Mapping the adaptation solution space - lessons from Jakarta for other coastal cities

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Abstract. Coastal cities are under increasing pressure to adapt to climate change. They suffer from the severe effects of increased frequencies and intensities of coastal hazards, particularly flooding, whilst oftentimes continuing to sprawl into hazard exposed areas and grow beyond the pace of sufficient infrastructure development. Even though these problems have been quite well understood for a while, there is still comparatively little knowledge on the scientific assessment of the solution space, i.e. on the options available for adaptation and the ways in which they are being perceived, framed and evaluated in the scientific literature.

Focusing on Jakarta, this study presents findings from a systematic assessment of peer-reviewed scientific ~~English~~ literature on the adaptation solution space ~~to counter~~with regard to current and future flooding. Jakarta is chosen as a case study since it is amongst the cities with the highest flood risk and adaptation pressure globally, whilst also being one of the most heavily researched coastal cities in this regard, certainly in the Global South. Based on a structured key word search, we assess 311 articles. Results indicate that the perceived solution space is skewed towards hard protection against flooding, while measures to accommodate flooding or retreat from exposed areas are less widely considered in the scientific debate. Soft adaptation measures for the reduction of social vulnerability receive less attention in the literature than those measures targeting the taming of flood hazards, often through engineering solutions. Likewise, hybrid adaptation approaches, which combine soft and hard measures in a complementary way, are only rarely considered. Looking into the future, the findings suggest that despite the importance of hard flood protection as a main adaptation solution in Jakarta, other fields of the solution space deserve increased scientific attention. This relates in particular to urgently needed feasibility and effectiveness assessments of ecosystems-based solutions for flood mitigation and adaptation options targeting social vulnerability. While the empirical results are specific to Jakarta, heuristic observations from research on other coastal cities suggest that similar scoping exercises of the predominantly perceived solutions space might be of relevance in many cities beyond Jakarta. ~~Jakarta is one of the most researched Lessons from Jakarta are hence of global reach and importance. Future science on the city can play a significant role in piloting new approaches on the pressing frontiers in adaptation research. But increased attention is needed on current epistemic gaps.~~

1. Introduction

Many coastal ~~and delta~~ cities around the world suffer from chronic flooding, straining their development (Hallegatte et al., 2013). Looking into the future, risks related to flooding in these cities are set to rise sharply (IPCC, 2019a). This rise in risk is driven by climate change effects (e.g. sea level rise and the increasing intensity of heavy precipitation, river flooding and storm surges) but also ~~some~~ effects of urbanization itself (e.g. land subsidence, urban sprawl into flood-prone areas or the accumulation of people and infrastructure ~~irrespective of future hazards~~) (Tellmann et al. 2020; Wolff et al. 2020). As a result, coastal ~~and delta cities~~ cities are under increasing pressure to adapt over time and in some instances transform fundamentally (IPCC, 2019a; Revi et al., 2020). While this is not a new phenomenon, even well-researched cities like Jakarta, Indonesia, with sound scientific knowledge on their flooding problems and considerable efforts to improve ~~ing~~ flood risk management and climate change adaptation, keep suffering from flooding year after year.

Persistent flooding hints towards the existence of "adaptation gaps" (UNEP, 2018). In order to better understand and address such gaps, this study looks at scientific research not only on past, current and future trends in flood risk but particularly adaptation for the case of Jakarta. Research on this city shows a pattern which appears to be typical for coastal cities: Whilst the problem of flooding and its drivers has been quite well researched for Jakarta (e.g. Abidin et al., 2015; Asdak et al., 2018; Budiyono et al., 2016; Garschagen et al., 2018; Latief et al., 2018; Mishra et al., 2018; Moe et al., 2017; Ward et al., 2011), much less attention has been given to analysing different potential adaptation options. The main focus of this paper is therefore on examining ~~the~~ how the so-called "adaptation solution space" for Jakarta is being covered and framed in the literature. The concept of "solution space" for adaptation to climate change has been receiving ~~increased~~ increasing attention since ~~its notion in~~ the IPCC's Fifth Assessment Report (WGII AR5) (IPCC, 2014). The adaptation solution space can broadly be understood as being made up of potential adaptation options including their synergies and trade-offs as well as barriers and enablers. Assessing the adaptation solution space, including the feasibility, effectiveness and adequacy of different adaptation options – and their combinations over time – is essential for informing the composition of adaptation pathways. The solution space for climate change adaptation therefore represents a socially constructed, multi-dimensional space of opportunities for adaptation that determines "why, how, when and who adapts to climate change" (Haasnoot et al., 2020:36), restricted by hard and soft limits to adaptation (Dow et al., 2013). ~~It represents a dynamic and flexible concept that changes in form and size depending on time, context and influencing actors, containing different and contested adaptation options and pathways on which decision-makers can draw to determine an adaptation strategy (Haasnoot et al., 2020).~~ This study assumes that scientific inquiry contributes to the evolution and shape of the solution space. ~~through research conducted on the different aspects of risk such as hazard trends, vulnerabilities to risk, mitigation and adaptation options.~~

Jakarta represents an example worthwhile analysing. The city's flood problems are so pressing ~~there~~ that it can serve as an early laboratory for current and future adaptation challenges many other major coastal cities will also have to deal with. The combination of continuing urbanization and environmental changes result in increasing risks for the urban population today and in the ~~future~~future, turning the city into one of the most at risk coastal cities globally (Hallegatte et al., 2013; Hanson et al., 2011). ~~Jakarta is one of the most obvious examples for this global trend, ranking among the 20 most at risk coastal cities today and in the future (Hallegatte et al., 2013; Hanson et al., 2011).~~

To examine which adaptation options are being considered in the scientific literature and how,~~,~~ the study uses a structured literature review to address the following research questions:

- ~~What are dominant research streams in~~Which flood risk drivers are considered in ~~flood~~ research ~~in~~ on Jakarta?
- To what extent does scientific research consider different hard, soft and hybrid ~~available adaptation options~~measures for risk management and adaptation and how are these measures being evaluated?
- ~~How are current risk management and adaptation responses being evaluated in the literature?~~

~~are these different options being perceived~~is flood governance described, framed and evaluated?

~~What are persistent problems and needs from the perspective of scientists?~~

~~Which gaps can be observed?~~

~~Ultimately, this study aims at showcasing how such an analysis can assess the adaptation solution space for flood risk management~~While the paper is focused on Jakarta, it aims at providing lessons for the assessment and understanding of adaptation solution spaces in other coastal cities facing similar risk and adaptation pressure.

The paper is structured into seven~~five main~~ parts. Section 2 lays out conceptual considerations around flood risk and adaptation adopted in this study before section 3 briefly introduces the flood context of Jakarta. Subsequently, section 4 describes the methods and data of our analysis ~~are described~~. Section 5 ~~3~~ presents the results starting with general publication patterns and

author affiliations. Subsequently, the results chapter describes drivers of flooding mentioned in the literature before it summarizes hard adaptation measures discussed. Then, soft and hybrid adaptation measures mentioned in the literature are presented. Section 64 summarizes and discusses the results, relating them to the solution space for flood adaptation for Jakarta. It also presents identified gaps.. Section 75 offers key conclusions and an outlook.

2. Conceptual considerations – flood risk and adaptation options

Climate change adaptation first and foremost means action to limit and reduce climate risks (Garschagen et al., 2019). In order to understand whether and how adaptation is being framed and perceived, it is therefore necessary to concentrate on the links between adaptation and risk, we argue. In other words, to unpack the adaptation solution space – or rather how it has been discussed in the scientific literature in this case – one therefore has to ask whether and how different adaptation options are considered to take effect on the different components and drivers of risk (Garschagen et al., 2019). In addition, a key question is which factors of risk might be underrepresented in the current adaptation literature. For these reasons, understanding how risk is being produced and composed is essential.

In this study, we draw on a few decades of risk research and understand risk in line with current concepts used in the IPCC to be a function of hazard, exposure and vulnerability (Wisner et al., 2004; IPCC, 2012). In that, hazards can be defined as (environmental or climate-related) events or processes with the potential to cause damage and harm (adapted from Weyer et al., 2019 in IPCC, 2019b). In the case of Jakarta this predominantly means floods. Exposure is understood as the presence of assets or activities (social or environmental) in the spatial, temporal and/or functional reach of hazards. Exposure therefore has a hybrid character as it can be altered by environmental changes (e.g. sea level rise) as well as the socio-economic change (e.g. urban sprawl). Vulnerability refers to the propensity or predisposition to be adversely affected if exposed to a hazard (adapted from Weyer et al., 2019 in IPCC, 2019b). For example, the degree of susceptibility of livelihoods or infrastructure to suffer harm from floods contributes to vulnerability.

Adaptation links into the causal fabric of risk by aiming to reduce existing as well as future vulnerability (e.g. through health care or other social security programmes), exposure (e.g. through planned retreat from hazard-exposed areas), and/or, where possible, hazards (e.g. by limiting flood intensity through retention areas) (Garschagen et al., 2019). Overall, adaptation can hence be defined as the process of adjustment to actual or expected climate change and its impacts, in order to moderate harm or, where possible, even exploit beneficial opportunities (adapted from Weyer et al., 2019 in IPCC, 2019b). Addressing the different risk components (hazards, exposure and vulnerability) involves assessing and selecting options for policy and action (Garschagen et al. 2019). Such decision-making entails evaluation of the effectiveness, efficiency, efficacy and acceptance of actions (ibid.). Limits to adaptation apply where available options do no longer allow actors to secure valued objectives, functions or assets from intolerable risk (Dow et al., 2018). While coastal cities might reach technical limits of adaptation only rather late (e.g. in terms of the engineering limits theoretically applying to coastal protection), financial, social and institutional barriers and limits are expected to be reached much earlier (Oppenheimer et al., 2019).

Risk analysis is often split into understanding the hazard and understanding other driving forces – including physical and/or social exposure as well as vulnerability. For a long time, scientific research has focused primarily on understanding the hazard with the objective to control nature and protect people from it (Hewitt, 1983; Wisner et al., 2004; IPCC, 2012). In the same vein, the role of "hard" adaptation solutions, which aim at controlling flood hazards and protecting exposed elements, have grown in importance, becoming a centrepiece of the predominant paradigm for risk reduction in the second half of the 20th century (Hewitt et al. 1983; Wisner et al., 2004). Hard adaptation measures in the context of flood risk reduction are mostly large-scale engineered human-built structures, e.g. floodwalls or storm barriers (Sovacool, 2011; Oppenheimer et al. 2019; Du et al. 2020). While they often meet their objective to protect people and systems from harmful events and are widely considered an important element within portfolios of risk reduction measures especially in coastal cities (Oppenheimer et al., 2019), they do rarely work towards reducing underlying hazard drivers or social vulnerability and they often entail significant downsides. First, they tend to be technologically complex – often prone to failure – and very cost-intensive (Sovacool, 2011). Second, they are comparably inflexible as concrete structures remain for a long time. This can be challenging in the face of high levels of uncertainty regarding climate change and dynamic trends in its impacts, which mean that they need constant assessment

and sometimes costly updates (David et al., 2016). Third, hard measures on aggregate generate comparatively little co-benefits and, depending on the planning and implementation process, have even been harmful to local communities and ecosystems (ibid.; Sovacool, 2011). And lastly, infrastructural measures might give people a false sense of security, increasing the overall damage potential in case of failure (IPCC, 2012). Risk reduction and adaptation regimes centred around hard protection predominantly or exclusively have therefore been problematized for their emphasis on technocratic fixes for solving symptoms rather than causes of risk (Ribot, 2011; Garschagen, 2014; Solecki et al., 2017); paving the way towards addressing the need for changing the protection paradigm towards more holistic risk management approaches (e.g. Viero et al, 2019).

Next to hard adaptation, the importance also of soft adaptation measures has therefore been emphasized since a while especially for reducing socio-economic vulnerability (Wisner et al., 2004; Ribot, 2011; Solecki et al., 2015) or for absorbing residual risk remaining beyond hard measures (Du et al., 2020). In contrast to hard adaptation, soft adaptation includes an emphasis on ecological and institutional responses, notably ecosystems-based approaches and institutional adjustments e.g. in terms of land-use planning, building codes, social protection or awareness raising. ~~The field~~Soft adaptation is less clearly defined as hard protection, meaning that also the consideration of properties, advantages and disadvantages of measures belonging to soft protection is multifaceted. Yet, a number of overall observations have been suggested in the literature, notably that soft protection is focused on empowering and capacitating local communities to respond to changing hazards and is often based on modular technologies which do not require large outlays of capital or human resources (Sovacool 2011). Yet, this is not to argue that certain soft measures also require a large amount of central planning, investment and steering, e.g. in the case of large-scale wetland or mangrove restoration. ~~.~~

Hard and soft adaptation measures are often combined and can both be mapped onto the main response types against sea level rise and coastal flooding as used by the IPCC, i.e. protection, accommodation, advance, retreat (Oppenheimer et al., 2019). However, certain clusters can be observed, e.g. in that protection typically relies on hard measures whereas accommodation typically also requires a stronger integration of soft measures. Assessing coastal adaptation approaches and potentials across the globe, the IPCC stresses that hard adaptation is technologically feasible and economically efficient for coastal cities and therefore will continue to play a central role in adapting such cities further (Oppenheimer et al., 2019). However, the IPCC also stressed that hard protection does not come without disadvantages and raises questions of affordability, particularly in poorer regions of the world (ibid.). There is therefore high agreement that hybrid approaches, combining different hard and soft approaches, is a promising way forward in many coastal settings (ibid.). For Shanghai, for instance, hybrid approaches of combining hard storm-surge barriers with wetland development and wet-proofing of infrastructure have been assessed to bring about the highest potential for overall risk reduction (Du et al., 2020). An example from Padova (Italy) shows how proper floodgate operations are ensured by including the end-user in designing and implementing control structures and protocols.

~~Looking at it from a more conceptual perspective,~~ The above considerations means that measures of both types jointly make up the so-called solution space for climate change adaptation which can be understood as a flexible space spanning across multiple dimensions (biological, political, institutional, socio-economic, cultural), scales and actors, containing all potential solutions for climatic risks (Haasnoot et al., 2020). The solution space is confined by soft and hard limits (Dow et al., 2013) and can hence change in form depending on internal and external influencing factors (Haasnoot et al., 2020).

This study assumes that scientific research in the field of flood risk management and adaptation represents one of these influencing factors. Through scientific inquiry, scholars assess and evaluate potential flood adaptation options from many different perspectives, creating a diverse and constantly widening landscape of adaptation options, which are readily available for consideration of decision-makers. Accordingly, ~~they~~scientific perspectives play a vital role in shaping the actual solution space.

3. Brief overview of Jakarta's flood risk, its root causes, ~~and~~ impacts and recent management

Urban flooding has a long history in Jakarta. The ~~since the~~ city is naturally prone to coastal hydrological hazards due to its geographical location~~s~~ in a low-lying coastal area facing the Java Sea, ~~40% of Jakarta's urban area lies below sea level being exposed to coastal hazards such as storms and sea level rise (Marfai, 2015, Salim et al., 2019). In addition, more~~ and with more than 13 rivers, including the Ciliwung river, flowing through ~~the city~~it ~~, which in the case of heavy precipitation in the catchment area can overflow~~ (Marfai, 2015). Urban ~~Especially~~flooding in Jakarta is most severe when ~~, when~~ heavy precipitation, high run-off rates and storm and/or high tide levels coincide ~~, urban flooding can be very severe~~ (Garschagen and Surtiari, 2018). ~~Over the past decades~~In the future, c~~C~~limate c~~C~~hange is expected to increase Jakarta's "natural" ~~has reinforced these natural~~ drivers of flood risk, mostly through sea level rise and the increasing potential for heavy precipitation ~~both~~ in the ~~city and~~entire Ciliwung catchment area (Mishra et al., 2018; Januriyadi et al, 2018) ~~in Jakarta. Among others, sea level rise and changing precipitation patters challenge the city's traditional flood protection mechanisms, leading to frequently reoccurring flood situations.~~

However, besides natural drivers of flooding, there are also multiple human-made causes which significantly contribute to the city's flood problem. First, continuous population growth, urbanization and land use changes in Jakarta as well as in its surrounding areas, including the upstream area of the Ciliwung River, have significantly altered the hydrological system and run-off patterns (Garschagen et al., 2018). ~~In the city,~~Urban densification processes ~~furthermore~~ led to a degradation of the urban drainage system as river and canals were ~~built over~~ filled and floodplains ~~reduced so that~~ paved over, reducing the retention and discharge ~~options decreased~~ potential (ibid.). Second, the narrowing of urban water ways due to informal settlements along the banks of the rivers, sedimentation and pollution with waste have further reduced water flow capacities and urban drainage (e.g. Mathewson, 2018). Third, land subsidence ~~represents~~is a~~n important~~ key driver of the city's flood ~~issue~~problem because it exacerbates the impacts of precipitation and sea level rise (Salim et al., 2019). Today, 40% of Jakarta's urban area lies below sea level (Marfai, 2015; Salim et al., 2019). Subsidence ~~It is caused by four different aspects~~has four major drivers: excessive groundwater extraction, natural consolidation of soil, increasing infrastructure and building load, and tectonic activities (Abidin et al., 2015).

The impacts of floods, resulting from the interplay of both, natural and human-made drivers as described above, represent a strain on the city's development until today. ~~This can be observed when for instance looking at m~~Major flood events ~~that~~ hit the city in the 21st century; i.e. in 2002, 2007, 2013, 2014 and 2020. All of them resulted in several deaths, up to 500.000 evacuees as well as massive direct and indirect economic losses related to infrastructure damages, reduction of productivity as well as business value losses (e.g. Budiyono et al., 2015; Djalante et al., 2017; Octivianti and Charles, 2019). The 2007 floods stand out in extent and severity. The floods submerged more than 60% of the city, causing an unprecedented flood extent, fatalities, damages and losses (Texier, 2008). ~~as they~~ They resulted from the confluence of high precipitation in the city, water run-off from upland areas and a strong spring tide pushing water into the city from the sea (Octavianti and Charles, 2019; Garschagen et al., 2018). ~~The floods submerged more than 60% of the city, causing an unprecedented flood extent, fatalities, damages and losses (Texier, 2008).~~

This extreme event~~new type of flooding~~, driven by compound flood drivers including the seaward intrusion of water, can be described as a demarcation point, triggering a paradigm shift in flood risk management in so far that sea level rise was from then on portrayed to be one of the ~~main root causes for~~ risk drivers ~~flooding~~ (Garschagen et al., 2018; Octivianti and Charles, 2019). While prior to the 2007 event the city government mostly focused on protecting the city from inland flooding, it then developed the so-called Jakarta Coastal Defence Strategy (JCDS) to also protect the city from coastal hazards (Garschagen et al., 2018). Since then, the city government concentrates its flood risk management on four key infrastructural measures; namely river and water way regulation, including dredging and clearance of river banks, canalization, expansion of water reservoirs and the development of a massive sea wall including land reclamation (ibid., Octavianti and Charles, 2019). The so-called Great Garuda is one of multiple flood protection measures of the National Capital Integrated Coastal Development (NCICD) plan adopted in 2014. Its shape resembles a Garuda, the Indonesian national bird. Developed by a consortium of Dutch and Indonesian planning consultancies, the "giant sea wall" is supposed to protect Jakarta's bay area from the sea. In combination with other infrastructural measures of the NCICD masterplan, the bay area will be completely re-invented and developed as a new residential and business district (Garschagen, Surtiari, et al., 2018), aiming at~~,~~ marrying coastal protection with urban

development while at the same time addressing land subsidence – a problem that started receiving increased attention particularly after major floods in 2013 and 2014.

~~2.~~4. Methods and data

This study builds on a two-tier analysis scheme. First, a systematic search for English scientific literature in the citation database Scopus ~~limited to the years 2000 to October 2019, was conducted,~~ aiming at getting an ~~full~~ overview of the state of research on adaptation and flood risk reduction in Jakarta. While capturing the majority of the international scientific literature, this selection ~~It is acknowledged that this~~ does not capture ~~as~~ studies published in other languages such as Indonesian ~~are not considered. Furthermore, publications might be missed when they do not mention the selected search terms.~~ Nonetheless, the scoping of articles as well as the discussion of our approach and preliminary findings with Indonesian colleagues suggest that our approach is able to capture the ongoing scientific debate quite comprehensively. This is to large part due to the fact that Indonesian scholars today quite actively contribute to the English-language peer-reviewed scientific literature, thereby transporting research results of many local to regional studies into that body of knowledge (Djalante, 2018; see also section 5).

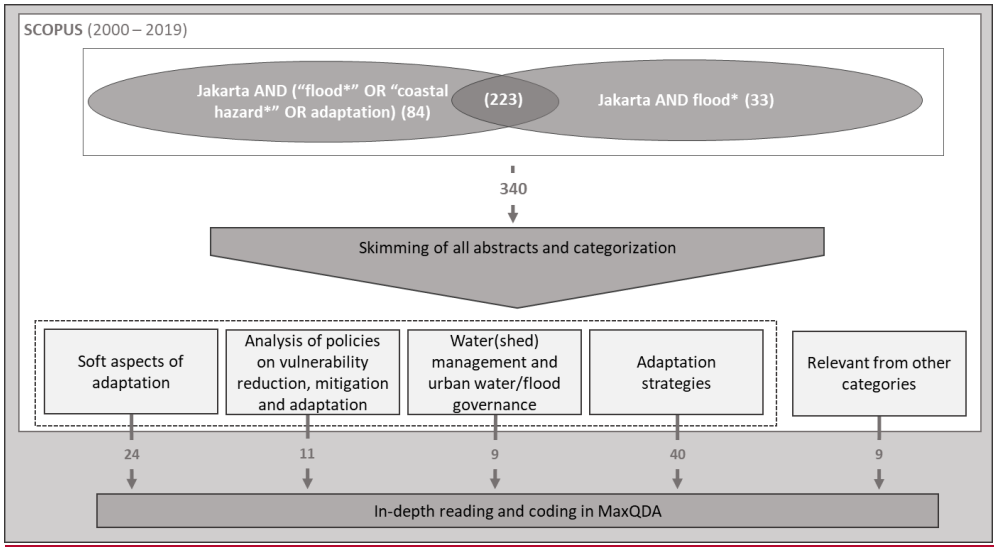


Figure 1: Literature search, extracted categories and numbers of resulting publications

As ~~visualized~~ shown in Figure 1, the S~~COPUS~~copus literature database was searched with a deliberately broad combination of the search terms Jakarta AND ("flood*" OR "coastal hazard*" OR "adaptation") ~~AND "Jakarta"~~, limited to roughly the past 20 years (2000 - ~~October~~ 2019). ~~Together with an additional search (Jakarta AND flood*)~~ In total, ~~and yielded~~ 311 ~~275~~ publications in English language resulted from the structural searches after ~~excluding~~excluding non-relevant research fields (medicine, mathematics, chemistry, biochemistry, nursing, chemical engineering, dentistry, immunology, veterinary)~~Annex XYZ)~~; building the basis for the following filtering and analyses. In a first step, ~~A~~all abstracts of resulting publications were skimmed and topical categories were developed, resulting in an inductively derived thematic scheme (see Table 1 and Appendix A). Based on the number of papers per category as well as their content, we obtained an overview of Jakarta's flood risk and adaptation research landscape ~~that is able to show its~~ and its centres of gravity. ~~adaptation and .~~ It is taken as an indication for whether and how different ~~which~~ fields of scientific inquiry ~~are more or less dominantly contributing~~contribute to the assessment of flood risk and adaptation solutions. Of course, ~~to filling and shaping the adaptation solution space. It is~~

acknowledged that tthe number of papers alone is does not sufficiently to evaluate the importance of a study field for framing the solution space and shaping political decision-making processes. Nonetheless, we argue that the number of publications can be one it is assumed that the number of papers influences the solution space that scientists open up for adaptation options considered in decision-making processes and that it is hence legitimate to use them as a proxy – amongst others- – for mapping the solution space for adaptation to flooding in Jakartaevaluating the intensity of a certain debate, in this case the engagement with particular flood drivers and adaptation solutions.

What is more, our analysis does not only draw on a bibliometric assessment but also on the content analysis of a subset of papers. In line with the research interest of our paper, we selected for a detailed content-analysis 93 publications which deal with otherwise underrepresented segments of the adaptation solution space, i.e. those focusing on soft and mixed adaptation options, including soft factors of adaptation and a focus on social vulnerability, policy analysis and integrated management (categories 1, 2, 7 and 8 of Table 1). The analysis was guided by the research questions (section 1). It follows the principles of a qualitative content analysis (Mayring and Früh, 2002) and draws on a combination of deductive and inductive codes (see Appendix B and C).

Table 1: Categories of publications

Code	Topic	Description
1	**Soft aspectsfactors of adaptation**	Papers on latentsoft factors that influence adaptation such as psychology, behavior, culture, understanding of risk, how risk is framed, willingness to pay for ecosystem services, participation in flood control strategy planning.
2	**Policy and legal analysis Analysis of policies on vulnerability reduction, mitigation and adaptation**	Papers focusing on e.g. institutional analysis, national policy analysis, legal frameworks for risk management and the political economy of flood protection.of risk management, vulnerability reduction and adaptation
3	**GreyHard/physical adaptation**	Papers that exclusively look at greyhard physical adaptation measures such as the Great Garuda Project, infrastructure for rainwater harvesting, polder, dikes and flood barriers, embankments and river diversions.
4	**Flood models & flood mapping**	Papers that present quantitative precipitation models, subsidence models, flood loss estimation models, urban drainage models, flood cost analysis, urban expansion and its effects, sea level rise models, community-based flood risk mapping, shoreline retreat models.
5	**Land-use (change) impact on flooding**	Papers that examine the criticality of watersheds or land-use change and its impacts on flooding with the help of quantitative models or qualitative case studies.
6	**New data types for flood mapping/response**	Papers that investigate the potential of using new data sources like social media, big data or high resolution data or new data generating formats such as crowd-sourcing or e-participation for flood risk mapping and analysis.
7	**Watershed (shed)management and urban water/water governance**	Qualitative analyses of reasons for flooding, water pollution, incl. drinking water source analysis/model.
8	**Soft and hybridComprehensive Aadaptation**	Papers that focus on soft and hybrid adaptation strategies incl. soft measures, local/community-led adaptation, firms and adaptation, resettlement/relocation, alternative energy sources, disaster management and urban adaptation planning.

9	**Early w~~W~~arning ~~for flooding~~**	Papers that present GIS-based ~~E~~early ~~W~~warning ~~S~~systems, risk communication and information needs during disasters.
10	**~~Information systems/indices for flood hazards~~Decision support systems**	Decision support system for location of warehouses, disaster information management system, socio economic vulnerability index, hydrological infrastructure flood vulnerability index, integrated assessment framework for subsidence.
11	**~~General~~Qualitative risk descriptions ~~of hazard impacts and trends~~**	Papers presenting information on flood events and impacts or evolution and impacts of land subsidence. In contrast to category 4, no quantitative hazard or risk models are employed.

~~Based on this and with the objective to learn about hybrid and non-structural adaptation strategies and policies, highly relevant and relevant publications of the categories "soft aspects of adaptation", "analysis of policies on vulnerability reduction, mitigation and adaptation", "water(shed) management and urban water/flood governance" and "adaptation strategies"[1] (75 publications) were read in detail and analyzed with the help of a coding scheme in MaxQDA, with the exception of five non-accessible papers (see Appendix B).~~

~~To compensate fields with lower numbers of publications, we selected four of them for deeper content analysis. Highly relevant and relevant publications of the categories "soft aspects of adaptation", "analysis of policies on vulnerability reduction, mitigation and adaptation", "water(shed) management and urban water/flood governance" and "soft and hybridadaptation strategies" (93 publications) were read in detail with the aim to better understand the state of literature on soft and mixed adaptation options discussed for the case of Jakarta – a field which the overview identified as comparatively underrepresented in flood research in Jakarta. The analysis was conducted with the help of a coding scheme in MaxQDA, with the exception of six non-accessible papers (see Appendix B).~~

~~The coding scheme was developed based on the authors' research interests and inductively expanded throughout the process following the methodology of a qualitative content analysis (Mayring and Früh, 2002) (Appendix C)). Since the main interest of the inductive literature search was to find out how the research landscape on flooding in Jakarta is composed, with a specific focus on non-structural adaptation strategies, the coding scheme focused mainly on (a) mentioned drivers of flooding, (b) considered adaptation or coping strategies, (c) described flood governance as well as (d) problems and needs from the perspective of the authors with respect to overall flood adaptation in Jakarta.~~

~~Acknowledging that this study is limited to English scientific literature, it is by no means exhaustive and does not claim comprehensiveness. Scientific literature in other languages than English, grey literature and media articles would provide further and potentially highly relevant insights and perspectives; however, the review of scientific literature of any type (not only peer-reviewed) can give a very good indication for the state of knowledge and focus of research regarding the given topic.~~

~~3.~~5. Results

As depicted in Figure 2, scientific research on flooding in Jakarta has been rapidly rising since the year 2015. Between the beginning of 2015 and today, almost 3 times as many documents were published compared to the period of 2000 to 2014. In comparison to global flood risk research, which increased steadily over the years, this represents a remarkable spike, hinting towards the relevance for the topic of flooding in Jakarta as well as an increasing scientific interest.

~~[1] The category "adaptation strategies" composes of publications that adopted a holistic understanding of flood risk and elaborated on hybrid and/or soft adaptation measures. In addition, few selected publications from other categories (Appendix ATable 1) were analyzed in a similar way, when they were deemed relevant for the context.~~

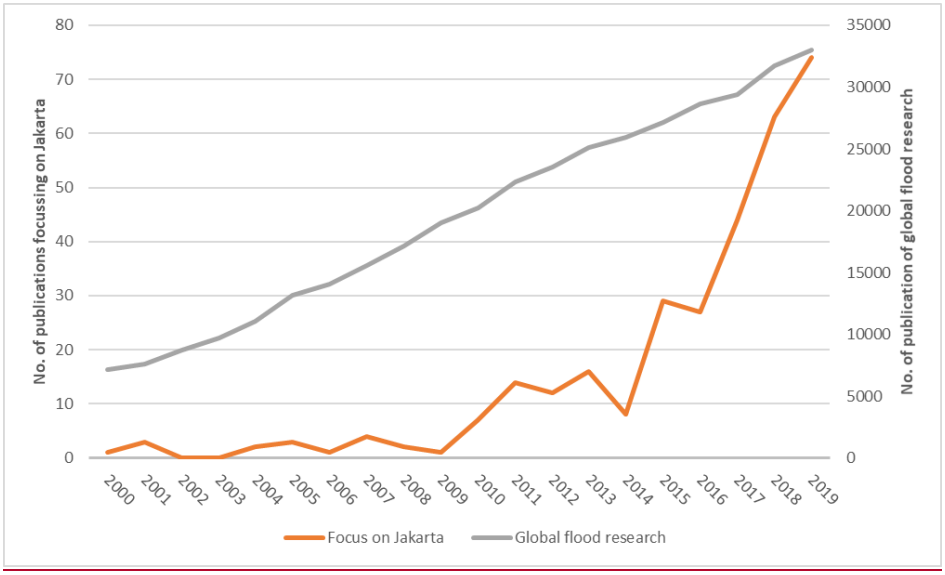


Figure 2: Number of scientific publications in flood and adaptation research in Jakarta and globally[2] ~~on flooding in Jakarta~~ (2000-2019) in Scopus~~COPUS~~

Research attention was especially high among Indonesian scholars. As visualized in Table 1, almost two third of first authors are affiliated with Indonesian institutions. With regard to international attention to Jakarta's flooding issue, most first authors are affiliated with Dutch institutions (20%) followed by researchers from Japan, Australia, Singapore and the USA.

Table 2~~1~~: Number of publications sorted by the location of affiliation of the first author

Country of affiliation	No. of publications	%
Indonesia	218	48.6
Japan	48	10.7
the Netherlands	47	10.5
unknown	26	5.8
Germany	20	4.5
USA	18	4.0
Australia	17	3.8
Singapore	15	3.3
Switzerland	14	3.1
UK	9	2.0
China	3	0.7
South Korea	2	0.4

[2] Searches in Scopus: 1. Jakarta AND (flood* OR "coast* hazard" OR adaptation"), 2. Flood* OR "coast* hazard" OR adaptation; both for the years 2000-2019 and excluding the following subject areas: medicine, mathematics, chemistry, biochemistry, nursing, chemical engineering, dentistry, immunology, veterinary

Thailand	2	0.4
Austria	1	0.2
Brazil	1	0.2
Canada	1	0.2
Denmark	1	0.2
EU	1	0.2
France	1	0.2
Greece	1	0.2
Italy	1	0.2
Philippines	1	0.2
Spain	1	0.2
~~Country of affiliation~~	~~No. Of publications~~	~~%~~
~~Indonesia~~	~~193~~	~~45.84~~
~~Netherlands~~	~~52~~	~~12.35~~
~~Japan~~	~~39~~	~~9.26~~
~~Australia~~	~~25~~	~~5.94~~
~~Singapore~~	~~21~~	~~4.99~~
~~USA~~	~~17~~	~~4.04~~
~~Germany~~	~~15~~	~~3.56~~
~~Switzerland~~	~~7~~	~~1.66~~
~~UK~~	~~7~~	~~1.66~~
~~China~~	~~5~~	~~1.19~~
~~France~~	~~4~~	~~0.95~~
~~Canada~~	~~3~~	~~0.71~~
~~Korea~~	~~3~~	~~0.71~~
~~Sweden~~	~~2~~	~~0.48~~
~~Thailand~~	~~2~~	~~0.48~~
~~Czech Republic~~	~~1~~	~~0.24~~
~~Denmark~~	~~1~~	~~0.24~~
~~Egypt~~	~~1~~	~~0.24~~
~~Italy~~	~~1~~	~~0.24~~
~~United Arab Emirates~~	~~1~~	~~0.24~~
~~Unknown~~	~~21~~	~~4.99~~

300 According to the subject fields provided by the Scopus citation databank (multiple possible per paper), more than three quarters of all ~~resulting~~ publications ~~originate~~ include ~~from~~ a natural science or engineering ~~discipline~~ perspective (environmental science, earth and planetary sciences, engineering, computer science, energy, physics and astronomy, agricultural and

biological sciences, materials science, mathematics, psychology, decision sciences~~environmental science, earth and planetary sciences, engineering, computer sciences, energy, agricultural and biological sciences, material sciences, physics and astronomy, medicine, chemistry, mathematics, biochemistry, genetics and molecular biology, chemical engineering, immunology and microbiology, veterinary~~) (cf. figure 3). Only ~~roughly~~ 15% can be attributed fully or partially to ~~fields from the~~ social sciences, ~~(social sciences, arts and humanities)~~ and very few ~~are~~ include an ~~from~~ economics perspective (Business, Management and Accounting, Economics, Econometrics and Finance). Only two percent are labelled to include an arts and humanities angle. ~~or other fields (Decision science, Nursing, Health Professions). However, this overview has to be considered with caution as one paper can be attributed multiple categories.~~

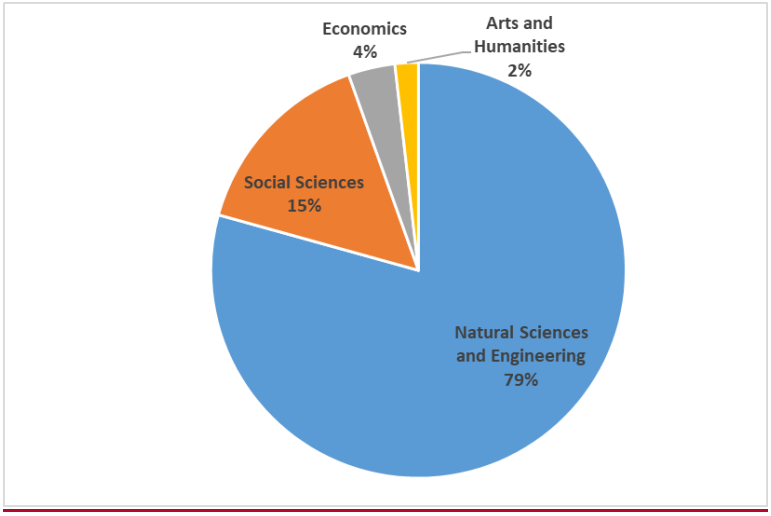
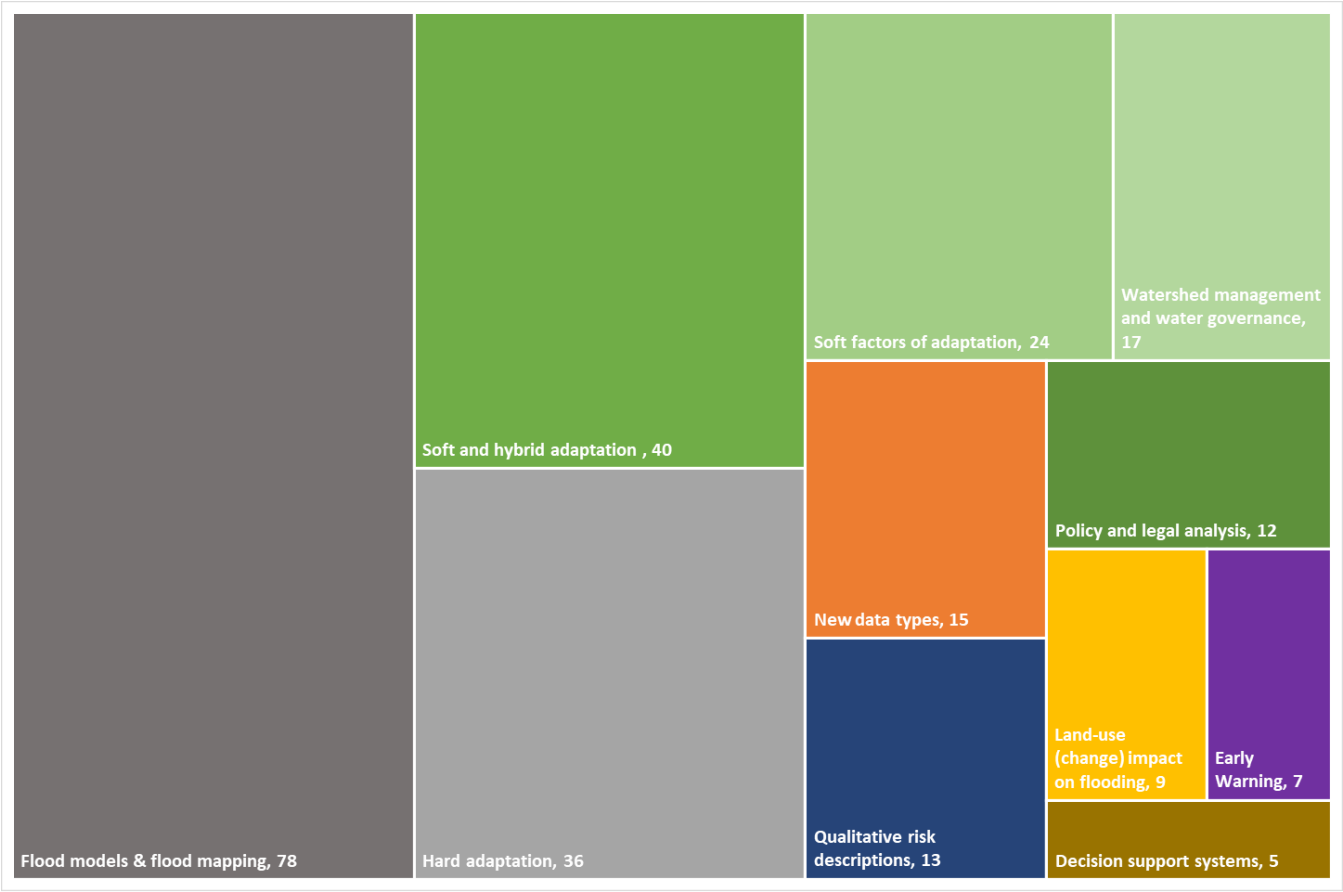


Figure 3: Subject fields of analyzed publications according to Scopus~~COPUS~~ classification

To get a clearer and more detailed overview, Figure ~~3~~4 shows a classification of the resulting publications in terms of the studies' content and focus, building on an inductively developed categorization scheme (Table 1). Some clear clusters and patterns emerge: First, studies on quantitative flood modelling, land use (change) impacts on flooding and hard~~physical~~ adaptation options together dominate the research field, representing almost 50% of all publications (grey fields). This corresponds with the high number of papers in subject fields from the natural sciences (see figure 3). Second, with around one third of all publications, studies in the areas of soft and hybrid adaptation analyses, soft factors of adaptation, policy and legal analyses as well as watershed management (green fields), ~~studies in the area of adaptation analyses, soft aspects of adaptation, climate adaptation policy and governance analyses as well as water management studies~~together represent another stream of scientific research. The rest of the studies of this analysis are very divers spanning from qualitative risk descriptions, over the employment of new data types for risk analysis and response to early warning systems and other decision support systems as well as land use change analysis in the context of flooding. Together, they represent roughly one quarter of all analysed publications.


Flood models & flood mapping, 78
Soft and hybrid adaptation , 40
Hard adaptation, 36
Soft factors of adaptation, 24
Watershed management and water governance, 17
New data types, 15
Policy and legal analysis, 12
Qualitative risk descriptions, 13
Land-use (change) impact on flooding, 9
Early Warning, 7
Decision support systems, 5

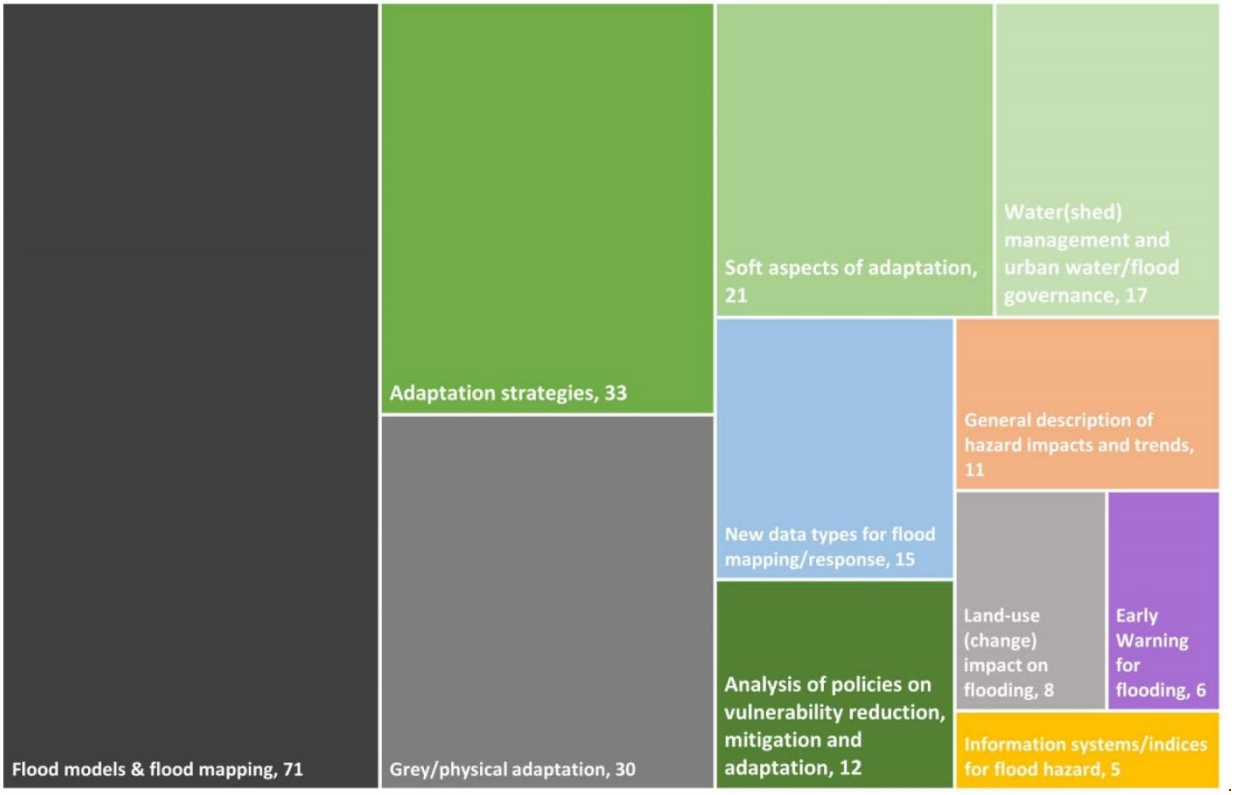


Figure 4: Thematic clusters of publications resulting from the structured literature search

~~3.1.~~5.1. Understanding the ~~physical determinants~~drivers of the flood hazard

As shown in figure 4, there is a strong focus on flood modelling and mapping, representing ~~more than a quarter~~almost one third of all papers published since the year 2000. Flood models (Bahtiar et al., 2018; Farid et al., 2012; Formánek et al., 2013; (Jati and Santoso, 2019.); Hurford et al., 2010; Kadri, 2008; Lin et al., 2016; Mishra et al., 2018; Ogie et al., 2016a; Remondi et al., 2016; Rojali et al., 2017; Takagi et al., 2016b; Tambunan, 2018) and non-model-based flood analyses (Asmadin et al., 2018; Priambodo et al., 2018; Syafalni et al., 2015; Yayuk Supomo et al., 2018), rainfall and/or run-off (Aditya et al., 2017; Anggraheni et al., 2018; Anindita et al., 2016; Farid et al., 2011; Hermawan et al., 2017; ; Moe et al., 2017; Otsuka et al., 2017; Rafiei Emam et al., 2016; Riyando Moe et al., 2017) and non-modelled rainfall/run-off analyses (Liu et al., 2015; Nuryanto et al., 2017; Wu et al., 2013) as well as models and analyses of land subsidence (Agustan et al., 2013; Andreas et al., 2019; Andreas et al., 2018; Chaussard et al., 2013; Koudogbo et al., 2012; Park et al., 2016) all aim at better understanding and simulating the physical factors that cause or influence flooding issues and measuring its impacts in Jakarta. The same holds true for flood damage or estimated losses models (Budiyono et al., 2015, 2016; Fajar Januriyadi et al., 2018; Kurniyaningrum et al., 2019; Marko et al., 2019; Wahab and Tiong, 2017; Ward et al., 2011b; Wijayanti et al., 2017).

With the objective to identify spatial patterns of rainfall (Latifah and Setiawan, 2014), subsidence (Abidin, 2005; Abidin et al., 2015; Prasetyo et al., 2018) and flooding/inundation (Andreas et al., 2017; Latief et al., 2018; Margatama et al., 2018; Nuswantoro et al., 2016; Tambunan, 2017; Ward et al., 2013c) the phenomena were mapped for specific rainfall and/or flood events. Soemabrata (2018) adopts a more comprehensive perspective, developing a flood risk map that also considers

vulnerability and urban growth and Padawangi et al. (2016) highlight the role of community risk perception and local knowledge by referring to the use of community-based and ~~/~~participatory flood mapping.

Apart from the latter two exceptions, ~~the mentioned~~ studies from the categories flood models & flood mapping as well as hard and ~~/~~physical adaptation tend to focus ~~focus~~ on climatic, hydrological and physical factors contributing to flooding, thereby providing key information on flood drivers and patterns. Such studies are much higher in number than ~~more comprehensive~~ risk assessments that also~~, i.e.~~ include~~ing~~ non-hydrological risk drivers (see below). ~~They provide sound evidence that contributes important aspects for understanding the occurrence and spatial patterns of flooding in Jakarta. However, their dominance over research that also assesses socio-economic and structural root causes of flooding (see paragraph on "Holistic, integrated approaches to flood risk management") also fuels the risk to cement the historically dominant framing of flooding as a natural phenomenon that can be controlled by physical measures, which partly persists until today (see Section 53.2.).~~

Publications which focus more on ~~from the categories~~ soft and hybrid adaptation as well as on social vulnerability issues ~~, soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management (all~~ i.e. the green categories in Fig. 4) predominantly argue that the flooding problem is not only caused by the local topography, geology, tidal influence and regional climatic patterns that successively change in the course of climate change but ~~more so~~also – potentially even more so – by ~~the interplay of these factors with a myriad of~~ anthropogenic factors (Aerts et al., 2013; Akmalah and Grigg, 2011; Asdak et al., 2018; Batubara et al., 2018; Costa et al., 2016; Esteban et al., 2017; Firman et al., 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Hellman, 2015; Ichwatus Sholihah and Shaojun, 2018; Kadri, 2008; Leitner and Sheppard, 2017; Marfai et al., 2015; Mathewson, 2018; Neise and Revilla Diez, 2018; Neise and Revilla Diez, 2019; Neolaka, 2012; Noviandi et al., 2017; Nurhidayah and McIlgorm, 2019; Octavianti and Charles, 2018, 2019; Padawangi and Douglass, 2015; (Rahayu et al., 2020); Salim et al., 2019; Shatkin, 2019; Sheppard, 2019; Simanjuntak et al., 2012; Simarmata, 2018; Texier, 2008; Varrani and Nones, 2018; van Voorst, 2014, 2016; van Voorst and Hellman, 2015; Ward et al., 2011a, 2013a; Wicaksono and Herdiansyah, 2019; Yoga Putra et al., 2019a; Yuliadi et al., 2016).

Three of the most important and frequently mentioned anthropogenic factors ~~mentioned in this stream of literature~~ are accelerating land subsidence (e.g. Andreas et al., 2019; Colven, 2017; Costa et al., 2016; Fitrinitia et al., 2018; Garschagen et al., 2018; Goh, 2019; Padawangi and Douglass, 2015; Salim et al., 2019; Sari et al., 2018; Shatkin, 2019; Ward et al., 2011b), river clogging due to waste disposal (e.g. Akmalah and Grigg, 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Kadri, 2008; Marfai et al., 2015; Mathewson, 2018; Padawangi and Douglass, 2015; Shatkin, 2019; Simarmata, 2018; Texier, 2008; Varrani and Nones, 2018; van Voorst and Hellman, 2015; Ward et al., 2011b) and land conversions (e.g. Asdak et al., 2018; Batubara et al., 2018; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Kadri, 2011; Marfai et al., 2015; Padawangi and Douglass, 2015; Shatkin, 2019; Varrani and Nones, 2018; Ward et al., 2011b, 2013a). ~~Authors stress the importance of anthropogenic factors contributing to flooding besides the well acknowledged environmental drivers and highlight that only an integrated, multivalent, cross scale approach, which addresses environmental, socio-economic as well as structural aspects of flooding and included soft adaptation measures will allow for identifying adaptation and mitigation measures that go beyond reactive infrastructural measures and provide more sustainable solutions (Akmalah and Grigg, 2011; Asdak et al., 2018; Costa et al., 2016; Goh, 2019; Noviandi et al., 2017; Rahayu et al., 2020; Saridewi and Fauzi, 2019; Shokhrukh Mirzo Jalilov et al., 2018; Varrani and Nones, 2018; Ward et al., 2013a; Wicaksono and Herdiansyah, 2019).~~

~~Besides this~~Yet~~, it is surprising that of the wealth of model studies and quantitative analyses of the flood hazard, only a few consider future changes in climatic conditions or land use changes (Budiyono et al., 2016; Fajar Januriyadi et al., 2018; Latief et al., 2018; Mishra et al., 2018; Rafiei Emam et al., 2016; Riyando Moe et al., 2017; Shokhrukh Mirzo Jalilov et al., 2018; Sutrisno, 2011; Takagi et al., 2016b; Vollmer et al., 2015, 2016; Ward et al., 2011bWard et al., 2013c). No study in the samplies considers future changes in exposure due to e.g. population growth or urban development. Furthermore, only a few take into account future changes in climatic conditions or land use changes (Budiyono et al., 2016; Fajar Januriyadi et al., 2018; Latief et al., 2018; Mishra et al., 2018; Rafiei Emam et al., 2016; Riyando Moe et al., 2017; Shokhrukh Mirzo Jalilov et al., 2018; Sutrisno, 2011; Takagi et al., 2016b; Vollmer et al., 2015, 2016; Ward et al., 2011b). The majority of the models and quantitative analyses base their findings and methodological developments on the examination of past events. Some use multiple return periods as changing variables in their models (Budiyono et al., 2015; Juliastuti et al., 2018; Kurniyaningrum et al., 2019; Liu et al., 2015; Syafalni et al., 2015; Yayuk Supomo et al., 2018), however without referringhowever, inferences to~~

~~the potential changes of return periods in the course of climate change remain vague at large. Other studies include different options for rainfall intensities/patterns (Lugina et al., 2018) and built-up area (Lin et al., 2016; Nuryanto et al., 2018; Remondi et al., 2016) but only in an abstract way, not building on future scenarios or models for these aspects.~~

~~3.2.~~5.2. ~~Physical/engineered~~Hard flood protection measures and their evaluation

Considering the focus on natural or ~~natural/~~geo-physical ~~reasons for~~drivers of flooding (see section 5.1), it is not surprising that there are many publications that concentrate exclusively on so called structural, engineered or hard flood protection measures. Such measures ~~, which~~ started being implemented already during colonial times ~~by the Dutch~~ and remain, ~~which are~~ until today, to be a main pillar of ~~popular in~~ Jakarta's approach to mitigate flooding (Colven, 2017; Garschagen et al., 2018; Goh, 2019; Mathewson, 2018; Octavianti and Charles, 2018; Owrangi et al., 2015; Padawangi and Douglass, 2015~~a~~; Simanjuntak et al., 2012; Ward et al., 2013a). Publications from the category of hard adaptation ~~patterns~~~~They represent around one tenth~~14 ~~percent~~ ~~of all identified studies on flooding in Jakarta, hence being an important pillar~~ form a major part of flood risk management research in Jakarta overall (Figure 4). ~~and~~ They focus on specific ~~engineered~~ solutions such as ~~for instance water barriers like~~ levees, dams, dikes and embankments and ~~analyzing~~ analyse or model their ~~vulnerability,~~ protective capacity or suitability for flood protection as well as their vulnerability (Mardjono et al., 2018; Mardjono and Setiawan, 2018; Ogie et al., 2016b; Su et al., 2018; Sujono, 2012; (Susilo et al., 2019); Suprayogi et al., 2018; Takagi et al., 2016a, 2017; Wurjanto, 2018). Some are concerned with water ~~channeling~~channelling, retention ponds and drainage systems as a means to mitigate flooding (Indrawati et al., 2018; Kadri, 2011; Kartolo and Kusumawati, 2017; Mahanani and Chotib, 2018; Mohajit, 2015; Nugroho et al., 2018; ~~(~~Sholichin et al., 2019; Wihaji et al., 2018) ~~as a means to mitigate flooding., and a few examine the effectiveness of land reclamation and polders as flood protection measure (Ajiwibowo, 2018; Mantasa Salve Prastica, 2018; Tanuwidjaja and Chang, 2017).~~

~~While these publications evaluate existing and potential future physical flood protection measures, a majority of them exhibits three rather weighty shortcomings: first, they do not consider social aspects such as their impact on social vulnerability or acceptance of the analyzed measures. These would however be very important to consider since they are often linked to major changes in communities, altering their vulnerability context. For instance, resettlements, which are often a precondition for the implementation of engineered adaptation measures, significantly influence communities' livelihood opportunities and social structures (Garschagen et al., 2018; Garschagen and Surtiari, 2018; Ichwatus Sholihah and Shaojun, 2018; Surtiari et al., 2017). Second, similar to the model studies described earlier, the publications on hard flood protection measures mostly neglect future climatic, demographic, socio-economic and land use changes. To assess the effectiveness of existing or suggested infrastructural measures for flood protection, some authors use return periods of rainfall events (Mantasa Salve Prastica, 2018) or floods (Ajiwibowo, 2018; Indrawati et al., 2018; Nugroho et al., 2018; Wurjanto, 2018); however, without referring to potential future changes. An exception (Takagi et al., 2017) evaluates the effectiveness of planned coastal dykes using flood and subsidence projections until the year 2050. Third, there are only very few publications that provide an overview or comparison of measures, e.g. between different infrastructural/physical measures (e.g. Lin, Shaad, and Girot 2016) to adapt to flooding or between physical and soft options of flood protection and adaptation (e.g. Fitrinitia et al., 2018). Altogether, the three shortcomings significantly limit the usefulness of the analyses for flood risk governance.~~

Some authors exclusively focus on the Great Garuda Project[3]~~,~~ the ~~a~~ central ~~and highly contested~~ element of the NCICD masterplan. Besides outlining the plan and its objectives, ~~the~~ a number of studies question its effectiveness regarding flood protection (Badriana et al., 2017) and its potential impacts on the local environment (Rusdiansyah et al., 2018; van der Wulp et al., 2016). Modelled scenarios of flooding with and without the Great Garuda by (Yahya Surya et al., 2019) show that the protection wall would slightly increase wave amplitudes, so that the authors conclude that the project requires improvements

~~[3] The Great Garuda is one of multiple flood protection measures of the NCICD adopted in 2014. Its shape resembles a Garuda, the Indonesian national bird. Developed by a consortium of Dutch and Indonesian planning consultancies, the "giant sea wall" is supposed to protect Jakarta's bay area from the sea. In combination with other infrastructural measures of the NCICD masterplan, the bay area will be completely re-invented and developed as a new residential and business district (Garschagen, Surtiari, et al., 2018).~~

to meet its aim of flood protection. (David et al., 2016) ~~for instance~~ point towards the option to complement the seawall project with ecosystem-based adaptation measures. ~~All in all, the Great Garuda is criticized to be a politically and economically driven, technocratic mega project that fails to comprehensively address the flooding problem. This is~~ The respective studies do not ~~argue that the projectthey are concerned that~~ because it neither addresses land subsidence nor other socio-economic factors ~~contributing to flooding and therefore does not present so that it does not represent a comprehensive and sustainable solution for the flooding problem (e.g. Colven, 2017; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Octavianti and Charles, 2019; Salim et al., 2019; Shatkin, 2019; Wade, 2019). Apart from questions around need and effectiveness, Salim et al. (2019) argue that the mega project represents a good example for "speculative urbanism" that binds international investments and pushes privatization, giving international investors as well as local elites a powerful role in determining the city's future development pathway.~~

~~Adopting the plan of the massive sea wall appears to follow Jakarta's traditional flood protection approach. In fact, it is however slightly different in that it marries the traditional approach of engineered flood protection with ambitious urban development objectives, meant to attract investments and push Jakarta's status and competitiveness to a higher level (Salim et al., 2019; Simarmata, 2018).~~

Studies outside the category of hard adaptation (Fig. 4)~~from the categories soft and hybrid adaptation, soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management~~ ~~-~~mostly adopt a rather critical perspective on infrastructural solutions in general and on the Great Garuda project in particular. The latter is criticized to be a politically and economically driven, technocratic mega project that fails to comprehensively address the flood problem (e.g. Colven, 2017; Octivianti and Charles, 20; Salim et al., 2019). The respective studies do not argue that the project cannot provide any protection from flooding but they are concerned that it neither addresses land subsidence nor other socio-economic factors contributing to flooding; it therefore does not present a comprehensive and sustainable solution for the flooding problem (e.g. Colven, 2017; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Octavianti and Charles, 2019; Salim et al., 2019; Shatkin, 2019; Wade, 2019). Infrastructural solutions in general are often portrayed as "technocratic fixes", which do not sufficiently address the hazard's root causes, which are argued to stem from socio-economic and structural context conditions and vulnerabilities, so that the problem persists (Colven, 2017; Padawangi and Douglass, 2015; Wade, 2019).

~~3.3.~~5.3. ~~Holistic~~Soft and hybrid~~, integrated~~ approaches to flood risk management and their evaluation

With a less model-driven and engineering-based ~~focus~~perspective, another stream of literature is dedicated to describe, analyze and/or propose adaptation strategies and flood governance approaches from a more integrated perspective, i.e. considering also soft measures ~~approaches~~ or hybrid approaches combining soft and hard measures~~.~~, which, according to the literature, are implemented through both, state-led and community driven initiatives. The analysed publications provide multiple examples of state-led soft measures. (Amri et al., 2017; Dwirahmadi et al., 2013; Faedlulloh et al., 2019; Hellman, 2015; Sugar et al., 2013; Yoga Putra et al., 2019a, 2019b) for instance mention the government's involvement in community empowerment and capacity building to facilitate and improve climate change adaptation ~~and mitigation~~. Other studies point to the involvement of government at different levels in the dissemination of information about flood risk and adaptation options, which help to raise awareness as well as prepare for and mitigate flooding (Dwirahmadi et al., 2013; Guinness, 2019; Texier, 2008; Ward et al., 2013a). Furthermore, the government's approach of combining hard ~~These include for instance XYZ. It is argued that the flooding problem is not only caused by the local topography, geology, tidal influence and regional climatic patterns that successively change in the course of climate change but more so by the interplay of these factors with a myriad of anthropogenic factors (Aerts et al., 2013; Akmalah and Grigg, 2011; Asdak et al., 2018; Batubara et al., 2018; Costa et al., 2016; Esteban et al., 2017; Firman et al., 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Hellman, 2015; Ichwatus Sholihah and Shaojun, 2018; Kadri, 2008; Leitner and Sheppard, 2017; Marfai et al., 2015; Mathewson, 2018; Neise and Revilla Diez, 2018; Neise and Revilla Diez, 2019; Neolaka, 2012; Noviandi et al., 2017; Nurhidayah and McIlgorm, 2019;~~

~~Octavianti and Charles, 2018, 2019; Padawangi and Douglass, 2015a; (Rahayu et al., 2020)Salim et al., 2019; Shatkin, 2019; Sheppard, 2019; Simanjuntak et al., 2012; Simarmata, 2018; Texier, 2008; Varrani and Nones, 2018; van Voorst, 2014, 2016; van Voorst and Hellman, 2015; Ward et al., 2011a, 2013a; Wicaksono and Herdiansyah, 2019; Yoga Putra et al., 2019a; Yuliadi et al., 2016).~~

~~Three of the most important and frequently mentioned anthropogenic factors are accelerating land subsidence (e.g. Andreas et al., 2019; Colven, 2017; Costa et al., 2016; Fitrinitia et al., 2018; Garschagen et al., 2018; Goh, 2019; Padawangi and Douglass, 2015a; Salim et al., 2019; Sari et al., 2018; Shatkin, 2019; Ward et al., 2011b), river clogging due to waste disposal (e.g. Akmalah and Grigg, 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Kadri, 2008; Marfai et al., 2015; Mathewson, 2018; Padawangi and Douglass, 2015a; Shatkin, 2019; Simarmata, 2018; Texier, 2008; Varrani and Nones, 2018; van Voorst and Hellman, 2015; Ward et al., 2011b) and land conversions (e.g. Asdak et al., 2018; Batubara et al., 2018; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Kadri, 2011; Marfai et al., 2015; Padawangi and Douglass, 2015a; Shatkin, 2019; Varrani and Nones, 2018; Ward et al., 2011b, 2013a). Authors stress the importance of anthropogenic factors contributing to flooding besides the well acknowledged environmental and physical drivers and highlight that only an integrated, multivalent, cross-scale approach, which addresses environmental, socio-economic as well as structural aspects of flooding and included soft adaptation measures will allow for identifying adaptation and mitigation measures that go beyond reactive infrastructural measures and provide more sustainable solutions (Akmalah and Grigg, 2011; Asdak et al., 2018; Costa et al., 2016; Goh, 2019; Noviandi et al., 2017; Rahayu et al., 2020; Saridewi and Fauzi, 2019; Shokhrukh-Mirzo Jalilov et al., 2018; Varrani and Nones, 2018; Ward et al., 2013a; Wicaksono and Herdiansyah). Applying such an approach in Jakarta would mean to also include non-infrastructural adaptation measures, which are also known as "soft adaptation" or "adaptive capacity"[4].~~

~~The body of literature on soft and hybrid approaches considers state-led and community driven adaptation measures.~~ flood protection infrastructure with relocation of exposed population as in the case of e.g. Great Garuda could be described as a hybrid approach, which is subject of discussion in many publications of this stream of literature (e.g. Colven, 2017; Rusdiansyah et al, 2018; Salim et al., 2019; Wade, 2019).

Local, community- or NGO-led adaptation initiatives ~~described in publications focussing on soft and hybrid adaptation, soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management~~ are argued to build on a wealth of context-specific knowledge about and experience with flooding and often compose of soft as well as hard measures (e.g. Bott et al., 2019; Fitrinitia et al., 2018; Marfai et al., 2015; Padawangi and Douglass, 2015; Purba et al., 2018; Simarmata, 2018; Sugar et al., 2013; van Voorst and Hellman, 2015; Yoga Putra et al., 2019b). The review of community-led adaptation efforts revealed a strong focus on the importance of what can be summarized as social capital for adaptation. ~~They~~A number of studies describe the key role of social networks, which allow for sharing knowledge, experience and best practices (Sugar et al., 2013; Yoga Putra et al., 2019a), which facilitate cooperation and coordination within and among communities, with NGOs and with universities (Fitrinitia et al., 2018; Goh, 2019; Hellman, 2015; Mathewson, 2018; Padawangi and Douglass, 2015; van Voorst, 2014; Yoga Putra et al., 2019a) and which foster mutual support as well as "practices of ~~commoning~~communing" (Leitner and Sheppard, 2017) such as pooling of resources (Guinness, 2019; Leitner and Sheppard, 2017; Padawangi and Douglass, 2015; van Voorst and Hellman, 2015). Social cohesion within networks has also been directly linked to collective action for adaptation (Rahmayati et al., 2017). Empirical examples put forward are for instance collective community works - in Indonesia known as "gotong royong" - for e.g. ~~trash collection and community gardens (e.g. Guinness, 2019; (Faedlulloh et al., 2019); Marfai et al., 2015; Padawangi and Douglass, 2015; Rahmayati et al., 2017; Vollmer and Grêt-Regamey, 2013; van Voorst and Hellman, 2015),~~ collective action in river monitoring and the issuance of flood warnings (Bahri and W Purwantiasning, 2019; Dwirahmadi et al., 2013; Fitrinitia et al., 2018; Hellman, 2015; Padawangi and Douglass, 2015; van Voorst, 2014, 2016), flood risk mapping (Dwirahmadi et al., 2013) and the establishment of local, community-based institutions to collectively develop and administer saving schemes and funds used for flood response and recovery (Dwirahmadi et al., 2013; Marfai et al., 2015; van Voorst, 2014).

~~[4] In the following all non-structural measures will be referred to as "adaptive capacity". According to the (IPCC, 2014) it is defined as "The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences."~~

Looking at how soft and hybrid measures are being evaluated in the literature, this review finds thatOverall, the reviewed literature on adaptation measures presents a quite dichotomous picture: While the few state led, mostly infrastructural adaptation strategies are criticized to be ineffective and sometimes even contra productive, community led, highly diverse initiatives to adapt to flooding are portrayed in a very positive way. oftentimes almost romanticized .

Besides the hard protection infrastructure, Aanalyzed state led adaptation efforts at city scale mostly focus on resettlement/relocation strategies, which accelerated since 2009 (Dovey and Achmadi., 2019Ichwatus Sholihah and Shaojun, 2018) and which are linked to the government's preference for infrastructural solutions for flooding. Many empirical studies raise questions about the effectiveness of such measures, claiming that relocations/ resettlements/ evictions for the purpose of flood protection often have serious negative effects on the environment and local communities (e.g. Dovey ., 2019Garschagen et al., 2018; Garschagen and Surtiari, 2018; Leitner and Sheppard, 2017; Neolaka, 2012; Rahmayati et al., 2017; Surtiari et al., 2017; Texier, 2008; van Voorst, 2016; van Voorst and Hellman, 2015; Ward et al., 2013a). Apart from state led resettlement and infrastructural measures, only very few other government initiatives to adapt to flooding are mentioned. many studies of the analysed studies focusing on soft and hybrid adaptation, soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management exhibit a rather critical perspective on state-led soft adaptation measures. (Fitrinitia et al., 2018; Mathewson, 2018; Ward et al., 2011a) elaborate that Despite an increased state of investments into non-structural, soft measures, as described above, such as awareness raising, laws and regulations, law enforcement, watershed planning and management, early warning and participatory planning (Ward et al., 2013a), many authors point out that they are not materializing on the ground (Fitrinitia et al., 2018; Mathewson, 2018; Ward et al., 2011a). (Hellman et al., 2018a) refer to this as an "implementation deficit", which they find being facilitated by Together with lacking reinforcement of laws and regulations. The state's hybrid approach, i.e. the combination of protective infrastructure and relocation of exposed population, is criticized to not only incomprehensively address flood risk (e.g. Colven, 2017; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Octavianti and Charles, 2019; Salim et al., 2019; Shatkin, 2019; Wade, 2019) but also to cause serious negative effects on the environment and local communities (e.g. Dovey and Achmadi., 2019; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Leitner and Sheppard, 2017; Neolaka, 2012; Rahmayati et al., 2017; Surtiari et al., 2017; Texier, 2008; van Voorst, 2016; van Voorst and Hellman, 2015; Ward et al., 2013a) due to the major relocations of informal settlers and urban poor in highly exposed areas at banks of the river and coastal areas in the name of flood mitigation (e.g. Goh, 2019; van Voorst and Hellman, 2015). This state-led approach is described to have accelerated since 2009 (Dovey and Achmadi., 2019; Ichwatus Sholihah and Shaojun, 2018) and some authors even claim these evictions to be a bigger threat to those evicted than flooding itself (Dovery et al., 2019; Hellman, 2015; Saridewi and Fauzi, 2019).this is also referred to as an "implementation deficit" (Hellman et al., 2018a). There is however involvement of government at different levels in the dissemination of information about flood risk and adaptation options, which help to raise awareness as well as prepare for and mitigate flooding (Dwirahmadi et al., 2013; Guinness, 2019; Texier, 2008; Ward et al., 2013a) and capacity building regarding flood preparedness and response (Amri et al., 2017; Dwirahmadi et al., 2013; Hellman, 2015; Sugar et al., 2013; Yoga Putra et al., 2019a, 2019b). (Faedlulloh et al., 2019) present a government driven project to empower communities to advance urban greening. But these initiatives do not seem to follow a systematic approach and papers do not elaborate on their quality. Overall, analyses of the governmental adaptation approach rWhen analysing the persisting dominance of ,the growing on its insufficiency to , a number of explanations are suggested in the literatureseen as one reason for (XYZ Reference needed)is argued to hinderis seen to facilitate. is seen to facilitatepresentedAt the same time, khas been argued tobe far less wide spread amongst and rather concentrate on its gaps and shortcomings, with a majority of publications providing a wide range of what is needed to improve the current adaptation strategy and its implementation (see Section 3.5.).

Interestingly, Llocal, community or NGO led adaptation initiatives that evolve in the absence of tailored effective and sustainable state led adaptation initiatives are mostly described in a positive way. They are argued to build on a wealth of context specific knowledge about and experience with flooding and often compose of soft as well as infrastructural measures as empirical studies show (e.g. Bott et al., 2019 Fitrinitia et al., 2018; Marfai et al., 2015; Padawangi and Douglass, 2015b; Purba et al., 2018; Simarmata, 2018; Sugar et al., 2013; van Voorst and Hellman, 2015; Yoga Putra et al., 2019b). These hybrid adaptation approaches to flood risk management provide evidence for the diverse landscape of options and measures, which are difficult to categorize/cluster so that in the following only the most frequently described non-structural measures will be listed.

~~The review of community led adaptation efforts revealed a strong focus of the authors on the importance of what can be summarized as social capital for adaptation. They describe the key role of social networks, which allow for sharing knowledge, experience and best practices (Sugar et al., 2013; Yoga Putra et al., 2019a), which facilitate cooperation and coordination within and among communities, with NGOs and with universities (Fitrinitia et al., 2018; Goh, 2019; Hellman, 2015; Mathewson, 2018; Padawangi and Douglass, 2015a; van Voorst, 2014; Yoga Putra et al., 2019a) and which foster mutual support as well as practices of commoning such as pooling of resources (Guinness, 2019; Leitner and Sheppard, 2017; Padawangi and Douglass, 2015b; van Voorst and Hellman, 2015). Also, strong s~~Social cohesion within networks is ~~has also~~ been ~~directly linked to collective action for adaptation (Rahmayati et al., 2017). Empirical examples put forward are for instance collective community works – in Indonesia known as "gotong royong" – for e.g. trash collection and community gardens (e.g. Guinness, 2019; (Faedlulloh et al., 2019)Marfai et al., 2015; Padawangi and Douglass, 2015a; Rahmayati et al., 2017; Vollmer and Grêt-Regamey, 2013; van Voorst and Hellman, 2015), collective action in river monitoring and the issuance of flood warnings (Bahri and W Purwantiasning, 2019; Dwirahmadi et al., 2013; Fitrinitia et al., 2018; Hellman, 2015; Padawangi and Douglass, 2015a; van Voorst, 2014, 2016), flood risk mapping (Dwirahmadi et al., 2013) and the establishment of local, community based institutions to collectively develop and administer saving schemes and funds used for flood response and recovery (Dwirahmadi et al., 2013; Marfai et al., 2015; van Voorst, 2014). Thus, social networks on the one hand help mobilizing community members to actively address the flood problem and on the other hand they provide a source for increasing their members' overall resilience. Impacts have been reported to go far beyond mitigating flood vulnerability as they function as social and financial security, addressing a wide range of vulnerabilities and helping to deal with the daily urban messiness (Hellman et al., 2018a; Padawangi and Douglass, 2015b; van Voorst, 2015).~~

At the same time, studies highlight ~~Evaluating soft adaptation approaches,~~ the potential of soft adaption measures to create co-benefits with other development objectives. Many studies analyse how ~~it is described that~~ the adaptation measures' impacts go far beyond mitigating flood vulnerability as they function as social and financial security, addressing a wide range of vulnerabilities (Hellman et al., 2018a; Padawangi and Douglass, 2015; van Voorst, 2015). However, social networks and community cohesion are also described to lead to ~~negative~~ problematic adaptation effects in some instances. An example is the preservation of exposure to flooding because individuals refuse to leave at-risk areas as they want to stay in the network that gives them a strong sense of belonging and livelihood security (Hellman, 2015; Neolaka, 2012; Rahmayati et al., 2017). Besides this, there are authors who criticise that the often positively portrayed community-led adaptation approaches ~~efforts often~~ do not lead to optimal and sustainable adaptation, as actions are often implemented in a reactive ad-hoc and rather uncoordinated manner without sufficient financial means (Marfai et al., 2015; Ward et al., 2013b).

~~In comparison to the publications focusing on hard infrastructures it is striking that publications on local adaptation efforts more often take into account "soft" aspects of the analyzed measures. Authors claim that e.g. risk perception and awareness, risk communication (e.g. van Voorst, 2016), behavioral and cultural factors (e.g. Bott et al., 2019; Yoga Putra et al., 2019b), collective action as well as participatory planning (e.g Sugar et al., 2013), coordination capacities (e.g. Marfai et al., 2015; Padawangi and Douglass, 2015b) and law enforcement are inherently intertwined with the success of mitigation and adaptation efforts, which is why they need to be better considered. With regard to risk awareness, authors agree regarding its importance for adaptation to flooding in Jakarta, however they show contrasting evaluations of the level of risk awareness of the city's inhabitants: While some argue that there is still urgent need to increase the risk awareness of the public as well as of authorities (Akmalah and Grigg, 2011; Farid et al., 2017; Firman et al., 2011; Neolaka, 2012), others attest Jakarta's inhabitants a high awareness of hazard risk (Esteban et al., 2017; Hellman, 2015; Padawangi and Douglass, 2015b; Varrani and Nones, 2018). However, high awareness does not automatically lead to adaptation – or at least not to proactive adaptation action in anticipation of future flood events. Inhabitants perceiving flood risk as daily normal may see no need to increase their efforts to adapt to it (Hellman, 2015; Neolaka, 2012; Simarmata, 2018; Texier, 2008), or they are lacking knowledge about adaptation and response measures (Amri et al., 2017).~~

~~All in all, it has to be considered that all listed adaptation measures are stemming from unique case studies, which illustrates the diversity and context specifics of adaptation at the local level. While all measures are analyzed in detail for one certain location, they are not linked or compared with each other or with infrastructural measures, which represents a major shortcoming in terms of informing decision-making.~~

It is widely acknowledged to be the most important driver of Jakarta's flood risk (Salim et al., 2019, Surya et al. 2019), however, if the NCICD will be able to solve it comprehensively is contested (Octivianti and Charles, 2018, 2019).

3.4. Jakarta's adaptation pathway since the turn of the century

While there hence exists empirical evidence for holistic and more integrated risk management approaches, these are mostly seen at community level, driven by the discourse of wanting to live with flooding. State-led policy approaches to govern Jakarta's flood risk remained predominantly technical, pursuing the wish to protect the city from flooding – despite the acknowledgement of socio-economic, political and structural root causes for flooding and a global turn towards soft measures to counter flooding (Garschagen et al., 2018; Garschagen and Surtiari, 2018; Mathewson, 2018; Octavianti and Charles, 2019; Padawangi and Douglass, 2015b; Simanjuntak et al., 2012; Simarmata, 2018; Ward et al., 2013b). The continuation of traditional technical flood protection pursued by the national government is described to root in four overarching aspects according to the literature.

Firstly, Jakarta's colonial legacy and contemporary Dutch influence are attributed responsibility for the continuation of technocratic approaches. Octavianti and Charles (2019) argue that policies of flood protection follow a path dependency, which occurs due to the reliance on technical flood protection measures since Dutch occupancy. Since early colonial times, flooding was always fought with well known and calculable technical measures like canalization, dredging and the build up of protective structures such as dams and embankments, which brought short term alleviations and political success. These positive feedback cycles facilitated the institutionalization of the implementation of such measures, resulting in a political lock-in regarding flood management, which inhibits changes until today (Octavianti and Charles, 2018, 2019). Following similar lines, (Colven, 2017) expands the argument by claiming that postcolonial relations between the Netherlands and Indonesia persist until today, leading to the export of Dutch hydrologic engineering and technology to Indonesia. Overall there is a high dependency on foreign funds; not only from the Dutch government but also from organizations such as the World Bank or JICA (Simarmata, 2018). Furthermore, major delays in the implementation of infrastructure projects due to funding issues are described to be leading to the continuation of the traditional approach. For instance, the East Flood Canal, presented in 1973, only started being built 30 years later in 2003 due to funding issues (Simanjuntak et al., 2012).

Secondly, the role of information and the medial framing of technocratic approaches are described to facilitate the implementation of infrastructural flood protection measures. Among others, Hellman explains that a lack of public information about engineered measures and their impacts contribute to lacking resistance and hence the continuation of technical flood protection measures (Hellman, 2015). Regarding the lack of public information as well as the implementation of "old" projects without any changes despite the presence of new knowledge, the media plays a crucial role. Freedom of speech, which evolved hand in hand with the process of decentralization, turned the media into an important instrument for shaping flood policies and public opinion. By staging flooding as a predominately physical/natural phenomenon that urgently requires responses, they simplify the problem and reinforced the traditional technical approach, which provides quick, reliable and financially feasible solutions, which at the same time represent a financial opportunity for Indonesian elites and international investors (Octavianti and Charles, 2018; Simanjuntak et al., 2012).

Thirdly, despite a high degree of fragmentation of political and private sector communities and a lack of cooperation between them (Hellman, 2015; Neise and Revilla Diez, 2019), the mutual economic political interests in establishing Jakarta as a modern world-class city facilitates the implementation of prestigious infrastructural flood protection measures. Exemplified by the Great Garuda Project, Colven explains that technical flood protection measures are seen as a win-win solution: while solving the flood issue, they are at the same time development projects, attracting private investment, facilitating innovative

and technologically advanced urban development to turn Jakarta in a world-class city as desired by urban elites (Colven, 2017; Octavianti and Charles, 2018; Simarmata, 2018).

Fourthly, a lack of cooperation across scales since decentralization hinders the implementation of more integrated approaches, especially in the face of varying knowledge and capacity levels at different scales (Firman et al., 2011).

Some publications (e.g. Salim et al., 2019) refer to the massive flood in 2007 as a demarcation point triggering a paradigm shift in so far that sea level rise was from then on portrayed to be the main root cause for flooding – despite the fact that land subsidence had a much bigger influence. While prior to the 2007 event the city government focused on protecting the city from flooding by physical infrastructures, this strategy continued but was from then on complemented by pursuing land reclamation to fight sea level rise. As a consequence, the government launched major resettlement initiatives to clear the banks of the river and coastal areas from highly exposed informal settlers and urban poor in the name of flood mitigation (e.g. Goh, 2019; van Voorst and Hellman, 2015). The evictions were seen as a two-fold benefit: getting control over informal settlers who were still perceived as partly responsible for flooding due to waste disposal in and narrowing of the rivers and at the same time the evictions made room for widening and straightening the river as well as for infrastructure projects and investments along its banks (e.g. Goh, 2019; Salim et al., 2019). According to (Goh, 2019; Leitner and Sheppard, 2017; Padawangi and Douglass, 2015a; Salim et al., 2019; Simarmata, 2018), this framing provides – until today – a powerful legitimization for evictions in the course of infrastructural flood protection measures such as among others the Jakarta Urgent Flood Mitigation Project/Jakarta Emergency Dredging Initiative Project (JUFMP/JEDI) supported by the World Bank or other national as well as international investments in cleared areas. The government's current flood management approach including the eviction and resettlement projects in the name of flood protection has however yielded harsh critique and did – so far – not lead to visible alleviations of the flooding problem as it fails to address the actual root causes of flooding (e.g. Garschagen et al., 2018; Goh, 2019; Salim et al., 2019). Salim et al. (2019) even argue that projects like the "Great Garuda", which are adopted under the current approach, can even be seen as maladaptation, making the city more vulnerable to flooding. Hellman et al. (2018b) and Simarmata (2018) argue that the adoption of certain flood management responses such as river bed clearing/relocation are shaped by diverging objectives of different actors at different scales: this includes for instance the divergence between the national approach of political leaders and elites that aims at protecting and at the same time developing exposed areas striving to become a global city, and the local communities, informal habitants and the urban poor with their objective to try to live with recurrent flooding and maintain their livelihoods. Such conflicts go beyond this simplified black-and-white perspective and – partly triggered by hazards such as flooding – shape the city's vulnerability to flooding.

3.5. Discussion: Evaluation of existing representation of solution space and its gaps Identified policy and research gaps

With regard to policy gaps in flood adaptation and overall disaster risk reduction, the analyzed publications point towards a myriad of different aspects that need to be addressed. One of the most frequently mentioned ones is the strong focus on engineered flood protection measures instead of adopting a hybrid adaptation approach that also includes soft measures (Akmalah and Grigg, 2011; Shokhrukh Mirzo Jalilov et al., 2018). To date, the integration of soft and hard flood adaptation measures is largely lacking, as is the integration of mitigation and adaptation policies as well as the integration of environmental policies with the wider development agenda Jakarta's. The "technocratic fixes" (Padawangi and Douglass, 2015a) do not address the hazard's root causes, which partly stem from socio-economic and structural context conditions and vulnerabilities, so that the problem persists.

Besides this, authors claim that as a sound basis for improving adaptation measures and their governance, there still is a need to strengthen the legal system by putting into effect developed laws and regulations and ensuring a strict law enforcement. Moreover, strong institutions for climate change adaptation need to be established (Akmalah and Grigg, 2011; Asdak et al., 2018; Firman et al., 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Nurhidayah and McIlgorm, 2019; Octavianti and Charles, 2018; Ward et al., 2013b) and moreover, a regional approach to land use and urban planning should be adopted (e.g. integration of upstream and downstream, Jakarta and Jabodetabek (Asdak et al., 2018; Firman et al., 2011; Goh, 2019; Mathewson, 2018; Noviandi et al., 2017). The latter is linked to critique on the currently insufficient cooperation and coordination between stakeholders (among state-actors, among non-state actors and between state and non-state actors) across

sectors and scales. In combination, these gaps lead to rather ad hoc, uncoordinated actions and redundant adaptation structures (Asdak et al., 2018; Marfai et al., 2015; Neise and Revilla Diez, 2018; Sugar et al., 2013; Varrani and Nones, 2018). It is argued that the decentralized structures, institutional path dependency and the belief in traditional policy approaches represent particular challenges for changing the current policy paradigm (Asdak et al., 2018; Ward et al., 2013b). In addition, the lack of knowledge among government authorities/officials about hybrid adaptation and its successful implementation at the urban scale (Asdak et al., 2018; Firman et al., 2011; Ward et al., 2011a) as well as not integrated or even conflicting visions of risk reduction of different actors at varying levels in the society and the policy arena shape the adopted pathway (Hellman et al., 2018b; Simarmata, 2018; Ward et al., 2013b) and may inhibit change (Garschagen et al., 2018). Despite the acknowledgement of the importance of bottom-up approaches, lacking participation of civil society actors and "non-elites" in urban development, facilitates the persistence of the traditional technical approach to adaptation (Akmalah and Grigg, 2011; Padawangi and Douglass, 2015b); especially because it goes hand in hand with the objectives of urban development of urban leaders and international investors.

Many authors mention a need to raise awareness for and educate about DRR measures and preparedness as well as the importance of environmental protection/conservation and participatory policy processes in order to facilitate the integration of local disaster risk knowledge, extend the dissemination of risk and response information and foster behavioral change within the public, authorities and among urban planners (Akmalah and Grigg, 2011; Amri et al., 2017; Esteban et al., 2017; Goh, 2019; Marfai et al., 2015; Neolaka, 2012, 2013; Nurhidayah and McIlgorm, 2019; van Voorst and Hellman, 2015; Ward et al., 2013b). Linked to this, e.g. Firman et al. (2011) and Yoo et al. (2014) demand for capacity building in the field of risk assessments as well as for policy development and management activities, more integrated legal and institutional frameworks for disaster risk reduction and climate change adaptation, increased community participation in risk management planning and decision-making (Goh, 2019) as well as resettlements/relocation (Ichwatus Sholihah and Shaojun, 2018; Texier, 2008).

Finally, relocations/resettlements/evictions for flood protection are stressed to be a key problem in Jakarta, which may even be a bigger threat to the urban poor than the flooding itself (Hellman, 2015). Without participation of the affected communities, relocations strategies are often implemented without timely warning and mostly for the benefit of engineered flood protection measures or the capitalization of exposed areas (Leitner and Sheppard, 2017; van Voorst and Hellman, 2015). For the urban poor residing in flood-exposed areas, resettlements and evictions undermine their capacities and collective action, which contributes to their overall vulnerability and marginalization (Garschagen et al., 2018; Ichwatus Sholihah and Shaojun, 2018; Leitner and Sheppard, 2017).

4.6. Discussion

Our reviewreview shows that there is a rich, and diverse and rapidly growing body of literature analyzing Jakarta's flood problem and identifying as well as evaluating adaptation options. Looking at the discussed drivers of flooding to answer our first research question, we find that one stream of literature; i.e. publications from the fields flood models & flood mapping as well as hard adaptation, predominantly frame flooding as being caused by environmental physical factors and hence as a hazard that can be controlled through engineering solutions and environmental management. Looking at the size of this body of literature measured by the numbers of publications, this can be considered anthe main important pillar stream of flood risk research in Jakarta. A significantly smaller body of literature composing of studies on soft and hybrid adaptation measures, including a focus on social vulnerability reduction and integrated water management, , soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management acknowledges the natural and /environmental drivers of flooding but also highlights the importance of socio-economic flood drivers, arguing that these drivers equally have to be considered in the consideration and design of adaptation solutions.

Research question two of this study asks which measures are considered for risk management and adaptation are considered in the literature. Our analysis shows that there are largely two separate perspectives on suitable measures for adapting to

flooding in Jakarta. One follows a protection approach, identifying predominantly infrastructural measures such as dams, sea walls, water canalization or reservoir constructions as solutions to protect the city from flooding. The second one is not opposed to infrastructural measures but criticises how they are implemented and demands among others for the inclusion of soft adaptation options to achieve comprehensive flood risk management and hybrid adaptation approaches. This literature argues that without a consideration of the root causes of social vulnerability and flood risk, hard infrastructure solutions are bound to be insufficient or even ineffective in the long-run. Likewise, these studies argue that social and environmental effects of hard protection measures need to be considered more stringently and that soft or hybrid approaches are oftentimes better-placed to create synergies with other development objectives.

Evaluating these findings ~~from our~~ own perspective we ~~and linking them to the evolution and current state of Jakarta's solution space for flood adaptation, we~~identify the following five points, which we argue might be helpful ~~in the following present five key messages, which provide valuable entry points~~ for ~~widening~~ advancing the debate and complementing the current perception on the adaptation solution space ~~the solution space and opportunities for improving risk-informed flood risk governance~~ in Jakarta: ~~.~~

First, the focus on natural drivers of flooding reinforces the perception of flooding being a hazard that can be controlled by technical measures, ~~fuelling~~skewing the perceived solution space towards hard~~/physical~~ adaptation ~~approaches~~measures. While it is, of course, ~~–~~very important to assess and understand natural drivers of flooding in Jakarta ~~in order to develop hard/physical adaptation measures~~, other drivers of flood risk need to be considered with the same rigour in order to design effective adaptation options. ~~their lacking consideration of socio-economic flood drivers are likely to skew Jakarta's solution space of adaptation measures towards infrastructural flood protection. While such~~ Hard measures are – and will be – undoubtedly an important part of ~~the~~Jakarta's solution space. Yet, a shortfall of consideration on the anthropogenic ~~, their lack in considering socio-economic~~ flood drivers ~~represents~~ yields the ~~a~~ risk ~~for~~ to ~~designing~~ design infrastructural solutions that only address parts of the flood problem, hence risking being less effective.

Second, we find an overall lack of considering future developments ~~of both – natural as well as socio-economic factors~~in terms of both environmental as well as socio-economic changes. Surprisingly, the ~~A~~majority of studies that focus on flood modelling does not yet consider future changes in environmental conditions due to climate change. Some studies look at ~~use multiple~~ different flood event return periods ~~as~~as a proxy for changing environmental conditions, however, with considerable uncertainties remaining ~~changing variables in their models~~ (Budiyono et al., 2015; Juliastuti et al., 2018; Kurniyaningrum et al., 2019; Liu et al., 2015; Syafalni et al., 2015; Yayuk Supomo et al., 2018)~~, however, inferences to the potential changes of return periods in the course of climate change remain vague at large~~. ~~Other studies include different options for rainfall intensities/patterns (Lugina et al., 2018), not building on future climate scenarios or models for these aspects.~~ Only a few of the publications focusing on flood modelling and hard~~/physical~~ adaptation measures consider future urbanization or socio-demographic changes and their impacts as drivers of flood risk. While some incorporate future changes in land-use (Budiyono et al., 2016; Fajar Januriyadi et al., 2018; Latief et al., 2018; Mishra et al., 2018; Rafiei Emam et al., 2016; Riyando Moe et al., 2017; Shokhrukh-Mirzo Jalilov et al., 2018; Sutrisno, 2011; Takagi et al., 2016b; Vollmer et al., 2015, 2016; Ward et al., 2011b; Ward et al., 2013c), no study in the sample considers future changes in exposure due to e.g. population growth or urban development.

Similarly, the publications on hard flood protection measures mostly neglect future climatic, demographic, socio-economic and land use changes when assessing the effectiveness of existing or suggested infrastructural measures for flood protection. Some authors use return periods of rainfall events (Mantasa Salve Prastica, 2018) or floods (Ajiwibowo, 2018; Indrawati et al., 2018; Nugroho et al., 2018; Wurjanto, 2018); however, without referring to potential future changes. An exception (Takagi et al., 2017) evaluates the effectiveness of planned coastal dykes using flood and subsidence projections until the year 2050.

The implications of this shortcoming for the solution space are rather weighty: developed solutions – hard, soft and hybrid – that are lacking the consideration of future developments have an inherent risk of not being sustainable and effective in the long run. While they might address current challenges very well, there is a risk that dynamic changes in environmental and/or socio-economic aspects will impact their effectiveness in the future.

Third, most publications that assess and evaluate the effectiveness of hard~~/physical~~ measures for flood management in Jakarta do not consider social aspects such as the measures' impacts on social vulnerability or the acceptance of the analyzed measures. ~~These would however be very important to consider since they are often linked to major changes in communities, altering their vulnerability context.~~ This can be an important shortcoming when evaluating the overall adequacy and success of a hard adaptation measure. For instance, resettlements, which are often a precondition for the implementation of hard adaptation measures, significantly influence communities' livelihood opportunities and social structures (Garschagen et al., 2018; Garschagen and Surtiari, 2018; Ichwatus Sholihah and Shaojun, 2018; Surtiari et al., 2017). Furthermore, authors claim that soft aspects such as e.g. risk perception and awareness, risk communication (e.g. van Voorst, 2016), behavioral and cultural factors (e.g. Bott et al., 2019; Yoga Putra et al., 2019b), collective action as well as participatory planning (e.g Sugar et al., 2013), coordination capacities (e.g. Marfai et al., 2015; Padawangi and Douglass, 2015) and law enforcement are inherently intertwined with the success of mitigation and adaptation efforts in the long run, ~~which is why they need to be better considered~~hence calling for a rigorous consideration. ~~With regard to risk awareness, authors agree regarding its importance for adaptation to flooding in Jakarta, however they show contrasting evaluations of the level of risk awareness of the city's inhabitants: While some argue that there is still urgent need to increase the risk awareness of the public as well as of authorities (Akmalah and Grigg, 2011; Farid et al., 2017; Firman et al., 2011; Neolaka, 2012), others attest Jakarta's inhabitants a high awareness of hazard risk (Esteban et al., 2017; Hellman, 2015; Padawangi and Douglass, 2015; Varrani and Nones, 2018). However, high awareness does not automatically lead to adaptation – or at least not to proactive adaptation action in anticipation of future flood events. Inhabitants perceiving flood risk as daily normal may see no need to increase their efforts to adapt to it (Hellman, 2015; Neolaka, 2012; Simarmata, 2018; Texier, 2008), or they are lacking knowledge about adaptation and response measures (Amri et al., 2017).~~

The neglect of aspects such as social acceptance as well as impacts of infrastructural flood protection on local communities influences the solution space in that hard adaptation measures will be considered for flood risk management despite their potential negative impacts on social vulnerabilities. Accordingly, the solution space contains measures, which are beneficial for some groups of people while representing a threat to other groups. While this is already alluded to in the assessed literature (e.g. Van Voorst and Hellman, 2015), this seems to have had only marginal influence on flood risk research in Jakarta until today.

Fourth, studies focusing on soft and hybrid adaptation measures converge in their critique of technocratic approaches and provide a broad variety of needs with respect to improving flood risk management, however without providing concrete recommendations how to achieve them. Many of these studies ~~publications of this field sketch the evolution of flood protection policies since Dutch occupancy (e.g. Dovey and Achmadi 2019; Garschagen et al., 2018; Mathewson, 2018; Octavianti and Charles, 2019) before providing different perspectives on flood risk, e.g. vulnerability of groups such as the urban poor, impacts, adaptation and coping mechanisms, factors that influence risk behaviour or governance aspects. Accordingly, this body of literature is very diverse regarding the range of topics it covers. Looking at their commonalities it can be stated that a majority draws on empirical data collected at community level. In combination with institutional analyses they examine the current flood management approach in Jakarta, with the commonly shared result of criticizing the technocratic approach and especially the linked resettlement policies (e.g. Dovery and Achmadi, 2019; Hellman, 2015; Ichwatus Sholihah and Shaojun, 2018; van Voorst and Hellman, 2015).~~

~~The studies focussing on soft and hybrid adaptation, soft aspects of adaptation, analysis of policies on vulnerability reduction, mitigation and adaptation and water(shed) management~~ suggest a broad range of needs to improve the current flood management approach in Jakarta. Depending on the perspective of the author(s), it is for instance advocated for more integrated and hybrid adaptation approaches (e.g. Akmalah and Grigg, 2011; David et al., 2016; Shokhrukh-Mirzo Jalilov et al., 2018) and awareness raising for and dissemination of risk and response information to foster behavioral change within the public, authorities and among urban planners (e.g. Akmalah and Grigg, 2011; Amri et al., 2017; Esteban et al., 2017; Goh, 2019; Marfai et al., 2015; Neolaka, 2012, 2013; Nurhidayah and McIlgorm, 2019; van Voorst and Hellman, 2015; Ward et al., 2013b). Others call for regional approaches to land use and urban planning (e.g. integration of upstream and downstream,

Jakarta and Jabodetabek[5] (Asdak et al., 2018; Firman et al., 2011; Goh, 2019; Mathewson, 2018; Noviandi et al., 2017) and more integrated legal and institutional frameworks as well as strong institutional bodies for disaster risk reduction and climate change adaptation (Akmalah and Grigg, 2011; Asdak et al., 2018; Firman et al., 2011; Garschagen et al., 2018; Garschagen and Surtiari, 2018; Nurhidayah and McIlgorm, 2019; Octavianti and Charles, 2018; Ward et al., 2013b). Moreover, studies highlight a need for stronger law enforcement (e.g. Akmalah and Grigg, 2011), increased community-participation in risk management planning and decision-making (Goh, 2019) as well as in resettlements/relocation (Ichwatus Sholihah and Shaojun, 2018; Texier, 2008).

However, the publications provide little concrete recommendations on how to achieve these goals: How to decide for different adaptation measures for a balanced hybrid adaptation approach? How to improve the legal and institutional setup, which would most likely include altering current political structures and decision-making processes? How to integrate flood risk policies with the wider development agenda? How to facilitate participatory flood risk management? ~~Etc. T~~There are only very few publications (e.g. Amri et al., 2017; Asdak et al., 2018; Firman et al., 2011; Nurhidayah and McIlgorm, 2019) providing slightly more detailed ~~indication~~ information on the ~~about their feasibility and more concrete suggestions for their~~ implementation and feasibility of suggested measures. ~~Most publications omit to look at the entire administrative hierarchy of the flood governance system and its myriad of state and non-state actors, including its decision-making processes. For example, the role of NGOs and CSOs is not comprehensively addressed yet. As a consequence, the political economy of and decision-making processes in flood management remain rather unclear. Only few authors mention problems that arose for flood management in the course of decentralization with respect to its overall effectiveness, problems related to the autonomy of local governments as well as the misalignment and disconnect between different administrative levels (Asdak et al., 2018; Simanjuntak et al., 2012; van Voorst, 2016).~~

While studies on soft and hybrid measures add valuable knowledge and potential options to the solution space, their lack of actionable recommendations ~~reduce~~limit their utility. They are more difficult to consider in actual adaptation planning – especially in comparison to hard~~/physical~~ adaptation measures which often have clear requirements and quantitative assessments of their use.

Fifth, there is a lack of studies that compare multiple adaptation solutions. Apart from a few exceptions (e.g. Lin, Shaad, and Girot 2016; Fitrinitia et al., 2018) ~~T~~this lack applies to comparisons between different infrastructural~~l/physical~~ measures ~~to adapt to flooding (like in Lin, Shaad, and Girot 2016) and~~ as well as between hard and soft ~~options~~ measures~~of flood protection and adaptation (e.g. Fitrinitia et al., 2018)~~. This is surprising against the background of the rich diversity of assessments of single measures – be it hard adaptation options such as levees, dams, dikes and embankments (Mardjono et al., 2018; Mardjono and Setiawan, 2018; Ogie et al., 2016b; Su et al., 2018; Sujono, 2012; Susilo et al., 2019; Suprayogi et al., 2018; Takagi et al., 2016a, 2017; Wurjanto, 2018), water channeling, retention ponds and drainage systems (Indrawati et al., 2018; Kadri, 2011; Kartolo and Kusumawati, 2017; Mahanani and Chotib, 2018; Mohajit, 2015; Nugroho et al., 2018; Sholichin et al., 2019; Wihaji et al., 2018) or soft adaptation measures like mutual support through social networks (Guinness, 2019; Leitner and Sheppard, 2017; Padawangi and Douglass, 2015; van Voorst and Hellman, 2015), collective action in e.g. river monitoring and early warning (Bahri and W Purwantiasning, 2019; Dwirahmadi et al., 2013; Fitrinitia et al., 2018; Hellman, 2015; Padawangi and Douglass, 2015; van Voorst, 2014, 2016) or self-organization of saving groups for flood response and recovery (Dwirahmadi et al., 2013; Marfai et al., 2015; van Voorst, 2014).

For the solution space, this aspect can be considered as the most important gap. The absence of comparisons of different measures leaves decision-makers without scientific guidance in understanding the advantages and disadvantages of one adaptation solution over the another. Without comparatively considering effectiveness, social and environmental impacts as well as feasibility of different measures ~~against each other~~, it is very difficult to identify "~~the~~ best" adaption options and combine them into sustainable adaptation pathways.

[5] Jabodetabek is an acronym for the metropolitan area of Jakarta. Besides the city of Jakarta, it includes Bogor, Depok, Tangerang and Bekasi.

Altogether, the presented key findings and their implications for the solution space are a valuable contribution to the field of flood risk research in Jakarta. Not only does this study complements existing findings, but it also adds new insights to the body of literature on flood risk research. Together, the three shortcomings limit the usefulness of these studies for flood risk governance in Jakarta.

The dominance of infrastructural measures, despite the growing critique on its insufficiency to address root causes of flooding (e.g. Garschagen et al., 2018; Goh, 2019; Salim et al., 2019) is already recognized by scholars and they provide a number of explanations for this persistence. Firstly, Jakarta's colonial legacy and contemporary Dutch influence are seen as one reason for the continuation of technocratic approaches (Colven, 2017; Octivianti and Charles, 2018). Since early colonial times, flooding was fought with well-known and calculable technical measures like canalization, dredging and the build-up of protective structures such as dams and embankments, which brought short term alleviations and political success. These positive feedback cycles as well as the belief in traditional policy approaches facilitated the institutionalization of the implementation of such measures, resulting in a political lock-in regarding flood management, which inhibits changes until today (Asdak et al., 2018; Octavianti and Charles, 2018, 2019; Ward et al., 2013b). Secondly, the role of information and the medial framing of technocratic approaches are described to facilitate the implementation of infrastructural flood protection measures (Hellmann, 2015). A lack of public information about engineered measures and their impacts contribute to lacking resistance and hence the continuation of technical flood protection measures (ibid.). Thirdly, a lack of cooperation across scales and actors since decentralization is argued to hinder the implementation of more integrated approaches, especially in the face of varying knowledge and capacity levels at different scales (Firman et al., 2011). In addition, lacking participation of civil society actors and "non elites" in urban development, is seen to facilitate the persistence of the traditional technical approach to adaptation (Akmalah and Grigg, 2011; Padawangi and Douglass, 2015). Fourthly, despite a high degree of fragmentation of political and private sector communities and a lack of cooperation between them (Hellman, 2015; Neise and Revilla Diez, 2019), the mutual economic political interests in establishing Jakarta as a modern world class city is seen to facilitate the implementation of prestigious infrastructural flood protection measures. Exemplified by the Great Garuda Project, Colven (2017) explains that technical flood protection measures are presented as a win-win solution: while solving the flood issue, they are at the same time development projects, attracting private investment, facilitating innovative and technologically advanced urban development to turn Jakarta in a world class city as desired by urban elites (Colven, 2017; Octavianti and Charles, 2018; Simarmata, 2018). At the same time, knowledge about hybrid adaptation and its successful implementation at the urban scale has been argued to be far less wide-spread amongst government authorities and officials (Asdak et al., 2018; Firman et al., 2011; Ward et al., 2011a).

Our study complements these explanations, using the analysis of the city's solution space as a means to understand current flood management approaches and identify potential gaps that need to be addressed to improve flood adaptation in Jakarta. It shows that the dominance of research on natural drivers of flood risk, a lack of considering future trends in environmental as well as socio-economic developments, a lack of considering social impacts of hard adaptation measures, the absence of actionable recommendations for the implementation of soft and hybrid adaptation measures as well as the lack of comparative studies of different adaptation options contributes to the persistence of While these publications evaluate existing and potential future physical flood protection measures, a majority of them exhibits three rather weighty shortcomings: first, they do not consider social aspects such as their impact on social vulnerability or acceptance of the analyzed measures. These would however be very important to consider since they are often linked to major changes in communities, altering their vulnerability context. For instance, resettlements, which are often a precondition for the implementation of engineered adaptation measures, significantly influence communities' livelihood opportunities and social structures (Garschagen et al., 2018; Garschagen and Surtiari, 2018; Ichwatus Sholihah and Shaojun, 2018; Surtiari et al., 2017). Second, similar to the model studies described earlier, the publications on hard flood protection measures mostly neglect future climatic, demographic, socio-economic and land use changes. To assess the effectiveness of existing or suggested infrastructural measures for flood protection, some authors use return periods of rainfall events (Mantasa Salve Prastica, 2018) or floods (Ajiwibowo, 2018; Indrawati et al., 2018; Nugroho et al., 2018; Wurjanto, 2018); however, without referring to potential future changes. An exception (Takagi et al., 2017) evaluates the effectiveness of planned coastal dykes using flood and subsidence projections until the year 2050. Third, there are only very few publications that provide an overview or comparison of measures, e.g. between different infrastructural/physical measures (e.g. Lin, Shaad, and Girot 2016) to adapt to flooding or between physical and soft options of flood protection and adaptation (e.g. Fitrinitia et al., 2018). Altogether, the three shortcomings significantly limit the

usefulness of the analyses for flood risk governance.Jakarta's current adaptation approach, which is dominated by infrastructural measures.

The analysis of the solution space lends itself for developing recommendations to reduce its limitations. Based on the analysis However, the publications provide little concrete recommendations on how to achieve these goals: How to decide for different adaptation measures for a balanced hybrid adaptation approach? How to improve the legal and institutional setup, which would most likely include altering current political structures and decision-making processes? How to integrate flood risk policies with the wider development agenda? How to facilitate participatory flood risk management? Etc. There are only very few publications (e.g. Amri et al., 2017; Asdak et al., 2018; Firman et al., 2011; Nurhidayah and McIlgorm, 2019) providing slightly more detailed indication about their feasibility and more concrete suggestions for their implementation. Similar to the studies on legal and political context conditions, publications omit to look at the entire administrative hierarchy of the flood governance system and its myriad of state and non-state actors, including its decision-making processes. This is of particular concern in the face of the completed decentralization process in Jakarta, which significantly increased the importance and responsibility of lower administrative levels. However, power distributions and mandates of stakeholders on the ground are barely examined. For example, the role of NGOs and CSOs is not comprehensively addressed yet. As a consequence, the political economy of flood management remains rather unclear. Only few authors mention problems that arose for flood management in the course of decentralization with respect to its overall effectiveness, problems related to the autonomy of local governments as well as the misalignment and disconnect between different administrative levels (Asdak et al., 2018; Simanjuntak et al., 2012; van Voorst, 2016).

The review shows that there is a rich and diverse body of literature analyzing the city's flood problem, however, it is characterized by a quite strong technocratic bias. This is hardly surprising against the backdrop of the predominant framing that flooding is caused by environmental physical factors and hence can be controlled. The dominance of this perspective fuels the bias towards research on modelling the hazard, its impacts and the effectiveness of potential or existing engineered protection measures, which the comparably high number of publications in this field clearly demonstrates. Due to the fact that these analyses exclusively consider engineered flood protection, mostly focusing on one single hazard impact and/or measure, they are of limited use for informing decision-making processes in the field of flood risk management in Jakarta. Neither do they consider soft aspects such as social acceptability and livelihood impacts in their evaluations, nor do they provide comparisons of different flood protection and adaptation measures, which would be most useful for policy and decision-makers. Finally, they also mostly fall short on considering future climatic and urban development trends, which further limits their utility. we conclude that while there is a rich diversity of studies on flood drivers and potential adaptation options to address flooding in Jakarta, the studies' described gaps and limitations open up a solution space that offers many adaptation solutions which are limited in their utility for developing an effective and sustainable adaptation approach for all or at least a majority of stakeholders. Considering our key findings, we propose five recommendations: First, increasing research on socio-economic drivers of risk. This has already started and is an emerging body of literature. Second, always consider potential future development when assessing and/or designing any kind of adaptation measure. This can happen qualitatively and quantitatively. Third, strengthening the consideration of social aspects when assessing the effectiveness of hard adaptation measures. This can reduce the occurrence of trade-offs, ensure social acceptance and equitable flood risk reduction. Fourth, improve the "guidance" capacities of studies on soft and hybrid adaptation measures. Instead of focusing on critique of state-led adaptation approaches which are linked to evictions, it would be helpful to provide sound evidence for effective alternatives in terms of soft adaptation measures and how they can be realized in the case of Jakarta. Fifth, increase comparative research between different hard measures as well as between hard and soft measures to adapt to flooding. For instance, it would be very useful to evaluate the effectiveness (in terms of money invested and protection secured) of a retention pond compared to a protective dam under the consideration of future changes of climatic, demographic and land use patterns. How much will the different options cost? How long will it need to build them and for how long will they provide effective and reliable flood protection? The comparison would also need to include "soft" aspects of adaptation such as the participation of all stakeholders in the planning process and the evaluation of the impact of these measures on the local community in terms of their livelihoods and physical as well as social vulnerabilities: What do local communities in the area prefer? How are their businesses and lifestyles influenced by the measures? Who benefits from the measures and are there actually negative impacts triggered through the measures in situ or also regionally? Similarly, non-structural measures such as awareness raising, law enforcement and capacity building would need to be evaluated to be able to find an adequate and feasible hybrid adaptation approach.

However, single case studies and evaluations of single measures do not provide the full picture and cannot create a comprehensive solution space for flood adaptation.

With regard to engineered flood protection measures, the small number on studies on the Great Garuda Project is startling, considering the scale and impact of the project as well as its important role for current political processes in Jakarta and Indonesia at large (e.g. Colven, 2017; Garschagen et al., 2018; Salim et al., 2019; Wade, 2019). The pursuit of such infrastructural measures despite their questionable effectiveness and major critique shows that the city government sticks to its traditional protection approach (e.g. Garschagen et al., 2018; Goh, 2019; Hellman, 2015; Octavianti and Charles, 2019). The project hence represents sound evidence for the absence of a true paradigm shift in addressing flood risk, even though current flood management plans and political rhetoric give a different impression.

Studies on Jakarta's flood governance approach that analyze among others relevant laws, mitigation and adaptation policies as well as political developments under changing administrations are of a predominantly descriptive character that point out potential entry points to improve current flood management structures, however, recommendations remain rather general (e.g. need for an inclusive social justice approach, better legal instruments to address climate change problems, stronger involvement of the public, adoption of a hybrid flood management approach). Most of the publications of this comparably small body of literature chronologically lay out and analyze the legal and political framework of flood risk management at national or city scale and how it changed during the evolution of different leaderships since Dutch occupancy. They adopt a predominately top-down perspective and there is a gap with respect to holistic empirical actor/stakeholder analysis or analysis of decision-making processes or something similar, with the consequence that they fail to examine the political economy of flood risk management, identify policy coherence issues and hence hardly provide actionable knowledge. Nonetheless, their value for understanding current legal, political and institutional context conditions is indispensable.

This rather small body of literature is complemented by and partly overlaps with publications on adaptation strategies. While many of them also sketch the evolution of flood protection policies since Dutch occupancy (e.g. Garschagen et al., 2018; Mathewson, 2018; Octavianti and Charles, 2019), they put a stronger emphasis on criticizing the dominance of engineered flood protection measures and identifying gaps of the political and institutional setup of current flood management, however, here as well, concrete guidance on how to achieve suggested improvements is largely missing. Authors look at this from various different perspectives (urban poor, governance, vulnerability, comparative study, manufacturing firms), which makes this body of literature much more diverse regarding the range of topics it covers. Looking at their commonalities it can be stated that a majority draws on empirical data collected at community level. In combination with institutional analyses they examine the current flood management approach in Jakarta, with the commonly shared result of criticizing the current technocratic approach and especially the linked resettlement policies (e.g. Hellman, 2015; Ichwatus Sholihah and Shaojun, 2018; van Voorst and Hellman, 2015). Depending on the perspective of the author(s), it is advocated for more integrated and hybrid approaches, public participation in policy planning and decision making, increased cooperation between all relevant stakeholders across scales and community-led adaptation and stronger law enforcement.

However, the publications provide little concrete recommendations on how to achieve these goals: How to decide for different adaptation measures for a balanced hybrid adaptation approach? How to improve the legal and institutional setup, which would most likely include altering current political structures and decision-making processes? How to integrate flood risk policies with the wider development agenda? How to facilitate participatory flood risk management? Etc. There are only very few publications (e.g. Amri et al., 2017; Asdak et al., 2018; Firman et al., 2011; Nurhidayah and McIlgorm, 2019) providing slightly more detailed indication about their feasibility and more concrete suggestions for their implementation. Similar to the studies on legal and political context conditions, publications omit to look at the entire administrative hierarchy of the flood governance system and its myriad of state and non-state actors, including its decision-making processes. This is of particular concern in the face of the completed decentralization process in Jakarta, which significantly increased the importance and responsibility of lower administrative levels. However, power distributions and mandates of stakeholders on the ground are barely examined. For example, the role of NGOs and CSOs is not comprehensively addressed yet. As a consequence, the political economy of flood management remains rather unclear. Only few authors mention problems that arose for flood management in the course of decentralization with respect to its overall effectiveness, problems related to the autonomy of

~~local governments as well as the misalignment and disconnect between different administrative levels (Asdak et al., 2018; Simanjuntak et al., 2012; van Voorst, 2016).~~

~~Furthermore, the publications which adopt a more holistic perspective on adaptation to flooding show a strong polarization and at the same time an interesting paradoxon: they criticize the technocratic approach of the national government, while praising local, bottom up adaptation initiatives. At the same time, it is argued that the engineered approaches are not implemented fast enough and that local initiatives are mushrooming in uncoordinated ways with insufficient funding and cooperation, risking sustainability, effectiveness and coherence.~~

~~Another major gap that could be revealed through the review is the lack of comparative studies of adaptation measures and options. While a large diversity of implemented, planned and envisioned adaptation measures from different actors are described and analyzed in an individual/context specific manner, they are neither set in context with each other, nor are different options compared with regard to their effectiveness and impacts. Also, projections of future changes are not considered. These limitations can be found in studies on structural as well as non structural measures and are problematic insofar that the rich diversity of studies does not allow for opening up a solution space that could guide policy and decision makers in their processes to find an adaptation approach that is valuable and effective for all or at least a majority of stakeholders. For instance, it might be very useful to evaluate the effectiveness (in terms of money invested and protection secured) of a retention pond compared to a protective dam under the consideration of future changes of climatic, demographic and land use patterns. How much will the different options cost? How long will it need to build them and for how long will they provide effective and reliable flood protection? The comparison would also need to include "soft" aspects of adaptation such as the participation of all stakeholders in the planning process and the evaluation of the impact of these measures on the local community in terms of their livelihoods and physical as well as social vulnerabilities: What do local communities in the area prefer? How are their businesses and lifestyles influenced by the measures? Who benefits from the measures and are there actually negative impacts triggered through the measures in situ or also regionally? Similarly, non structural measures such as awareness raising, law enforcement and capacity building would need to be evaluated to be able to find an adequate and feasible hybrid adaptation approach. However, single case studies and evaluations of single measures do not provide the full picture here.~~

~~5.~~7.Conclusions and outlook

This study aimed at assessing how the solution space for flood risk reduction and climate change adaptation in Jakarta is currently being perceived, framed and evaluated in the academic literature. ~~An underlying goal was to learn from the case of Jakarta, one of the coastal cities with the highest flood risk and adaptation pressure globally which is very particular in many respects but still presents important lessons and observations.~~ Learning from Jakarta, one of the cities with the highest flood-risk globally, is relevant since many other cities around the globe will be faced with similar challenges over the course of the next decades. ~~It is acknowledged that the numbers of scientific publications in the different categories used in this study do not determine flood management policies or decision making in this realm. However, they provide a valuable overview of centers of gravity in the research landscape and serve as a first indication of the shape of the adaptation solution space. In this regard, t~~The findings of this analysis show that the scientific debate ~~of flood risk management~~ to date is skewed as ~~it~~they do~~es~~ ~~not adequately consider all dimensions of risk and vulnerability (Birkmann et al. 2013) to flooding in a balanced way. This is particularly true for~~ The overview of the analysed studiesThe findings show~~s~~ that a focus on environmental flood drivers, numeric flood modelling and hard flood protection solutions constitutes the main centre of gravity within the current epistemic landscape of the flood risk and adaptation science on Jakarta. ~~focus on understanding the hazard and analyzing engineered flood protection measures, often referred to as "grey", "physical", or "infrastructural" approaches and while this research is very valuable and needed to contribute to adaptation to flooding, it shall also be highlighted that s~~Soft and hybrid adaptation measures as well as potential shortcomings in hard protection approaches receive increasing, yet overall considerably less, scientific attention. While hard adaptation measures are – and will remain to be – of key importance for Jakarta to address

current and future flood risk in an effective manner, the results nevertheless suggest that the identified imbalance in the current focus is problematic. If not complemented by other perspectives, the focus on hard protection bears the risk that measures which address flood symptoms are prioritized over those addressing the root causes of flood risk and the sources of social vulnerability. In addition, there is the risk that the potential of additional or complementary soft adaptation measures at different scales and implemented by different actors (state, civil society, private sector) – is not being given adequate attention in adaptation discourses at the science-policy-interface and eventually will not be used~~lifted~~ and fostered for crafting actual adaptation pathways. Hence, the findings suggest that a considerable part of the potential solution space remains to be underrepresented in the debate and not advanced with full proficiency. While these lessons from Jakarta cannot easily be transferred one-to-one to other risk context, we hope that the perspectives and questions raised in this paper are useful to inspire studies on the solution spaces in other high risk settings. While detailed studies on the framing of solution spaces in other cities are largely lacking to date, recent global assessments (Oppenheimer et al., 2019) suggest the many cities might be facing similar patterns as the ones identified for Jakarta here – which calls for follow-up research.

~~will be needed to complement grey approaches (David et al., 2016). These have however received much less attention according to this review. There are significantly less publications analyzing soft adaptation options such as social insurance schemes or community led adaptation focusing among others on social and natural capital, empowerment and capacity building (Sovacool, 2011). Also, hybrid adaptation approaches, which combine soft and hard measures in a complementary way, are rarely considered. This represents a particularly problematic gap since hybrid adaptation approaches provide many co-benefits for mitigation and overall sustainable development, going beyond addressing flood problems alone (David et al., 2016; Oppenheimer et al., 2019). The lack of studies of soft and hybrid adaption options as well as the lack of comparative studies of adaptation options is assumed to be an additional reason for why Jakarta's flood management approach is still dominated by infrastructural solutions.~~

~~the assessment of future risk trends, where~~ The emphasis on understanding the risk context is characterized by ~~a heavy emphasis is on modelling future hazard trends while future dynamics in the exposure and vulnerability of the cities' inhabitants;, its infrastructure and ecosystems are not assessed in a dynamic and forward-looking manner, e.g. though scenarios techniques. Results also indicate a bias towards flood protection, paying less attention to options like sustainable retreat or living with floods, i.e. accommodation (Klein et al., 2014). Studies tend to focus on understanding the hazard and analyzing engineered flood protection measures, often referred to as "grey", "physical", or "infrastructural" approaches(David et al., 2016), while much less attention has been given to the analysis of soft adaptation options such as social insurance schemes or community-led adaptation focusing among others on social and natural capital, empowerment and capacity building (Sovacool, 2011). Also, hybrid adaptation approaches, which combine soft and hard measures in a complementary way, are rarely considered. This represents a particularly problematic gap since hybrid adaptation approaches provide many co-benefits for mitigation and overall sustainable development, going beyond addressing flood problems alone (Oppenheimer et al., 2019).~~

Relating these findings to global research frontiers, it is striking that the above gaps in the state of science on Jakarta's flood risk and its reduction are so persistent. The literature on Jakarta has been rising sharply and Jakarta certainly belongs to the most-researched coastal high-risk cities in the world. Yet, our analysis suggests that this high potential has so far not been sufficiently used to inform and advance some of the most pressing frontiers in coastal urban risk and adaptation research: How to develop and test better approaches to model and assess future trends in socio-economic vulnerability within cities; how to evaluate different competing adaptation options in an integrative way whilst also including aspects of social acceptance and equity; how to design adaptation pathways with a mixture of hard and soft adaptation options so as to seek synergies whilst overcoming the shortcoming any isolated approach would have; how to chart and navigate transformational adaptation that shifts the political economy of risk production and the existing paradigms of adaptation away from ~~superficial~~ technocratic fixes and towards the root causes of flood risk and social vulnerability ~~and solely technocratic solutions~~. Jakarta can be a globally leading pilot and laboratory in these respects. But it requires the future science on Jakarta to ~~shift~~ expand its emphasis.

1135 **Appendices**

Appendix A: Literature categories and counts (Scopus 2000-2019)

Code	Topic	Sub topics	Resulting Publications (2000- 2019)
1	**Soft factors of adaptation**	psychology	**24**
		behavior	
		culture	
		understanding of risk	
		vulnerability analysis	
		framing of flood and subsidence	
		willingness to pay for ecosystem services of river communities	
		participation in flood control strategy planning	
2	**Policy and legal analysis**	institutional analysis	**12**
		national policy analysis	
		legal framework	
		political economy of flood protection	
3	**Hard adaptation**	Great Garuda Project	**36**
		lakes and rainwater harvesting	
		polder	
		dikes and flood barriers	
		embankments	
		river diversions	
4	**Flood models & flood mapping**	Precipitation models	**78**
		Subsidence models	
		flood loss estimation models	
		urban drainage model	
		flood cost analysis	
		urban expansion and effects	
		Sea level rise models	
		community-based flood risk mapping	
		shoreline retreat model	
5		criticality of watershed	**9**

	Land-use (change) impact on flooding	land-use change assessment and impacts	
6	**New data types**	Social media	**15**
		Big Data	
		crowd-sourcing	
		e-participation	
		high-resolution data	
		PetaJakarta project	
7	**Watershed management and water governance**	qualitative analysis of reasons for flooding	**17**
		water pollution	
		drinking water source analysis/model	
8	**Soft and hybrid adaptation**	local/community-based adaptation	**40**
		firms and adaptation	
		resettlement/relocation	
		alternative energy sources	
		disaster management	
		urban adaptation planning	
9	**Early Warning**	GIS-based EWS	**7**
		risk communication	
		information needs during disasters	
10	**Decision support systems**	DST for location of warehouses	**5**
		Disaster Information Management System	
		socio-economic vulnerability index (SEVI) + MCA	
		hydrological infrastructure flood vulnerability index (HIFVI)	
		Integrated Assessment Framework (IAF) for subsidence	
11	**Qualitative risk descriptions**	subsidence types	**13**
		flood impact	
x	**No link to flooding or Jakarta**		**70**
	Conference proceedings		**14**

Code	Topic	Sub-topics	Resulting Publications (2000- Nov. 2019)	%
1	**Soft aspects of adaptation**	psychology	**21**	7.8
		behavior		
		culture		
		understanding of risk		
		vulnerability analysis		
		framing of flood and subsidence		
		participation in flood control strategy planning		
2	**Analysis of policies on vulnerability reduction, mitigation and adaptation**	institutional analysis	**12**	4.5
		national policy analysis		
		legal framework		
		political economy of flood protection		
3	**Grey/physical/engineered adaptation**	Great Garuda Project	**30**	43.5
		lakes and rainwater harvesting		
		polder		
		dikes and flood barriers		
		embankments		
		river diversions		
4	**Flood models & flood mapping**	Precipitation models	**71**	26.4

		~~Subsidence models~~		
		~~flood loss estimation models~~		
		~~urban drainage model~~		
		~~flood cost analysis~~		
		~~urban expansion and effects~~		
		~~Sea level rise models~~		
		~~community based flood risk mapping~~		
		~~shoreline retreat model~~		
~~5~~	~~**Land use (change) impact on flooding**~~	~~criticality of watershed~~	~~**8**~~	~~3.0~~
		~~land use change assessment and impacts~~		
~~6~~	~~**New data types for flood mapping/response**~~	~~Social media~~	~~**15**~~	~~5.6~~
		~~Big Data~~		
		~~crowd sourcing~~		
		~~e-participation~~		
		~~high resolution data~~		
		~~PetaJakarta project~~		
~~7~~	~~**Water(shed) management and urban water/flood governance**~~	~~qualitative analysis of reasons for flooding~~	~~**17**~~	~~6.3~~
		~~water pollution~~		
		~~drinking water source analysis/model~~		
~~8~~	~~**Adaptation strategies**~~	~~local/community based adaptation~~	~~**33**~~	~~12.3~~
		~~firms and adaptation~~		
		~~resettlement/relocation~~		

		alternative energy sources		
		disaster management		
		urban adaptation planning		
9	**Early Warning for flooding**	GIS-based EWS	**6**	2.2
		risk communication		
		information needs during disasters		
10	**Information systems/indices for flood hazard**	DST for location of warehouses	**5**	1.9
		Disaster Information Management System		
		socio-economic vulnerability index (SEVI) + MCA		
		hydrological infrastructure flood vulnerability index (HIFVI)		
		Integrated Assessment Framework (IAF) for subsidence		
11	**General description of hazard impacts and trends**	subsidence types	**11**	4.1
		flood impact		
x	**No link to flooding or Jakarta**	-	**26**	9.7
-	**Conference proceedings**	-	**14**	5.2

Appendix B: Not considered literature

Identified literature that could not be accessed:

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Istiani, M.R. (2016). The association of traits personality and pro-social behavior among volunteers in Jakarta. DOI: 10.1166/asl.2016.6752~~))~~

Identified literature that could not be found:

Van Voorst, R., Handgraaf (2012). Coping with floods in a riverbank-settlement in Jakarta Indonesia The influence of material and cognitive indicators on human actor's risk behavior.

~~**French literature:**~~

~~Texier et al. (2010). Réduction des risques d'inondation à Jakarta. BAGF – Géographies.~~

Appendix C: Coding scheme in MaxQDA

- Methodology/research design
- Location of flooding
- Root causes for flood risk
  - Socio-economic causes
  - Political/structural causes
  - Environmental/physical causes
- Coping or adaptation strategy/measure
  - Hybrid approach
    ~~Collective action~~
  - Non-structural/soft measures
  - Structural/hard/physical measures
- Flood governance system
- Needs and/or suggestions
- Gaps and/or persisting problems

Author contribution

Matthias Garschagen and Mia Wannewitz designed the study. Mia Wannewitz performed the literature analysis. Mia Wannewitz and Matthias Garschagen drafted the manuscript.

Competing interests

The authors have no competing interests.

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Figure 1: The logo of Copernicus Publications.