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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 solution space, i.e. on the options available for adaptation and the ways in which they are being perceived, framed and evaluated.

Focusing on Jakarta as one of the cities with the highest flood risk and adaptation pressure globally, this study presents findings from a systematic review of scientific English literature on mitigation options and the adaptation solution space to counter the city's chronic flood problem. Results indicate that the perceived solution space is skewed towards protection against flooding, while soft adaptation options as well as measures to live with flooding or retreat from exposed areas are less widely considered. This appears to not only stem from the government's traditional preference for engineered flood protection measures but also from a bias of scientific analyses towards focusing on understanding the hazard and analyzing engineered flood protection measures, while giving much less attention to soft adaptation options and community-led adaptation focusing among others on social and natural capital, empowerment and capacity building. Similarly, 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 a more integrative scientific approach would be helpful to populate and balance the considered solution space. Jakarta is one of the most heavily researched coastal cities worldwide and 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, 2019). 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 are under increasing pressure to adapt over time and in some instances transform fundamentally (IPCC, 2019; Revi et al., 2020). While this is not a new phenomenon, even well-researched cities like Jakarta, Indonesia, that have sound scientific knowledge on their flooding problems and that already put considerable effort into improving flood risk management and climate change adaptation, keep suffering from flooding year after year.

Against this background, persistent flooding hints towards the existence of the frequently mentioned "adaptation gap" (UNEP, 2018). In order to better understand and address this gap, this study looks at scientific research on past, current and future trends in flood risk and adaptation for the case of Jakarta. Research on this city shows a pattern which is very typical for coastal cities: Whilst the problem of flooding and its drivers has been quite well researched for Jakarta (e.g. Garschagen et al., 2018), much less attention has been given to analysing different potential adaptation options. The main focus of this paper is therefore on examining the so-called "solution space" for Jakarta and how it is being covered and represented in the literature. The

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concept of "solution space" for adaptation to climate change started receiving increased attention since its notion in the IPCC's Fifth Assessment Report (WGII AR5) (IPCC, 2014). Therein, it is presented as an approach to collect, illustrate and assess potential adaptation options including their overlaps and contradicting aspects as well as limiting factors acting as boundaries to the solution space, in order to identify and evaluate adaptation pathways. Similar to vulnerability, the solution space for climate change adaptation 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 certain 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).

Assuming that scientific research influences the evolution and shape of the solution space, an analysis of the development and current state of research of adaptation to flooding in Jakarta may contribute to understand the adaptation gap in two distinct ways: First, a thematic overview will reveal research foci and paradigms that determine which adaptation options are considered for the solution space and hence influence its content. Second, the analysis of the content of the reviewed literature will help understand the evolution of the solution space and its boundaries, identifying influencing factors and opportunities to close gaps as well as extend limitations, thereby widening the current solution space.

Jakarta represents an example worthwhile analyzing because flood problems are so pressing there that the city might 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 constant urban growth with all its characteristics such as among others densification, social inequalities, congestion, land conversion and environmental degradation with the increasing occurrence and intensification of natural hazards such as flooding culminates in an ever increasing risk for the urban population today and in the future. 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).

Looking at Jakarta's long history of flood protection and risk research, this paper argues that analyses and policies to date miss to consider some essential aspects such as soft and hybrid adaptation options as well as the influence of current risk governance structures. We argue that this is partly caused by a bias in scientific research towards understanding the hazard, which limits the solution space of Jakarta's flood adaptation, resulting in the persistence of chronic flooding including its negative impacts in Jakarta until today. To examine these hypotheses, the study is guided by the following research questions: What are dominant research streams in flood research in Jakarta? To what extent does scientific research consider different available adaptation options? How are these different options being perceived, framed and evaluated? Which gaps can be observed?

To answer these questions, the study examines how research explains the flood problem with regard to physical causes and which adaptation measures the studies focus on. Furthermore, identified gaps and problems mentioned by scholars are analysed to see which future directions for research are suggested.

The paper is structured into five main parts. Section 2 presents the methods and data of our analysis. Section 3 presents the results. This section is guided by the above research questions. Starting with a general overview of the development and composition of the flood research landscape of Jakarta, the understanding of the physical determinants of the flood hazard as described in the literature are presented. Subsequently, evidence for research on physical/engineered and holistic adaptation measures are described before detailing how they were implemented in Jakarta since the turn of the century. Finally, identified gaps in policy and research as described by the studies are reviewed to assess potential future research pathways. Section 4 summarizes and discusses the results. Section 5 offers key conclusions and an outlook.

2. Methods and data

This study builds on a systematic search for English scientific literature in the citation database Scopus, limited to the years 2000 to October 2019, aiming at getting a full overview of the state of research on flooding and adaptation in Jakarta. An in-depth analysis of research focusing on non-structural/engineered adaptation measures allowed for the evaluation of its state of the art and to what extent this field is currently considered in food research in Jakarta.

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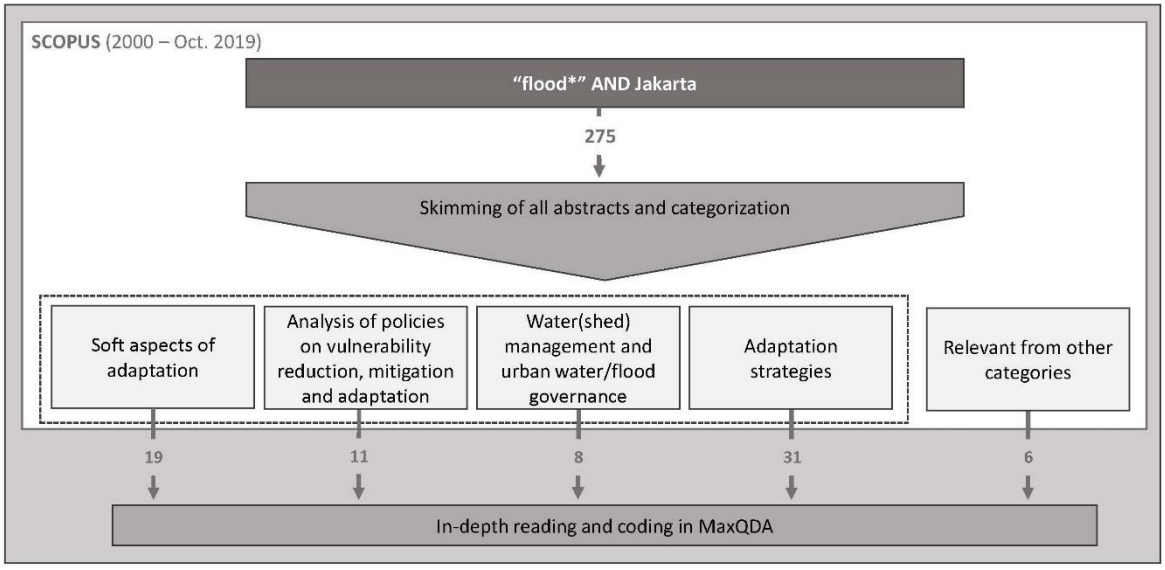

Figure 1: Literature search, extracted categories and numbers of resulting publications

As visualized in Figure 1, the SCOPUS literature database was searched with a deliberately broad combination of the search terms "flood*" AND "Jakarta", limited to the past 20 years (2000 - October 2019) and yielded 275 publications in English language. All abstracts of resulting publications were skimmed for their relevance and simultaneously categorized into an inductively derived thematic scheme (Appendix A) in order to get a first overview of the flooding research landscape. 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).

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.

[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 (Table 1) were analyzed in a similar way, when they were deemed relevant for the context.

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3. 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.

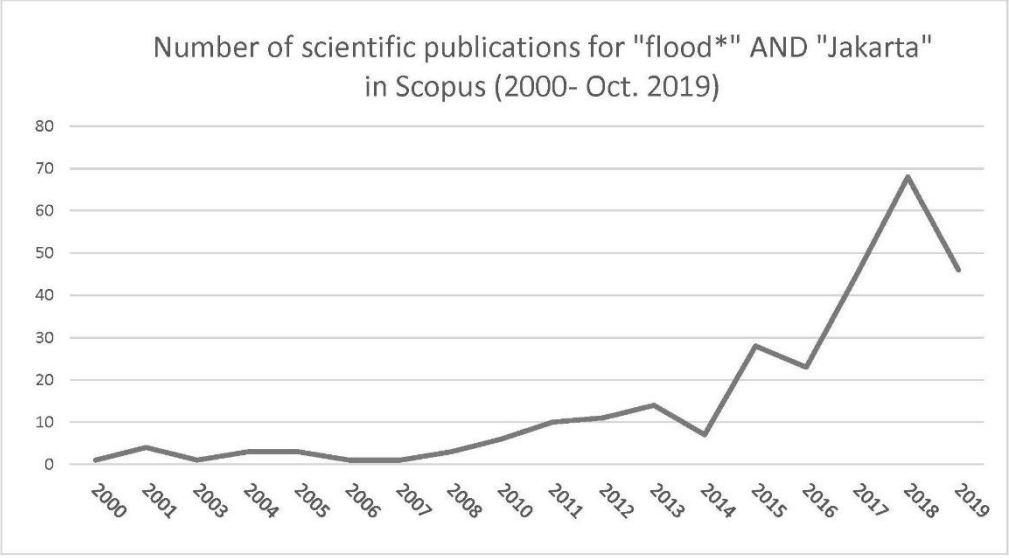

Figure 2: Number of scientific publications on flooding in Jakarta (2000-2019) in SCOPUS

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

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

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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

According to the subject fields provided by the Scopus citation databank, more than three quarters of all resulting publications originate from a natural science discipline (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). Only roughly 15% can be attributed to fields from the social sciences (social sciences, arts and humanities) and very few are from economics (Business, Management and Accounting, Economics, Econometrics and Finance) 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.

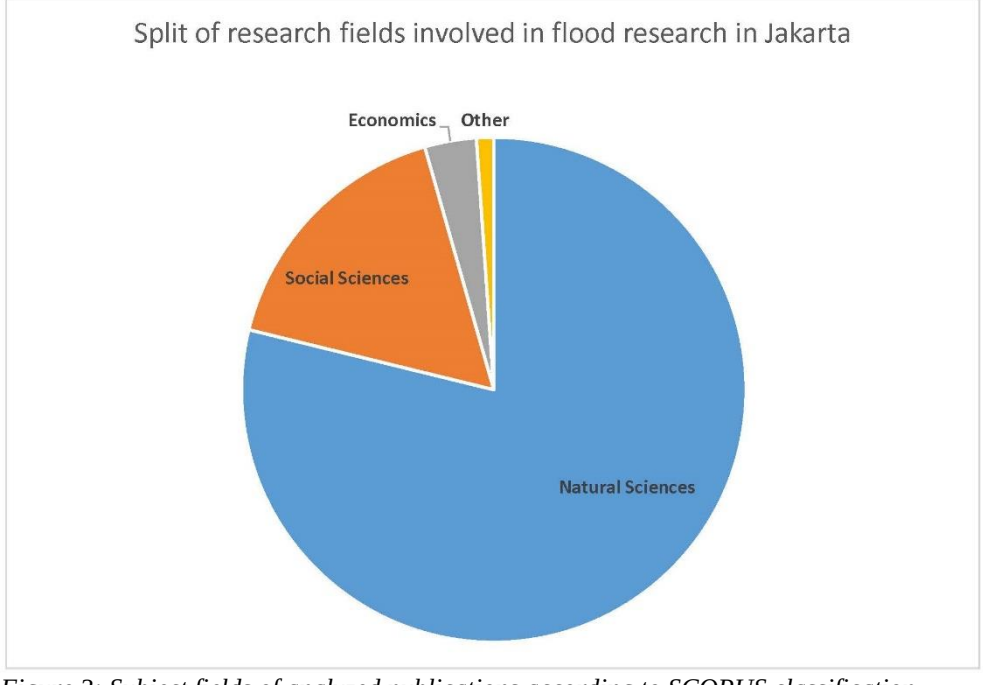

Figure 3: Subject fields of analyzed publications according to SCOPUS classification

To get a clearer and more detailed overview, Figure 3 shows a classification of the resulting publications in terms of the studies' content and focus, building on an inductively developed categorization scheme. Some clear clusters and patterns emerge: First,

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studies on quantitative flood modelling and physical adaptation options dominate, representing almost 50% of all publications (grey fields). This corresponds with the high number of papers in subject fields from the natural sciences. Second, with around one third of all publications (green fields), studies in the area of holistic adaptation analyses, soft aspects of adaptation, climate adaptation policy and governance analyses as well as water management studies represent another strong stream of scientific research.

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

3.1. Understanding the physical determinants of the flood hazard

As shown in figure 4, there is a strong focus on flood modelling and mapping, representing more than a quarter of all papers published since the year 2000. Flood models (Bahtiar et al., 2018; Farid et al., 2012; Formánek et al., 2013; 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-of (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., 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

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al., 2015, 2016; Fajar Januriyadi et al., 2018; Kurniyaningrum 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) the phenomena were mapped for specific rainfall and/or flood events, identifying the locations and extent of the hazard. Soemabrata (2018) adopt a more comprehensive perspective developing a flood risk map and Padawangi et al. (2016) highlight the role of community risk perception and local knowledge by referring to the use of community-based/participatory flood mapping.

Apart from the latter two exceptions, the mentioned studies focus on climatic, hydrological and physical factors contributing to flooding. 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 3.2.).
Besides this, 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., 2011b). No studies consider 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 referring to potential changes of return periods in the course of climate change. 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. Physical/engineered flood protection measures

Considering the focus on natural/physical reasons for flooding, it is not surprising that there are many publications that concentrate exclusively on so called structural, engineered or hard flood protection measures, which started being implemented already during colonial times by the Dutch and which are until today 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, 2015a; Simanjuntak et al., 2012; Ward et al., 2013a). They represent around one tenth of all identified studies on flooding in Jakarta and focus on specific engineered solutions such as for instance water barriers like levees, dams, dikes and embankments analyzing or modelling their vulnerability, protective capacity or suitability for flood protection (Mardjono et al., 2018; Mardjono and Setiawan, 2018; Ogie et al., 2016b; Su et al., 2018; Sujono, 2012; Suprayogi et al., 2018; Takagi et al., 2016a, 2017; Wurjanto, 2018). Some are concerned with 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) (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

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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[2], a central and highly contested element of the National Capital Integrated Coastal Development (NCICD) masterplan. Besides outlining the plan and its objectives, the 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). 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 because it neither addresses land subsidence nor other socio-economic factors contributing to flooding 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).

3.3. Holistic, integrated approaches to flood risk management

With a less model-driven and engineering focus, another stream of literature is dedicated to describe, analyze and/or propose adaptation strategies and flood governance approaches from a more integrated perspective. 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; 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; 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. Colven, 2017; Costa et al., 2016; Fitrinitia et al., 2018; Garschagen

[2] 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).

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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-economical as well as structural aspects of flooding 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; Shokhrukh-Mirzo Jalilov et al., 2018; Varrani and Nones, 2018; Ward et al., 2013a). 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"[3].

Overall, 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.

Analyzed state-led adaptation efforts at city scale mostly focus on resettlement/relocation strategies, which accelerated since 2009 (Ichwatus 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. 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). Apart from state-led resettlement and infrastructural measures, only very few other government initiatives to adapt to flooding are mentioned. Despite an increase of investment into non-structural measures 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). Together with lacking reinforcement of laws and regulations 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). 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 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.).

Local, 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 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. 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,

[3] 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."

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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 social cohesion within networks is 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; 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 (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 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). However, social networks and community cohesion are also described to lead to negative 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, the positively portrayed community-led adaptation 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. 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-specificy 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.

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

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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

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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. 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

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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. Discussion

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.

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.

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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

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515 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. Conclusion

520 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 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 is relevant since many other cities around the globe will be faced with similar challenges over the course of the next decades. The findings of this analysis show that the 525 scientific debate to date is skewed as they do 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 assessment of future risk trends, where a heavy emphasis is on modeling 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 530 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, 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 535 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 540 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 chart and navigate transformational adaptation that shifts the political economy of risk production and the existing paradigms of adaptation away from superficial fixes and technocratic solutions. Jakarta can be a globally leading pilot 545 and laboratory in these respects. But it requires the future science on Jakarta to shift its emphasis.

Appendices

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

Code	Topic	Sub topics	Resulting Publications (2000- Nov. 2019)	%
1	**Soft aspects of adaptation**	psychology	**21**	7.8
		behavior		

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		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		

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		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

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		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:

Karyono T.H., Melyan N.H., Salsa S.Y., Fariz E. (2017). Flood Responsive Design of the Low-Income Settlements in Kampung Melayu, Jakarta, Indonesia. Book chapter. Doi: 10.1007/978-3-319-49601-6_12

Karyono T.H., Bachtiar F. (2017). Adapting City for frequent floods: A case study of Jakarta, Indonesia. Book chapter.DOI: 10.1007/978-3-319-49601-6_8

Karyono T.H., Burhanudin D., Timothi B. (2017). Sustainable fishing settlement in Muara Angke, North Jakarta. Book chapter. DOI:10.1007/978-3-319-49601-6_10

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:

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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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