Review article: Mapping the adaptation solution space – Lessons from Jakarta

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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
10 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 literature on the adaptation solution space 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
15 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
20 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.

1. Introduction

Many coastal 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 effects of urbanization itself (e.g. land subsidence, urban sprawl into flood-prone areas or the accumulation of
30 people and infrastructure) (Tellmann et al. 2020; Wolff et al. 2020). As a result, coastal 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 flood risk management and climate change adaptation, keep suffering from flooding year after year.

35 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),

40 much less attention has been given to analysing different potential adaptation options. The main focus of this paper is therefore on examining 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 increasing attention since 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

45 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). This study assumes that the scientific discource is one important arena in which the soluation space is formed and

50 shaped. The question which adaptation solutions are being conceived in science and how they are being scientifically evaluated has great influence on the practical and political debate shaping actual solution decisions (Haasnoot et al., 2020). This paper therefore focuses on the assessment of scientific literature and how adaptation solutions are being perceived and treated in them. Further research might complement this analysis with empirical work on adaptation perceptions amongst, for example, practitioners, policy-makers and affected actors.

55 Jakarta represents an example worthwhile analysing. The city's flood problems are so pressing that it can serve as an early laboratory for current and future adaptation challenges many other major coastal cities, which are also located in low elevation coastal zones, e.g. Mumbai, Dhaka, Ho Chi Minh City or Lagos, will also have to deal with (IPCC, 2019a). The combination of continuing urbanization and environmental changes result in increasing risks for the urban population today and in the future, turning the city into one of the most at risk coastal cities globally (Hallegatte et al., 2013; Hanson et al., 2011).

60 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:

- Which flood risk drivers are considered in research on Jakarta?

- To what extent does scientific research consider different hard, soft and hybrid measures for risk management and adaptation and how are these measures being evaluated?

65 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 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. Section 5 presents the results starting with general publication patterns and author affiliations. Subsequently, the results chapter describes drivers of

70 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 6 summarizes and discusses the results, relating them to the solution space for flood adaptation for Jakarta. It also presents identified gaps. Section 7 offers key conclusions and an outlook.

2.   Conceptual considerations – flood risk and adaptation options

75 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

80 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 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. 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).
135 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
140 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
145 (Mel et al., 2020).

The above considerations mean 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
150 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, scientific perspectives play a vital role in shaping the actual solution space.

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

Urban flooding has a long history in Jakarta. The city is naturally prone to coastal hydrological hazards due to its geographical location in a low-lying coastal area facing the Java Sea, and with more than 13 rivers, including the Ciliwung river, flowing through it (Marfai, 2015). Urban flooding in Jakarta is most severe when heavy precipitation, high run-off rates and storm
160 and/or high tide levels coincide (Garschagen and Surtiari, 2018). In the future, climate change is expected to increase Jakarta's "natural" drivers of flood risk, mostly through sea level rise and the increasing potential for heavy precipitation in the entire Ciliwung catchment area (Mishra et al., 2018; Januriyadi et al, 2018).

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
165 surrounding areas, including the upstream area of the Ciliwung River, have significantly altered the hydrological system and run-off patterns (Garschagen et al., 2018). Urban densification processes led to a degradation of the urban drainage system as river and canals were filled and floodplains paved over, reducing the retention and discharge 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 is a key
170 driver of the city's flood 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 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. Major flood events hit the city in the 21st century;
175 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). 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). This extreme event, 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 risk drivers (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., Octivianti 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 (cf. Figure 1). 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. The question to which extent the entrie project with all its elements will be implemented is subject of continued debate (cf. Garschagen et al. 2018; Minkman et al. 2021).
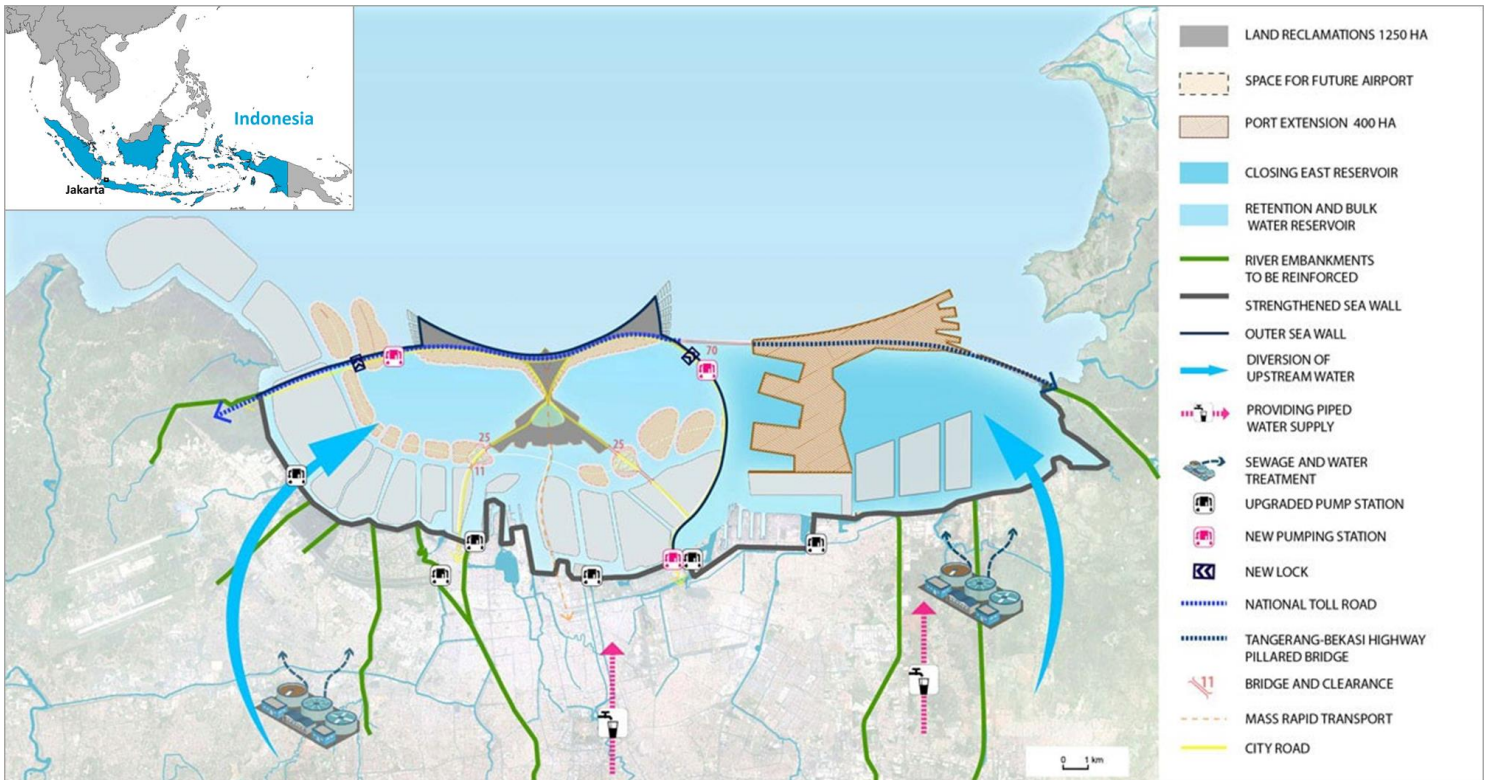
Figure 1: The Great Garuda project in its originally planned version (taken from Mezzi, 2016, based on the NCICD Master Plan 2014 Coordinating Ministry for Economic Affairs of the Republic of Indonesia, 2014)

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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 was conducted, aiming at getting an 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 does not capture studies published in other languages such as Indonesian. 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).
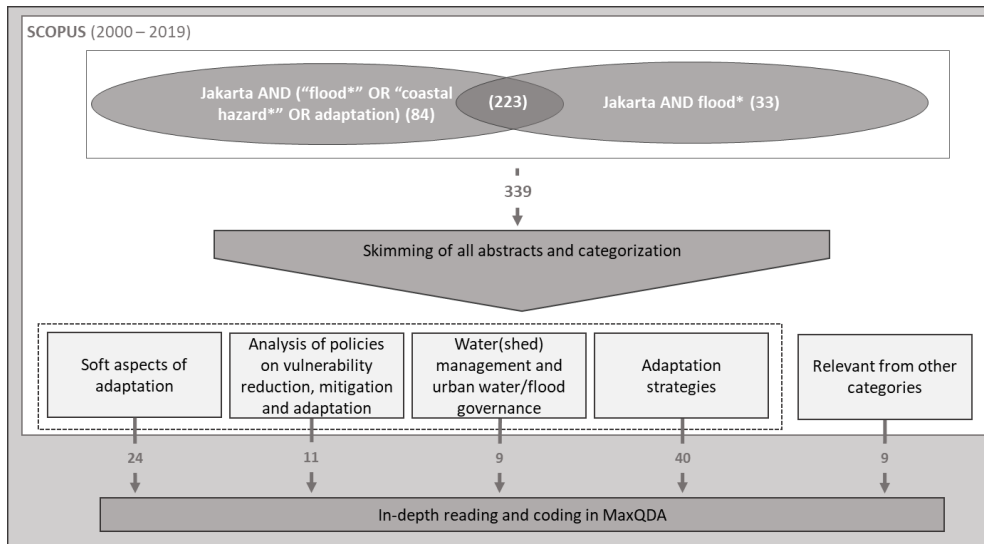
Figure 2: Literature search, extracted categories and numbers of resulting publications

As shown in Figure 2, the Scopus literature database was searched with a deliberately broad combination of the search terms Jakarta AND ("flood*" OR "coastal hazard*" OR "adaptation"), limited to roughly the past 20 years (2000 - 2019). In total, 339 publications in English language (see Appendix A) resulted from the structural searches after excluding non-relevant research fields (medicine, mathematics, chemistry, biochemistry, nursing, chemical engineering, dentistry, immunology, veterinary); building the basis for the following filtering and analyses. Seven papers could either not be accesses or no full-text versions could be found (Appendix B). In a first step, all abstracts of resulting publications were skimmed and topical categories were developed, resulting in an inductively derived thematic scheme (see Table 1 and Appendix C). 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 and its centres of gravity. It is taken as an indication for whether and how different fields of scientific inquiry contribute to the assessment of flood risk and adaptation solutions. Of course, the number of papers alone does not sufficiently evaluate the importance of a study field for framing the solution space and shaping political decision-making. Nonetheless, we argue that the number of publications can be one proxy – amongst others – for evaluating 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 C and D).

Table 1: Categories of publications

Code	Topic	Description
1	**Soft factors of adaptation**	Papers on soft factors that influence adaptation such as psychology, behavior, culture, understanding of risk, how risk is framed, willingness to pay for ecosystem services, participation in planning.
2	**Policy and legal analysis**	Papers focusing on e.g. institutional analysis, national policy, legal frameworks of risk management, vulnerability reduction and adaptation
3	**Hard adaptation**	Papers that exclusively look at hard 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**	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 management and water governance**	Qualitative analyses of reasons for flooding, water pollution, incl. drinking water source analysis/model.
8	**Soft and hybrid adaptation**	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 warning**	Papers that present GIS-based early warning systems, risk communication and information needs during disasters.
10	**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	**Qualitative risk descriptions**	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.

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5. Results

As depicted in Figure 3, 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
240 towards the relevance for the topic of flooding in Jakarta as well as an increasing scientific interest.
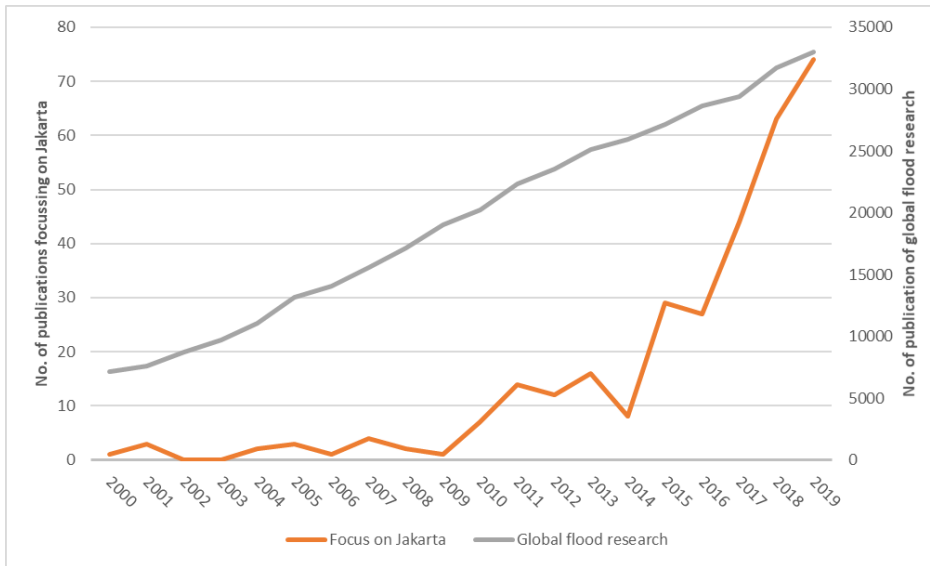
Figure 3: Number of scientific publications in flood and adaptation research in Jakarta and globally[1] (2000-2019) in Scopus

Research attention was especially high among Indonesian scholars. As visualized in Table 2 almost 50% of first authors are
245 affiliated with Indonesian institutions. With regard to international attention to Jakarta's flooding issue, most first authors are
affiliated with Japanese and Dutch institutions, each making up roughly 11% of the resulting publications, followed by
researchers from Germany, the US, Australia, and Singapore.

Table 2: 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

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[1] 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

China	3	0.7
South Korea	2	0.4
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

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According to the subject fields provided by the Scopus citation databank (multiple possible per paper), more than three quarters of all publications include a natural science or engineering perspective (environmental science, earth and planetary sciences, engineering, computer science, energy, physics and astronomy, agricultural and biological sciences, materials science, mathematics, psychology, decision sciences) (cf. Figure 4). Only 15% can be attributed fully or partially to social sciences, 255 and very few include an economics perspective (Business, Management and Accounting, Economics, Econometrics and Finance). Only two percent are labelled to include an arts and humanities angle.
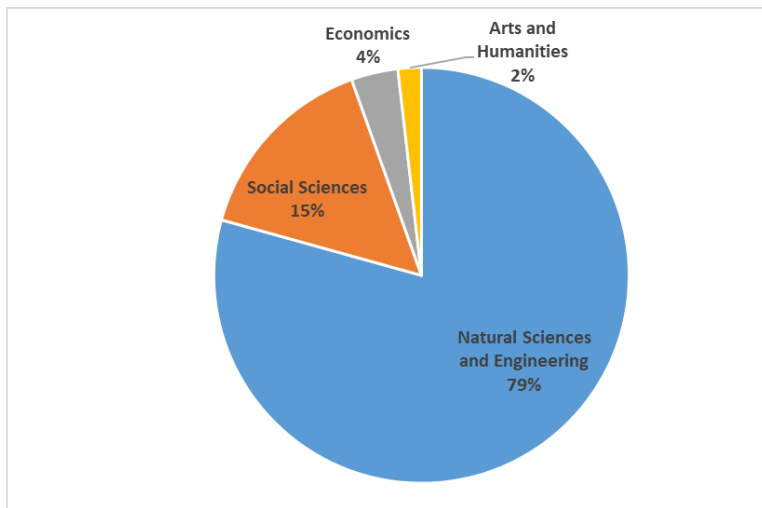
Figure 4: Subject fields of analyzed publications according to Scopus classification

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To get a clearer and more detailed overview, Figure 5 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 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 4). 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), 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.
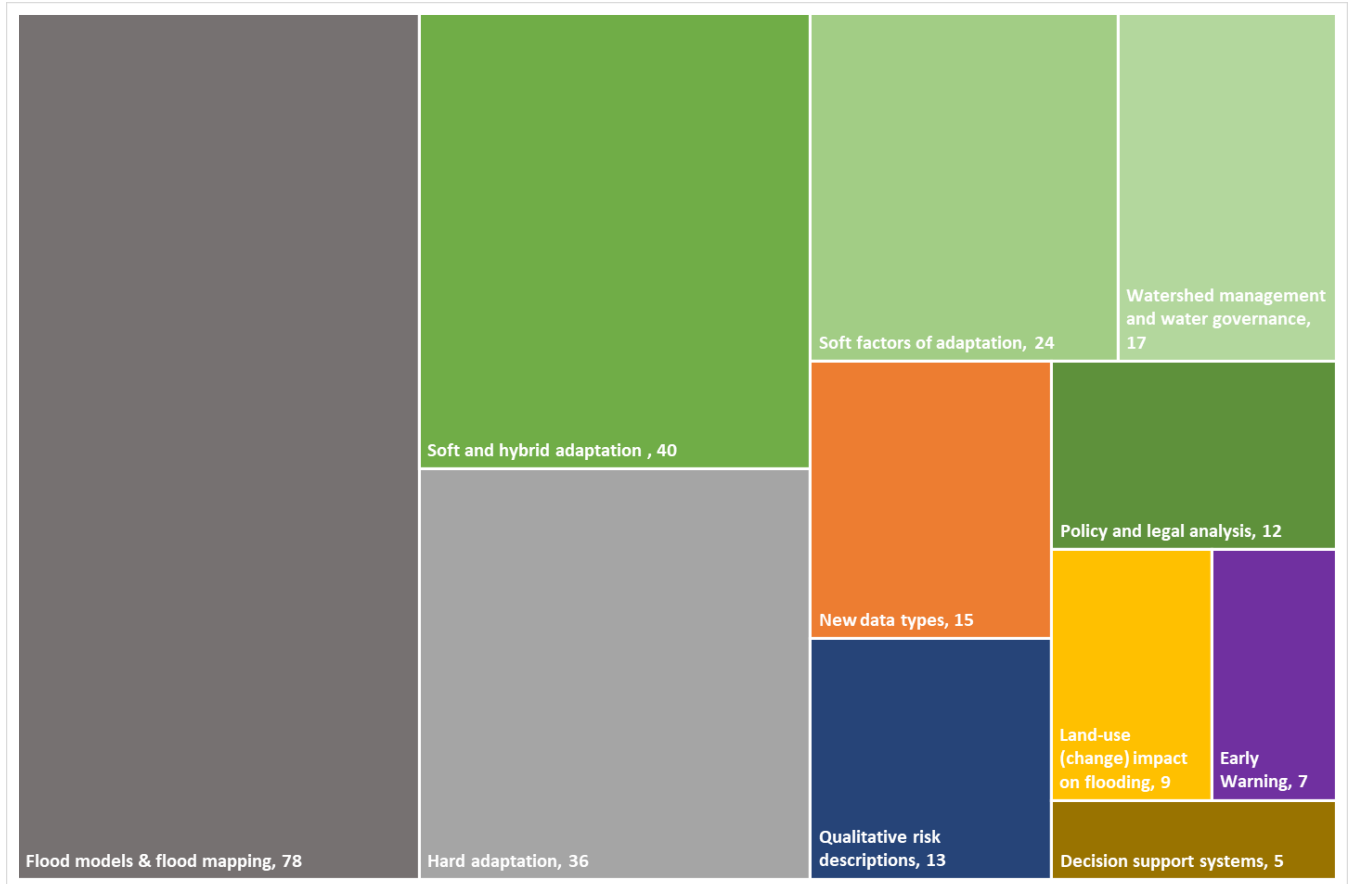
Figure 5: Thematic clusters of publications resulting from the structured literature search

5.1. Understanding the drivers of the flood hazard

As shown in Figure 5, there is a strong focus on flood modelling and mapping, representing 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; Kurniawan, 2019; 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, studies from the categories flood models & flood mapping as well as hard and physical adaptation tend to 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 risk assessments that also include non-hydrological risk drivers (see below).

Publications which focus more on soft and hybrid adaptation as well as on social vulnerability issues (i.e. the green categories in Fig. 5) 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 also – potentially even more so – by 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 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).

5.2. Hard flood protection measures and their evaluation

Considering the focus on natural or geo-physical 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 started being implemented already during colonial times and remain, until today, to be a main pillar of 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; Simanjuntak et al., 2012; Ward et al., 2013a). Publications from the category of hard adaptation form a major part of flood risk management research in Jakarta overall (Figure 5). They focus on specific solutions such as levees, dams, dikes and embankments and analyse or model their 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 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).

330 Some authors exclusively focus on the Great Garuda Project the central element of the NCICD masterplan. Besides outlining the plan and its objectives, 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 to meet its aim of flood protection. 335 (David et al., 2016) point towards the option to complement the seawall project with ecosystem-based adaptation measures.

Studies outside the category of hard adaptation (Fig. 5) 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 340 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 345 problem persists (Colven, 2017; Padawangi and Douglass, 2015; Wade, 2019).

5.3. Soft and hybrid approaches to flood risk management and their evaluation

With a less model-driven and engineering-based 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 350 soft measures 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. Other studies point to the involvement of government at different 355 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 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).

360 Local, community- or NGO-led adaptation initiatives 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. A number of studies describe the key role of social 365 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 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). 370 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. 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).

Looking at how soft and hybrid measures are being evaluated in the literature, this review finds that many studies exhibit a rather critical perspective on state-led soft adaptation measures. (Fitrinitia et al., 2018; Mathewson, 2018; Ward et al., 2011a) elaborate that increased state investments into non-structural, soft measures, as described above, are not materializing on the ground. (Hellman et al., 2018a) refer to this as an "implementation deficit", which they find being facilitated by 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).

At the same time, studies highlight the potential of soft adaption measures to create co-benefits with other development objectives. Many studies analyse how 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 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 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).

6. Discussion

Our review shows that there is a rich, 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 the main 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, 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 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
420 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 identify the following five points, which we argue might be helpful
425 for advancing the debate and complementing the current perception on the adaptation solution space 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, skewing the perceived solution space towards hard adaptation measures. While it is, of course, very
important to assess and understand natural drivers of flooding in Jakarta, other drivers of flood risk need to be considered with
the same rigour in order to design effective adaptation options. Hard measures are – and will be – undoubtedly an important
430 part of Jakarta's solution space. Yet, a shortfall of consideration on the anthropogenic flood drivers yields the risk to 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 in terms of both environmental as well as socio-economic
changes. Surprisingly, the 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 different flood event return periods as a proxy for
435 changing environmental conditions, however, with considerable uncertainties remaining (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). Only a few of the
publications focusing on flood modelling and hard 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;
440 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;
445 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
450 environmental and/or socio-economic aspects will impact their effectiveness in the future.

Third, most publications that assess and evaluate the effectiveness of hard 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. This
455 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
460 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, hence calling for a rigorous consideration. 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.
465 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 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[2] (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? 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 information on the implementation and feasibility of suggested measures. While studies on soft and hybrid measures add valuable knowledge and potential options to the solution space, their lack of actionable recommendations limit their utility. They are more difficult to consider in actual adaptation planning – especially in comparison to hard 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) this lack applies to comparisons between different infrastructural measures as well as between hard and soft measures. 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, it is very difficult to identify "best" adaption options and combine them into sustainable adaptation pathways.

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

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. 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. The findings show 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. 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 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..

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 technocratic fixes and towards the root causes of flood risk and social vulnerability.

While our findings and lessons from Jakarta cannot easily be transferred one-to-one to other risk context, recent global assessments (Oppenheimer et al., 2019) suggest the many cities might be facing similar patterns as the ones identified for Jakarta, calling for follow-up research. We therefore hope that the perspectives and questions raised in this paper are useful to inspire studies on the solution spaces in other high risk settings.

Appendices

Appendix A: Results from the structured literature search

In total, 339 publications were identified by the keyword search. 14 proceedings and two publications for which no full-text version were available have been excluded. The below list shows the remaining 323 publications. All references that are marked with an asterics were included in the detailed content analysis and are cited in the paper.

*Abidin, H. Z.: Land Subsidence in Urban Areas of Indonesia: Suitability of levelling, GPS and INSAR for monitoring, GIM Int., 19, 12–15, 2005.

Abidin, H. Z., Andreas, H., Gamal, M., Gumilar, I., Napitupulu, M., Fukuda, Y., Deguchi, T., and Riawan, Y. M. & E.: Land subsidence characteristics of the Jakarta basin (Indonesia) and its relation with groundwater extraction and sea level rise, in: Groundwater Response to Changing Climate, CRC Press, 2010.

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., and Fukuda, Y.: On the Roles of Geospatial Information for Risk Assessment of Land Subsidence in Urban Areas of Indonesia, in: Intelligent Systems for Crisis Management: Geo-information for Disaster Management (Gi4DM) 2012, edited by: Zlatanova, S., Peters, R., Dilo, A., and Scholten, H., Springer, Berlin, Heidelberg, 277–288, https://doi.org/10.1007/978-3-642-33218-0_19, 2013.

*Abidin, H. Z., Andreas, H., Gumilar, I., Yuwono, B. D., Murdohardono, D., and Supriyadi, S.: On Integration of Geodetic Observation Results for Assessment of Land Subsidence Hazard Risk in Urban Areas of Indonesia, in: IAG 150 Years, vol. 143, edited by: Rizos, C. and Willis, P., Springer International Publishing, Cham, 435–442, https://doi.org/10.1007/1345_2015_82, 2015a.

Abidin, H. Z., Andreas, H., Gumilar, I., Yuwono, B. D., Murdohardono, D., and Supriyadi, S.: On Integration of Geodetic Observation Results for Assessment of Land Subsidence Hazard Risk in Urban Areas of Indonesia, in: IAG 150 Years - Proceedings of the 2013 IAG Scientific Assembly, Postdam,Germany, 1–6 September, 2013, vol. 143, edited by: Rizos, C. and Willis, P., Springer International Publishing, 435–442, https://doi.org/10.1007/1345_2015_82, 2015b.

Abidin, H. Z., Andreas, H., Gumilar, I., and Brinkman, J. J.: Study on the risk and impacts of land subsidence in Jakarta, Proc. Int. Assoc. Hydrol. Sci., 372, 115–120, https://doi.org/10.5194/piahs-372-115-2015, 2015c.

Achmad Santosa, M., Khatarina, J., and Assegaf, R. sjarief: Indonesia, in: Climate Change Liability: Transnational Law and Practice, edited by: Brunnée, J., Rajamani, L., Lord, R., and Goldberg, S., Cambridge University Press, Cambridge, 178–205, https://doi.org/10.1017/CBO9781139084383.011, 2011.

*Aditya, M. R., Hernina, R., and Rokhmatuloh: Geographic Information System and Remote Sensing Approach with Hydrologic Rational Model for Flood Event Analysis in Jakarta, IOP Conf. Ser. Earth Environ. Sci., 98, 012008, https://doi.org/10.1088/1755-1315/98/1/012008, 2017.

*Aerts, J., Botzen, W., Bowman, M., Dircke, P., and Ward, P.: Climate Adaptation and Flood Risk in Coastal Cities, Routledge, https://doi.org/10.4324/9781849776899, 2013.

*Agustan, A., Sanjaya, H., and Ito, T.: Jakarta Land Subsidence and Inundation Vulnerability Based on SAR Data, 34th Asian Conference on Remote Sensing (ACRS) 2013, Bali, Indonesia, 2013.

*Ajiwibowo, H.: The Influence Of The Jakarta Bay Reclamation On The Surrounding Tidal Elevation And Tidal Current, Int. J. GEOMATE, 15, https://doi.org/10.21660/2018.48.22773, 2018.

*Akmalah, E. and Grigg, N. S.: Jakarta flooding: systems study of socio-technical forces, Water Int., 36, 733–747, https://doi.org/10.1080/02508060.2011.610729, 2011.

Alatas, I. F.: Becoming Indonesians: The Bā 'Alawī in the Interstices of the Nation, Welt Islams, 51, 45–108, https://doi.org/10.1163/157006011X556120, 2011.

Alfida, A., Maryam, S., and Rianti, F.: Information in the Age of Misinformation: Counteracting the Problems of Online Radicalization with Digital Literacy, Libr. Philos. Pract. E-J., 2019.

Álvarez, J. C. and Resosudarmo, B. P.: The cost of floods in developing countries' megacities: A hedonic price analysis of the Jakarta housing market, Indonesia, Departmental Working Papers, The Australian National University, Arndt-Corden Department of Economics, 2018.

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Appendix C: 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	**Land-use (change) impact on flooding**	criticality of watershed	**9**
		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**

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Appendix D: Coding scheme in MaxQDA

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

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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

1415 The authors have no competing interests.

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