in section 3.2.1, we estimated changes in the magnitude of 1-day precipitation sums for the different return periods used in this study, based on data from five GCMs and four RCPs, i.e. 20 GCM–RCP combinations. In Figure 3.7, we present precipitation factors that show changes in extreme 1day precipitation for different return periods, whereby a factor "1" represents the extreme 1-day precipitation under baseline conditions. The results for 2030 and 2050 are shown in Figure 3.7.

The results show that the impacts of climate change on extreme 1-day precipitation in 2030 and 2050 are highly uncertain. The median values of both 2030 and 2050 show lower 1-day precipitation sums by ca. 20 % (2030) and 19 % (2050) compared to baseline conditions, with very little variation between the different return periods (standard deviations 0.8 and 1.2 % in the sequential years). However, whilst the median values indicate a decrease, the uncertainty is extremely large, as reflected by the large range in values, and the large range between the 25th and 75th percentiles. Even the sign of the change is highly uncertain. Moreover, Figure 3.7 also shows that this spread in the distributions of change in 1-day precipitation sums increases as the return period increases, reflecting even greater uncertainty in changes in the precipitation events with a longer return period.

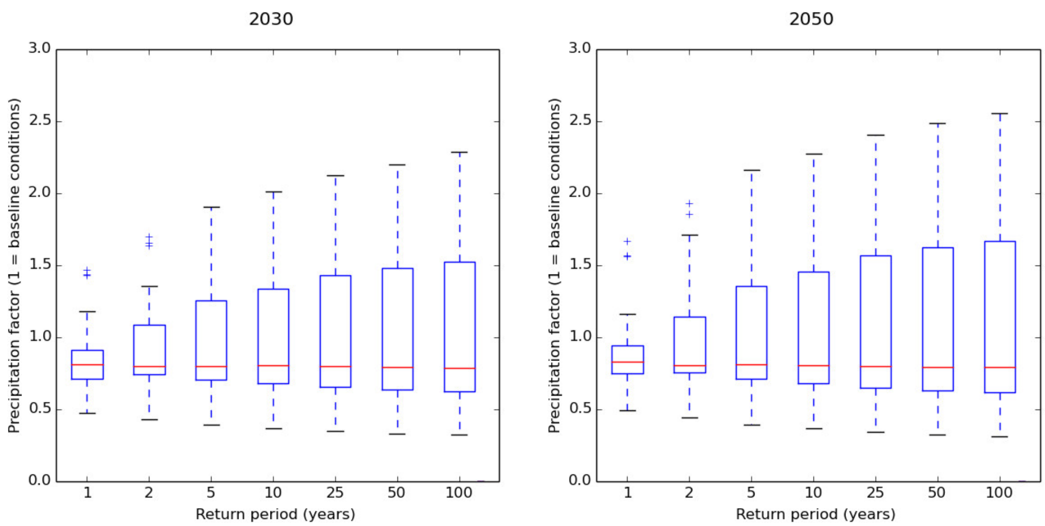

Figure 3.7 Box-and-whisker plots showing the distributions of precipitation factors (where a factor of "1" equals baseline conditions) for extreme 1-day precipitation for several return periods, ranging from 1 to 100 years. The results are shown for 2030 and 2050. The results are based on five GCMs and four RCPs. The box plots show the median values for the 20 GCM–RCP combinations (red lines), the 25th and 75th percentiles (top and bottom of boxes), and the range (whiskers). Outliers as shown as "+".

In terms of the median values, we found little difference in the precipitation change factors between the different RCPs (Table 3.4). For 2030 these ranged from 0.76 for RCP4.5 to 0.85 for RCP8.5, and for 2050 they ranged from 0.79 for RCP2.6 to 0.96 for RCP8.5. Across the five different GCMs, the standard deviation in these precipitations change factors is large (Table 3.4), showing the large uncertainty of how this variable may change in the future.

Table 3.5 Median and standard deviation of flood risk (million US$) between the 5 GCMs, for each RCP in 2030 and 2050

	Low SLR		High SLR	
	Median	Standard deviation	Median	Standard deviation
2030				
RCP 2.6	118.0	51.8	152.4	47.1
RCP 4.5	112.0	80.6	147.1	75.5
RCP 6.0	118.3	85.1	152.6	79.1
RCP 8.5	127.0	82.6	160.4	77.7
2050				
RCP 2.6	118.1	48.5	152.5	43.9
RCP 4.5	121.8	83.5	155.7	78.6
RCP 6.0	118.6	97.8	152.9	93.7
RCP 8.5	148.0	102.2	179.1	98.5

3.3.3 Impacts of future changes in individual risk drivers on flood risk

In this section, we describe the potential changes in flood risk between the baseline estimate of US$ 186 million p.a., and the future, for each of the risk drivers separately.

3.3.3.1 Climate change

Firstly, we show the potential influence of climate change only on future flood risk compared to baseline flood risk. The results are shown in Table 3.5. Here, we show the future risk (in 2030 and 2050) for each of the different combinations of precipitation intensity (represented by the RCP scenarios) and sea level rise (low and high scenarios). The median and standard deviation of the results across the five GCMs are shown for each combination of RCP and sea level rise scenario. From these results, there is no clear signal of change in future flood risk as a result of climate change alone.

Table 3.6 Percentage of total inundated area and total flood damage found in each land use category. Results are shown here for baseline land use and idealized land use in 2030.

Land use class	Baseline land use		2030 land use	
	Inundated area (% of total)	Flood damage (% of total)	Inundated area (% of total)	Flood damage (% of total)
Government facility	3.1	9.7	0.0	0.1
Forestry	0.0	0.0	0.0	0.0
Industry and warehouse	12.4	33.3	17.3	46.6
Commercial and business	13.2	41.8	10.6	30.8
Residentials	17.2	4.1	58.0	19.1
Residentials with greenery	44.5	10.4	1.6	1.2
Agriculture and open space	2.4	0.0	12.0	2.2
Swamp river and pond	4.9	0.1	0.5	0.1

For 2030, under the low sea level rise scenario, the median risk is in fact lower than for the baseline (US$ 186 million p.a.) for all RCPs. However, the standard deviation is large. Under the high sea level rise scenario, the median risk is higher than baseline for two RCPs, and lower for the other two RCPs; again the standard deviation between GCMs is large. For 2050, the results generally show slightly higher risk compared to 2030, under both sea level rise scenarios.

Across all 40 combinations of GCMs, RCPs, and sea level rise scenarios (five GCMs × four RCPs × two sea level rise scenarios), the risk estimates range from US$ 24 million to US$ 380 million p.a. for 2030, and US$ 34 million to US$ 517 million p.a. for 2050. For 2030, a decrease in risk compared to baseline was simulated in 28 of these combinations, with an increase under the other 12 combinations. For 2050, a decrease was simulated in 22 of the combinations, with an increase in the other 18 combinations. The wide amplitude of flood risk and the variations of GCM–RCP combinations quantitatively display uncertainty of climate projection and the resulting flood risk; see Sections 3.4.1 and 3.4.2 for further discussion.

In 2030, the highest risk values are simulated under RCP6.0 and RCP8.5, whilst there are only small differences between the other RCPs. According to IPCC (2014), the global radiative forcing by 2030 is the highest under RCP8.5. By 2050, we see an increase in the difference between the risk estimates under RCP8.5 and those under the other RCPs.

3.3.3.2 Land use change

As stated earlier, two approaches were used to estimate the influence of land use change. The main one used is the idealized scenario, based on the official Spatial Plan 2030. This represents an idealized situation, in the case that the land use planning envisioned for the coming decades is successfully implemented, rather than a scenario of unplanned development. Assuming this Spatial Plan 2030, and assuming no other changes in physical or socio-economic factors, flood risk would decrease between the baseline situation and 2030 by 12 %. More detailed results are presented in Table 3.6, which shows the percentage of both the total inundated area and damage associated with each land use class. The results show that the majority of the inundated areas are found in locations with residential land use classes. This is both the case under baseline land use (62 %; summation of "High density urban kampung" and "Planned house") and under 2030 land use (60 %; summation of "Residentials" and "Residentials with greenery"). However, the largest share of total damages are found in the land use classes related to commercial areas, i.e. "Industry and warehouse" followed by "Commercial and business". Combined, these two land use classes account for ca. 75 % of total damages under baseline land use, and 77 % under 2030 land use.

To carry out a simple comparison with the potential increase in risk if this idealized land use scenario for 2030 is not achieved, we also used a simple method to extrapolate simulated damages using the 1980, 1995, 2002, and 2009 land use maps to 2030 (see section 3.2.2). Using this simple approach, flood risk in 2030 (due to land use change alone) is US$ 270 million, i.e. an increase of 45 %. In reality, we do not know whether the past trend in land use change observed over the period 1980–2009 will continue at the same rate until 2030. Hence, this should be considered as a firstorder estimate, assuming that this trend continues, and that the Spatial Plan is not implemented successfully.

3.3.3.3 Land subsidence

Assuming only an increase in land subsidence for 2030, we found an increase in annual expected damage of 126 % between the baseline and 2030, i.e. an increase from US$ 186 million to US$ 421 million p.a.

The increase in risk resulting from projected subsidence, however, is not uniform across the city. In Figure 3.8, we see the percentage increase in flood damage per grid cell over the period 2010–2030 due to subsidence alone, following the rates of subsidence shown in Figure. Note also that the actual influence of subsidence will strongly depend on the changes in other environmental and socio-economic drivers (as discussed in section 3.4.3).

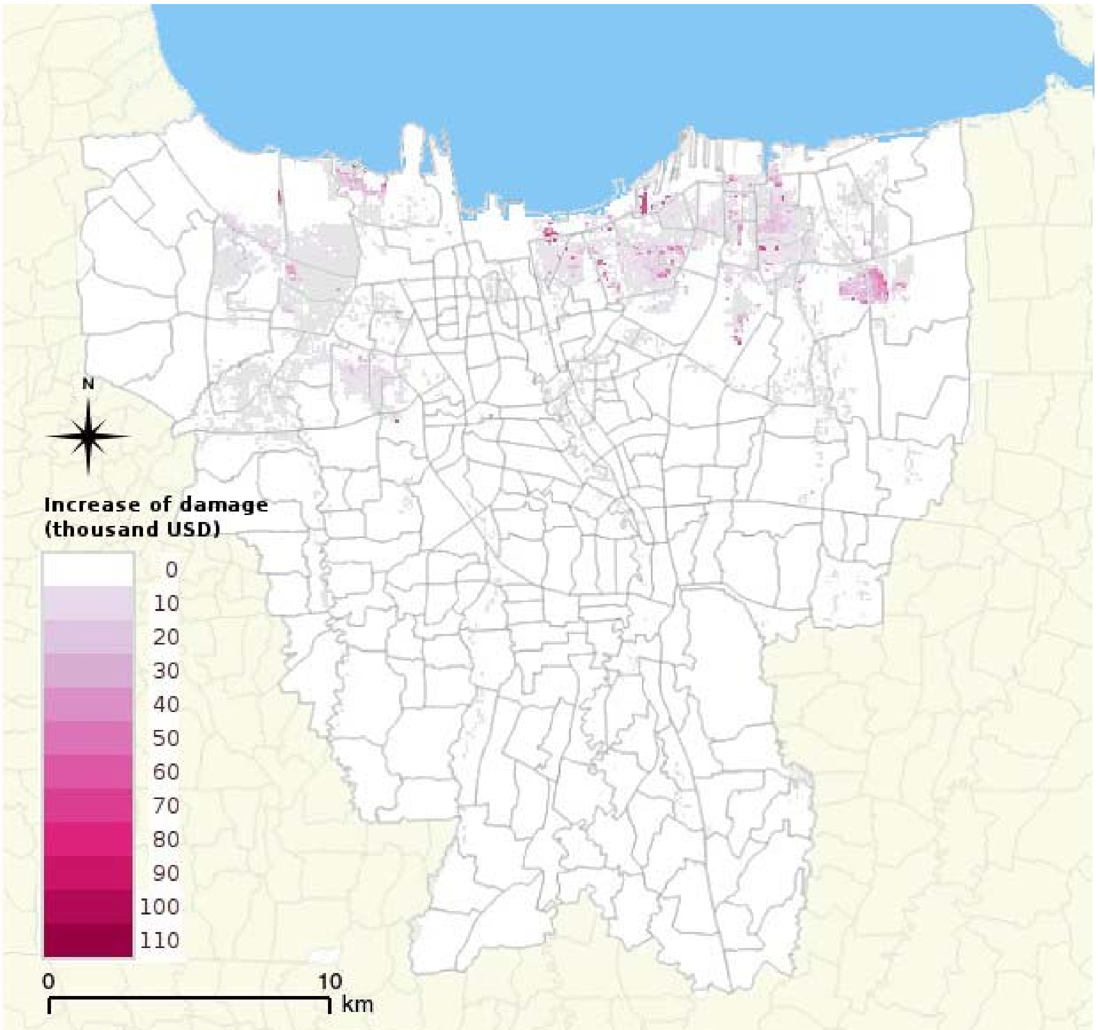

Figure 3.8 Increase of damage per grid cell at a return period of 100 years between the baseline condition and idealized land use map 2030 due to land subsidence alone.

3.3.4 Impacts of future changes in combined risk drivers on flood risk

In the previous subsections, the change in risk between the baseline situation and the future scenarios has been shown for each risk driver separately. In reality, the future situation will depend on the combined change of all the drivers. Hence, in this section we show the impacts of combinations of different risk drivers on future risk.

In Figure 3.9, we show probability density functions (PDFs) of the simulated annual expected damage, whereby each PDF is derived from a two-parameter gamma distribution fit to the 20 GCM/RCP combinations. A similar approach was followed by Ward et al. (2014c) for including climate change in probabilistic projections of flood risk along the Rhine in Europe. The dotted black vertical line represents baseline flood risk, i.e. US$ 186 million p.a.

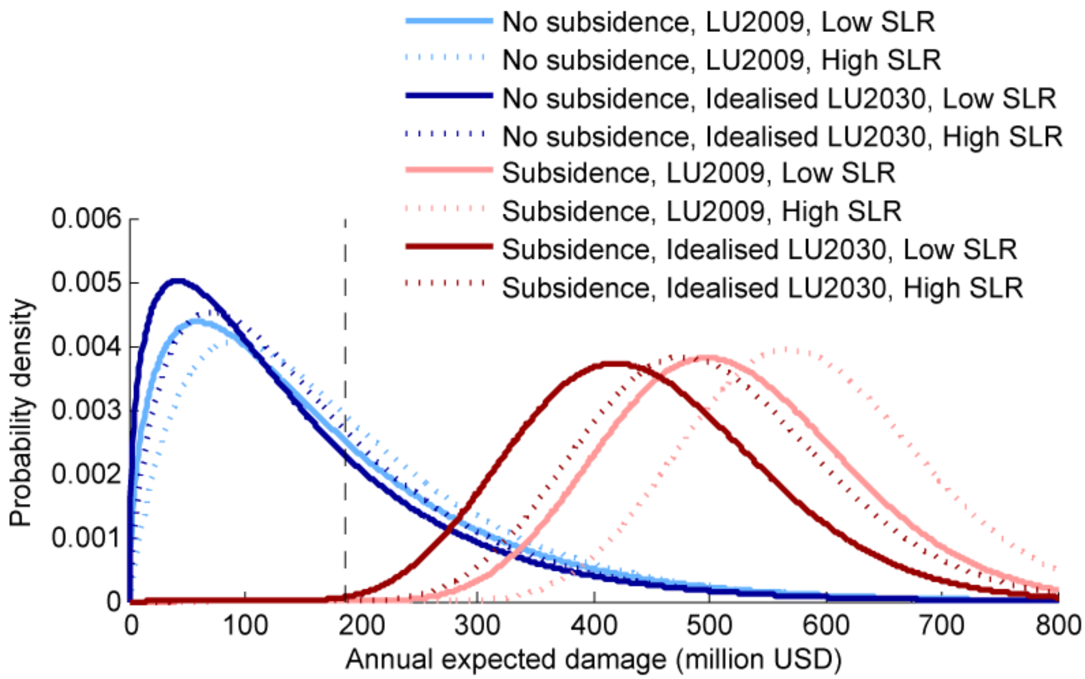

Figure 3.9 Probability distribution function (PDFs) of future flood risk in Jakarta under different scenarios. The black vertical dashed line shows risk associated with baseline conditions (186 million US$ p.a.). The PDFs are obtained by applying a two-parameter gamma distribution to simulated risk values from five GCMs and four RCP emission scenarios. PDFs are shown for different combinations of the following scenarios: (a) subsidence and no subsidence; (b) land use under baseline conditions (LU2009) and under the idealized land scenario for 2030 (LU2030); and (c) high or low sea level rise (SLR).

Figure clearly shows the strong influence of projected subsidence on the overall change in risk. All of the PDFs representing scenarios with subsidence (shown in red) show much higher annual expected damage than those without subsidence (shown in blue). The PDFs also clearly show the large uncertainty associated with the projected changes in precipitation from the different GCMs and RCPs, which is large under all of the PDFs. However, the results show that if we include land subsidence in the future projections, the probability of future flood risk exceeding baseline flood risk exceeds 99.999 % (when accounting for changes in precipitation).

The results also show the importance of the interaction between different drivers. For example, if we examine the difference between the PDFs for low and high sea level rise, we see a small difference under the scenarios with no subsidence and land use 2030. However, if we make a similar comparison using the scenarios that include subsidence, we see a larger difference between the low and high sea level rise scenarios. Similar differences can be found when comparing the scenarios with and without projected land use change. The differences between the two scenarios are amplified with higher rates of subsidence and/or sea level rise.

From Table 3.7, we summarize the results of the influence on risk of the individual drivers and the combined scenarios for 2030. For scenarios with climate change, we show both the median and 5th–95th percentile values based on the gamma distributions. From the table, it is clear that land subsidence has the largest influence on future risk, assuming our simple scenario of land subsidence. If the increase in risk due to land use change continues at the rate as over the period 1980– 2009, this has the second highest influence on risk, followed by sea level rise. Given the high range of uncertainty in the influence on risk of future changes in precipitation intensity, the 5th–95th percentiles of this variable span a very large range, from an increase in risk of 104 to a decrease in risk of 94 %.

Table 3.7 Flood risk (annual expected damage) in 2030 for different risk drivers, and percentage change in risk compared to baseline.

Scenarios	Flood risk (US$ million)	Percent change
Baseline	186	N.A.
Baseline + change of precipitation	101 (median)	–46
	11–379 (5^{th}–95^{th} percentiles)	–94 to +104
Baseline + change of land use (idealized)	163	–12
Baseline + change of land use (extrapolation)	270	+45
Baseline + sea level rise	212 (median)	+14
	200 – 224	+7 to +20
Baseline + land subsidence	421	+126
Baseline + all future changes combined*	521 (median)	+180
	393–673 (5^{th}–95^{th} percentiles)	+111 to +262

* Using idealized land use scenario for 2030

3.4 Discussion

3.4.1 Uncertainty in projections of change in precipitation intensity

In section 3.3, we showed the impacts of climate change on flood risk, whereby the impacts of climate change are expressed through both sea level rise and changes in the magnitude of extreme 1-day precipitation totals. In terms of the latter, our analyses show this variable to be highly uncertain. Whilst the median projections (Table 3.4) show a decrease compared to baseline – which results in lower median flood risk in the future when combined with the low sea level rise scenario (Table 3.5) – the PDFs in Figure 3.9 show that there is deep uncertainty attached to the impacts of changes in precipitation on the risk. Nevertheless, this does not mean that it is not an important factor to consider. In fact, some of the GCM–RCP combinations indicate an increase in risk of a factor greater than 2.4 as a result of climate change alone. It should be noted that here we used all possible combinations of RCPs to represent changes in precipitation intensity and the two sea level rise scenarios (high and low).

The uncertainty in future risk projections is confirmed by other research in the region. For example, rainfall observations across Indonesia as a whole for the second half of the twentieth century suggest that mean annual rainfall may have decreased by ca. 2–3 %, mainly in the wet season from December to February (Boer and Faqih, 2004). Earlier projections of mean annual rainfall over the twenty-first century taken from several climate models suggest that mean annual rainfall may increase in the future across most of Indonesia, although in Java it may decrease (Hulme and Sheard, 1999). Naylor et al. (2007) downscaled output from the Intergovernmental Panel on Climate Change AR4 suite of climate models for the twenty-first century, to the regional level, and found a large uncertainty on the monsoon onset in West Java/Central Java region. Moreover, they found that precipitation totals may decrease (by up to 75 % in the tails) during the dry season, although this research did not address the wet season, when flooding generally occurs in Jakarta. Scoccimarro et al. (2013) investigated potential changes in extreme precipitation events by 2100 using RCP8.5 and several Coupled Model Intercomparison Project Phase 5 (CMIP5) models. They found that the 90th and 99th percentiles of heavy rainfall may increase during the months June–August in Indonesia. However, this is the dry season, whilst flooding in Jakarta usually occurs during the wet months of December– February.

Recently, Chadwick et al. (2013) carried out climate model experiments to assess the potential changes in regional patterns of precipitation and atmospheric circulation resulting from a "ramp-up" of CO2 levels from pre-industrial levels (280 ppm) until quadrupling (1120 ppm) after 70 years (and scenarios of 3× CO2 , 2× CO2 , and 1.5× CO2), followed by 10 years of stabilization, and then a 70-year ramp-down to pre-industrial levels. During the ramp-up phase, they found decreased precipitation in the part of the tropical western Pacific where Indonesia is located. Chadwick et al. (2013) suggest that this regional redistribution of rainfall is caused by circulation changes associated with changing gradients of sea-surface temperatures in the tropical Pacific.

Further uncertainties in the future response of precipitation to climate change in the region result from potential changes in the frequency and/or magnitude of El Niño–Southern Oscillation (ENSO). ENSO shows strong linkages with precipitation in parts of the Indonesian archipelago (Aldrian and Susanto, 2003; Aldrian et al., 2007; Hendon, 2003; Qian et al., 2010), and is linked to anomalies in both discharge (Poerbandono et al., 2014) and flood volumes (Ward et al., 2014a). The current generation of climate models shows little agreement on whether (and if so how) the frequency of ENSO could change due to climate change (Guilyardi et al., 2009; Paeth et al., 2008; Van Oldenborgh et al., 2005). However, a recent study suggested that extreme El Niño events (which are associated with negative flood anomalies in western Java; Ward et al., 2014a) may become more frequent (Cai et al., 2014).

To account for this large uncertainty, we developed the probabilistic projections of flood risk under climate change shown in Figure 3.9. Instead of only describing potential changes in the median flood risk under climate change (a decrease with a low sea level rise scenario and a slight increase with a high sea level rise scenario), these provide much more information, by describing the change in flood risk across the entire distribution of the 20 GCM–RCP combinations (five GCMs × four RCPs).

3.4.2 Relative influence of different drivers on flood risk

In this section, we discuss the relative influence of the different drivers on the simulated flood risk. As stated in the introduction, this Chapter is not intended to provide a full uncertainty assessment. For each driver of risk, we used the best available data to develop the future scenarios, meaning that more scenarios are available for some drivers (e.g. climate change) than others (e.g. land subsidence and land use change). Therefore, the results should be interpreted as first-order estimates of the potential order of magnitude of the future changes in risk, and they certainly should not be interpreted as covering the entire uncertainty space.

From Table 3.7, we see that land subsidence is the single driver with the greatest contribution to increased flood risk compared to the baseline, assuming the land subsidence scenario used in this study. If we consider a linear increase from 2013 to 2030, it equals an annual rate of US$ 13.8 million (7.4 %) p.a. Given an assumption of a 2.5 cm rate of subsidence p.a. (on average over the whole city), this would mean an increase in risk of US$ 5.5 million per cm subsidence. In reality, the rate of land subsidence is geographically heterogeneous, with higher rates in the north of the city. The land subsidence scenario used in this study is of course highly simplistic, but it does give a powerful indication of the order of magnitude of the problem in terms of its impacts on risk. If the government's target of reducing groundwater extraction is not reached, the rate of subsidence could be even higher.

The problem of land subsidence is a serious issue in many other low-lying coastal and delta cities (Syvitski et al., 2009; Erkens et al., 2014; Brown and Nicholls, 2015). Ward et al. (2011a) also showed this driver to be the main factor contributing to projected increases in future coastal flood risk in Jakarta. The annual rate of increase in flood risk due to subsidence calculated for Jakarta is similar to that for Bangkok during the 1990s, which was US$ 12 million p.a. (DMR, 2000 in Phien-wej et al., 2006). In Taiwan, the Yunlin area has similar subsidence rates to northern Jakarta, ranging from 3.5 to 14.3 cm $year^{-1}$ (Tung and Hu, 2012). In this area, high flood damages have also been simulated, for example US$ 171 million for a 200-year return period flood.

Using the idealized land use scenario for 2030, we actually found that flood risk could be reduced by 12 % (if all other drivers are kept constant). This shows the huge potential of land use planning to mitigate flood risk, as discussed in section 3.4.3. On the other hand, using our simple extrapolation of increased risk due to unplanned land use growth, risk could increase by 45 % by 2030. This is somewhat higher than the increase in risk that we simulated due to sea level rise alone (increase of 7–20 %), but of the same order of magnitude. However, the mechanisms behind these forcings are different, as is the geographical distribution in the change in risk.

Since sea level rise affects river flooding by making discharge of excess waters to the sea more difficult, most of the increase in risk simulated under the sea level rise scenarios is concentrated towards the coastal area. Using the average values across the different sea level rise scenarios, the increase translates to an increase in risk of ca. US$ 1.5 million p.a., or US$ 2.6 million per cm sea level rise.

On the other hand, the change in risk associated with land use change is distributed more evenly across the city. Finally, Table 3.7 also shows that the combined impact of all drivers on risk (+180 % under the median scenario of precipitation change, and assuming the idealized land use scenario for 2030) is much greater than the summation of the impacts of the individual flood drivers.

3.4.3 Implications for risk management

The flood risk problem in Jakarta results from the interplay of a large number of drivers, both physical and socio-economic in nature. Hence, measures and strategies to reduce that risk must be taken in an integrated way (e.g. Jha et al., 2012). The development of such strategies is indeed taking place in Jakarta, a good example being the National Coastal Integrated Coastal Development program. Whilst the most wellknown aspect of this program is the planned "giant sea wall" (over 35 km long), it also integrates plans to construct and strengthen other defences in the short term, as well as address pressing issues such as land subsidence, water supply, and water sanitation. The program builds on initial findings of the Jakarta Coastal Defence Strategy, 2011; Jeuken et al., 2015).

Clearly, concerted efforts to address the land subsidence issue are paramount to reducing the increasing flood risk in Jakarta, as we have shown the potentially very large influence that land subsidence could have on future river flood risk. The subsidence scenarios used in this study are a simple extrapolation of past trends, and future subsidence rates may turn out to be higher or lower. It has been suggested to target measures for reducing soil water extraction, which is the main cause of land subsidence in Jakarta (Abidin et al., 2011). Soil water extraction takes place both for supplying water for drinking and industry, as well as in the construction of high-rise buildings. PAM Jaya (2012), the water industry board of Jakarta, supplies water to 61.1 % of consumers in Jakarta. They report that an additional 8–10 m^3 s^{-1} would be needed to erase the need for all deep wells while sufficing the needs of the rest currently not sufficed. According to a synthesis of results in reports by PAM Lyonaise Jaya (2012) and Aetra Air Jakarta (2014) this would require an investment of ca. US$ 389 million. Whilst this is a large investment, it is of the same order of magnitude as our projected increase in risk per annum resulting from land subsidence, land use change, and climate change. Hence, whilst this is a very simplistic example, it shows that the costs of the measures to increase and improve water supply appear to be small in relation to the damages that they could help to avoid, even without factoring in the other benefits. Indeed, strict regulations on groundwater pumping (accompanied by the supply of alternative water sources) have been shown to be effective in reducing land subsidence. For example, the rate of subsidence in Bangkok was ca. 12 cm year during the 1980s, but was reduced to 2 cm year after strict regulations on deep well pumping (Phien-wej et al., 2006). A nested modelling approach by Aichi (2008) has shown that the groundwater regulations in Tokyo have led to decreased subsidence since the mid-1970s. The groundwater regulation was effective for Tokyo and the surrounding three prefectures for 14 years from January 1961 until April 1974 (Tokunaga, 2008). As mentioned earlier, high-rise building construction also extracts water from the soil (dewatering) during the process. This intensive extraction of soil water in the short term has been reported to result in severe localized land subsidence (Zhang et al., 2013). Hence, it may also be useful to consider other piling processes, such as auger piling (Abdrabbo and Gaaver, 2012). If dewatering is unavoidable for Jakarta, it may be useful to focus such high-rise development in those parts of the city where the lithology is more compacted, such as in the southern part (Bakr, 2015).

In this study, we represented changes in land use using both an idealized scenario for 2030, in which the official Jakarta Spatial Plan 2030 is fully implemented, and a simple extrapolation of past increases in flood risk due to land use change to the future. Our results show that under the idealized scenario (land use change alone), risk would decrease by 12 %, compared to an increase of 45 % using the extrapolation of past trends to the future. Whilst we acknowledge that these should only be considered as first order estimates, these large differences do indicate the large potential of land use planning to mitigate flood risk, especially when combined with other measures. The results for the idealized land use scenario are particularly encouraging, if the plan can be successfully implemented, given the fact that changes in exposure through urban development are seen as one of the main drivers of risk in developing countries (Jongman et al., 2012; UNISDR, 2013). Moreover, the land use plan scenario does not include assumptions on potential measures or strategies that could be taken to further reduce flood risk. For example, in Indonesia as a whole, Muis et al. (2015) simulated increases in both river and coastal flood risk by 2030, assuming a scenario where building is allowed in flood-prone areas, and several scenarios where new buildings are prohibited (with different levels of enforcement) in the 100-year flood zone. They found that river flood risk could be reduced by about 30–60 %, and coastal flood risk by about 65–80 %, compared to the scenario in 2030 with no building restrictions in the flood-prone zone.

Although we have assumed vulnerability (as represented by the depth–damage functions) to be constant through time, in reality, vulnerability is also temporally variable. For example, Mechler and Bouwer (2014) have shown that vulnerability to flooding in Bangladesh reduced over the last decade, due to early warning systems, flood preparedness, and so forth. Measures are also available to reduce the physical vulnerability to floods, such as dry-proofing and wet-proofing of houses in flood-prone areas (e.g. Kreibich et al., 2005, 2011; Kreibich and Thieken, 2009; Poussin et al., 2012; Thurston et al., 2008). In Jakarta, measures are already being taken at the household level, such as the building of second stories on houses so that valuable possessions can be moved upwards away from flood waters in the event of a flood, and using traditional building methods such as rumah panggung (elevated wooden house that stands on piles) in ways that are more commensurate with flooding (e.g. Marfai et al., 2015; Wijayanti et al., 2015). It would be of interest to assess the decrease in risk that could be achieved throughout the city if such measures were to be implemented on a larger scale, for example through the use of building codes.

3.4.4 Limitations and future research developments

In this study, we have made use of the best available scenarios for each of the drivers of risk. However, this entailed making large assumptions, and the quality of the scenarios differs between the drivers. Given the uncertainty in climate change projections, future development of official tailored climate scenarios for Jakarta (or indeed Indonesia) should be a research priority. Such a set of scenarios would allow for a more consistent modelling of climate impacts, not only in terms of flood risk analysis, but indeed in terms of climate impacts across a full range of hazards and sectors (e.g. Aerts et al., 2014). Moreover, tailored scenarios of land subsidence and land use change, using storylines commensurate with the storylines of the climate change scenarios, would allow for a more consistent assessment of the relative influence of the different driving forces. The development of a dedicated land use model for Jakarta would be an important step forward for future flood risk assessments.

In addition, we have only examined river flood risk, while Jakarta also experiences regular flooding due to coastal and flash flooding. The former has been assessed for Jakarta in Ward et al. (2011a), and Muis et al. (2015) have assessed both river and coastal flood risk at the scale of Indonesia using globally available data sets and models. Nevertheless, the impacts of river and coastal flooding can interact with each other – for example when high tides occur at the same time as extreme discharges – and this interaction should be a priority for future flood risk research, not just in Jakarta, but elsewhere (see, e.g., Keef et al., 2009; Klerk et al., 2015; Svensson and Jones, 2004). To enable an assessment of these interactions, one would need to develop time series of both high river discharge and high sea levels, in order to examine the temporal interactions and joint probabilities between these two variables. However, at present, long time series of simulated sea levels are only available for limited regions (e.g. Haigh et al., 2013), although global modelling efforts may extend this possibility in the future.

In this study, vulnerability is only represented through the use of depth–damage functions. As mentioned earlier, these do not include social vulnerability, which is also an important concept for the overall resilience of a system. Moreover, we assume that vulnerability is constant through time. The overall assessment of future flood risk could be improved through future projections of changes in vulnerability. Very few examples exist in the scientific literature of studies where temporal changes in vulnerability are considered. However, Jongman et al. (2015) recently showed that vulnerability to flooding has been reducing over the last 20–30 years in many developing countries. Hence, it would be useful to try to develop scenarios of potential vulnerability change in the future, and assess how this may affect the overall risk.

In our future projections, we do not include adaptation measures that could be taken to reduce future risk (other than those measures that are already in place). Research by Muis et al. (2015) at the national scale for Indonesia has shown that the growth in future river and coastal flood risk could be contained to a large degree by increasing protection levels through the building of structural measures such as dikes, and by spatial zoning to limit developments in the most floodprone locations, or at least to make future developments in those zones more commensurate with flooding. Moreover, local research in different parts of Jakarta shows that individual households and communities are already taking smallscale measures to reduce vulnerability, such as building second stories on homes, moving valuable items upstairs during floods, and placing elevated entrances to houses (Marfai et al., 2014). Our model does not account for this kind of autonomous adaptation, although it could be included in the model code in the future.

3.5 Concluding remarks

In this Chapter, we have extended the river flood risk model for Jakarta, developed by Budiyono et al. (2015), to include projections of flood risk under future scenarios of land subsidence, climate change (sea level rise and changes in extreme precipitation), and land use change. By combining scenarios of different drivers of risk in a simple flood risk model, we have developed a method that can relatively quickly provide first-order estimates of the influence of each of these drivers on overall risk in a quantitative manner. Moreover, in this Chapter we have developed probabilistic scenarios of the influence of climate change on risk, which allows us to gain a better understanding of the potential future changes than if we only use several climate change scenarios.

Combining all of these scenarios, we find a median increase in flood risk of 183 % in 2030 compared to baseline conditions. This value is based on our median projection for the influence of changes in extreme precipitation on flood risk. However, since we found the influence of climate change on extreme precipitation to be highly uncertain, we also developed probabilistic projections of flood risk by developing PDFs based on 20 GCM–RCP combinations. The resulting increases in risk for the 5th and 95th percentiles are 111 and 262 % respectively (when combined with the other drivers). This shows that whilst the influence of climate change on precipitation intensity in the region may be uncertain, when combined with the other drivers of risk, the increase is always large, and hence adaptation is imperative, irrespective of the chosen climate scenario or projection. This probabilistic approach allows us to include a much wider range of information on the potential impacts of climate change on risk, than assessments based on just one or two scenarios. Unfortunately, the data required to develop such probabilistic scenarios of the other risk drivers are not available at this time, hence developing such scenarios would be a useful research priority.

The single driver with the largest influence on future flood risk is land subsidence (+126 %). Clearly, addressing this driver could potentially have a large influence on reducing future flood risk. We showed that under an idealized land use scenario for 2030, whereby the official Jakarta Spatial Plan 2030 is fully implemented, flood risk could be reduced by 12 % compared to baseline conditions, if all other driving factors are held at baseline levels. On the other hand, if past trends in risk increase due to land use change continue, flood risk could increase by 45 % by 2030 due to land use change alone. This demonstrates the importance of effective land use planning for flood risk reduction. We show that the largest share of total damages is found in land use classes related to commercial areas; these account for ca. 75 % of total damages under baseline land use and 77 % under the idealized land use scenario for 2030. However, in terms of area affected by flooding, residential areas have a great share. Hence, future efforts to reduce risk must focus on optimal land use planning for both classes.

Chapter 4

4 FLOOD RISK IN POLDER SYSTEMS IN PRESENT JAKARTA AND IN THE FUTURE

Budiyono, Y., Marfai, M.A., Aerts, J., Moel, H. de, Ward, P.J., 2017. Flood Risk in Polder Systems in Jakarta: Present and Future Analyses, in: Disaster Risk Reduction in Indonesia, Disaster Risk Reduction. Springer, Cham, pp. 517–537. doi:10.1007/978-3-319-54466-3_21

Abstract

Polder systems in Jakarta have been implemented since 1965, but their development has been hindered by social and political issues. Currently, the government of Jakarta has started to consider polder system as seen in the Spatial Plan 2030. This chapter assesses the benefits/costs of the polder system in Jakarta under current conditions and under future scenario of climate change, land use change, and subsidence.

We calculate the benefits of each polder using Damagescanner-Jakarta, which is a flood risk model developed in previous study. Cost estimates are based on the costs of 22 dike projects in Java. We use flood design standards at 2, 5, 10, 25, and 50 years, as set out in the Minister of Public Works.

The results show that benefit/cost ratios greater than 1 exist at 21 out of 66 polders reducing 25% of risk under current conditions, and at 31 out of 66 polders reducing 52% of risk under the future scenario (for a return period of 2 years). Much of this risk reduction could be achieved in just 3 polders, namely Kapuk Muara, Penjaringan Junction, and Kapuk Polgar, in which 50% of the current risk could be reduced. The study also shows that operating twelve polders could reduce risk by 81% in the future, and polders with very high net benefits are located away from the coastline. Sensitivity test using lower (4%) and higher (10%) discount rates show the number of net benefiting polders reduces as the discount rate increases in a predictable trend.

4.1 Introduction

Since 2012, Jakarta has been operating a second major structural measure to overcome flooding, the Eastern Flood Canal (Banjir Kanal Timur). This canal complements the Western Flood Canal (Banjir Kanal Barat), which has been in operation since 1922 and has been revitalized over time. An overview of historical flood management practices in Jakarta can be found in Caljouw et al. (2005) The two canals act as a horseshoe that prevents floodwaters from entering the city, diverting major discharges from the upland to the west and to the east. The construction of the Western Flood Canal was initiated in 1917, as part of the Van Breen plan (Caljouw et al., 2005), which was revised in 1973 as part of the Master Plan for Drainage and Flood Control of Jakarta published by the Ministry of Public Works with the help of Netherlands Engineering Consultants (Nedeco). From 1975, the Western Flood Canal was heavily extended and was completed in 1983 with the completion of the Cengkareng drain (Gunawan, 2010). The Eastern Flood Canal was also based on recommendations in the Master Plan for Drainage and Flood Control of Jakarta plan, which was detailed by Nippon Koei in 1997.

Now, the government of Jakarta is examining another structural measure to reduce flooding, namely improving and upgrading the city's polder system. The system was already proposed in the van Breen plan (Caljouw et al., 2005) that was prepared by the committee for Jakarta flood prevention (Kopro Banjir) in 1965 (Gunawan, 2010). Kopro banjir was formed by the President's authority (Kepres) number 29/1965 (Diskominfomas DKI, 2011). Polder implementation was started in the same year with the construction of Pluit retention lake, which was later recognized as Pluit polder. In 1972, the committee was changed into Greater Jakarta Flood Control Project (PBJR), resulting in two more polders, i.e. Sunter Timur and Marunda (Gunawan, 2010). Ever since, the development has been hindered by riverbank squatting, solid waste disposal (Baker, 2012) and lack of planning. Referring to Provincial Government Regulation number 1/2012 about Spatial Plan 2030 (Perda DKI Jakarta 1, 2012), the government of Jakarta plans to intensify the use of polder systems to prevent floods. In the regulation, 43 existing polders are recognized and 23 new polders in Jakarta are planned.

Table 4.1 Flood return period of the drainage design criteria for different types of cities and catchment sizes

Type of city	Catchment area (ha)			
	<10	10-100	100-500	>500
Metropolitan city	2 year	2-5 year	5-10 year	10-25 year
Big city	2 year	2-5 year	2-5 year	5-20 year
Medium city	2 year	2-5 year	2-5 year	5-10 year
Small city	2 year	2 year	2 year	2 year

Source: Permen PU 12 (2014)

Minister of Public Works Regulation 12/2014 (Permen PU 12, 2014) states the flood return period of the draining design criteria for polders in different types of cities and for different catchment areas (see Table 4.1). For Jakarta, polders should have a design standard of between 2 and 25 years, depending on the polder size. The size of the polders in Jakarta ranges from 32ha to 2,954ha. To contain excess water, a storage capacity is designed relative to the volume of the design rainfall and the time needed by the pumping system to discharge excess water away from the polder. As a revived policy, some polders already have the required retention capacity, while others do not.

Using the polder system plan of Jakarta 2030 (Perda DKI Jakarta 1, 2012) and flood risk study, this Chapter aims to provide a first-cut estimate of the potential benefit and costs of each polder, both under current conditions, and under a scenario of future climate change, land subsidence, and land use change. This adds the widely available studies on polders generally focus on the individual function of polders as e.g. flood control, agriculture, recreation (e.g. Roth and Warner, 2007; Klijn et al., 2010; Ritzema et al, 2011).

A large amount of scientific literature is available that examines technical aspects of polders and their functioning, including flood control, agriculture, and recreation (e.g. Roth and Warner, 2007; Klijn et al., 2010; Ritzema et al, 2011). Several studies have assessed the potential reduction in flood stage or inundation extent or depth that can be achieved in polder or retention areas (e.g. Apel et al., 2004; Förster et al., 2005; Huang et al., 2007; Bouwer et al., 2009). However, few studies have specifically examined the risk reduction potential of polder systems. This is despite the fact that recent decades have seen a move towards a more risk-based approach towards flood management. In this sense, flood risk combines the probability of a flood event with its potential consequences. The concept of flood risk is usually operationalized as being a function of three elements: hazard, exposure, and vulnerability (e.g. Kron, 2002; UNISDR, 2013, 2015). Jonkman et al. (2004) and Bouwer et al. (2010) have assessed how flood risk may change in several polders in future scenarios of climate change, and Kind (2014) assessed the costs and benefits of a large number of polder systems in the Netherlands. However, studies on the risk reduction potential of polders and their costs elsewhere are sparse in the scientific literature. Budiyono et al. (2015) recently developed a flood risk assessment model for Jakarta, which allows for the assessment of flood risk, called Damagescanner-Jakarta, and used it to assess flood risk under current conditions and future scenarios of land use change, climate change, and subsidence Budiyono et al. (2016). However, the model has not been used to assess the potential impact of risk reducing measures on risk.

To address this, we use the polder system plan of Jakarta 2030 (Perda DKI Jakarta 1, 2012) Damagescanner Jakarta to provide a first-cut estimate of the potential benefit and costs of each polder, both under current conditions, and under a scenario of future climate change, land subsidence, and land use change.

4.2 Methodology

In this study, we estimate the costs and benefits of upgrading the 43 existing polders and constructing the 23 planned polders mentioned in the Spatial Plan 2030. The benefits are estimated as expected annual damage (EAD) without the polder system, minus the EAD with the polder system. EAD is a common metric used in natural hazard risk assessment (e.g. Meyer et al., 2009), and can be interpreted as the average damage per year that one would expect over a very long period of time; its calculation is further described in section "Estimation of benefits". EAD is calculated using the existing Damagescanner Jakarta flood risk model (Budiyono et al., 2015, Budiyono et al., 2016). The costs are estimated as the total construction and maintenance costs of the polder system. The benefit/cost ratio (B/C ratio) was assessed using the standard formula:

$$B/C = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}$$

Where n is the number of years over which the project costs and benefits are evaluated, t are the costs and benefits for individual years, B is the sum of benefits in a given year (t), C is the sum of costs in a given year (t), and i is the discount rate expressed as a decimal. In this study, we used a time horizon (n) of 100 years, and a discount rate (i) of 0.07 (i.e. 7%), 0.04, and 0.10 (see section "Estimation of benefits").

In this section, we describe the methods used to estimate these costs and benefits in more detail; an overview of the approach can be found in Figure 4.1.

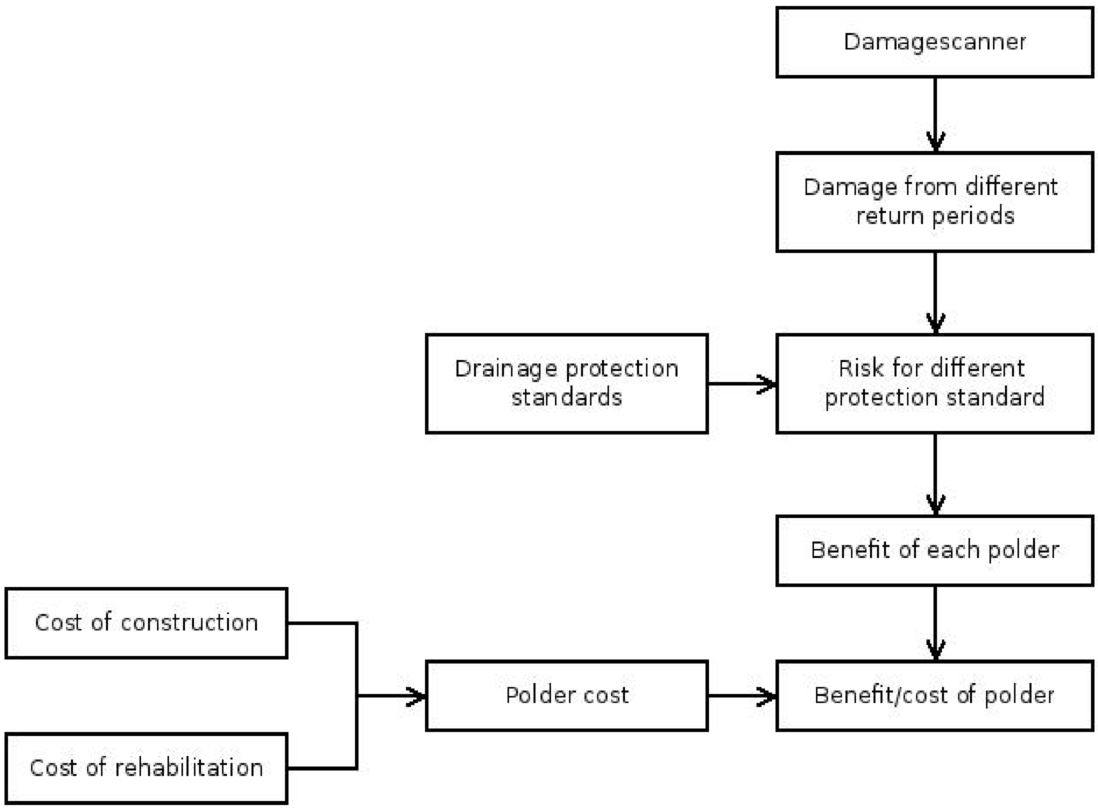

Figure 4.1 The research framework of analysis. (Source: Author's design)

4.2.1 Estimation of benefits

We estimated the annual benefits of the polder system as the EAD without the system, minus the EAD with the system. We assumed a project lifetime of 100 years, and a discount rate of 7% (Hallegatte, 2014), and calculated the total benefits over this project lifetime. Note that in section "Uncertainty and sensitivity test" we also carry out a sensitivity analysis using discount rates of 4% and 10%. The lower rate was according to target inflation rate 2016-2017 in Ministry of Treasury Regulation (Permenkeu 93/PMK.011, 2014), while the higher rate was according to the highest target of the Central Bank of Indonesia (Public Information Service, 2013).

Damagescanner–Jakarta was developed by Budiyono et al. (2015, 2016) as a model in Python to calculate flood risk. Here, we provide a brief overview of the model; for details of the setup and model structure, we refer the reader to Budiyono et al. (2015) and Budiyono et al. (2016). In essence, DamagescannerJakarta is a grid-based flood risk model, which runs at a horizontal resolution of 50 m×50 m. It works by combining flood hazard maps and exposure maps (showing the land use in each cell and its associated maximum economic damage) with a depth–damage function to represent vulnerability. For each cell, Damagescanner-Jakarta identifies the inundation depth from the flood hazard map produced by the SOBEK Hydrology suite (Deltares, 2014). Then, for this cell it identifies the land use class available from the office of city planning (DTR DKI, 2007) and its associated maximum economic damage, which was derived by Budiyono et al. (2015) through expert interviews and workshops. The model includes a set of depth-damage functions per land use class, which show the proportion of the maximum damage that would occur for floods of different depths. As with the values of maximum economic damage, these were derived from expert interviews and workshops described in Budiyono et al. (2015).

Damagescanner-Jakarta takes the depth-damage function for the land use class of the cell in question, and uses it to identify what proportion of the maximum damage would occur for the inundation depth in that cell. This procedure is used to simulate direct economic damage for floods of several return periods between 2 and 100 years. Then, the EAD is estimated as the area under the exceedance probability-loss (risk) curve, whereby the area is estimated using a trapezoidal approximation (e.g. Meyer et al., 2009); see visualization in Figure 4.2.

For the current situation, we assume that the polder system does not provide protection against flooding. Hence, the damages simulated for floods of all return periods are used in the calculation of EAD. We then calculated the EAD that would occur if the polder system were implemented to provide protection against floods of different return periods, namely 2, 5, 10, 25, and 50 years; these are based on the return periods stated in the Permen PU 12/2014. This is carried out by assuming zero flood damage to occur for floods up to this return period (Figure 4.2). This is first carried out for current climate conditions and based on the current land use map of Jakarta.

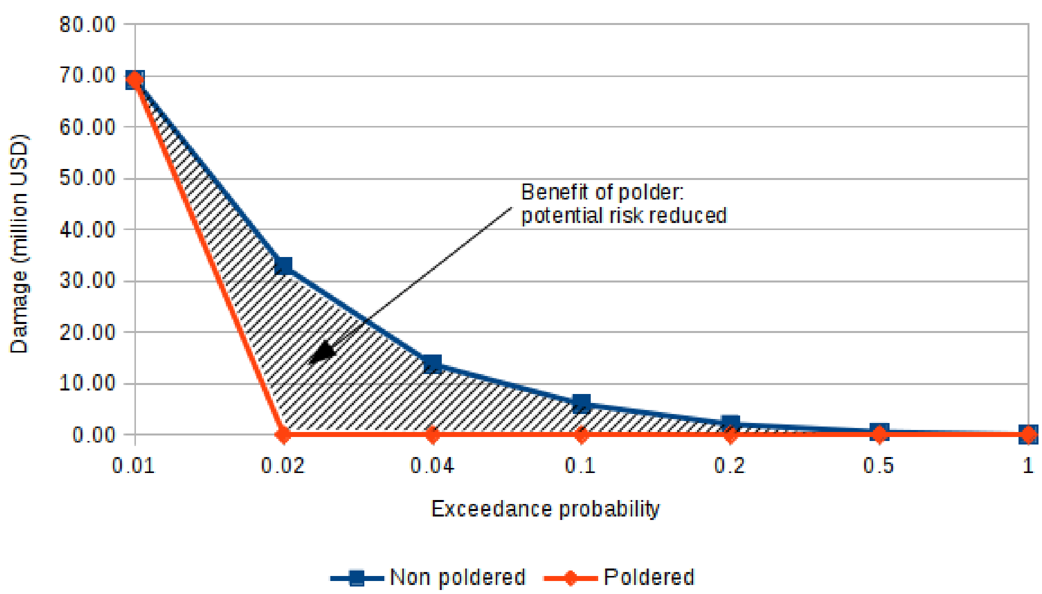

Figure 4.2 Theoretical example of the damages for different exceedance probabilities (1/return period) with and without a polder system showing benefit of polder designed at 50 years return period. (Adopted from Mechler, 2005)

Next, we calculated the benefits that could be achieved under a scenario of climate change, land use change, and land subsidence. For this study, to demonstrate the use of the method, we use the median scenario amongst all scenario combinations described in Budiyono et al. (2016), which is US$ 521 million per year. Future climate change in 2030 and 2050 was represented by taking changes in precipitation intensity. from downscaled output data of five global climate models (GCMs), namely GFDL-ESM2M, HadGEM2-ES, IPSLCM5A-LR, MIROC-ESM-CHEM, and NorESM1-M (Hempel et al., 2013), forced by four Representative Concentration Pathways (RCPs), namely RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (IPCC, 2014). For sea-level rise, we used the likely range in global sea level rise projections of the IPCCs Fifth Assessment Report (AR5) (IPCC, 2013, Table AII7.7) for 2010-2030 of 6cm to 11cm, and 14cm to 24cm for 2010-2050. For land use change, we used the official Jakarta Spatial Plan 2030 (Perda DKI Jakarta 1, 2012), which is an idealized land use scenario for 2030.

Finally, a hypothetical scenario of land subsidence was developed, in which the current rate of subsidence (Abidin et al., 2011) continues at the same rate, and ultimately stops in the year 2025. This is based on an assumption that the government will successfully implement the “100-0-100 sanitation policy” (Direktorat Jenderal Cipta Karya, 2015), which means that the government will provide 100% of water supply needed by Jakarta by 2019 and consequently groundwater extraction and subsidence would cease, as also seen in Tokyo (Endo et al., 2001), Tokyo lowlands (Aichi, 2008), and Bangkok (Phien-wej et al., 2006).

4.2.2 Estimation of costs

The costs are estimated as the total construction and rehabilitation costs of 22 dike projects carried out in Java during the period 2007-2012 by the Ministry of Public Works (Direktorat Bina Program, 2012). The cost of construction per meter is estimated at US$ 554.26 while the cost of rehabilitation is estimated at US$ 371.48. The minimum and maximum length of the dikes for these projects is 2,000m and 65,157m respectively, with an average length of 7,308m. This is comparable to the dike lengths of 2,431m34,229m required for the polder systems in Jakarta. The maintenance costs per polder are assumed to be 1% of the construction costs per year, and begin in the year after dike construction. Note that the costs of each polder omit the price that could be shared by two adjacent polders, in order to make the costs comparable. We assumed the costs to be constant for different return periods of protection, since the dikes mostly follow street lines on top of older streets without the need for reworking the basis. The cost also neglects the need for retention lakes and pumping systems as suggested by e.g. Moerwanto et al. (2009) and Mechler (2005), which means that the results are subject to underestimation. As with the benefits, we assumed a project lifetime of 100 years, and a discount rate 7%, and calculated the total costs over this project lifetime. Again, note that in section “Uncertainty and sensitivity test” we also carry out a sensitivity analysis using discount rates of 4% and 10%.

4.3 Results

In this section, we describe results of our benefit/cost analysis for the 66 polders found in Jakarta Spatial Plan 2030. Section “Current situation” describes the results for the current situation, followed by results for the future scenario in section “Future situation”. To simplify the discussion, we use the term net benefiting polders to refer to polders with a B/C ratio greater than 1. Similarly, we use the term polders with very high net benefits to refer to polders with a B/C ratio greater than 20.

We also use the division of western polders and eastern polders using the Ciliwung Lama river as border. The Ciliwung Lama is the lower part of the main river of Jakarta and is contained in the Pluit polder. The Ciliwung is the biggest river system in Jakarta, extending from the mountains (Puncak) to the coast. At Manggarai, most of the water is diverted to the Western Flood Canal to avoid excess water from entering the city center. We take the border following PAM Jaya area service division (PAM Jaya, 2012; PAM Jaya, 2015) from 1997. The western area has long benefited from the Western Flood Canal while the eastern area has only benefited from the Eastern Flood Canal since 2010 (Adhi Ksp., 2010).

In Figure 4.3, we show the current distribution of flood risk, before the construction/upgrading of the polder system. Here, flood risk is expressed in terms of expected annual damage, as calculated using Damagescanner-Jakarta. In Figure 4.3, we also show the location of the polders that make up the polder system in the plan discussed in this Chapter.

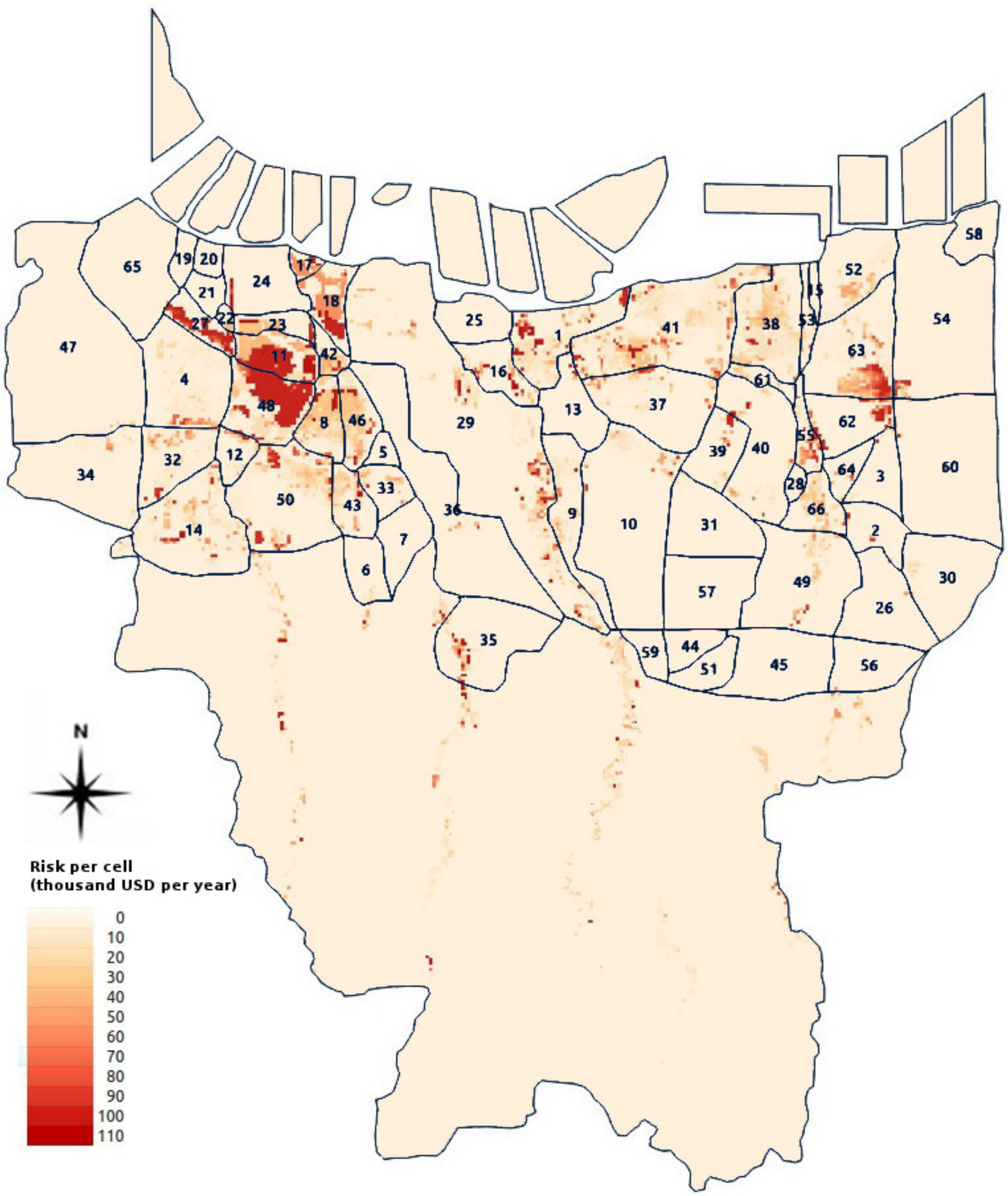

Figure 4.3 The 66 polders (43 existing and 23 new) overlaid on a map of simulated flood risk 2013. (Source: Author's analysis). (For polder numbering refers to number in Table 1 and Table 2)

4.3.1 Current situation: Kapuk Muara and Penjaringan Junction give the highest net benefits

Table shows the B/C ratios that could be achieved by increasing the design standards for the existing polders, under current climate and land use conditions. Zero benefits in a cell means that our model simulates no risk. From the table, we see that 13 of the 43 polders could give immediate net benefits even if they were designed for a relatively frequent 2 year return period flood. Nine of them are situated in the west, while the other four are in the east. Fifteen polders could provide net benefits at the higher design return periods of 5, 10, 25 and 50 years. The table also shows that two polders, Kapuk Muara (Kapuk I, II, III) and Penjaringan Junction, give very high net benefits with B/C ratios of 23 and 49 respectively.

Table 4.2 Benefit/cost ratio of existing polders in Jakarta on current risk.

No	Polder name	Size (ha)	Perimeter	Design return period (year)				
			(km)	2	5	10	25	50
1	Ancol Pademangan	557	12	1	2	2	3	3
2	Cakung Timur Selatan	278	8	1	2	2	3	3
3	Cakung Timur Utara	290	9	0	0	0	1	1
4	Cengkareng	791	11	4	9	11	13	14
5	Grogol	82	4	0	0	0	0	0
6	Hankam Slipi	247	7	0	0	0	0	0
7	Jati Pulo	304	8	0	0	0	0	0
8	Jelambar Barat (Wijaya Kusuma II)	286	8	1	2	3	6	7
9	Johar Baru	468	15	0	0	0	0	0
10	K. Item Serdang	1530	18	1	3	3	4	4
11	Kapuk Muara (Kapuk I, II, III)	329	8	49	114	144	160	167
12	Kedoya Green Garden	165	5	3	7	10	12	13
13	Kemayoran	377	10	0	1	1	1	1
14	Kembangan	896	12	1	3	5	6	7
15	Komplek Dewa Ruci	53	5	0	0	0	0	0
16	Marina	302	8	1	3	4	6	6
17	Muara Angke	70	4	0	0	0	0	1
18	Muara Karang	290	9	0	2	3	6	7
19	Pantai Indah Kapuk	36	2	7	16	20	23	24
20	Pantai Indah Kapuk	95	4	0	0	0	0	0
21	Pantai Indah Kapuk	107	5	0	0	0	0	0
22	Pantai Indah Kapuk	128	5	0	1	2	2	2
23	Pantai Indah Kapuk	172	7	3	10	14	16	18
24	Pantai Indah Kapuk	491	9	1	2	2	3	3
25	Pasar Ikan	313	7	0	0	0	0	0
26	Penggilingan	601	11	0	0	0	0	0
27	Penjaringan Junction	202	7	23	55	71	81	86
28	Perum Walikota (Don Bosco)	58	3	2	3	4	4	4
29	Pluit	2954	34	0	1	2	2	3
30	Pulo Gebang	701	11	0	0	1	1	1
31	Pulo Mas	589	10	0	0	0	0	0
32	Rawa Buaya	443	9	8	18	23	27	29
33	Rawa Kepa	203	6	0	2	2	3	4
34	Semanan	946	13	4	10	13	15	16
35	Setiabudi Barat	754	11	0	2	3	3	4
36	Siantar Melati	1365	25	0	0	0	0	0

37	Sunter Selatan	773	11	0	1	2	2	2
38	Sunter Timur I (Kodamar) atas	800	14	0	1	1	1	2
39	Sunter Timur I (Kodamar) bawah	335	7	1	3	4	6	6
40	Sunter Timur III (Rawa Badak)	650	11	0	1	1	1	2
41	Sunter Utara	1324	18	1	2	3	4	4
42	Teluk Gong	108	5	0	1	1	1	2
43	Tomang Barat	253	7	1	2	2	3	4

(Source: Author's analysis).

For planned polders, Table 4.3 shows that 8 out of 23 polders give immediate net benefits even for a design return period of 2 years. All of the polders are situated on the east. Four polders give net benefits for higher return period design standards (5, 10, 25, and 50 years). Among the 9 net benefiting polders at a design standard of 2 years, Kapuk Polgar has a very high B/C ratio of 29, while the maximum B/C ratio among the other 8 polders is 3.9. The most inland planned polder is Kayu Putih, situated in the east (17km from coast).

Table 7 Benefit/cost ratio of planned polders on current risk

No	Polder name	Size (ha)	Perimeter	Designed return period (year)				
			(km)	2	5	10	25	50
44	Cipinang	181	6	0	0	0	0	0
45	Duren Sawit	671	13	0	0	0	0	0
46	Jelambar Timur	284	8	0	0	2	4	5
47	Kalideres	2230	23	0	1	1	1	1
48	Kapuk Polgar	527	10	29	66	84	94	98
49	Kayu Putih	980	14	1	3	4	4	4
50	Kedoya Taman Ratu	942	12	1	3	5	6	6
51	Klender	211	6	0	0	0	0	0
52	Komplek Dewa Kembar	529	10	1	3	4	4	5
53	Kramat Jaya	109	8	0	1	1	1	1
54	Marunda besar	1555	18	0	0	1	1	1
55	Marunda kecil	241	7	0	0	0	0	0
56	Pegangsaan Dua	159	7	4	8	10	12	13
57	Pondok Kopi	381	8	0	0	0	0	0
58	Pulo Gadung	628	10	0	0	0	0	0
59	Rawa Bunga	151	6	0	0	0	0	0
60	Rorotan	1405	16	0	0	0	1	1
61	Sunter Timur I B	101	6	0	0	0	0	0
62	Sunter Timur II KBN	398	9	2	6	8	10	11
63	Sunter Timur II Kebantenan	784	12	1	2	3	4	4
64	Sunter Timur II Petukangan	156	6	1	3	4	4	4
65	Tanjungan	928	12	0	0	0	0	0
66	Warung Jengkol Vespa	262	8	2	5	6	7	8

(Source: Author's analysis).

For planned polders, Table 4.3 shows that 8 out of 23 polders give immediate net benefits even for a design return period of 2 years. All of the polders are situated on the east. Four polders give net benefits for higher return period design standards (5, 10, 25, and 50 years). Among the 9 net benefiting polders at a design standard of 2 years, Kapuk Polgar has a very high B/C ratio of 29, while the maximum B/C

ratio among the other 8 polders is 3.9. The most inland planned polder is Kayu Putih, situated in the east (17km from coast).

In Figure 4.4, we show the distribution of the B/C ratios, assuming a design return period of 25 years, which relates to the highest standards for a Metropolitan City, as stated in the Permen PU 12/2014. See also Figure 4.6 for the increase between present situation and future scenario for twelve polders with high net benefits.

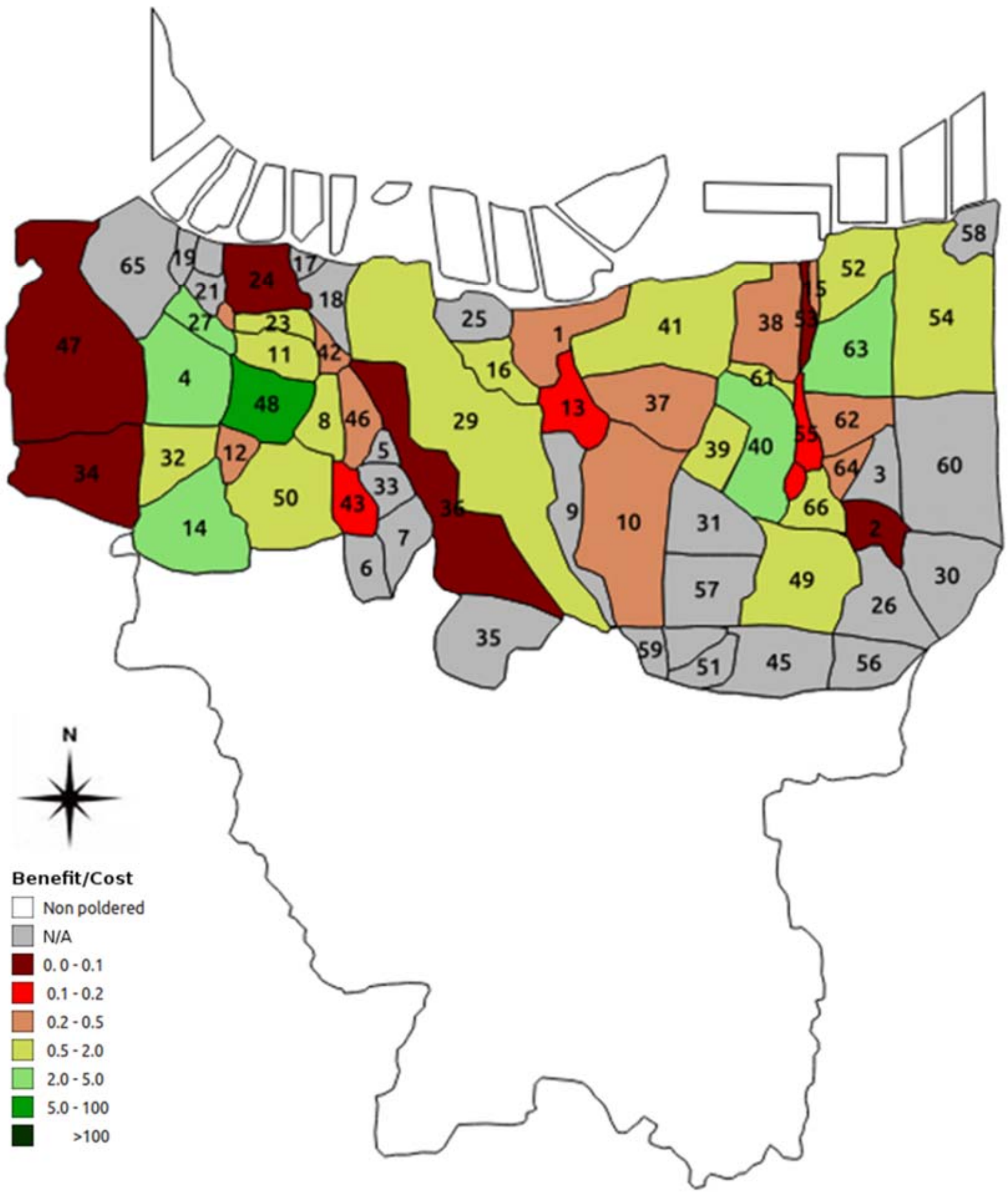

Figure 4.4 Distribution of benefit/cost for present situation (The grey area ("N/A") relates to polders where no risk is simulate using Damagescanner-Jakarta) (Source: Author's analysis).

4.3.2 Future situation: Kapuk Poglar and nine others give high net benefits

When designing structural flood defense measures, investments are made for a long time horizon. Therefore, we also assessed the B/C ratios for the different polders using a future scenario including climate and land use change. As described in the methods section, the results shown here refer to the median scenario of all scenario combinations used to assess changes in precipitation intensity, sea level, land use, and subsidence. This scenario results in expected annual damage of US$ 493 million, when the polder system is not taken into account.

The resulting B/C ratios for existing polders are shown in Table 4.4. The results show that 19 out of 43 polders could provide net benefits at a 2-year return period design standard; 11 of these polders are situated in the west, while the other eight are in the east. Seven more polders could provide net benefits for higher return period design standards.

Table 4.4 Benefit/cost ratio of existing polders for the future scenario of climate change, sea level rise, land use change, and land subsidence (Source: Author's analysis).

No	Polder name	Design return period (year)				
		2	5	10	25	50
1	Ancol Pademangan	35	53	60	63	64
2	Cakung Timur Selatan	0	0	1	1	1
3	Cakung Timur Utara	0	0	0	0	0
4	Cengkareng	11	18	21	22	23
5	Grogol	0	0	0	0	0
6	Hankam Slipi	0	0	0	0	0
7	Jati Pulo	0	0	0	0	0
8	Jelambar Barat (Wijaya Kusuma II)	7	12	14	15	15
9	Johar Baru	0	0	0	0	0
10	K. Item Serdang	0	1	1	1	2
11	Kapuk Muara (Kapuk I, II, III)	44	67	77	81	83
12	Kedoya Green Garden	1	1	1	2	2
13	Kemayoran	1	1	1	1	2
14	Kembangan	6	12	15	17	18
15	Komplek Dewa Ruci	6	9	10	11	11
16	Marina	9	14	17	18	19
17	Muara Angke	31	47	54	57	58
18	Muara Karang	24	36	41	43	44
19	Pantai Indah Kapuk	12	18	20	21	22
20	Pantai Indah Kapuk	0	0	0	0	0
21	Pantai Indah Kapuk	0	0	0	0	0
22	Pantai Indah Kapuk	0	0	0	0	0
23	Pantai Indah Kapuk	10	16	18	20	20
24	Pantai Indah Kapuk	0	0	0	0	0
25	Pasar Ikan	0	0	0	0	0
26	Penggilingan	0	0	0	0	0
27	Penjaringan Junction	78	120	137	146	149
28	Perum Walikota (Don Bosco)	0	0	1	1	1
29	Pluit	1	2	2	3	3
30	Pulo Gebang	0	0	0	0	0
31	Pulo Mas	0	0	0	0	0
32	Rawa Buaya	2	4	5	6	7
33	Rawa Kepa	0	0	0	0	0
34	Semanan	0	0	0	0	1

35	Setiabudi Barat	0	0	0	1	1
36	Siantar Melati	0	0	0	0	0
37	Sunter Selatan	7	11	13	14	14
38	Sunter Timur I (Kodamar) atas	5	10	12	13	14
39	Sunter Timur I (Kodamar) bawah	3	5	6	6	6
40	Sunter Timur III (Rawa Badak)	85	127	145	153	157
41	Sunter Utara	54	81	92	98	100
42	Teluk Gong	4	6	7	7	8
43	Tomang Barat	1	1	2	2	3

Table 4.5 shows the B/C ratios using the future scenario, for planned polders. From the table, 13 out of 23 polders could provide net benefits for all return period design standards; only two of the polders are on the west. The increase of net benefiting planned polders using the future scenario compared to the current situation shows the importance of considering future changes when considering the polder system. Figure 4.5 shows the distribution of B/C ratios for future scenario.

Table 4.5 Benefit/cost ratio of planned polders for future scenario resulting from median of three scenarios i.e. climate change, sea level rise and land subsidence (Source: Author's analysis).

No	Polder name	Design return period (year)				
		2	5	10	25	50
44	Cipinang	0	0	0	0	0
45	Duren Sawit	0	0	0	0	0
46	Jelambar Timur	2	3	4	4	4
47	Kalideres	0	0	0	0	0
48	Kapuk Poglar	91	139	158	168	172
49	Kayu Putih	1	3	4	4	5
50	Kedoya Taman Ratu	2	4	5	5	6
51	Klender	0	0	0	0	0
52	Komplek Dewa Kembar	31	47	54	57	58
53	Kramat Jaya	5	8	9	9	9
54	Marunda besar	1	2	2	3	3
55	Marunda kecil	0	0	0	0	0
56	Pegangsaan Dua	1	2	3	3	3
57	Pondok Kopi	0	0	0	0	0
58	Pulo Gadung	0	0	0	0	0
59	Rawa Bunga	0	0	0	0	0
60	Rorotan	0	0	0	0	0
61	Sunter Timur I B	11	17	20	21	21
62	Sunter Timur II KBN	1	2	2	3	3
63	Sunter Timur II Kebantenan	17	28	33	36	38
64	Sunter Timur II Petukangan Timur	1	2	2	2	3
65	Tanjungan	0	0	0	0	0
66	Warung Jengkol Vespa	2	4	5	6	6

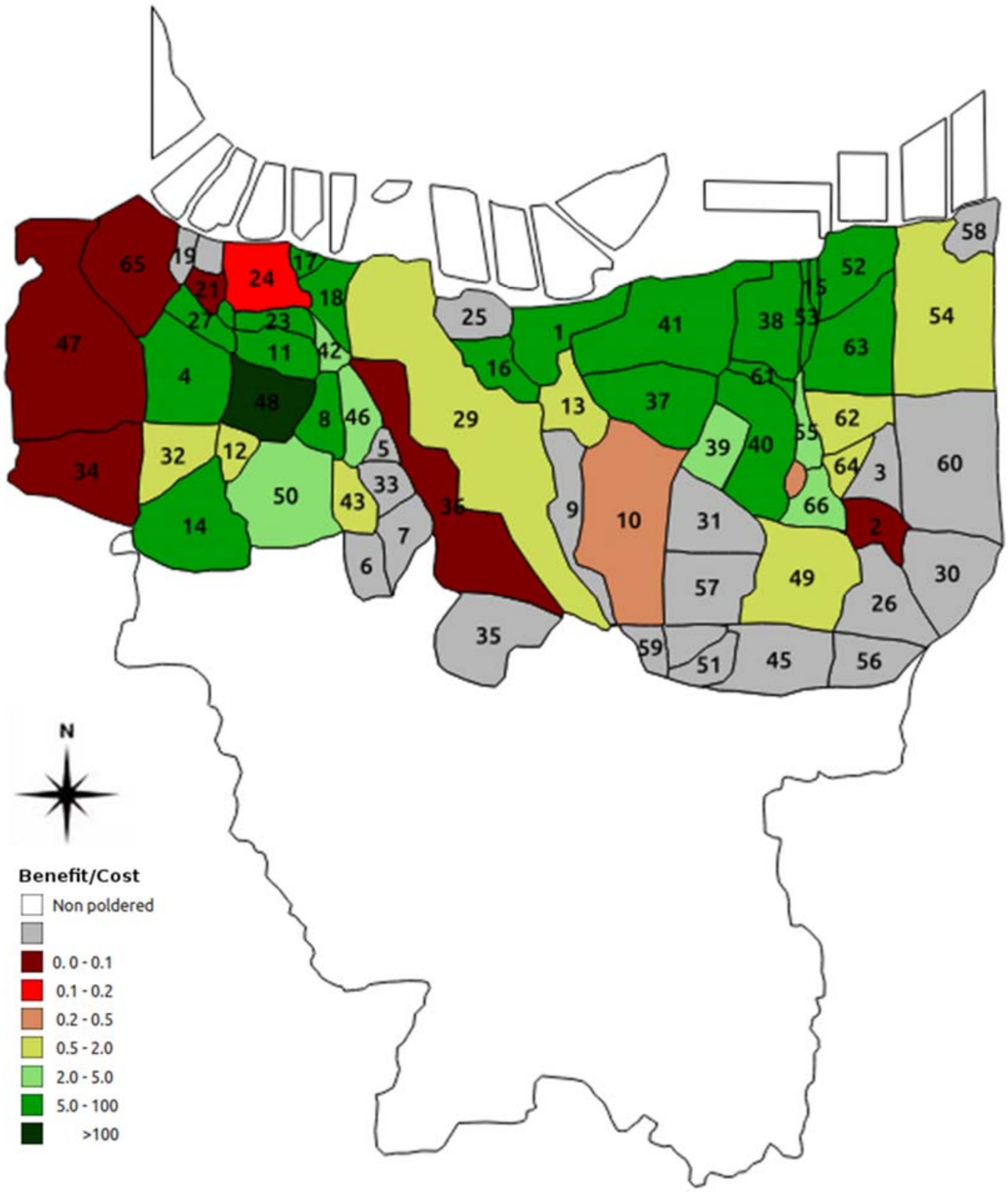

Figure 4.5 Distribution of benefit/cost for future scenario (The grey area ("N/A") relates to polders where no risk is simulate using Damagescanner-Jakarta) (Source: Author's analysis)

Combining data on the net benefiting polders available in Table 4.2 to Table 4.5, we produce Figure 4.6, which shows the number of polders with a B/C ratio greater than one for the different return period design standards. Looking at the steepness, existing polders are more sensitive to the selection of return periods than planned polders for both current situation and the future.

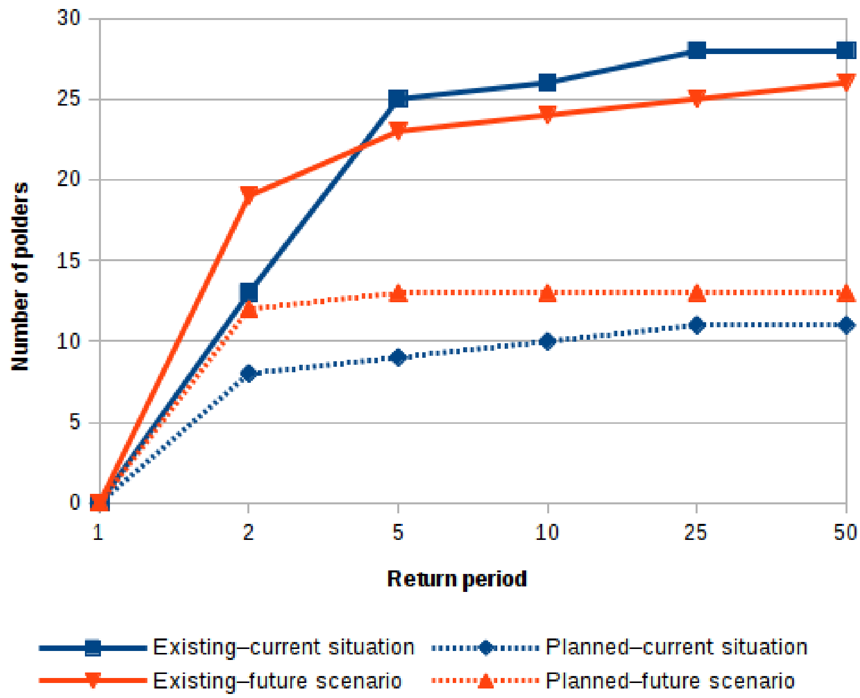

Figure 4.6 Plot of the number of net benefiting polders for each return period design standard. (Source: Author's analysis)

We assessed the B/C ratios under the current and future scenarios for the 12 polders with the highest net benefits; these results are shown in Figure 4.6. The total risk reduction that could be achieved through the implementation of these polders is very large, both under current conditions (US$ 104 million per year) and future conditions (US$ 400 million per year). Again, the figure also shows the importance of considering the future conditions when planning for such structural measures with a long lifetime, since the overall benefits of the projects are much higher when the potential future changes are included.

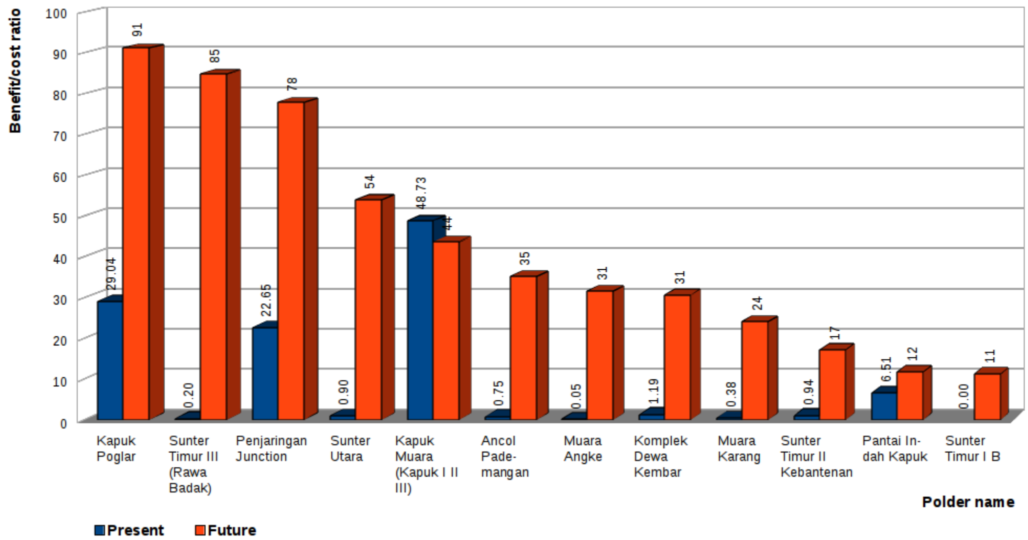

Figure 4.7 Bar chart showing the B/C ratios for the 12 polders with the highest net benefits for current situation and future scenario. (Source: Author's analysis)

4.4 Discussion

Overall, we show that the implementation of the polder system could greatly reduce flood risk compared to the current situation. In the current situation, even if polders were designed for a 2 year return period flood, they could reduce risk by 25% (from a current risk of US$ 186 million per year without polders, to US$ 139 million per year with polders). The potential reduction of future risk is even greater. Again, if polders were designed for a 2 year return period flood, they could reduce risk in 2030 by 52% (from a current risk of US$ 521 million per year without polders, to US$ 261 million per year with polders). Of course, we show that bet benefits are not achieved for all polders, and so our benefit-cost results are also useful for highlighting those polders where the benefits are expected to outweigh the costs. In the following sections, we first discuss the polders in which these potential net benefits are particularly high. We then discuss policy implications of the polder system, before discussing the uncertainty and sensitivity tests carried out for this study, and potential future research directions.

4.4.1 Polders with very high net benefits are located away from the coastline

From Figure 4.4, we can see that the polders with very high net benefits for the current situation are located away from the coastline. This is similar to the situation in the Netherlands (Klijn et al., 2010), but with a different rationale. In the Netherlands, the lower benefit of further compartmentalization in coastal polders was due to the prior existence of many ancient and secondary embankments including road and railroad verges.

It is also important to note that the high number of polders with very high net benefits in this study may be related to an underestimation of costs. As stated previously, we do not include operational costs and costs of pumping stations, which can add significantly to the overall costs (Špačková and Straub, 2015). Here, we provide first cut estimates that reveal that the plan may be beneficial for a large number of polders, but for those polders more detailed studies would be required to assess the costs more accurately, and also to assess the potential co-benefits (e.g. using the storage lakes for recreation and so forth). For this first study, it was difficult to include the costs of pumping in a way that would allow comparison of the results between polders, because the techniques used can vary widely. For example, Tanjungan pumping station uses screw pumps with lower maintenance while Pluit pumping station uses axial pumps that require more energy and capital investment. Also the Tanjungan polder depends on a long shore type of retention pond that diverts flood water slower (and tends to give more risk) compared to the state of the art Pluit Lake together with the solid waste filtration system and the recreational park. Similar variations also exist in Ancol station, which is moderately active compare to Tanjungan and Pluit. In addition to that, morphology of inland and near shore polders will make large differences in costs between polders, which should be examined in detailed studies of each polder.

4.4.2 Policy implications of polder systems in Jakarta

Our results show that the implementation and management of just 3 polders, namely Kapuk Muara (Kapuk I, II, III), Kapuk Poglar, and Penjaringan Junction (see Table 4.2 and Table 4.3), could have a huge impact on reducing overall risk. These could reduce risk by US$ 92 million per year under the current situation, or US$ 153 million per year under the future scenario (50% of current risk). The three decrease 31% of risk under the future scenario. Total investment of the three is US$ 10.25 million, or 3.2% of total cost for all 66 polders.

Our results suggest that building and maintaining the twelve polders shown in Figure 4.6, to a return period design standard of 50 years (see last column of Table 4.2 to Table 4.5), could reduce the current risk by US$ 104 million per year (i.e. 56 % of current risk), or by US$ 400 million per year under the future scenario (i.e. 81% of future risk). These examples show how risk based benefitcost analysis can help to identify and prioritize polder construction.

4.4.3 Uncertainty and sensitivity test

As mentioned previously, this study is intended to provide first cut estimates of the costs and benefits of the proposed polder system. This allows us to identify polders where the potential net benefits are the highest, which could be prioritized. However, the study is subject to large uncertainties. Especially, the costs considered here do not include the costs for the pumping stations and retention lakes, which could add up to a significant part of project costs. Therefore, for polders with a B/C ratio that only exceeds 1 by a relatively small amount, caution must be exercised. For all polders, if one were to want to move towards implementation, much more detailed studies of both the costs, benefits, and hydraulics systems would be required at the local scale. Nevertheless, the results are useful for opening a dialogue between planners and decision-makers on the potential of the proposed polder system to reduce risk.

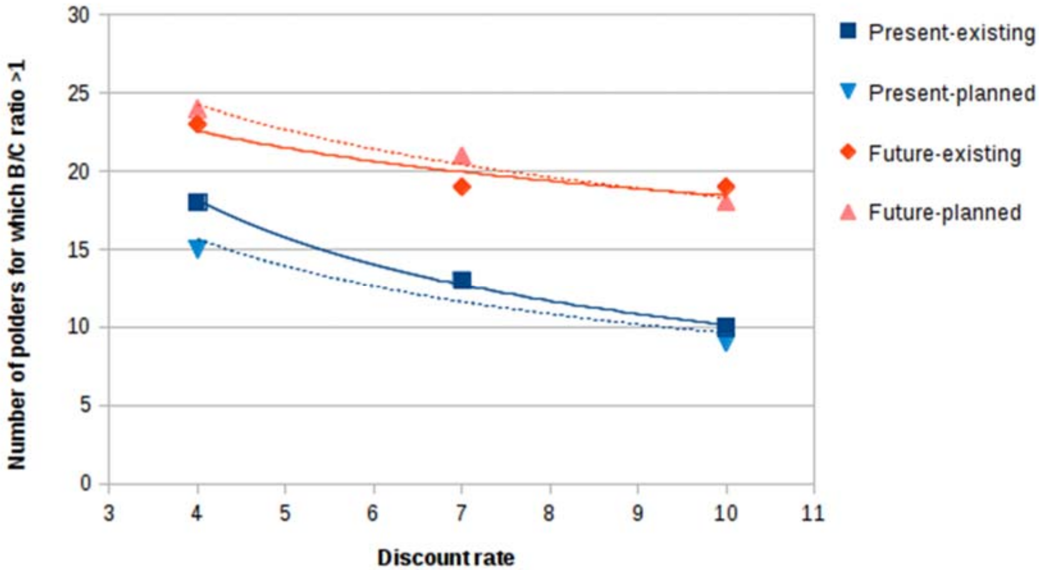

Figure 4.8 Sensitivity test using inflation rate 4%, 7% (discussed in previous section), and 10% showing number of polders that give immediate benefit at return period 2 years. (Source: Author's analysis).

We tested the sensitivity of the BCA to the choice of discount rate, by also carrying out the analyses using lower (4%) and higher (10%) discount rates, and examining the number of polders for which the resulting B/C ratio > 1. The results are shown in Figure 4.8, including a power fit between the discount rates of 4, 7, and 10%. As expected, the number of net benefiting polders reduces as the discount rate increases, since most of the costs are incurred early on whilst the benefits accrue over the lifetime of the polder. Nevertheless, even at the higher discount rate, a large number of polders show a B/C ratio > 1, indicating that these polders are relatively insensitive to the discount rate used.

4.4.4 Future research needs

This study provides a first cut analysis of the costs and benefits of the described polder system. In future work, it will be important to use more detailed local information to assess the costs and benefits of the polder systems more accurately, especially for those polders that have shown potentially high net benefits in this Chapter. In this regard, learning from existing polders that show cases of good practice would be useful; a case in point is Pluit polder. Such future studies would need to include detailed data on aspects such as the dike line, the underlying soil type, retention lake capacity and placement, and costs of the pumping system. Moreover, the co-benefits of the polders should be examined, such as potential uses of the retention lakes for recreation and ecosystem services.

This Chapter estimates the potential benefits based on hydraulic modeling of fluvial flooding. However, flash floods in the polders can also be caused by local precipitation, as seen in the flood of 19 February 2015 (Siswanto et al., in press). These extreme rainfall events may become more frequent or extreme in the future. It would be beneficial to also develop a flood hazard model based on scenarios of current and future pluvial flooding within a polder, which could increase the potential benefits of the polder system.

The results presented here for the future scenario are based on the median scenario of a large number of future scenarios of climate change, land use change, and subsidence, carried out by Budiyono et al. (2016). In future studies, it would be useful to examine the B/C ratios under all of the scenarios, in order to give a more complete picture of how the B/C ratios develop under each of the different scenarios.

Finally, this study does not examine the institutional and/or governance issues related to the potential implementation of polders in Jakarta; future research on this aspect is also essential.

4.5 Conclusions

We have demonstrated the use of a risk-based benefit-cost analysis for assessing potential effectiveness of the polder system described in Permen PU 12/2014 in Jakarta. The study provides first cut estimates of the benefits and costs involved, although costs of the pumping stations and retention lakes are not included in the analysis. Nevertheless, the results are useful for identifying polders where the potential benefits are the highest, and for prioritizing those polders. The results showed that implementing three polders could reduce current flood risk by 50%, namely Kapuk Muara (Kapuk I, II, III), Penjaringan Junction, and Kapuk Poglar. If we account for a future scenario of climate change, land use change, and land subsidence, the future risk could be reduced from US$ 493 million per year to US$ 340 million per year. Under this future scenario, nine additional polders could also provide net benefits, namely Sunter Timur III (Rawa Badak), Sunter Utara, Ancol Pademangan, Muara Angke, Komplek Dewa Kembar, Muara Karang, Sunter II Kebantenan, Pantai Indah Kapuk (19) and Sunter Timur IB. The twelve polders could decrease 81% of future flood risk, with the benefits far outweighing the costs.

Based on the findings, it appears that the highest immediate benefits could be obtained from developing the first group of polders. In the longer run, developing the other polders showing high net benefits could further reduce the risks from fluvial flooding in Jakarta.

Chapter 5

5 FLOOD RISK DECREASE RESULTING FROM FLOOD EARLY WARNING SYSTEM IN JAKARTA

Yus Budiyono, Pini Wijayanti, Siswanto Siswanto, Jeroen C.J.H. Aerts, Philip J. Ward, 2018. Flood risk decrease resulting from Flood Early Warning System in Jakarta, in review.

Abstract

In the past decades, the flood problem in Jakarta has become an important issue. Next to traditional structural measures to reduce the likelihood of flooding, such as dikes, levees, and flood canals, there is more and more attention for non-structural measures. An example of a non-structural measure to decrease flood risk is an SMS-based flood early warning system (FEWS). In this study, we examine the potential economic damage that could be avoided in Jakarta by coupling an SMS-based FEWS system with a hydrodynamic model. Damages can be avoided if a timely warning allows inhabitants of a potentially flooded area to take actions to save their assets, in effect reducing their vulnerability to the flood. We calculated the potential reduction in economic damage using the Damagescanner-Jakarta model, and used information from a survey to adapt the model for assessing the effectiveness of the FEWS to reduce economic damage. We found that the expected annual damage (EAD) without the FEWS system is US$ 186.2 million. If the FEWS system were to be implemented, this could be reduced by between 1.9% and 12%, depending on how many households take measures to reduce vulnerability based on warnings. Risk reduction by FEWS in only residential areas ranges from 13% to 84%. As an example, FEWS can reduce damage from a 1/30 flood with US$ 11.1 million. As the survey results reveal that household level adaptation measures are already able to reduce risk for inundation depths up to 125 cm, it is recommended to provide financial incentives to implement such measures, or develop building codes to stimulate risk reduction measures at the household level. Future research needs to be carried out to assess the thresholds at which flood warnings should be issued, in order to maximize the potential benefits of correct warnings, and minimize the false alarms.

5.1 Introduction

In the past decades, the flood problem in Jakarta has become a huge issue. For example, the major floods in 2002, 2007, 2013, and 2014 caused billions of dollars of direct and indirect economic damage, and huge social upheaval (Bappenas, 2007; Ward et al., 2013; Sagala et al., 2013). Hence, measures are needed to try to reduce the impacts of the flood problem. Traditionally, most planned measures to decrease flood risk in Jakarta have focused on structural approaches such as dikes, canals, and flood gates. This follows the traditional approach to flood management, whereby limiting the impacts of floods is mainly achieved by reducing the likelihood of the hazard by implementing flood abatement structures.

The flood risk management approach has become more and more mainstream in the last few decades. Here, risk is defined as a function of the hazard, exposure, and vulnerability (UNISDR, 2011). In this approach, measures are taken to address all aspects of flooding, not only reducing the magnitude and/or frequency of the hazard, but also measures to decrease the impacts of a flood if it should occur. Such an approach calls for a more integrative approach, combining technical, institutional, socioeconomic and financial aspects in the planning of flood risk management. An example of a non-structural measure to decrease flood risk is a flood early warning system (FEWS). FEWS have traditionally been used by inhabitants along rivers in many parts of Indonesia. During the flood season, members of the community serve shifts as guards near the river bank, monitoring the depth of the river and sending flood alarms to other inhabitants using a traditional instrument, namely the kentongan (wooden or bamboo gong). In this traditional system, a four knock rhythm means the flood is about to occur (YPM, 2010). In a critical situation, one constant knock (kentongan titir) (Lucas, 1977) means that an emergency is happening or that flood water is actually overflowing the dike.

In the case of volcanic eruptions, the effectiveness of this traditional form of early warning system has been assessed by Lavigne et al. (2008). They carried out a survey on Mt. Merapi, which showed that it was implemented in over 70% of the area and was understood by 46% of the inhabitants. In this case study, the sound of the kentongan could penetrate up to 2 km during the night time, which is the same as 2-meter band VHF radio penetration (Kesper and Zein, 2010). In Jakarta, with the norm of placing a guard hut in each block, each kentongan alarm covers a radius of 100m. In Jakarta, a traditional FEWS has been augmented by the implementation of gauges using automatic water level recorder (AWLR). At some posts, the monitoring stations have guards working in 24 hours shifts. The result of this system is that floodwaters flowing from the most upstream station in the mountains (50 km upland) can be recognized up to nine hours before reaching the city (BPBD Provinsi DKI Jakarta, 2016). Different from communal alarm systems, gauge guards do not send alarms directly to the people. The guards have a mandate from the provincial government who install the system. Using the information, the government creates a siaga 1-2-3-4 system (BPBD Provinsi DKI Jakarta, 2016). The higher the siaga number shows the necessity of preparing for a coming flood from the upland. Based on the alarm from the system, the Governor of Jakarta issued the letter for the flood case of January 2014 (Keputusan Gubernur Provinsi Daerah Khusus Ibukota Jakarta 70, 2014) regarding a period of emergency response.

The development of this system is an example of how planned flood management in Jakarta is moving towards a more risk based approach, also incorporating measures to increase preparedness. Combining FEWS and the response system, Adi et al. (2012) developed a more advanced approach using the hazard map that appeared in the flood risk study of Budiyono et al. (2015). The system is able to alarm people, and provide information including the predicted inundation depth and duration of impending floods. With the wide ownership of mobile phones and TV, timely predictions of floods can be broad-casted directly to users around the modeled inundation areas via digital TV or short messaging service

(SMS), as has been recognized in the Decree of the Minister of Communication and Information Technology number 32/2013 (Permenkominfo 32, 2013).

The potential benefits of such an SMS-based FEWS system have been recognised in several case studies. For example, a survey in Bangladesh showed that SMS-based FEWS are the second preferred method of early warning for floods after radio/television broadcast (Rahman et al., 2013). Shah et al. (2012) asserted that warnings from multiple sources can be beneficial, since they increase the confidence that information could be cross-checked, despite the fact that the information originates from a single source. The potential benefits have also been discussed in several studies (e.g. by Jha (2011); Lamond et al. (2012); Molinari et al., (2013)). However, to date quantitative studies on the potential benefit of SMS-based FEWS systems are limited. Using a spatial analysis, Balbi et al (2016) reported benefits to an area in Switzerland in terms of reduced number of injuries and likelihood of death. In terms of economic damage, Parker and Priest (2012) estimated the minimum and maximum benefits of a FEWS system in Europe by assessing the percentage of damage that could be avoided if a warning is issued and acted upon.

In this study, we examine the potential economic damage that could be avoided in Jakarta should an SMS-based FEWS coupled with a hydrodynamic model be implemented. Damages can be avoided if a timely warning allows inhabitants of a potentially flooded area to take actions to save their assets, in effect reducing their vulnerability to the flood. The potential reduction in economic damage is calculated using the Damagerscanner-Jakarta model (Budiyono et al., 2015), which is a flood risk model designed specifically for assessing direct economic damages in Jakarta. Information derived from a survey on inhabitants in flood prone areas was used to adjust Damagescanner-Jakarta, so that it can be used to assess damages in cases where flood warnings are or are not issued and acted upon. The survey was carried out along the Pesanggrahan River, which according to the 2010 census is moderately populated (13,363 persons/km2 (South Jakarta), compared to 14,469/km2 for Jakarta as a whole (BPS, 2010)). This area was selected for two reasons. Firstly, Pesanggrahan is the second largest/longest river/catchment flowing through Jakarta, but has received less research than the larger Ciliwung River. Secondly, the government has carried out river normalization in the lower Pesanggrahan, which makes it better suited to the spatial interpolation methods used in this study. In the lower Pesanggarahan, the survey also covers its tributaries, namely the Angke River and the Cengkareng Drain.

5.2 Method

In this study, the potential economic damage caused by floods is simulated using the Damagescanner-Jakarta flood risk model, developed by Budiyono et al. (2015, 2016). The original version of Damagscanner-Jakarta was setup assuming that no FEWS system is in place. In this study, we used information from a survey carried out by Wijayanti et al. (2015) in Jakarta to adapt the Damagescanner-Jakarta for also assessing the economic damage if a FEWS system is in place. By comparing simulations carried out with and without FEWS, we are able to provide an estimate of the decrease in damage that can be achieved though the FEWS system.

In this section, we first briefly describe Damagescanner-Jakarta. We then explain how the results of the survey by Wijayanti et al. (2015) were used in this study to adapt the model. The overall flow can be seen in Figure 5.1.

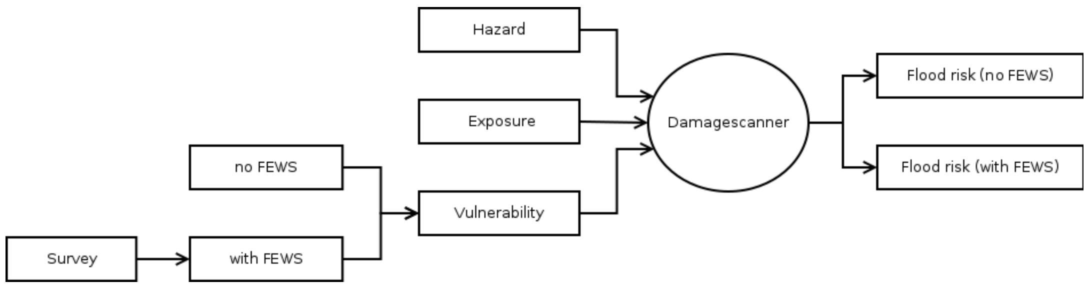

Figure 5.1 Framework of analysis effectiveness of flood early warning system

5.2.1 Damagescanner-Jakarta

Damagescanner-Jakarta is a raster-based flood risk assessment model, specifically designed for Jakarta. The model was originally developed by Budiyono et al. (2015), and updated by Budiyono et al. (2016). In this study, we use the model setup from the latter paper. The model, input data, and validation are described in detail in the two aforementioned papers, so here we only provide an overview of the most important aspects. The text is therefore based strongly on Budiyono et al. (2015) and Budiyono et al. (2016).

In brief, Damagescanner-Jakarta estimates flood risk as a function of hazard, exposure, and vulnerability, following the definition earlier in the Chapter. It is a raster-based model, with a grid size of 50m x 50m, which works by combining maps of hazard and exposure with a depth–damage function to represent vulnerability. For each grid cell, the model identifies the depth of flooding from the hazard map. For the same cell, the model identifies the land use class and its associated maximum damage. The depth–damage functions are used to determine what proportion of the maximum damage would occur at different flood depths, whereby a different vulnerability curve is used for each land use class. Damagescanner-Jakarta simply combines these three elements in order to provide an estimate of the direct economic damage. This procedure is carried out for floods of several return periods between 2 and 100 years. The expected annual damage (EAD) is then calculated as the area under the exceedance probability-loss (risk) curve, whereby the area is estimated using a trapezoidal approximation (e.g. Meyer et al., 2009).

In the following sub-sections, we describe the data used to represent hazard, exposure, and vulnerability.

5.2.1.1 Hazard

Flood maps showing the extent and depth of flooding for different return periods are generated using the SOBEK Hydrology Suite, which employs a Sacramento rainfall/runoff model and a 1D/2D hydrodynamic model (Deltares, 2014). The input data and hydraulic schematisation used in this study are described in Budiyono et al. (2016), and are taken from the Flood Hazard Mapping (FHM) project and the Flood Management Information System (FMIS) project (Deltares et al., 2012). Flood maps were produced for the following return periods: 1, 2, 5, 10, 25, 50 and 100 years.

5.2.1.2 Exposure

Exposure is represented using land use maps. For each land-use class, we have an estimate of the maximum damage that could occur in the event of a flood (in US$ per hectare). Following Budiyono et al. (2016), for this study we used the official land use map of Jakarta for 2009, issued by the Office of City Planning, Jakarta (Perda Provinsi Daerah Khusus Ibukota 1/2012). The land use classes of this map were reclassed to the following classes by Budiyono et al. (2015): industry and warehouse; commercial and business; government facility; planned house; transportation facility; education and public facility; high-density urban kampung; low-density urban kampung; forestry, river, and pond; park and cemetery; and agriculture and open space. The maximum damage values assigned to each of these land use classes can be found in Budiyono et al. (2015). They were derived from a series of expert meetings and a workshop carried out in Jakarta in 2012.

5.2.1.3 Vulnerability

As mentioned earlier, the vulnerability element of the risk framework is represented in Damagescanner-Jakarta through the use of depth-damage functions (e.g. Merz et al., 2010b). In this sense, they only represent the physical vulnerability of buildings and assets in the flood-prone region, and do not consider social vulnerability (e.g. Cutter and Finch, 2008; Cutter et al., 2013; Gain et al., 2015).

The original depth–damage functions for Jakarta were derived by Budiyono et al. (2015), through a series of expert meetings and a workshop, following the fuzzy cognitive mapping method (Groumpos, 2010; Stach et al., 2010). We refer the reader to this paper for a description of this process as well as the resulting functions.

5.2.2 Adapting depth-damage functions based on survey

For this study, we also adapted the depth-damage functions for the residential land use classes to portray the economic damage that could occur if a warning is obtained from the FEWS system with an adequate warning time. To do this, we used information from a survey carried out by Wijayanti et al. (2015). In the following subsections, we briefly describe the survey, in particular the parts of it used for this study. Since we only use results based on a limited part of the survey, we only focus on those parts. For a detailed description of the survey, we refer the reader to Wijayanti et al. (2015).

5.2.2.1 Survey of households in Pesanggrahan

The survey used in this study was conducted during April and May 2013. This survey was conducted a few months after the major flood that took place in this area in 2013, and one of its aims was to assess the economic damage experienced by different households as a result of this flood. Since the survey was carried out so soon after the flood, biases due to the length of time between the flood and the survey are limited.

The survey was carried out at households along the Pesanggrahan river. This area was particularly hard hit by the flood, with residents reporting that it was the largest flood event in living memory. The return period of this flood event is estimated to be ca. 30 years. We estimated this using a long hourly observed precipitation time-series measured at Jakarta Observatory from the Digitisasi Data Historis (DiDaH) project (www.didah.org), aggregated to the daily level (Siswanto et al. 2015; Können et al. 1998). The data from 1900 onward were used because of evidence of a discontinuity before that (Siswanto et al. 2016; Siswanto et al. 2015). This series is now available on the Southeast Asian Climate Assessment & Dataset (SACA&D) (van den Besselaar et al. 2015). To compute the return period and addressing the trend in the probability of occurrence over time, we fitted the annual maxima precipitation (Rx1day) data to a Generalised Extreme Value (GEV) distribution with position μ parameter depending on time (Coles, 2001).

The survey was carried out by holding interviews, using trained interviewers. A random sample was taken, including six villages (kelurahan) out of 48 kelurahans that experienced inundation during the January 2013 flood, namely: Ulujami, Kebayoran Lama and Cipulir, Kedoya Selatan, Sukabumi Selatan, and Rawa Buaya. In total, 327 out of the 1,706 inundated households were interviewed. The total area of the sampled villages is 12.3 km2 (BPS Jakarta, 2007). Structured questions and semi-structured interviews were used to derive information at the household level, including: building characteristics, owner characteristics, flood characteristics, economic damage due to the flood, costs of recovery, and flood emergency response. The interviews were carried out with the head of the household. Interviews were also carried out with small businesses. In this case the interviews were conducted with the business owner or manager. For each household or business, information was also recorded on the distance to the nearest river channel, noting positive correlation with flood perception in previous study by Heryanti and Kingma (2012). Figure 5.2 shows the survey locations in Jakarta.

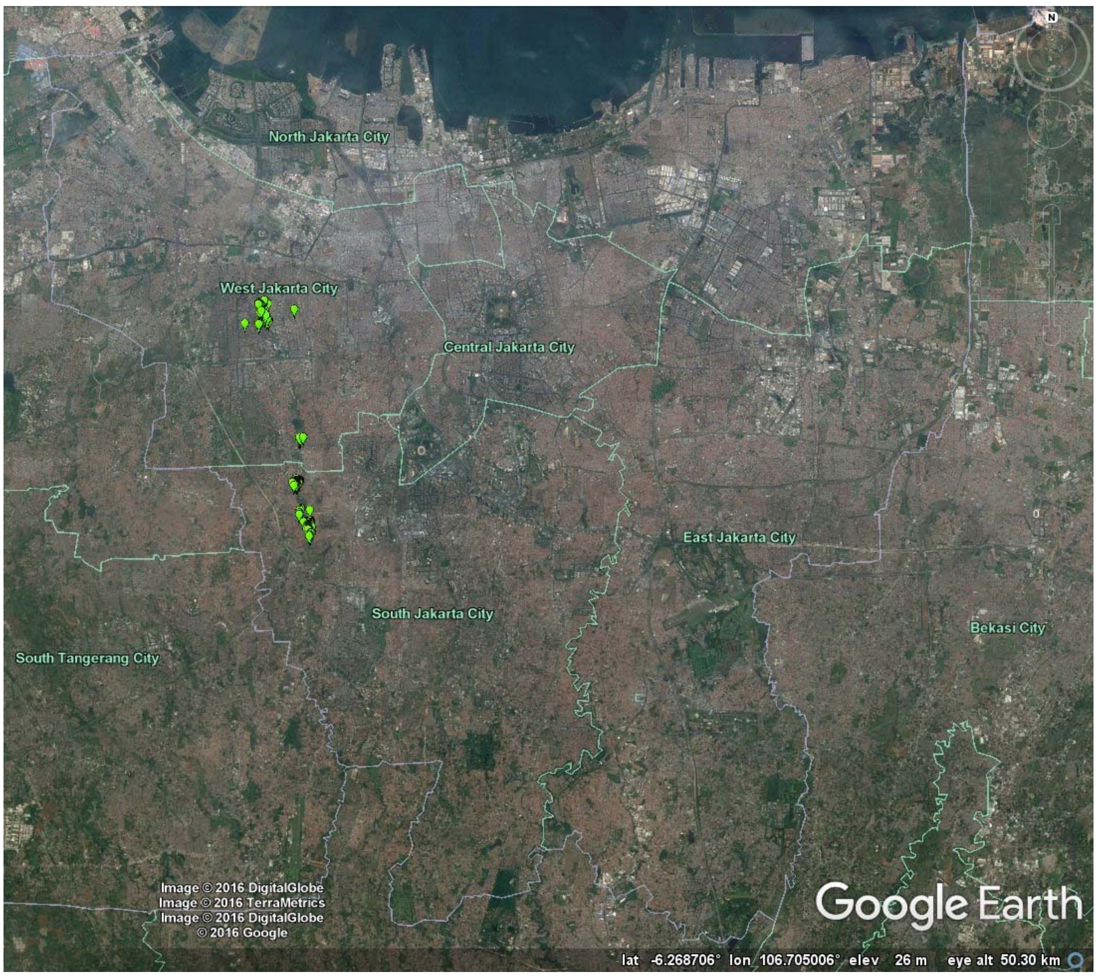

Figure 5.2 Sample sites (green balloons) along the Pesanggrahan at South and West Jakarta.

5.2.2.2 Using the survey to adjust the depth-damage functions

As part of the survey, the respondents were asked to state measures that they take to reduce vulnerability based on a warning. For example, by moving valuable assets to higher storeys or raising them from the ground, damages for shallow inundation depths can be reduced. For more detail, see section 5.3.1. We used this information in two ways to adapt the vulnerability curves. Firstly, we developed an "optimistic scenario". This scenario shows the potential vulnerability reduction if all households took measures to completely avoid flood damage for inundation depths up to the inundation depth interval of 100 cm to 125 cm. These depths are the highest inundation depths against which the survey respondents reported being capable of taking adaptation measures to avoid damage, although only few respondents took measures up to this depth (see Table 5.1). Since this is highly optimistic, we also developed a second scenario, accounting for the frequency of measures taken by respondents. For example, 24.5% of respondents reported taking measures to avoid damages for floods of depths between 1-25 cm. Therefore, we lowered the vulnerability curve for floods of 1-25cm by 24.5%; we call this the "realistic scenario".

Following the survey analysis, we conducted Fuzzy Cognitive Maps (FCM) (Budiyono et al., 2015; Groumpos, 2010; Stach et al., 2010) to verify the survey results and the integration into vulnerability curves. The same group of experts as those consulted during our initial stage of FCM workshop in 2012 (Budiyono et al., 2015) gave their opinions on the change of depth-damage curve that were formulated.

5.2.3 Estimating flood risk with and without FEWS

We then used the Damagescanner-Jakarta model to calculate flood risk in Jakarta, assuming that a FEWS is in place (i.e. using the adapted depth-damage functions) and assuming that no FEWS is in place (i.e. using the original depth-damage functions). Here, we assumed that enough time is available for people in flood-prone areas to take actions to reduce their vulnerability, between the warning being issued and the flood occurring. This is also based on the observation from the survey that 96.6% of respondents in the survey stated that they would have had sufficient time to respond to a flood warning during the 2013 event. We applied the new depth-damage functions to all regions in Jakarta, even though the survey only took place along the Pesanggrahan river. Moreover, we assume that all households are able to take the actions required to reduce vulnerability. Hence, the results in this Chapter should be regarded as indicative of the potential flood risk reduction that could potentially be achieved should a FEWS system be 100% effective.

5.3 Results

In this section, we first present the results from the survey on the potential damage that could be avoided in the study area by implementing measures at the household level to decrease economic damages due to floods, and how this information was used to adjust the vulnerability curves. We then show the results of how much flood risk could be avoided in Jakarta, using the original and adjusted depth-damage functions.

5.3.1 Survey results on potential damage reduction

As part of the survey, respondents were asked to state which measures they used to reduce the damage to their households or businesses, during the 2013 flood event. In Figure 5.3, we show a bar-graph showing all of the measures taken by the respondents.

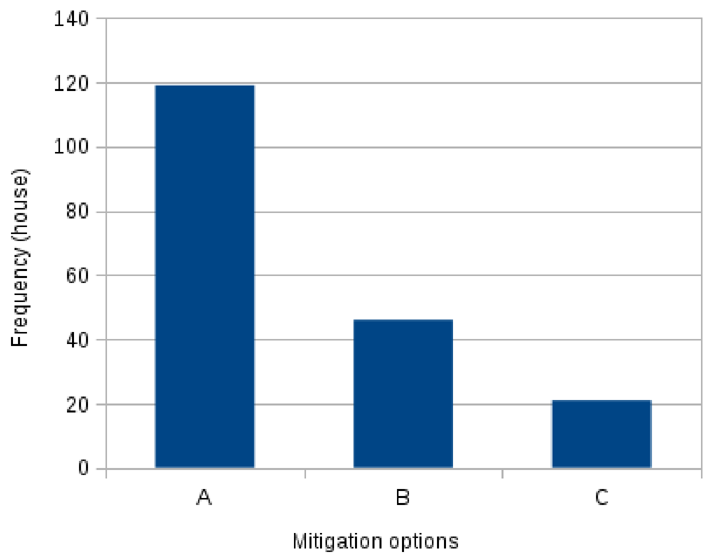

Figure 5.1 Frequency of mitigation options taken by survey population: (A) Move assets upwards; (B) Personal dike; (C) Put important assets atop bench/desk (n=327).

The most common measures are those that entail moving valuable assets upwards to a higher location (or away from the potential hazard area in the case of cars), or measures that protect individual buildings from floods up to a certain depth. For example, such measures include: elevating floors from street level; building concrete dikes in front of the door; putting important assets (e.g. refrigerator) atop a wooden bench; or increasing impermeability by preparing a piece of lumber and moldable plastic to seal potential leaks, thus acting as a removable polder.

During the survey, we also observe that 60% of the surveyed population have prepared personal mitigation measures that could be taken if a warning is issued, to protect against different inundation depths. These depths generally vary between 10-125 cm (see Table 5.1 for detail of frequency).

Table 5.1 Frequency of personal mitigation height in the survey.

No	Mitigation height (cm)	Frequency
1	1-25*	80
2	26-50	71
3	51-75	13
4	75-100	5
5	101-125	3

5.3.2. Adjusted depth-damage functions

From the results described above, we can see that it is possible to reduce damages from floods with depths up to about 125 cm, by taking the measures described above. Hence, to adjust the depth-damage functions, we assumed that measures can be taken in the event of an early warning to avoid damage up to a depth of 125 cm, using the 'optimistic' and 'realistic' scenarios described previously.

The original depth-damage functions for the residential land use types were therefore adjusted to reflect this; the original and adjusted curves are shown in Figure 5.4. For the optimistic scenario, the dashed line shows that the adjusted curve assumes zero damage for inundation depths below or equal to 100cm, with a linear increase up to 125 cm, after which the depth-damage functions are the same as the original ones. In the realistic scenario, the depth-damage functions are decreased in comparison with the original ones, according to the percentage of the population that reported being able to take measures to mitigate against damage up to each depth.

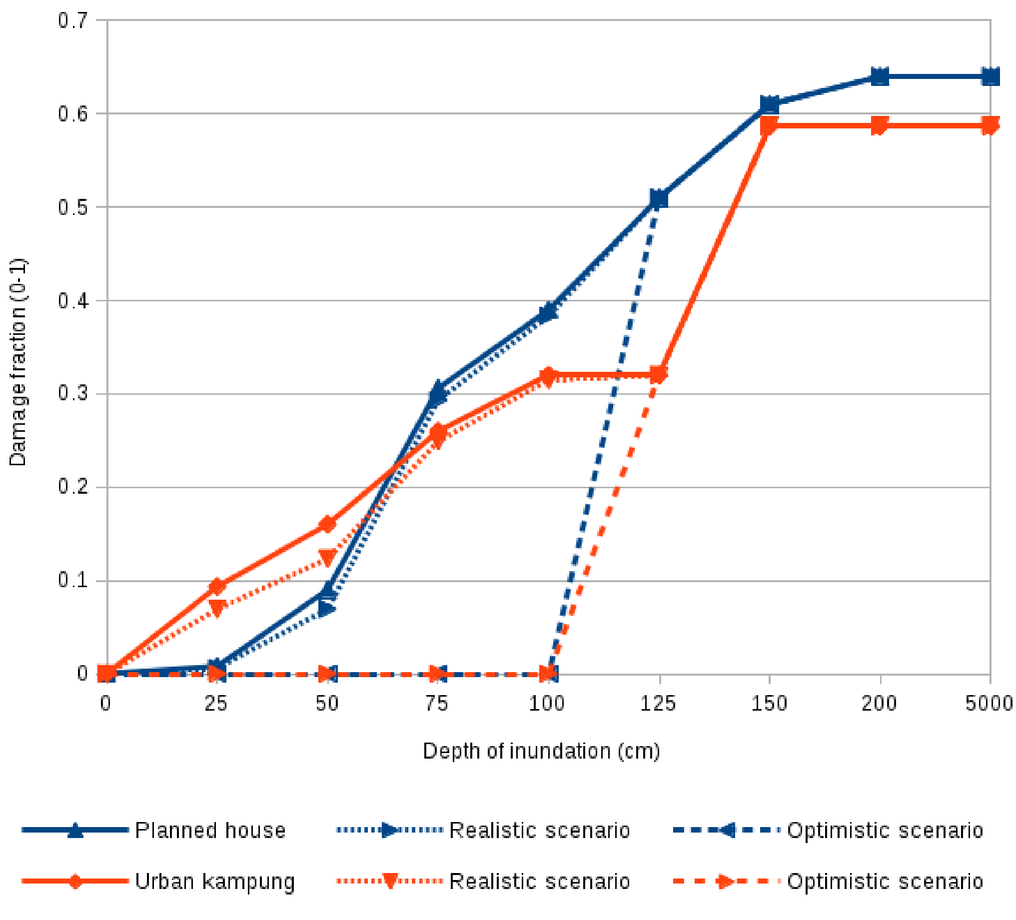

Figure 5.4 Original depth-damage functions by Budiyono et al. (2015) (full lines) and adjusted depth-damage functions based on the survey both at realistic (fine dashed lines) and optimistic (dashed lines) scenarios.

5.3.3 Potential flood risk reduction in Jakarta through vulnerability reducing

measures associated with SMS-based FEWS

We applied the original and the adjusted depth-damage functions to estimate flood risk, in terms of EAD, for Jakarta. EAD based on the original functions is US$ 186.2 million. Using the adjusted functions, EAD becomes US$ 182.8 million and US$ 163.6 million for the realistic and optimistic scenarios respectively. This means a reduction of US$ 3.5 million and US$ 22.6 million, or ca. 1.9% and 12% respectively. As stated above, our survey results only revealed vulnerability reducing measures being taken in combination with the FEWS in residential areas, and therefore this reduction is due to flood risk reduction there. Without the FEWS, EAD in residential areas is US$ 27.0 million/year, and simulated EAD with FEWS in residential areas is US$ 23.5 million/year in the realistic scenario. Hence, for this land use class, this reveals a potential reduction of 13%. Of this, 58% is in planned house areas, and 42% in high density urban kampung areas. In the optimistic scenario, the simulated EAD with FEWS is US$ 4.4 million/year, i.e. a reduction of 84%, with 70% and 30% of this reduction for the planned house areas and high density urban kampong areas respectively.

As mentioned earlier, the survey also showed that 96.6% of respondents stated that there would be sufficient time between the issuing of a warning and the flood occurrence in order to take these vulnerability reducing measures. For this reason, the vulnerability curve reduction was applied to all residential households.

In a traditional warning system based on kentongan, the effectiveness of the warning can be expected to decrease with increasing distance to the stream, since the penetration range of the audible signal is limited. This problem can be overcome using an SMS-based FEWS system. To test this, we assessed whether there is any relationship between the distance from the nearest stream and the avoided losses that residents who were flooded report having made as a result of the warning prior to the 2013 flood. Figure shows that there is no significant relationship between these two variables, suggesting that indeed the system is effective independent of the distance to the stream or river.

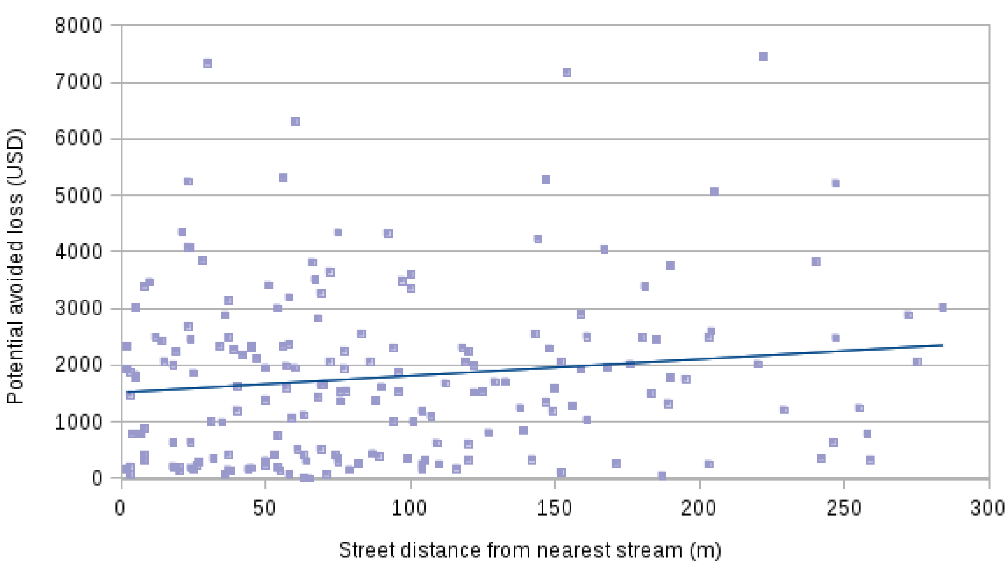

Figure 5.5 Relationship between potential benefit and street distance from nearest stream for income group 2 (slightly below standard wage for Jakarta, 63% of survey). R^2 of line fit is 0.019.

5.4 Discussion

5.4.1 Comparison of results to previous studies

Our results show that an SMS-based FEWS can provide a large contribution to reducing flood risk in Jakarta. By moving assets upwards (or outwards in the case of vehicles) and protecting properties with household-level structures, expected annual damage in residential areas in Jakarta could be reduced by up to 84% under an optimistic scenario. This equates to an overall reduction in EAD of 12%, but note that we have not been able to include the potential reduction in non-residential land use classes. As stated previously, this is a very optimistic value, since we assume that all residents receive the early warning, have enough to act on it, and do indeed act on it. Under the 'realistic scenario', the reduction is much lower, i.e. 2%. This is based on the actions that residents already take to reduce vulnerability due to flood warnings. Hence, there is ample opportunity to take more actions, as shown by the number of respondents to the survey who are already able to mitigate flood damage up to depths of ca. 1m.

The importance of FEWS for reducing flood risk is well recognised (e.g. Jha et al., 2011, UNISDR, 2015). However, to date there have only been a few studies in the literature attempting to assess the effectiveness in terms of risk reduction. Based on surveys in Pennsylvania, USA, Day et al. (1969) found the effectiveness of a FEWS system to be ca. 17%, in terms of avoided damages for a given flood event. Day et al. (1969) also added conditions that the government guarantees 8-12 hours of warning were effectively disseminated to all residential properties, and that all of these are 100% likely to take action. Based on a realistic situation in Gippsland, Australia, Molinari and Handmer (2011) found 15% of effectiveness in risk reduction. These reductions in potential damage are of the same order of magnitude as those found in our study under the optimistic scenario. Note that the two aforementioned studies also found reduction in damages in non-residential land use classes, which suggests that the overall potential risk reduction in Jakarta due to the FEWS may be higher than that found in our study.

5.4.2 Implications and future research

Our results show that under the realistic scenario, the implementation of the SMS-based FEWS system could reduce direct economic risk in Jakarta by ca. 2% in total, or by 13% in residential areas. In residential areas, this already represents significant avoided damages (US$ 11.1 million for 2013 flood case), and increased welfare for those households who take these measures. However, the results also show that if the use of measures for reducing flood damage up to inundation depths of 125 cm are implemented broadly, the potential reduction in direct economic risk could be as high as 12% in total, or 84% in residential areas. Whilst we acknowledge that this is an optimistic scenario, it demonstrates the risk reduction that could be achieved by more widely implementing relatively cheap risk reduction actions that are already taken by some households in flood-prone parts of Jakarta.

Since the survey results reveal that household level adaptation measures are already able to reduce risk for inundation depths up to 125 cm, it may be possible to provide financial assistance to take such measures, or develop building codes to ensure that household level risk reduction measures are taken. In doing so, it would be possible to increase the potential effectiveness of an SMS-based FEWS system from the current realistic scenario towards the optimistic scenario.

Whilst we have not assessed the costs and benefits of the FEWS system, past studies have shown warning systems to potentially provide large returns on investment (e.g. Pappenberger et al., 2015). The hydraulic modeling system itself has already been developed for Jakarta, and the cost of broadcasting a warning via SMS is extremely low. The price of bulk SMS served by the country's main mobile phone operator is about 6c per 205 SMS. Therefore, the cost of sending warnings to potentially flooded people is negligible with regards the potential losses due to a flood. Clearly, though, a flood early warning system will only be effective if people trust the warning. If too many flood warnings are issued in vain, the likelihood of people heeding the warning and taking action to reduce damages will decrease (e.g. Coughlan de Perez et al., 2016). Future research needs to be carried out to assess the thresholds at which flood warnings should be issued, in order to maximize the potential benefits of correct warnings, and minimize the false alarms. One way that can be used to increase the potential uptake and trust of warnings is to engage with non-governmental institutions to broadcast the warning. Research by van Voorst (2015) and Mei et al. (2013) suggests that this can maximize FEWS effectiveness.

It is also very important to note that our study only assesses the potential reduction of direct economic damages. Another major advantage of FEWS systems is the avoidance and minimization of potential casualties and fatalities. We have not assessed this issue in this Chapter as we do not have models or methods for assessing injuries or fatality. However, future research focusing on this aspect is very important, and could be achieved using agent-based modelling frameworks to incorporate human behavior, such as evacuation. Examples of such research in the flood literature are the work of Dawson et al. (2011) and Liu and Lim (2016).

In the survey that was used in this study to assess the changes in the depth-damage functions that could be achieved by implementing the FEWS, the higher income residential classes are under-represented. Therefore, the potential reduction in effectiveness may not be applicable to all income levels. In future research, we recommend following survey strategies that better cover all income groups, to assess whether the potential avoided damages change significantly at higher incomes. Moreover, it would be beneficial to see if the potential damages can be related to more variables than flood depth alone, for example using multi-variate analyses. Nafari et al. (2016) found multi-variate analysis proved to be able to predict flood loss better than depthdamage functions in Australia, even though their survey did not include income groups.

5.5 Conclusion

We have quantified the potential economic damage that could be avoided in Jakarta through the implementation of an SMS-based flood early warning system coupled with a hydrodynamic model. The potential damage was assessed using the Damagescanner-Jakarta flood risk model. We used results from an existing survey carried out along the Pesanggrahan River to examine the measures that households took to avoid flood damages during the 2010 flood.

From the survey, we found that a FEWS system could lead to a decrease in flood risk, as people report taking actions to move assets upwards or to prevent floodwaters entering households, if sufficient warning is available. The survey shows that some households take measures to avoid damages for inundation up to a depth of 125 cm. By using these findings to amend the depth-damage functions in Damagescanner-Jakarta, we were able to simulate first order estimates of flood risk with and without the FEWS.

We found that the FEWS system could lead to a decrease in overall flood risk by 2%, or US$ 11.1 million under the realistic scenario. In this scenario, the model was setup to represent the percentage of households that currently take measures to reduce damage as a result of inundation up to a depth of 125 cm, based on traditional warnings. Under an optimistic scenario, under which all households would take measures to avoid damage up to this inundation depth, the potential decrease in risk is 12%. The survey only identified measures taken in residential areas. If we only examine flood risk in residential areas, the risk could be reduced by 13% in the realistic scenario, and 84% in the optimistic scenario.

The portions of the reduction that can be assigned to planned housing areas and high density urban kampong areas are 58% and 42% respectively for the realistic scenario, and 70% and 30% respectively for the optimistic scenario

Whilst the results are first order estimates, they show that the potential risk reduction due to the implementation of the FEWS is large. Future research should be carried out to better quantify the thresholds required to issue flood warnings, considering the tradeoff between false alarms and avoided losses; to assess the potential reduction in casualties and fatalities that could be achieved through the use of the FEWS; and to assess the potential costs and benefits. Given the potential damages that can be avoided, we recommend examining ways to increase the number of households taking measures to reduce flood risk at the household scale.

6 SYNTHESIS AND OUTLOOK

6.1 General overview

Flooding is a huge problem in Jakarta, with river floods occurring mostly during the wet months of December, January and February. For example, the flood in January 2013 caused economic losses estimated at US$ 3 billion (Munich Re, 2013). In addition, there were 47 fatalities, and over 100,000 houses were destroyed or damaged. Other major floods in the 21st century include those of 2002 and 2007, which are estimated to have caused direct losses of ca. US$ 1.5 billion and US$ 890 million, respectively (Bappenas, 2007).

This dissertation assessed flood risk in Jakarta in the current situation and under future scenarios of climate, environmental, and socioeconomic changes. A flood risk model was developed (Damagescanner-Jakarta), in which risk is considered a product of hazard, exposure and vulnerability. To represent hazard, a fluvial model setup was used to simulate inundation depths for different scenarios of climate change, sea level rise, and land subsidence. Exposure was represented by land use maps for the current situation and 2030, with an associated economic value. Vulnerability was represented using depth-damage functions. Using the flood risk simulations, the Thesis also assessed how flood risk could be reduced in Jakarta, by evaluating various structural and non-structural adaptation options.

The Thesis addressed the following main research objectives: (a) developing a model for assessing river flood risk in Jakarta; (b) using the model to assess the impacts of changes in physical and socioeconomic drivers on flood risk; and (c) using the model to assess the impacts of various adaptation measures on flood risk.

In order to address these objectives, the following research questions were formulated:

- Can we develop a model to rapidly assess river flood risk in Jakarta, and how well does it simulate reported flood damage?
- How sensitive is the flood risk model to the use of different vulnerability curves?
- What are the possible future changes in river flood risk in Jakarta as a result of climate change, land subsidence, and land use change?
- How much could flood risk in Jakarta be reduced under current and future conditions by upgrading and installing polder systems, and what are the costs and benefits?
- What is the potential reduction in flood risk that could be achieved in Jakarta through the implementation of an SMS-based Flood Early Warning System?

These questions have been addressed in Chapters 2-5 of this Thesis, and each chapter has been published as a research paper or book chapter. In Section 6.2, a synthesis of the answers to each research question is provided. This is followed by a discussion of the potential applications of the results (Section 6.3), and finally a discussion of several key limitations and recommendations for future research in Section 6.4.

6.2. Main results per research questions

6.2.1. Can we develop a model to rapidly assess river flood risk in Jakarta, and how well does it simulate reported flood damage?

A flood risk model for rapidly assessing flood risk in Jakarta (Damagescanner-Jakarta) was set up and described in Chapter 2 (Budiyono et al., 2015), and further refined in Chapter 3 (Budiyono et al., 2016). The model is based on the Damagescanner model, adapted for Jakarta using local information on hazard, exposure, and vulnerability.

In the model, hazard is represented by inundation maps developed using the SOBEK Hydrological-hydrodynamic model. Flood hazard is represented by maps showing inundation depth and extent for seven return periods (1, 2, 5, 10, 25, 50, and 100 years). Exposure is represented by a map showing the economic exposure per grid cell of 50m x 50m, based on land use data. The third element, vulnerability, is represented by depth-damage curves, for each land use class. By combining the information on hazard, exposure, and vulnerability, economic damage is calculated for each return period. The expected annual damage is then calculated as the area under an exceedance probability-damage curve.

In the initial version of the model (Budiyono et al., 2015), the hazard maps were developed using a schematisation of the SOBEK model based on the hydrological situation in 2007. Exposure was represented using an official land use map of the situation in 2002. For each land use class, the maximum potential damage due to flooding was estimated based on expert knowledge and meetings held in 2012. During the same meetings, vulnerability curves were also developed for each land use class. The expected annual damage due to river flooding in Jakarta was estimated at US$ 321 million per year.

The flood event of 2007 is estimated to have had a return period of about 50 years, and the 2002 flood is estimated to have had a similar return period. The simulated damages for a 50 year return flood (US$ 1,415 million) are compared with the reported damage for 2002 (US$ 1,510 million) and 2007 (US$ 890 million). The result shows that simulated damages are of the same order of magnitude as the reported damages, and that the spread of the damage across the different land use classes is similar to reported. These findings give confidence in the use of the model for flood risk assessment.

In an updated version of the model (Budiyono et al., 2016), two main improvements were made. Firstly, a more recent land use map from the year 2009 was used to represent exposure. Secondly, an updated version of the SOBEK model is used, in which the hydraulic schematisation is updated with flood protection measures implemented after 2007, including flood gates and weirs, and the completion of the East Flood Canal (Banjir Kanal Timur). Compared to the previously used hazard maps, the simulated floods in the eastern half of the city are about 27% and 34% lower in terms of flood extent and flood volume, respectively. These maps were compared with empirical flood maps produced by the National Disaster Management Office (BNPB), showing good agreement. Using the new model setup, the simulated expected annual damage is US$ 186 million per year. This seems reasonable given the aforementioned changes in the hydrological and hydraulic situation since that time. The new model setup was used as the baseline for future projections of river flood risk in 2030 and 2050.

6.2.2. How sensitive is the flood risk model to the use of different curves for representing vulnerability?

One of the key challenges in developing Damagescanner-Jakarta was deriving vulnerability curves. To do this, two approaches are tested in this Thesis, and we assessed the sensitivity of the risk estimates to the use of different vulnerability curves. First, an implementation of existing curves representing vulnerability of economic exposure of different land use classes from five existing studies in south-east Asia was carried out. The results are found to be highly sensitive to the choice of vulnerability curve. For example, the difference in expected annual damage between the curves with the lowest values (from a study in Bangkok) and highest values (from a study in Kampung Melayu) is a factor eight higher. Moreover, the use of some of the curves led to an overestimation of damage by several magnitudes, compared to reported damages during the 2002 and 2007 floods.

Our findings therefore have important implications for flood risk assessments, and demonstrate that flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves. Flood risk assessments in many regions are often carried out by transferring vulnerability curves from other countries, but the results of this Thesis show that this can lead to large errors.

As a result of the sensitivity assessment of vulnerability curves, additional locally tailored vulnerability curves were developed. To do this, a series of expert meetings and a workshop were held with local stakeholders to develop vulnerability curves specific for Jakarta. The damage estimates using these curves performed much better against empirical data (See section 6.2.1).

6.2.3. What are the possible future changes in river flood risk in Jakarta as a result of climate change, and subsidence, and land use change?

After developing and validating the Damagescanner-Jakarta model, it was applied in Chapter 3 to assess future trends in flood risk (2030) under several future scenarios: climate change (both changes in precipitation and sea level rise), land subsidence, land use change, economic development, and a combination of these factors (Budiyono et al., 2016).

Combining all of these scenarios, the median increase in flood risk between the current baseline situation and the year 2030 is +180%. This value is based on a median projection for the influence of changes in extreme precipitation on flood risk. The Thesis shows that given the high range of uncertainty in future projections of changes in precipitation in Jakarta, the influence of climate change on flood risk is also highly uncertain. To address this, probabilistic projections of flood risk were made by developing probability density functions based on 20 GCM–RCP combinations. Using projections of changes in precipitation only (i.e. all other risk drivers are left at 2010 values), this led to changes in risk for the 5th and 95th percentiles of between -94% and +104% respectively (i.e. US$ 11 million - US$ 379 million). The signal of change due to sea level rise is more clear. Using two scenarios of sea level rise (high and low), the Thesis suggests an increase in risk due to sea level rise alone of between +7% and +20% by 2030, to US$ 200 million - US$ 224 million respectively.

Under the scenarios used in this study, the single driver with the largest contribution to the overall increase in risk is land subsidence, alone leading to an increase by +126%, to US$ 421 million. The importance and severity of land subsidence in Jakarta is already very well realized and is high on the political agenda. This Thesis provides the first quantitative estimate of its potential impact on flood risk.

In terms of the impacts of land use change, using extrapolated rates of land use change observed over the period 1980-2009, leads to an increase in risk of +45% by 2030, to US$ 270 million. However, under an “idealized” land use change scenario, which assumes that the official Jakarta Spatial Plan 2030 is fully implemented, risk could be reduced by -12%, to US$ 163 million, for example through the designation of river corridors as open space. Given that changes in exposure through urban development are generally seen as one of the main drivers of risk in developing countries, such a development would be highly positive. However, it should be noted that achieving such a development would entail enhanced governance structures, with an integration of spatial planning laws and water management.

In summary, it can be concluded that whilst the influence of climate change on precipitation intensity in the region may be uncertain, when combined with the other drivers of risk mentioned in the first paragraph, the increase is always large, and hence adaptation is imperative, irrespective of the chosen climate scenario or projection. This probabilistic approach allows us to include a much wider range of information on the potential impacts of climate change on risk, than assessments based on just one or two scenarios.

6.2.4. How much could flood risk in Jakarta be reduced under current and future conditions by upgrading and installing polder systems, and what are the costs and benefits?

Following the operationalization of Jakarta's Western and Eastern Flood Canals, the government of Jakarta has turned part of its focus to a polder system. This system would divide the northern part of Jakarta into 66 polders, protected by levees. Using Damagescanner-Jakarta, the potential reduction in risk that could be achieved through this system was assessed, and the avoided risk (benefits) were compared with a first order estimation of the costs. Such a benefit/cost analysis was carried out for each polder, using both current conditions and future scenarios of climate change, land use change, and land subsidence.

Overall, it was shown that the implementation of the polder system could greatly reduce flood risk compared to the current risk. In current condition, even if polders were designed for a 2 year return period flood, they could reduce risk by 25% (from a current risk of US$ 186 million per year without polders, to US$ 139 million per year with polders). The potential reduction of future risk is even greater. Again, if polders were designed for a 2 year return period flood, they could reduce risk in 2030 by 52% (from a current risk of US$ 521 million per year without polders, to US$ 261 million per year with polders). Much of this risk reduction could be achieved in just 3 polders, namely Kapuk Muara, Penjaringan Junction, and Kapuk Polgar. These three polders contribute to 50% of the total risk reduction under current conditions and 31% of risk reduction under the future scenario.

The study also provides first cut estimates of the benefits (B) and costs (C) that would be involved. The results show that B/C ratios greater than 1.0 exist for 21 out of 66 polders under current conditions, and for 31 out of 66 polders under the future scenario (for a return period of 2 years). According to the B/C assessment, there are twelve polders that could play a significant role in reducing flood risk in Jakarta. Implementing 12 polders (adding 9 polders to the best three, i.e. Sunter Timur III (Rawa Badak), Sunter Utara, Ancol Pademangan, Muara Angke, Komplek Dewa Kembar, Muara Karang, Sunter II Kebantenan, Pantai Indah Kapuk (19) and Sunter Timur IB) could reduce risk by 56% under the current scenario, and 81% under the future scenario. The total risk reduction that could be achieved through the implementation of these polders is very large, both under current conditions (US$ 104 million per year) and future conditions (US$ 400 million per year). Based on the findings, it appears that the highest immediate benefits could be obtained from developing the first group of polders. In the longer run, developing the other polders showing high net benefits could further reduce the risks from fluvial flooding in Jakarta. The study also shows the importance of considering future conditions when planning for such structural measures with a long lifetime, since the overall benefits of the projects are much higher when the potential future changes are included.

6.2.5. What is the potential reduction in flood risk that could be achieved in Jakarta

through the implementation of an SMS-based Flood Early Warning System?

After having developed and validated the Damagescanner-Jakarta model, it was used to assess the potential economic damage that could be avoided through the implementation of an SMS-based flood early warning system. Currently, inhabitants of flood-prone areas in Jakarta are used to the traditional flood early warning system in the form of a bamboo gong. However, a more advanced system could reduce risk, since the traditional approach is limited by sound wave penetration. For this, a hydrodynamic model was coupled with an SMS-based Flood Early Warning System (FEWS). Using the results of a survey of inhabitants along the Pesanggrahan river in South and West Jakarta, the vulnerability curves were adjusted to reflect the damage that inhabitants could potentially avoid for different flood depths, for a given warning time from the new SMS based early warning system. Damagescanner-Jakarta was then run with the original and adjusted vulnerability curves to examine how much risk could be avoided, for residential land uses.

From this analysis, it was found that an SMS-based Flood Early Warning System could reduce annual flood risk in Jakarta by US$ 3.5 million (1.9%) under a realistic scenario, and up to US$ 22.6 million (12%) under an optimistic scenario. In the realistic scenario, it was assumed that risk reduction measures would be taken only by the percentage of households that currently take adaptation measures according to the survey. In the optimistic scenario, it was assumed that all households would take measures to avoid damage based on the warning.

Whilst these reductions appear modest, it should be noted that the risk in residential areas could be reduced by 13% under the realistic scenario and 84% under the optimistic scenario, which represent significant reductions in risk. However, it should be noted that this study did not examine how the effectiveness of such a system could be affected by false alarms, which could damage the trust of inhabitants in the system. Future analyses should also include this component. It should also be noted that in this study the potential risk reduction was only examined for residential land uses, whilst in reality risk could also be reduced for other land uses. Moreover, only direct economic damage was assessed, whilst early warning systems can play an important role in reducing casualties and fatalities.

6.3 Usefulness of the results in practice

Prior to this study, quantitative assessments of the impacts of future changes in physical and socioeconomic conditions on flood risk in Jakarta were few. In part, this is due to the lack of flood risk assessment tools. Through this Thesis, a new flood risk model has been developed: Damagescanner-Jakarta. This model can now be used by stakeholders in Jakarta to carry out flood risk assessments. Another potential reason for the lack of flood risk assessments in Jakarta under future conditions, is the lack of officially mandated scenarios of climate and socioeconomic change. As a result, for this Thesis several scenarios were used as input to Damagescanner-Jakarta on an ad hoc basis. This has allowed for a first assessment of the influence of changes in physical and socioeconomic conditions on flood risk, and for the assessment of the potential of several adaptation measures to reduce that risk. Once more detailed scenarios of these changes for Jakarta become available, their impacts on factors related to flood risk can be assessed using the now available Damagescanner-Jakarta model.

Since quantitative risk-based assessments are relatively new in Indonesia, especially in terms of flood damages, this Thesis provides useful information for stakeholders involved in disaster risk reduction in Jakarta, such as the National Office for Disaster Management and Special Capital Region of Jakarta. Besides that, several of the study results can also benefit the public directly. In this section, several of the key potential uses of the findings are described.

Flood risk assessments can provide valuable information to the public in flood prone areas on how individual actions that they take to reduce damage to their own assets can lead to reductions in their individual risk. For example, in chapter 5 it was shown that taking actions based on an SMS-based Flood Early Warning System (FEWS) can reduce damage to an individual's property and/or assets. These actions include things like moving valuable assets to a higher elevation or protecting individual buildings up to a certain flood depth. The results of the survey show that some households take measures to avoid damages for inundation up to a depth of 125 cm. By using these findings to amend the depth-damage functions in Damagescanner-Jakarta, it was possible to simulate first order estimates of flood risk reduction with the FEWS early warning system, varying from 13-84%. Whilst the higher estimate is a very optimistic scenario, it demonstrates the risk reduction that could be achieved by more widely implementing relatively cheap risk reduction actions that are already taken by some households in flood-prone parts of Jakarta.

Flood risk mapping is particularly useful for decision-makers, since it gives a clear idea of areas where flood risk is highest. The flood risk maps developed for this Thesis clearly show that most damage is concentrated in northern Jakarta and is predominantly focused on certain land use classes. Compared with the existing inundation maps available in Jakarta, this information provides a large step-forward in terms of their potential for both awareness raising and adaptation planning. An example of an existing inundation map showed inundated areas based on reports from village managers. The delineation of the inundated areas is merely based on district boundary information. Hence, if a flood was reported in any part of the district, the entire district was displayed in the map as inundated. The flood hazard and risk maps produced in this Thesis provide more detailed spatial information, and include not only flood extent and depth, but also damage. Already, the Damagescanner-Jakarta tool and the resulting maps are being used in practice in Jakarta. For example, the use of the model for assessing the risk in several polders was sponsored by CTC-N/UNEP (Project Number 65800016), carried out jointly by DHI and the Jakarta Research Council, leading to the production of risk-based policy recommendations on flood management at the polder scale. Recently, the risk study approach passed the second assessment by the Korea International Cooperation Agency, which aims to assess polder based flood management.

The flood risk problem in Jakarta results from the interplay of a large number of drivers, and this Thesis has been the first effort to attempt to quantify the relative influence of changes in these different drivers on future risk. The largest single driver of the projected increase in risk is land subsidence. Therefore, concerted efforts are needed to address the land subsidence issue. It has been suggested to target measures for reducing soil water extraction, which is the main cause of land subsidence in Jakarta (Abidin et al., 2011). Soil water extraction takes place both for supplying water for drinking and industry, as well as in the construction of high-rise buildings. PAM Jaya (2012), the water industry board of Jakarta, supplies water to 61.1 % of consumers in Jakarta. They report that an additional 8–10 $m^3 s^{-1}$ would be needed to erase the need for all deep wells while sufficing the needs of those who are currently not sufficed. According to a synthesis of results in reports by PAM Lyonaise Jaya (2012) and Aetra Air Jakarta (2014), this would require an investment of ca. US$ 389 million. Whilst this is a large investment, it is of the same order of magnitude as our projected increase in risk per annum resulting from land subsidence, land use change, and climate change. Whilst simplistic, this example shows that the costs of the measures to increase and improve water supply are small in relation to the damages that they could help to avoid.

In terms of climate change, whilst its influence on precipitation intensity in the region is highly uncertain, sea level rise will have a significant influence, and hence adaptation is imperative, irrespective of the chosen climate scenario or projection.

The future risk projections under scenarios of land use change are also relevant for decision making. The results show that if the official Jakarta Spatial Plan 2030 is fully implemented, risk could be reduced by -12%. This would be a significant achievement if such a plan were to be fully implemented, as globally urban development is known to be one of the main drivers of risk in developing countries. However, as noted earlier, actually achieving such a scenario would require increased coordination between spatial planning and water management in the policy domain.

Through the workshop and series of expert meetings that were held to develop the vulnerability curves and maximum damage values for different land use classes, it became clear that there is an opportunity for the insurance industry to develop a new flood insurance market. At present, flood insurance is merged with fire insurance in Jakarta. The flood hazard maps for current and future conditions developed in this study could help in making a preliminary assessment of the feasibility of such a market.

6.4 Future research and recommendations

In this thesis, answers have been provided to the original research questions. Of course, the approach contains limitations, as described in the separate chapters. In this final section, a few of the main limitations are discussed, and recommendations are made on how they could be addressed in future research.

- To date there is a lack of officially mandated scenarios of climate, environmental, and socioeconomic change for Jakarta. Therefore, the scenarios used to carry out the future projections were selected on an ad hoc basis. This selection often entailed making large assumptions, and the quality of the scenarios differs between the drivers. Given the uncertainty in climate change projections, future development of official tailored climate scenarios for Jakarta (or Indonesia for that matter) should be a research priority. Such a set of scenarios would allow for more consistent modeling of climate impacts, particularly at the detailed scale. Moreover, tailored scenarios of land subsidence and land use change, using storylines commensurate with the storylines of the climate change scenarios, would allow for a more consistent assessment of the relative influence of the different driving forces.

- A full assessment of the uncertainty in the overall risk estimates to all input and model parameters has not been carried out. Instead, the sensitivity of the model results to various input variables has been assessed. Nevertheless, it would be beneficial to attempt to capture the uncertainty of the risk estimates to a large range of model parameters, for example using Monte Carlo modeling techniques.

- Flood risk has only been assessed resulting from river flooding, whereby hazard is seen as a result of rivers overtopping their banks. In the coastal region, the hazard model used does include vertical dynamics at the coast as boundary conditions for the river inundation model, but coastal flooding was not simulated. Future research could benefit from examining the risks from river and coastal flooding, both separately and where they occur simultaneously (i.e. compound flooding), for example, when high tides occur at the same time as extreme discharges. Such interactions are now high on the scientific agenda, and future risk assessments in Jakarta should attempt to include both processes. To enable an assessment of these interactions, one would need to develop time series of both high river discharge and high sea levels, and couple these processes in a model, in order to examine the temporal interactions and joint probabilities between the two variables.

- The Thesis did not assess the impacts of pluvial flooding. It would be beneficial to also include this form of more localized flooding in the modeling chain. In particular, floods inside the proposed polder system can also be caused by local precipitation as seen in the flood of 19 February 2015. Also, note that these extreme rainfall events may become more frequent or extreme in the future. In terms of the hydraulic simulations, the model parameterization does not include the planned Polder System Plan 2030 or the measures in the Masterplan National Capital Integrated Coastal Development (NCICD). In order to assess their influence on the inundation extents and depths in Jakarta, it is recommended to carry out new hydrodynamic simulations in which these structures are included. This would also allow for a detailed assessment of their effectiveness in reducing current and future flooding.

- Throughout this study, vulnerability is only represented through the use of depth–damage functions, which misses social vulnerability. Moreover, future projections in this thesis use static vulnerability curves (i.e. they are not changed in the future scenarios). However, as shown in chapter 4, some individuals do take private adaptation measures to reduce their individual flood risk, such as building small concrete retaining walls in front of houses to prevent inundation from relatively shallow floods and moving valuable goods to the second storey of houses to avoid damages during floods. This study is one of the first to assess how this could lead to a reduction in flood risk. However, in the future projections discussed in Chapter 3, vulnerability is not dynamic. There are very few examples in the scientific literature of studies where temporal changes in vulnerability are considered, with exceptions of Mechler and Bouwer (2015) and Jongman et al. (2015). The development of future projections of vulnerability is therefore seen as a research priority for the flood risk community as a whole, not just in Jakarta.

- In chapter 4, the Thesis provides a first cut estimate of the costs and benefits of the proposed polder system. This allows us to identify the polders where the potential net benefits are the highest, which could be prioritized. However, the study is subject to large uncertainties. In particular, the costs considered do not include costs for the pumping stations and retention lakes, which are in reality a significant part of project costs. Therefore, for polders with a B/C ratio that only exceed 1 by a relatively small amount, caution must be exercised. In future work, it would be important to use more detailed local information to assess the costs and benefits of the polder systems more accurately. In this regard, learning from existing polders that show cases of good practice would be useful, such as the Pluit polder. Such future studies should include detailed data on factors including the precise dike line, underlying soil type, retention lake capacity and placement, and costs of the pumping system. Also, co-benefits of the polders should be examined, like potential uses of the retention lakes for recreation and ecosystem services.

- In Chapter 5, the potential risk reduction of an SMS-based Flood Early Warning System was examined. However, only the potential reduction of direct economic damages was examined, whilst generally one of the major advantages of a FEWS system is the reduction of potential casualties and fatalities. Future research should attempt to include this aspect, for example by using agent-based models that can incorporate human behavior such as evacuation (e.g. Dawson et al. (2011) and Liu and Lim (2016)). In this Thesis, the issue of trust in such a system has not been examined. If too many flood warnings are issued in vain, the likelihood of people heeding the warning and taking action to reduce damages will decrease (e.g. Coughlan de Perez et al., 2016). Future research needs to be carried out to assess the thresholds at which flood warnings should be issued, in order to maximize the potential benefits of correct warnings, and minimize the false alarms. One way suggested in the thesis to do this is to engage with non-governmental institutions to broadcast the warning.

APPENDIX A.

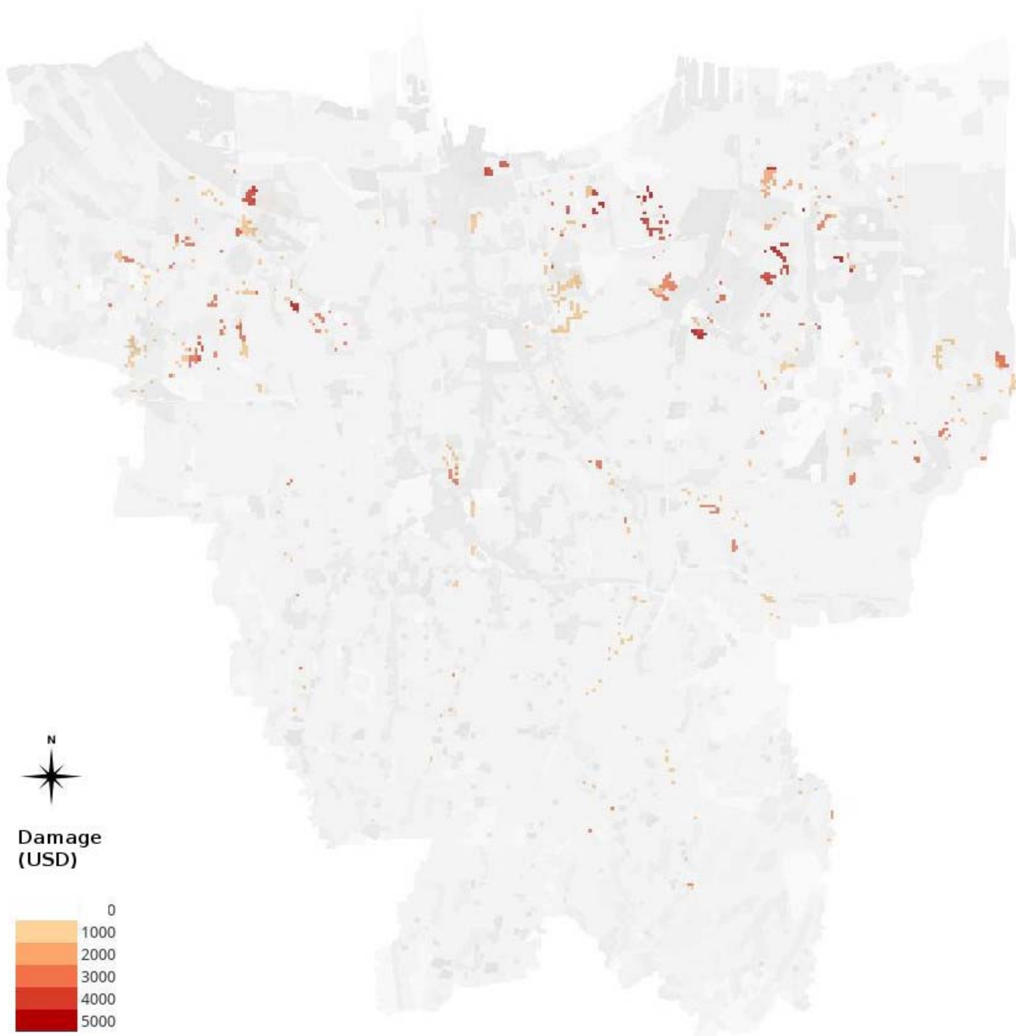

Figure A.1 Damage map at return period 2 years

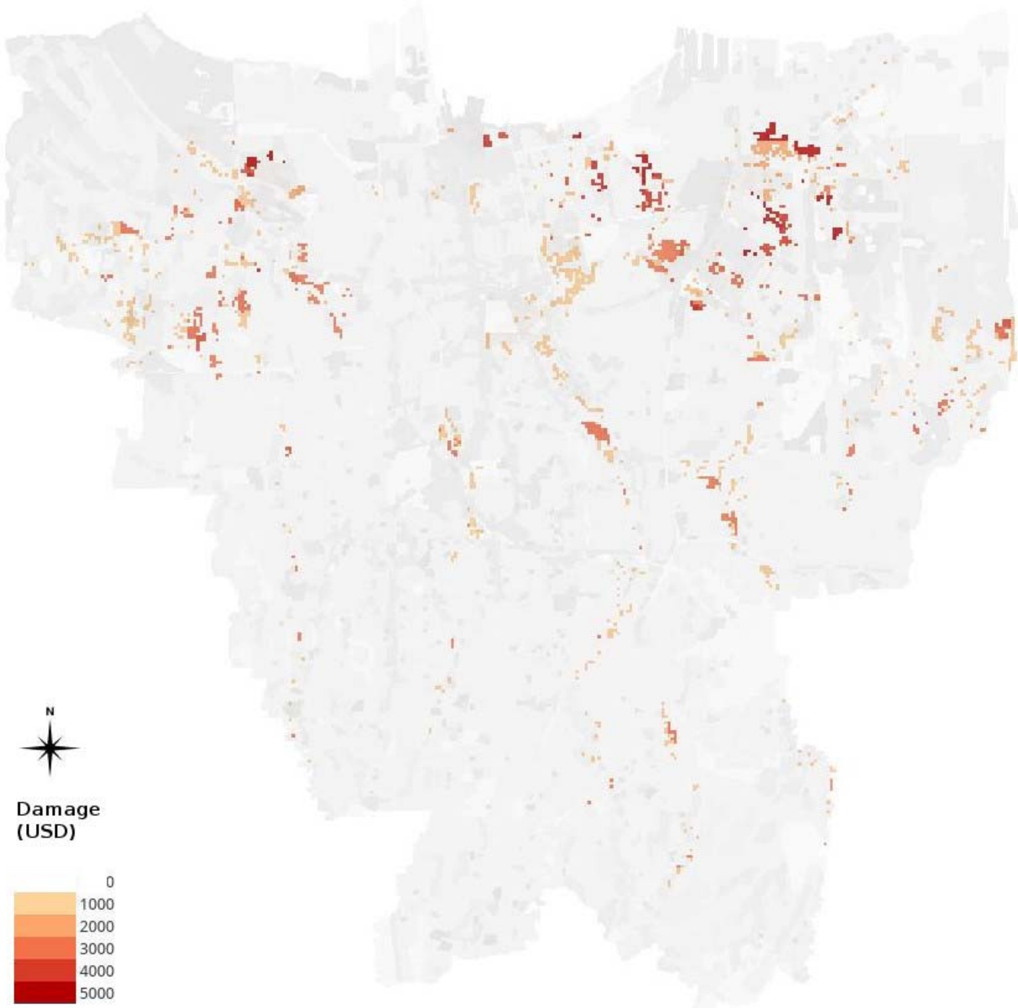

Figure A.2 Damage map at return period 5 years

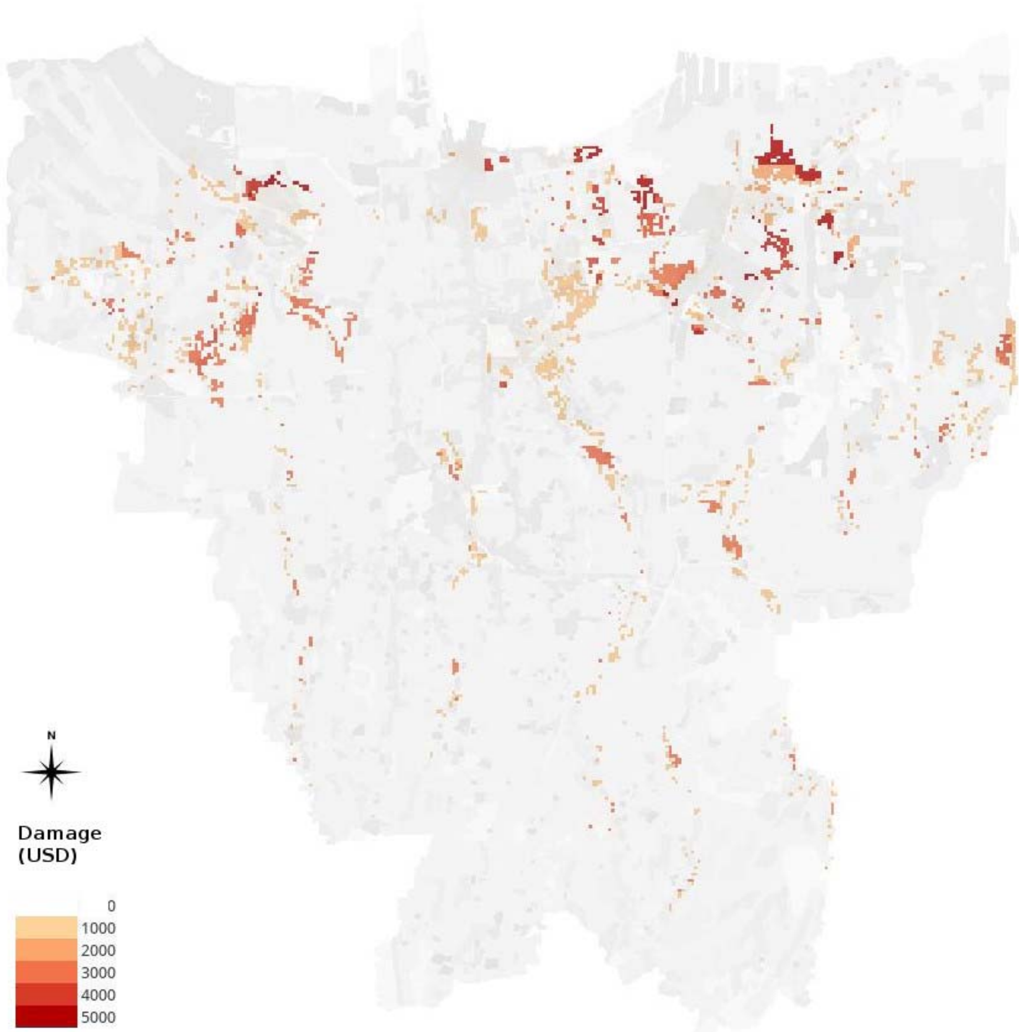

Figure A.3 Damage map at return period 10 years

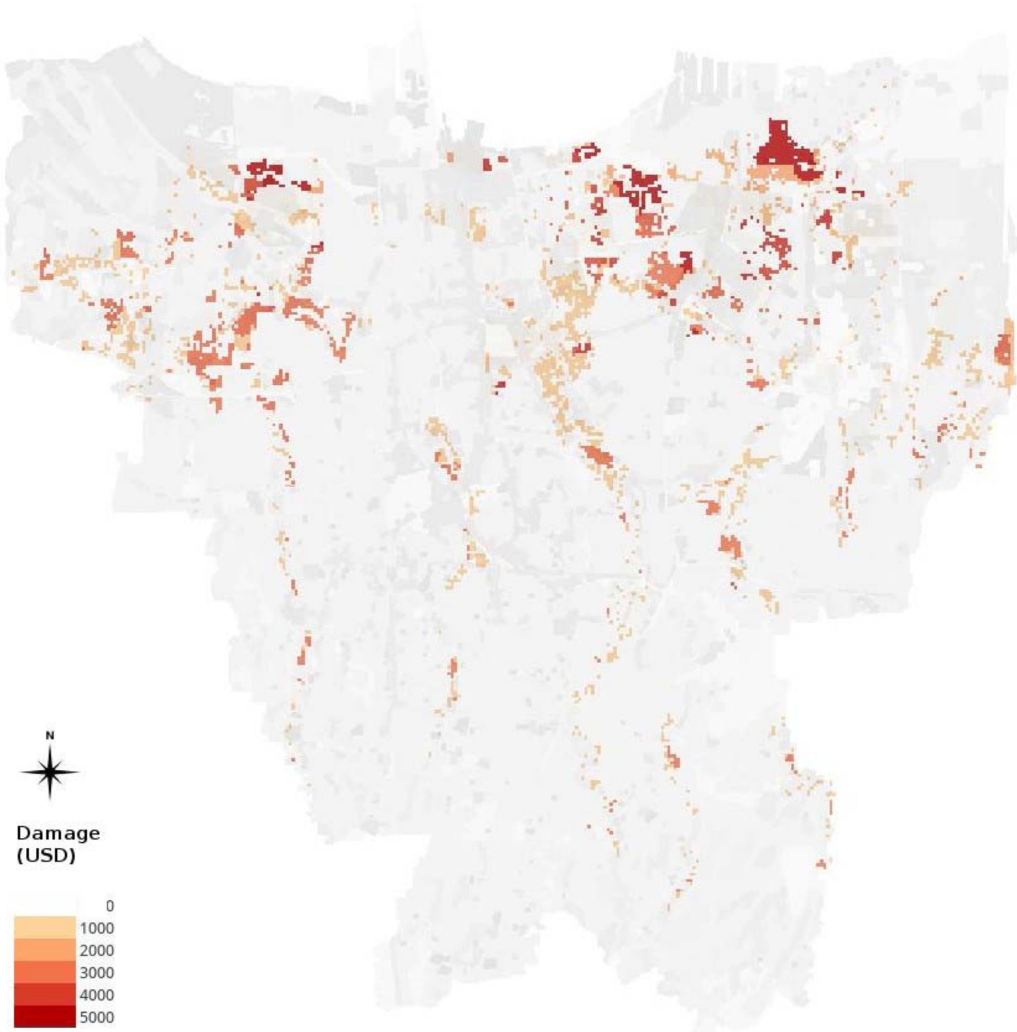

Figure A.4 Damage map at return period 25 years

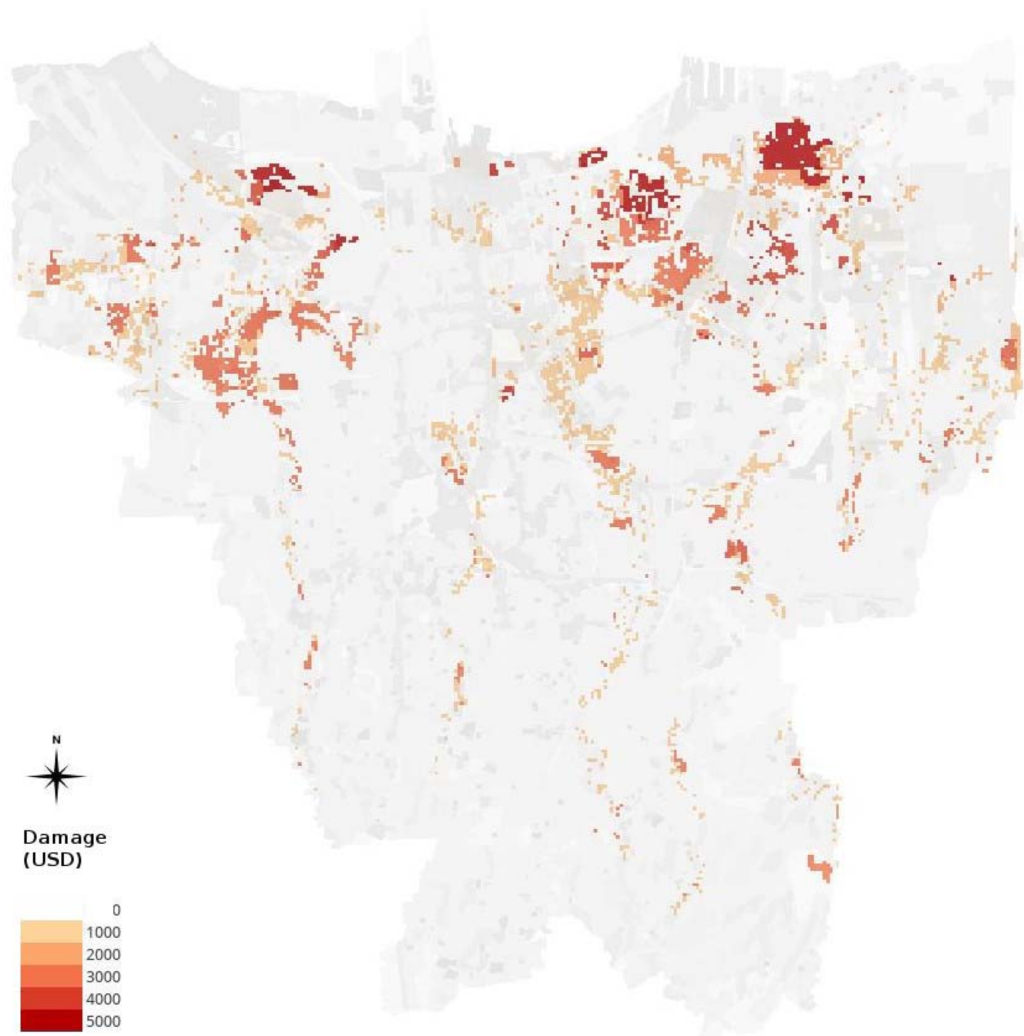

Figure A.5 Damage map at return period 50 years

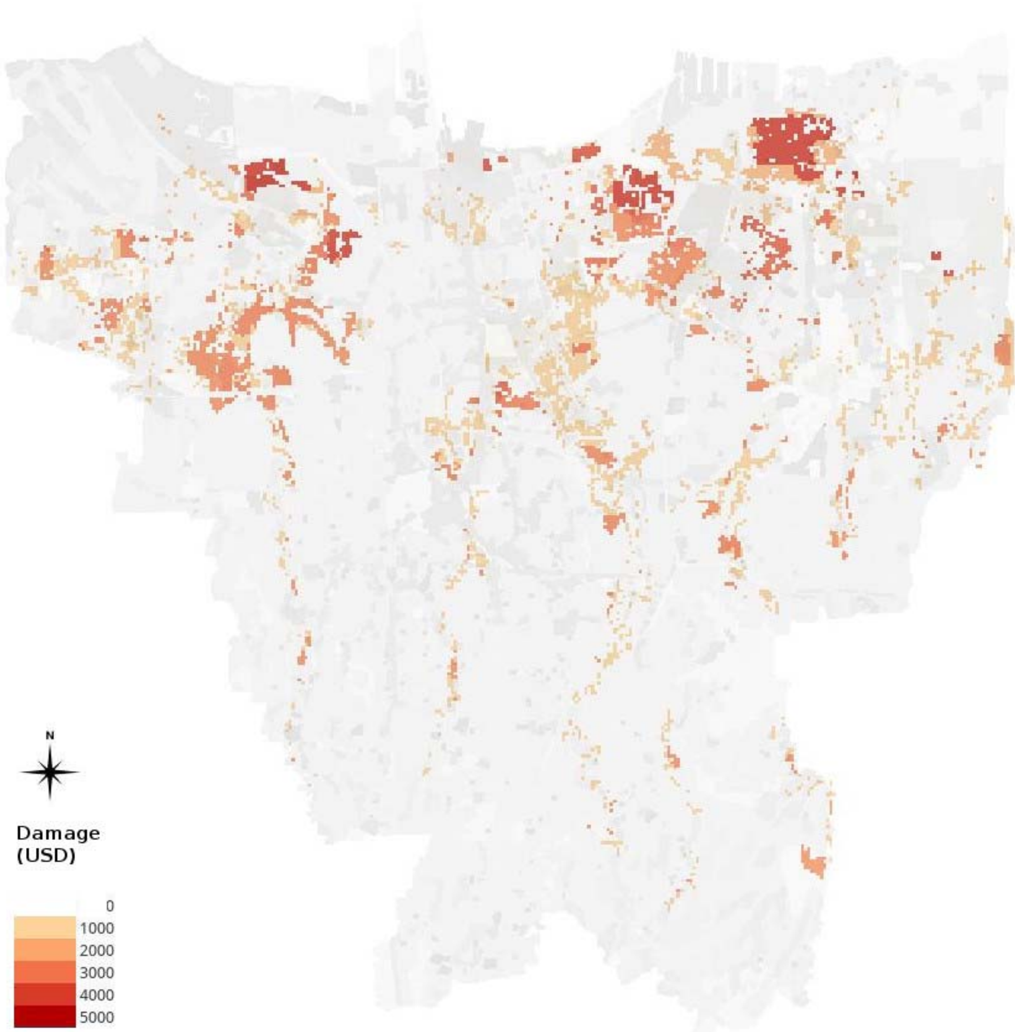

Figure A.6 Damage map at return period 100 years

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Flooding is a huge problem in Jakarta. As in most parts of the world, flood management in Jakarta has traditionally focused on technical protection measures, in order to lower the probability of the flood hazard. Given the increasing impacts of flooding for both physical and socio-economic drivers on risk, recent years have seen a shift towards a more flood-risk-management-based approach. This Thesis develops a flood risk model and explores the usefulness of the approach for governments, private organizations, and citizens of Jakarta and possibly other delta cities today and in the future under climate and socioeconomic change.

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