Flood Resilience in Delta Cities

An explorative research on monitoring flood resilience in Delta Cities

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Preface

This thesis is the final assignment of my master study Landscape Architecture & Spatial Planning at Wageningen University. The topic 'flood resilience' is chosen because I'm interested in landscape adaptation to climate change. Flood resilience is an approach to withstand or adapt to flooding. Application of this approach is highly relevant in times of sea level rise. This thesis develops a method that enables the monitoring of flood resilience in delta cities. The method is tested and refined for flood resilience in two delta cities.

This research has been accomplished under supervision of Maarten Van der Vlist and Mark Zandvoort (Wageningen University). Maarten mainly guided the starting phase of the research by helping to define the required focus for this study based on his experience in flood risk management. Mark helped to structure the research and underpin my work scientifically in his critical, constructive and involved way of supervising.

Martine Rutten was the external supervisor from contractor Delta Alliance who kept me motivated with enthusiastic and realistic ideas based on the practical relevance of this research for Delta Alliance.

Piet Dircke (Arcadis) introduced me to the field of flood resilience and proposed several organizations that could be involved in this research which led to the cooperation with Delta Alliance.

This research would not have been possible without the support of Catharien Terwisscha who introduced me to the Delta Alliance Wing of Bangladesh. Catharien provided a place to work at the Wageningen Project Office in the Institute of Water Modelling in Dhaka and shared her network of potential interviewees in Bangladesh. I want to thank Kousik Achmed and Mrs. Dipty from the Wageningen Project Office for their help regarding the practical arrangements for the case study in Bangladesh.

Mr. David Mohammed Khan of the Institute of Water Modelling was so kind to exchange views on my research and provided useful background information on flood resilience. Professor Shah Alam Khan shared his expert knowledge on flood resilience in Dhaka which facilitated the assessment of Dhaka. Next, I want to thank all the representatives of the Institute of Water Modelling who joined the workshop and provided feedback on the framework.

I hope you enjoy reading this report,

Renze Haitsma, Wageningen 2016

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Abstract

A promising concept to lower the vulnerability of cities to flooding is resilience. However, it is not clear how flood resilience can be achieved. The objective of this thesis is to operationalize the concept of flood resilience into a framework of indicators that enable monitoring resilience in delta cities. A systematic literature review on resilience and two case studies led to the development of the Resilience Wheel: a framework based on 5 dimensions and 19 indicators of flood resilience which structure what needs to be measured for flood resilience monitoring in delta cities. Rotterdam and Dhaka are assessed on their flood resilience which results in insights for refinement of the Resilience Wheel and insights in the current strengths and weaknesses of the resilience of both cities. With designing, offering a protocol for application and testing the Resilience Wheel, this thesis offers an operationalization of resilience and an applicable method for monitoring resilience.

Keywords: flood resilience, vulnerability, delta cities, spatial planning, indicators, Dhaka, Rotterdam.

Summary

Climate change causes a rising sea level and more extreme precipitation. The impacts of sea level rise on coastal areas are enormous and have the potential to cause great damage through urban flooding and coastal erosion (IPCC 2013). Currently, more than half of the world's population lives in coastal zones, primarily in delta cities. The vulnerability of delta cities to floods will increase when urbanization of coastal areas and increasing investments in cities are combined with a lack of coastal management. A promising concept to lower this vulnerability is flood resilience. However, resilience is an ambiguous concept and operationalization of resilience is not clear. The problem statement of this research is: there is lack of an applicable framework to make resilience measurable in practice.

The research question is: *Which indicators of flood resilience offer a coherent framework for operationalizing and monitoring of flood resilience of delta cities?*

The ambiguous concept of resilience is operationalized in a framework with indicators that enables monitoring of flood resilience in delta cities. This thesis starts from the conception of resilience as the antonym of vulnerability. Vulnerability is defined as the various degrees of a delta city to experience harm or damage as a result of exposure to an adverse event. Resilience is the ability of systems to withstand or adapt to changes without being harmed in their functionality. Resilience offers insight in aspects of a delta city where vulnerability can be lowered.

This research is performed by a mixed methods approach. A systematic literature review and case study research were used to respectively find the indicators of flood resilience and test the suitability of these indicators for resilience monitoring. By means of Scopus, an online database for peer reviewed articles, 40 relevant articles for urban flood resilience were selected and retrieved. These articles were analysed to select terms that characterize flood resilience and can measure resilience through rapid assessment of cities. This systematic review delivered a list of 5 conceptual dimensions and 107 indicators of flood resilience. These conceptual dimensions were linked to the 19 most prevalent and measurable indicators which together form the proposed framework, called the Resilience Wheel. With this Resilience Wheel, the flood resilience of delta cities can be monitored by scoring the indicators in this framework on an ordinal 5-point scale. Expert knowledge and document study of the delta cities are used to score the indicators. To test the functioning of the framework, Rotterdam and Dhaka were assessed on their flood resilience.

A document study on Rotterdam led to insights in the functioning of the Resilience Wheel. The rapid assessment gave a score of 3.78 for Rotterdam's flood resilience and two possible improvements on the Wheel. A case study in Dhaka started with improvement of the Resilience Wheel before the city was assessed. Feedback on the Wheel from experts in the field of flood risk management was compared with the insights on the functioning of the Wheel in Rotterdam. This led to an improved Resilience Wheel that was used to assess Dhaka on flood resilience. The assessment resulted in a flood resilience score of 2.40. The assessment delivered weak points of Dhaka that could be improved by spatial planning. The conclusion states that the Resilience Wheel proved to be a tool that operationalizes the ambiguous concept of resilience and offers the characteristics of resilience that can be monitored. The Wheel helps to diagnose strengths and weaknesses of delta cities that can respectively be built upon or improved. The application on Rotterdam and Dhaka gave insight in where improvement for flood resilience might be found. For Rotterdam in the financial funding for flooding and the self-organization of residents, for Dhaka in the institutional capacity, public participation and learning capacity. This thesis gives a broad overview of how flood resilience can be understood, gives the reader a synthesis in a framework and first evidence of applying the Resilience Wheel in two delta cities. By developing a framework for resilience, this thesis contributes to the demand of making resilience operational that is debated in resilience discourse. It thus contributes to explore and reduce the vulnerability of delta cities confronted with the adverse effects of climate change.

1.Introduction

This chapter introduces the motives for this research and states the problem that is researched. A research objective is converted into research questions that are shortly explained.

1.1 Climate Change

The world is facing the challenge of adaptation to climate change. Resilience is an adaptive approach to deal with the consequences of climate change. However, these consequences are numerous. Climate change causes an increasing sea level and more extreme precipitation and evaporation. The fifth assessment report of the Intergovernmental Panel on Climate Change projected an increase in global temperatures between 1.1°C and 6.4 °C over the next century, with a global sea level rise up to 100 cm by 2100 (IPCC 2013). Figure 1 presents the likely range of sea level rise which shows that sea level is rising but the extent of sea level rise is uncertain. The ranges for the mean over the period 2081–2100 for all scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line (IPCC 2013).

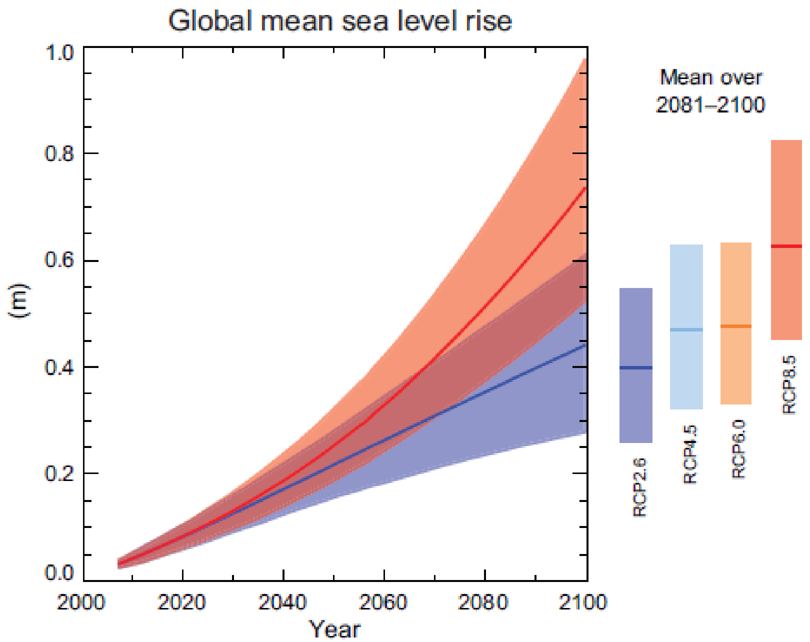

Figure 1 - Projections of global mean sea level rise over the 21st century according to four climate change scenario's.

The impacts of sea level rise on coastal areas are enormous and have the potential to cause great damage through urban flooding and coastal erosion (IPCC 2013). In other words: sea level rise increases the vulnerability of coastal areas.

1.2 Vulnerability

According to Snover et al. (2007): "Vulnerability is the various degrees of a system to experience harm or damage as a result of the exposure". Exposure is about the proneness to a particular threat with a focus on the proximity, incident frequency, duration or magnitude of a disturbance (Jonkman, van Gelder & Vrijling 2003). Vulnerability and exposure determine the risk of a system. Snover et al. (2007) and Zandvoort & Van der Vlist (2014) expressed risk in the following equation:

Risk= probability * consequences (exposure * vulnerability)

This relates to resilience as an antonym to the vulnerability facet within the equation. It is not to say that this equation grasps the full meaning of risk, see (Jonkman, van Gelder & Vrijling 2003; Neuvel 2009). Neuvel (2009) states probability as "the chance that an impact will occur" and consequences as "the effect or result of an (climate change) impact". The equation services the purpose of showing the relation between risk components but mainly relates to resilience as main concept analysed in this thesis. To prevent floods with disastrous impacts on cities, the vulnerability of delta cities could be lowered by strengthening resilience (Aerts et al. 2009). Resilience can thus be seen as the positive counterpart of vulnerability.

1.3 Resilience

One of the first definitions of resilience is offered by Holling (1973): "Resilience is the amount of disturbance a system can withstand without changing its self-organising structures and processes". In this definition, resilience was applied to ecological systems. In the course of time resilience was applied to many different systems such as communities, socio-ecological systems or cities. A more coherent definition was stated by Restemeyer, Woltjer& Van den Brink (2015): "Resilience is the ability of systems to withstand or adapt to changes without being harmed in their functionality". This definition is adopted for this study, since it describes that resilience is a concept that should be applied to a system. Next it shows the versatility of the concept since resilience consists of both withstanding and adaptation. The objective of implementing resilience is the continuation of a system's functioning by minimizing the consequences of a disturbance (Barocca 2013). Functioning can be explained in terms of living, working, the continuation of traffic and energy supply (Adewole et al. 2014). Lu&Stead (2013) stated: "Resilience is related to both preparations to minimize disturbances (or change) and actions to deal with disturbances once they have occurred". Resilience in its broadest sense is conceptualized as good for safety, health and welfare of the urban population since resilience is about resistance and adaptation to diverse risks and disasters (Chang et al. 2013). Resilience once had a pure physical meaning. It was defined as the resistance of a material to shocks (Vis et al. 2003). Since there is debate on resilience for a long time, the concept shifted from resistance towards adaptation and 'bouncing back' (Liao 2012). According to Godschalk (2003) "A resilient strategy does not only react on the consequences of a flood but also anticipates prior to a flood by taking the possibility of flooding into account". Over the last decades, resilience got more importance because of the challenges related to climate change adaptation. The increasing attention for resilience in literature also resulted in numerous interpretations of the concept and a lack of clarity on resilience implementation. Stead (2013) discusses the ambiguity around resilience as a symptom of the immaturity of a policy concept. He states that "Resilience is currently not operationalized but will increase in clarity over time". However, the increasing sea level rise requires implementation of resilience on the short term to prevent potential damage as result of flooding and urbanization.

1.4 Urbanization

Currently, over half of the world's population lives in coastal zones, especially in deltas. According to Coleman and Huh (2007): "A delta is a landform that is formed where a river flows into an ocean or sea". Within deltas most people live in cities. A city is here understood as a spatially integrated social and economic system at a given location, or metropolitan region (Friedmann 1986). The definition of delta cities in this research is: "Coastal cities on the confluence between sea and river". However, there is an important relation between delta cities and the surroundings. A delta city interacts with the surrounding area (e.g., upstream measures for the river can have consequences for downstream areas). Next to an increasing urbanization of coastal areas, investments in flood-prone areas continue for developing ports, industrial centres, housing, infrastructures and financial businesses. Urbanization and investments in delta cities cause an increasing loss potential in case of flooding. Table 1 shows the increase in loss potential which means that the vulnerability of cities to flooding and the consequences in case of flooding are higher.

Table 1 - Increase in mega-disaster loss potential from 2005 to 2015 (Bouwer et al. 2007)

Population estimates (million)				Estimated GDP ($ billions)		
Tokyo, Japan	35.2	35.5	0.8	1191	1452	22
Mumbai, India	18.2	21.9	20.2	126	226	79
Mexico City, Mexico	19.4	21.6	11.1	315	489	55
Sao Paulo, Brazil	18.3	20.5	12.0	225	336	49
New York, USA	18.7	19.9	6.2	1133	1408	24
Delhi, India	15.0	18.6	23.6	93	170	82
Shanghai, China	14.5	17.2	18.8	139	261	88
Kolkata, India	14.3	17.0	18.9	94	167	77
Dhaka, Bangladesh	12.4	16.8	35.5	53	94	81
Jakarta, Indonesia	13.2	16.8	27.3	98	184	88

Next to higher loss potential, the vulnerability of delta cities to experience damage will also increase due to a lack of coastal management (Aerts et al. 2009). Urbanization and a lack of coastal management increase the demand for resilience as an adaptive approach to limit the damages caused by flooding.

1.5 The role of spatial planning in flood resilience.

The implementation of flood resilience by spatial planning can improve coastal management in delta cities. The debate on resilience within spatial planning started in the nineties as a reaction to climate change. There was an increasing awareness among spatial planners that physical and infrastructural adjustments to resist disturbances were not sustainable on the long term (Mileti 1999). There was a need for resilient strategies that provide more flexible, robust and adaptive approaches in spatial planning (Lu&Stead 2013). Implementing resilience became the responsibility for policymakers and spatial planners. According to Barocca (2013) "Urban planners have a large share in implementation of policies and spatial interventions to adapt to climate change and increase a city's flood resilience".

The construction, operation and protection of essential functions and infrastructures are vital for a city's resilience. The functioning of infrastructures and essential functions contribute to a continuing function of the city (Godschalk 2003). Implementation of flood resilience also requires a flexible and receptive attitude of urban planners and policy makers since the 'traditional' way of planning changes into an adaptive way of planning (Barocca 2013). Resilience implementation entails new measures, legislation and building codes in spatial planning to ensure a certain standard of flood resilience. To identify this standard of flood resilience, monitoring could be used. Monitoring is often used in spatial planning as an approach of collecting, analysing and using information to measure a specific feature of a system. It is also used to track progress of a planning approach to guide management decisions (Wong 2003). The monitoring approach can be used as a tool to determine the success of resilience implementation in cities. In contrast to assessments (single measuring), monitoring aims to measure a specific feature on the longer term. The ultimate aim of monitoring is to improve the feature (resilience) based on the outcomes of the measuring of that feature (Rae &Wong 2012). However, before resilience can be monitored and improved in practice, some problems have to be overcome.

1.6 Problem statement

Although the current scientific debate is shifting from defining resilience towards generating insights into 'doing' resilience in practice, the implementation of resilience in practice is still difficult (Restemeyer, Woltjer & Van den Brink, Pizzo 2015). Balsells et al. (2015) states: "The step from theory to practice is not made. If we don't know what to look up, we don't know how we can implement resilience". Liao (2012) confirms this problem: "Without a rigorous definition and some form of measurement, resilience would not be a useful concept for practice". The step to put the theoretical concept of resilience into practice could be facilitated by an operational framework that defines the components of resilience that can be measured in practice. Monitoring is needed to determine the extent to which flood resilience is applied to delta cities and to identify the domains for resilience improvement. Indicators are often used for measurement. Currently, monitoring resilience is problematic since it is unclear what aspects need to measured. The problem statement is: There is lack of an applicable framework with indicators that operationalizes the concept of resilience and enables monitoring of resilience in cities. In the light of adaptation to climate change, the concept of resilience is applied on flooding and therefore called 'flood resilience' in this research.

1.7 Objectives and research question

The research objective is to create a coherent framework with indicators that characterize flood resilience and are measurable through assessment of cities. A coherent resilience framework operationalizes the fuzzy concept resilience into a specific and integral overview. Second it offers an coherent framework that enables the monitoring of resilience in cities.
The research question for this research is:

Which indicators of flood resilience offer a coherent framework for operationalizing and monitoring flood resilience of delta cities?

The objective and main research question are converted in three sub-questions:

1. *What indicators exist in the literature to measure flood resilience of delta cities?*

This research builds on the literature to identify dimensions and indicators of flood resilience. A literature review delivers the existing indicators in the main resilience discourse. This question results in an analytical tool with indicators to monitor the flood resilience of delta cities.

2. *What insights for the coherence of the framework can be derived from measuring the flood resilience by rapid assessment?*

The coherence of the developed framework in the first question will be tested by applying the resilience framework in assessment of Rotterdam. Using the framework for measuring resilience results in insights in the functioning of the framework. Next to insights in the functioning of the framework, the assessment provide insights in the flood resilience of Rotterdam.

3. *What does a comparison of different applications offer for refining the procedure of measuring resilience?*

Another case study is performed in Dhaka (Bangladesh) as an iterative step to verify the insights based on the first case study. The insights in the functioning of the framework after two case studies are compared to determine how the resilience framework should be refined. The representation of resilience and the coherence of the framework is refined by the addition of new indicators and the alteration of the ways in which the indicators could be measured.

Outline

Chapter 1 introduces the motive for the research, provides theoretical background on the concepts vulnerability and resilience and states the problem and research questions. The methods for answering these research questions are described in chapter 2. The results of the literature review and a first version of the framework are presented in chapter 3. Chapter 4 and 5 are the applications of the framework with assessments of respectively Rotterdam and Dhaka on their flood resilience. In chapter 6, the results of these assessments are compared and the differences are analysed. The discussion in chapter 7 provides answers to the research questions and reflects upon the methodology. Conclusions of this research are drawn in chapter 8 which also contains advice for expansion of the resilience framework and recommendations for further research.

2. Research methodology

This chapter describes what methods are used to achieve the research objective and answer the research question. The objective was to create a coherent framework with indicators that characterize flood resilience and are measurable through assessment of cities. An iterative process was used to achieve this objective. First, I explored how the theory of resilience could be translated/operationalized into indicators for measuring flood resilience. In the two subsequent steps I tested if the indicators are usable for monitoring flood resilience.

2.1 Mixed methods research

According to Creswell (2014), a combination between different research methods will improve the research since data are acquired in several ways. This is a mixed methods research since literature study, interviews and workshops were used to gain data. There is chosen to use a mixed methods approach since the use of different methods and different types of data strengthens the validity of the research. This will be elaborated in paragraph 2.6 about validity of the research. The generic approach of an iterative (repeating) process using mixed methods was chosen since the development and refinement of a framework requires repeated steps. A literature review leads to the first version of the framework. After a case study in Rotterdam and a feedback workshop in Dhaka I refined the framework into a new version. With this refined version, the flood resilience of Dhaka is measured. After this second assessment is decided if additional changes are required for the framework.

2.2 Literature review

The first step was a systematic literature review to determine what in scientific literature is characterised as indicators and conceptual variables of resilience. This was performed by means of Scopus to select relevant articles on flood resilience. I analysed the articles with Atlas.ti to find indicators and conceptual variables of flood resilience. Indicators are measurable parameters of resilience and conceptual variables are general dimensions of resilience. Regarding to the data collection and data analysis, the systematic literature review focuses on primary data since the indicators are directly derived from articles.

2.2.1 Search for articles

The systematic review of planning literature was done by using Scopus as the online database of articles. I used Scopus because it contains all peer reviewed articles and enables advanced searching by the use of field codes and filters. Using these tools ensured the selection of a sufficient set of articles for this research. A sufficient set of articles was set around 40 or more based on studies executed before (Biesbroek et al. 2013; Karpouzouglou et al. 2016). A Boolean expression was chosen to gain the results for the review in a reproducible way based on the study of Leenaars et al. (2012). However, a challenge in searching relevant articles is the required balance between comprehensiveness and precision in the search terms. To be comprehensive, a high sensitivity is needed. This means that a search identifies as many potentially relevant articles as possible. A very high precision in the Boolean expression (search term) could result in a low amount of relevant results but a low precision could result in a high number of hits that are not relevant. A combination of search terms was applied to find the balance between comprehensiveness and precision. After some experimentation with different formulations of the Boolean expression to get at a sufficient amount (>40) of relevant articles (based on reading the abstracts), the Boolean expression in table 2.1 was used:

Table 2.1 - Boolean expression in Scopus

Block	Search term	Demarcation
Object	Urban AND flood OR water	Title, abstract, keywords
Dependent	Resilien*	Title only
Types of documents	Articles, review papers	
Included languages	English	

The full advanced search term was:
TITLE (resilien*) AND TITLE-ABS-KEY (urban) AND TITLE-ABS-KEY (flood OR water) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"ip") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(LANGUAGE,"English")

The title 'resilien*' was chosen, since the term resilience is often formulated as resiliency or resilient. By putting the '*'sign, Scopus took into account the words 'resilience', 'resiliency' and 'resilient'. The first code for the title, abstract and key was 'urban' since this research is on delta cities. The second code was 'flood OR water' since the perspective of this research is resilience against flooding and not against (e.g.) diseases or terrorism. A delineation on flooding might increase the chance that indicators in the articles are suitable for flood resilience. All these terms (resilient, urban, food and water) can be interpreted in different ways but combining them in one operator increases the chance of relevant articles in the field of interest. Applying this Boolean expression resulted in 179 documents. The results were refined by limiting to articles and reviews, while excluding conference papers, books, and letters. This choice was made since the goal of this literature review was to derive flood resilience indicators from the main scientific resilience discourse. This led to a set of 134 documents. For practical reasons only articles in English were included (n=124). The final list of articles that were scanned on abstracts to further determine the relevance for the research question contained 124 articles. The graph (figure 2.1) shows that most articles are from last years and illustrates that the resilience debate is of quite recent date.

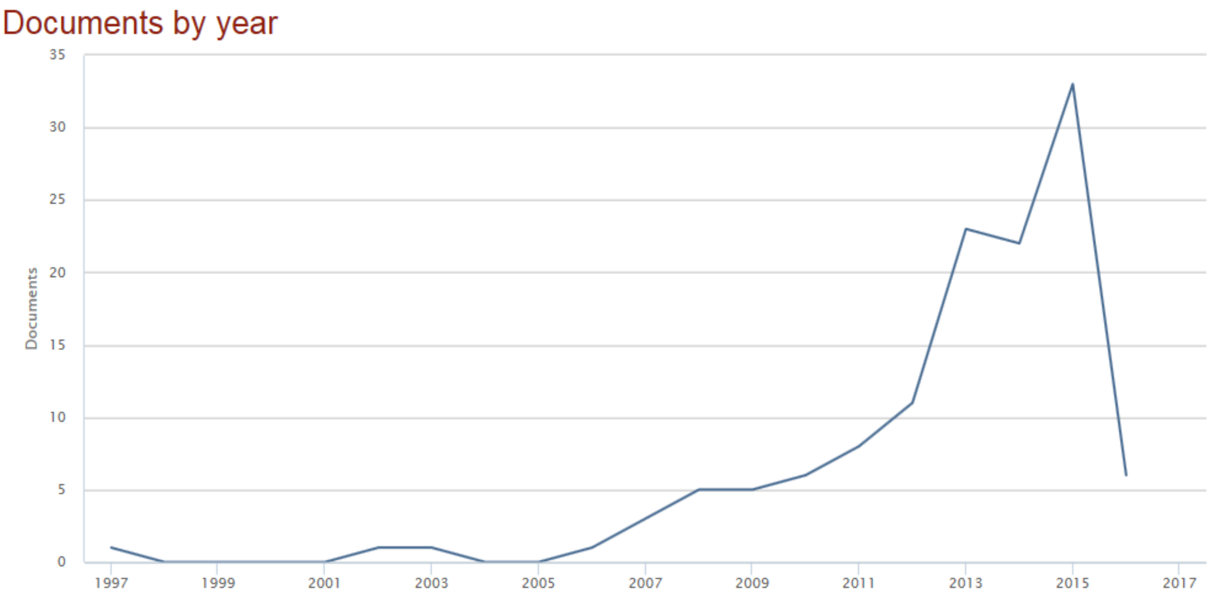

Figure 2.1 - Documents derived for the systematic review according to year of publication

2.2.2 Assessing the abstracts

Resilience is applied to many different fields (e.g. diseases, drought, terrorism). Therefore, it was necessary to exclude the articles that did not fit within the topic of this research: resilience to urban flooding. I assessed the abstracts on their description of urban flood resilience to see if the article dealt with resilience to urban flooding. The key-words of an article also provided information about the content of the article. I excluded reviews and articles that were not about resilience to urban flooding and gave a short motivation why they were left out. Most irrelevant articles were omitted for their different research topic. They were assessed as irrelevant and classified in different categories. In total, I categorized 84 articles as irrelevant. The list of 124 relevant and irrelevant articles are attached in appendix 1. Figure 2.2 illustrates the proportion of the irrelevant articles.

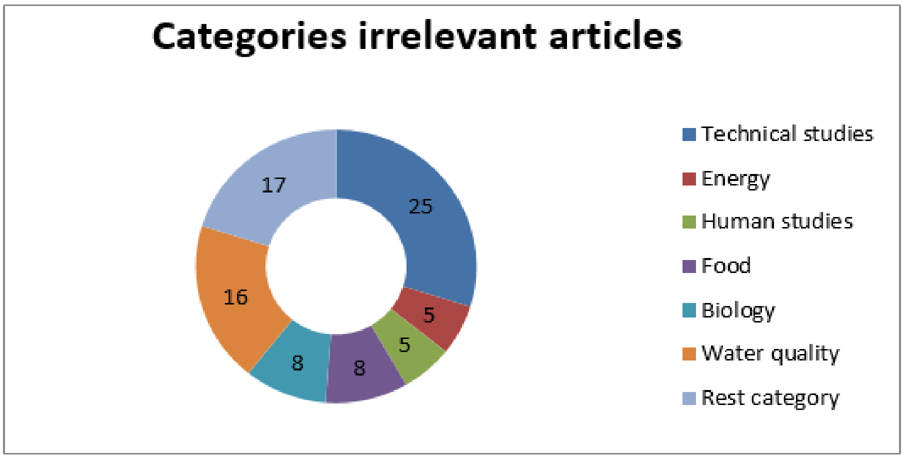

Figure 2.2 - Categories of irrelevant articles

In the case of doubt about the relevance of the article for the review, I checked the full version of the article for elaboration on resilience. Some articles were not specifically about urban flooding but did contain indicators of resilience. These articles were included and analysed with Atlas.ti to distil the indicators for this study. The final amount of articles deemed relevant for the analysis was 40. I retrieved the full text papers via Scopus, Web of Science and the authors' home institution library.

2.2.3 Coding for indicators and contextual variables

In the next step, the relevant articles were assigned to Atlas.ti, a qualitative data analysis software tool. I read all 40 relevant papers and coded resilience characteristics to construct an appropriate list of terms that could be used as indicators of resilience. I did this by reading an article and selecting the quotations that elaborate on resilience. These quotations were given codes (names of the indicator). For example, Hamilton (2009) stated "the management of emergency help is crucial to flood resilience". This resulted in the code 'emergency management'. Codes show how often an indicator occurs in the selected resilience literature.

Selection of indicators.

Indicators of resilience were selected to clarify the abstract concept of resilience in specific characteristics and to enable monitoring of resilience in cities. The definition of an indicator is "A measurement used operationally to define flood resilience in order to guide policy making on flood resilience" (Wong 2003). According to Wong (2003) there is a development of indicators as "involving a methodological process of moving from an abstract concept to more specific and concrete measures to yield policy intelligence". In this research, the abstract concept is flood resilience. It is important that the indicators characterize flood resilience and are measurable in cities. Next to the specific indicators, several contextual variables of resilience were selected by reading the articles. These contextual variables are defined as dimensions that define resilience but are not directly measurable and operational in practice. The conceptual variables of resilience were not used as indicator but strengthened the operational definition of resilience and were helpful in dividing indicators in dimensions of resilience. The indicators and conceptual variables were linked in Atlas.ti by using the network function. This function enabled to cluster indicators in dimensions of resilience.

Interpretation

The selection of indicators depends on my interpretation since I decided in a systematic review which terms could function as indicators. The choice for selecting and coding an indicator was mainly based on the context in which an indicator is stated. When a specific measurable term was mentioned to characterise resilience, I selected the term and coded it as an indicator. For coding an indicator, the link with flood resilience should be described. This is interpreted by thoroughly reading whether the term was used as component of resilience or just as characteristic of flood risk management in general. This method of analyses requires to read sentences in a wider context.

Content analysis

I tried to limit the coding of the same indicator in one article to avoid a skewed view on the amount of indicators in the total selection of the flood resilience literature. For example, Andrew et al. (2015) identified the term 'resourcefulness' as key element of resilience in six sentences with the same meaning. Also coding this indicator six times would give a misrepresentation of the occurrence of 'resourcefulness' in total resilience literature. Therefore, this indicator was coded once and when another author also mentioned it, it was coded again. A list with all the indicators was copied from Atlas.ti to Microsoft Excel as file with data.

2.2.4 Development of the framework

The list of all coded indicators presented the frequency of the indicators and conceptual variables in resilience literature. The development of the resilience framework was inspired by the Adaptive Capacity Wheel of Gupta et al. (2010). The form, structure and function of the resilience framework are based on the Adaptive Capacity Wheel. This wheel contains indicators clustered in different dimensions of adaptive capacity. The details and the working of the wheel will be further explained in chapter 3.3 but based on this wheel I decided to operationalize resilience in 5 resilience dimensions that enabled the clustering of indicators. The dimensions of resilience were the basis for the development of the framework. As described in paragraph 2.2.3, I used the network function in Atlas.ti to present the relation between conceptual variables (dimensions) and indicators. The division of indicators in different dimensions provided overview in the framework and presented the different components of resilience. For each of the dimensions, the 4-5 most frequently coded indicators were added which resulted in the resilience framework. I decided to use a maximum of 20 indicators in the framework to ensure an uncluttered framework and an easy manageable instrument for monitoring. Next, it is possible to cover the content of resilience with 20 indicators.

Operational definitions of indicators

In order to use the indicators as measurement tools, they had to be specific and measurable in cities. Although this criterion was applied for the selection of indicators in the literature review, most indicators needed extra specification on how they could be measured in cities. The formulation and explanation of the indicators was performed in such a way that people from different countries can understand what is meant by the indicator. However, the specific interpretation of indicators might differ per stakeholder so therefore operational descriptions were added. These operational descriptions sharpened the definitions in a way it is clear what aspects of a city can be measured to score the specific indicator. This was performed by reading the codes again and including the descriptions of measurements that were associated with these definitions. For example, the indicator emergency management was made operational by adding the description: "Availability of warning systems, evacuation plans, aid coordination procedures" (Hamilton 2009). In this way, it became clear how the indicator could be measured in cities without changing the meaning of the indicator. The operational descriptions added information that could not directly be derived from the original definitions of the indicator from literature review but is necessary to use indicators for measuring resilience. The operational definitions can be found in chapter Results, table 3.3.

2.3 Case study research.

Two case studies were performed in order to test the developed framework in practice. The case studies might deliver improvements of the framework in terms of sharpening of indicators or adding of indicators.

2.3.1 Case study research

A case study is a common way of research in planning because a specific situation can be highlighted and analysed in detail (Creswell 2014). Monitoring resilience in delta cities is a form of studying location-specific characteristics. As mentioned before, the situation in one delta can differ greatly from another one in terms of culture, wealth, and knowledge. Studying context dependent situations asks for thinking outside boundaries. Not all information can be generalized (Flyvberg 2001). Therefore, it is important to notice that data from different contexts needs to be put in perspective and discussed to distinguish and clarify the differences.

2.3.2 Case selection

The website of 100 resilient cities and the books of Connecting Delta Cities (Aerts et al. 2009) were used to find information about the challenges global delta cities face in order to select two cases for the application of the framework. The amount of case studies is limited to two, because this research is a search for indicators and the development of a resilience framework. Cases were selected based on a clear difference in culture (ethnic culture and planning culture). The difference in planning culture determines how cities deal with landscape adaptation to climate change by spatial planning. The differences in spatial planning can provide insights in the functioning of the framework in situations with different planning methods. The other criterion for selection was the availability of data about both cities. The availability of data is required about the cities is required to test the framework and get insight in the flood resilience of both cities. Rotterdam and Dhaka were selected as the two cases for advancing the measurement of flood resilience. Rotterdam was chosen because of its rich experience in adaptation to climate change. In Rotterdam, climate change adaptation is performed by multiple physical and institutional measures which are also documented in plans and articles (Aerts et al. 2009; Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017). Rotterdam is an appropriate city to test the framework because of its distinctive adaptive way of planning and the availability of data about the city.

Dhaka is chosen because of the high priority of flood risk management in the city. Relative sea level rise is expected to continue and the water discharge of Bengal rivers is a continuous concern. The low location and the yearly rainy season resulted in a high frequency of urban floods in the past (Stalenberg &Vrijling 2009). Therefore, the implementation of flood resilience in Dhaka is highly required. The planning culture in this city is 'traditional' compared to the adaptive way of planning in Rotterdam (Khan 2016). Since Dhaka is very vulnerable to flooding, many (international) experts are working on flood risk management in Dhaka. This available expertise makes Dhaka an appropriate case for this research since the experts can be consulted to give their opinion about resilience monitoring that helps to answer the research questions. Regarding to the insights on the flood resilience of both cities, recommendations for resilience improvement in Dhaka can be based on insights of Rotterdam and vice versa.

2.4 Case study Rotterdam

The case study in Rotterdam was performed by an operation of the indicator framework to analyse its functioning in practice for the first iteration.

2.4.1 Collecting the data

The following data sources were used to find information about the resilience indicators in Rotterdam: policy documents, laws, assessment reports, statistical websites and scientific articles about the city. These sources were reviewed to find information about the occurrence of the indicators in Rotterdam in order to score the indicators. A criterion for the use of documents was their recentness since monitoring was intended to give relevant insight about the resilience of the city of today. The data were found by web search, a search operator that combined the specific indicator with the word 'Rotterdam'. For example, searching for 'Protection of critical infrastructures Rotterdam' led to a policy plan of the municipality of Rotterdam and a Water plan that describes the current state of affairs related the critical infrastructures and the way it should be improved (Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2012).

2.4.2 Analysing the data

The next step was to analyse the collected data to score the indicators of flood resilience for Rotterdam. I scored the indicators from 1-5 (from absent to very high) based on their occurrence in Rotterdam as described in the documents. In order to increase the reliability of this method, several documents with information on the indicator were compared. In this way, the scores were never based on a single document. When several sources confirmed the occurence of a specific indicator to a large extent, the indicator was scored high (4). It differs per indicator what can be seen as 'high'. For example, the Beleidsplan Crisisbeheersing 2014-2017 (2013 p.6) identified "infrastructure, embankments, water supply and chemical industry" as vital infrastructure and explained the existing safety measures for these sectors. I compared this information with data from the Beleidsplan Veiligheidsregio Rotterdam-Rijnmond (2012) that confirmed the high protection of critical infrastructures in Rotterdam but stated that there was still room for improvement. Therefore, I scored the indicator 'Protection of critical infrastructures' with 4, which means 'high protection' and not with 5 (very high) since there was still room for improvement. When documents contradicted each other on the occurrence of an indicator or when they noticed a medium availability of the indicator, the score was medium. The quantification of indicators also simplifies the comparison of flood resilience within and between delta cities. Still, it was a form of relatively measuring since most values are relative and not absolute. Converting qualitative data into low, medium and high scores gives the score according to the person who scores the resilience indicators. Data about the country that also applies to the city (e.g. safety standards or building codes) was used for the quantification of that indicator when specific data on the city could not be found. When data on a specific indicator were lacking, no score was given. I could have decided to give a low score when information was lacking but this is only based on assumption and the main goal of this case study was to improve the resilience framework. The scores and sources of information about the indicators were placed in tables and an explanation of the scores was added.

2.4.3 Insights for the coherence of the framework

The case study research was related to the second sub question. The framework was used to test the coherence of the framework by assessing the occurrence of the indicators in Rotterdam. After the case study, I noticed the immeasurable indicators and explained why these indicators could not be scored. This can be caused by a lack of data about the indicator or an unclear description of the indicator what makes it difficult to measure it. I decided not to directly improve the framework based on this single case study since the next step was a feedback workshop on the framework with expert in the case study Dhaka. After feedback from experts on the framework was collected, a comparison between the insights from the case study in Rotterdam and the suggestions of the experts was made. The refinement of the framework is related to the third sub question and will be described in the methodology about the case study in Dhaka. After I refined the framework, it was used to measure the flood resilience in Dhaka.

2.5 Case study Dhaka

The case study in Dhaka was performed by a multi-method approach. The case study consisted of two steps. First, I describe the data collection and data analysis methods for the refinement of the framework. This was performed by means of a workshop with experts and led to a new version of the framework. This refined framework is used to measure flood resilience in Dhaka. Next, I describe the data collection and analysis methods for the assessment of Dhaka's flood resilience. This was performed by means of surveys, interviews and a document study.

2.5.1 Collecting data for refinement of the framework

The data for improvement of the framework consisted of feedback on the indicator framework by experts in water management. I decided to organize a workshop as the method to gain data for improvement of the framework (Berg 2009). In the workshop, attendants could react on each other's comments on the framework. In this way, the indicators could be sharpened. The workshop was held in the Institute of Water Modelling in Dhaka. In total, 30 people were invited. The invitees were all experts that worked on water management and spatial planning at the Institute of Water Modelling. These experts were from different divisions that dealt with water issues in Bangladesh. Their difference in division could provide a multifaceted view on flood resilience.

Selection of invitees

The selection of the participants was based on a group representing the fields of flood risk, management, spatial planning and governance since these are the disciplines that deal with flood resilience improvement in cities. The representatives were experienced in water modelling and writing advices for improvement of water management in Dhaka. Table 2.2 shows the divisions and the amount of representatives at the workshop, in total 18 representatives were present. Their names and functions are attached to appendix 2.

Table 2.2 - Amount and background of attendants at workshop

Division	Representatives
Flood Management Division (FMG).	5
Directors of Institute of Water Modeling	2
Engineering Division (REN)	3
Survey & Data Division (SDT)	2
Water Resources Planning Division (WRP)	2
Coast, Port & Estuary Division (CPE)	2
River, Irrigation Management Division (IRM)	2
Total	18

Content of the workshop

To derive the data for improving the framework, I started the workshop with an explanation of the framework. I explained the research objectives, the indicators of flood resilience and the operation of the framework. Next, the group was divided into five subgroups. Each group had to discuss the measurability of 3-4 indicators. The feedback from this discussion was trilateral: written suggestions for new resilience indicators, comments on how the definition of indicators could be sharpened and feedback on how the measurability of indicators could be improved. A discussion in small groups enabled to discuss all the indicators in one hour and lowered the threshold for attendants to speak. The attendants formed groups of 4-5 persons and ensured that the different divisions were divided among the groups. To derive the required data for the framework improvement, two questions were discussed:

- What are key elements of flood resilience?

This question was stated to gain data in the form of new indicators of flood resilience. The idea of flood resilience in practice might differ from the theoretical concept of flood resilience and therefore the experts got the change to deliver new resilience indicators.

- Are the indicators in the framework measurable in practice? If not, how could they be sharpened?

In groups of four or five, the experts read the definitions of the indicators and wrote on posters the best way to measure these indicators in delta cities. A table with the indicators and (operational) definitions was provided on the posters so they could easily add their input. This part of the workshop delivered specifications for the definitions of indicators and suggestions how the indicators might be measured in delta cities.

After the discussion in groups, the completed posters were circulated amongst the groups every 5 minutes. Since each group first only discussed 3-4 indicators, the experts now got the possibility to react on each other's posters and add necessary elements for refinement of the framework. After reading the posters with comments of the first group and the explaining table, additions were written on the poster. When all the posters were reviewed by all the groups, there was a moment for questions or remarks before the workshop was closed.

2.5.2 Analysing data for framework improvement

I read all the comments to analyse the data. The comments on the framework were analysed with two criteria for refinement. The first criterion was if the suggested improvements for the framework contributed to the objective of the framework: measuring flood resilience in delta cities. For example, an attendant of the workshop noticed: 'water quality could be measured'. However, this comment was not used for refinement of the framework since water quality is not part of flood resilience. The second criterion for data analysis was if the input still represented flood-resilience as the ability of a system to withstand or adapt to a flood while keep functioning. I compared the delivered suggestions for new indicators with the reviewed resilience literature. This was done to check if the suggested indicators were consistent with main scientific resilience discourse and not only ideas from experts themselves. Next, additions that sharpened the operational definition of an indicator without changing the meaning of this indicator, were included. Although this data analysis was based on my interpretation, the use of two criteria for refinement of the framework clarified the analysis. Finally, the arguments from experts for suggested changes in the framework were important in deciding if the suggestions were taken into account for refinement of the framework. I refined the existing framework into a new version. A comparison of the insights on the coherence of the framework based on the case study in Rotterdam with the feedback of the experts in Dhaka led to refinements. The comparative analysis was performed directly after the workshop with the experts. The comments that were supported with persuasive arguments and met the two criteria for refinement were converted into refinement for the framework. Suggested additional indicators that represented flood resilience were added in the framework. Immeasurable indicators were sharpened in their definition or left out when there were no data about this indicator. Based on the comments on the measurability of the indicators I sharpened the operational definitions of indicators in a way it was clear how they can be measured in cities. The sharpened definitions were derived from resilience literature and were added to the list of defined indicators from the systematic literature review. I used this refined framework to perform the measuring of flood resilience in Dhaka.

2.5.3 Collecting data for scoring flood resilience

I conducted a survey with 11 respondents to collect the data collection for scoring the resilience indicators in Dhaka. To gain as much data as possible, I chose to use digital anonymous surveys since these could be send to a large group of experts. The surveys were created in Google form (an online tool to make digital surveys and forms). The survey allowed stakeholders in the field of water management, spatial planning and governance to assess how Dhaka performs on resilience. The survey started with an explanation of the framework and the procedure for scoring the indicators with an ordinal 5-point scale. All the answers on the questions could be supported with arguments. Finally, I asked to write down the required spatial and political measures that should be taken to increase Dhaka's flood resilience in the experts' point of view. This delivered the data where the framework can contribute to: provide spatial and policy interventions urban flood resilience improvement. The total list with questions is attached to appendix 3.

Although a digital survey enables to get data from a large group of respondents in a fast way, there was a chance that respondents would not take the effort to provide arguments for their scores. To anticipate on lacking supporting arguments for the scores and to ensure more qualitative information on the occurrence of the indicators, I conducted a semi-structured interview with a key stakeholder in the field of flood risk management: Professor Shah Alam Khan. Although it was a semi structured interview, the list of questions in appendix 3 was used as a guideline for the conversation.

2.5.4 Analysing data for scoring flood resilience

After the experts rated the indicators in the digital survey, I counted the average scores per indicator. All the given scores on an indicator were added and divided by the amount of respondents. Next, I reviewed information from policy documents, assessment reports, laws and statistical data on the indicators in the city. I compared this information with the outcomes of the survey and the interview. This was done to verify if the expert knowledge was consisted with the information in policy documents, assessments and statistics. The document study was performed by reading the documents and analysing how the occurrence of indicators was described. This was an interpretative analysis of information about the indicators. The information on the indicators was converted into a score of absent (1), low (2), medium (3), high (4) or very high (5). When the information from the document study confirmed the score given by the expert, the score was unaltered. If there was a discrepancy, the end score of the indicator was averaged (on whole numbers) between the two sources and I described the (size of the) discrepancy. In addition, the data from the interview with professor Khan was used to corroborate the arguments on the scores of indicators. The assessment of Dhaka's flood resilience was the first use of the refined framework. Based on the measurability of the indicators in Dhaka and the availability of data, there was decided if and how the framework should be refined.

2.6 Validity of methods

A mixed methods approach might strengthen the validity of the research. Recognizing that research methods have limitations, the use of multiple methods for data collection and data analysis might neutralize the effect of this limitations (Creswell 2014). For example, the method of literature review can result in a too theoretical perspective on flood resilience. Continuing the research with a case study ensures a practical perspective on resilience which neutralizes the limitation of the theoretical perspective from the literature review.

Systematic literature review

In the systematic literature review, I tried to limit the coding of the same indicator in one article. The reason is to avoid a skewed view on the amount of indicators in the total selection of the flood resilience literature. The overall view on indicators from resilience literature was presented most transparent by this way. Sometimes authors cited each other which gave a repeat of exactly the same indicators. Although this problem did not occur frequently, an example can illustrate the method of dealing with this. Lu&Stead (2013) stated that redundancy, strength and adaptability were indicators of resilience and they referred to Godschalk (2003). Exactly the same indicators were already coded after reading Godschalk (2003). Hence another coding of the same indicators would give a wrong image on the occurrence of indicators in the overall resilience literature. This procedure was only applied when authors derived the indicators from already reviewed articles. Oftentimes indicators were identified by the author himself and could be coded without a misrepresentation of their frequency in the total list of articles.

Triangulation

Triangulation is a tool to strengthen the validity of a research (Creswell 2014). In this research, a triangulation of sources was applied to strengthen the research since input was derived from literature, expert knowledge. Literature review, workshops and interviews complemented each other in the development and the test of the framework. Triangulation was also applied to the performance of the framework to quantify the flood resilience of delta cities. The scores from the experts given in surveys were verified with a document study and an interview to see if the data were right.

3. Results

The systematic literature review by means of Scopus and Atlas.ti provided an overview on how the concept 'resilience' is described in scientific literature. In total 107 indicators were derived from the 40 articles. The following paragraphs show the operationalization of resilience where 18 indicators are clustered in 5 resilience dimensions. After the definitions of indicators and dimensions are given, the framework is presented. The last paragraph explains how the framework can be used for monitoring resilience.

3.1 Dimensions

In the review, I found five dimensions of resilience. The first is recovery which is defined by Adewole et al. (2015) as: "The speed and ability of a system to recover from the stressors caused by a disaster". An essential element of resilience is bouncing back to a normal safe state after a flood which is often described as recovering. In resilience literature, the word 'recovery' is used interchangeable with 'response' (Liao 2012; Lu&Stead 2013).

The second dimension is resistance. Resistance is the ability of a community to absorb perturbation and withstand the impacts of flooding (Adewole et al. 2015). Some authors stated resistance as the opposite of resilience since resistance is about withstanding the flood and resilience is about adjusting to the flood (Siebeneck et al. 2015; Stead 2013). However, most authors mentioned resistance as essential part of resilience since a certain amount of withstanding and absorption is needed to prevent a complete destruction (Adewole et al. 2015; Balsells et al. 2013; Liao 2012;).

Adaptability is the third dimension of flood resilience. It is defined as: "The processes of adjustment to actual or expected changes and its consequences, disregarding system boundaries by moving thresholds in order to make the system persist within the same regime" (Blackmore &Plant 2008; Chelleri et al. 2015. According to Restemeyer, Woltjer & Van den Brink (2015), adaptability implies an adjustment to flooding in a way a flood event may come without leaving substantial damage. Therefore, adjustments of the physical as well as the social spheres are required. Adaptability is often focused on the long term (Stead 2013).

The fourth dimension of resilience is the vulnerability of the population. This dimensions shows the close relation between resilience and vulnerability. The vulnerability of the population is the percentage of the population that is vulnerable for many reasons: age above 65 or below 14, people with few asset and low income people. The vulnerability of the population is an indicator of resilience since it represents the lack of resilience in the socio-economic sphere. Vulnerable people are most sensitive to the impacts of a flood since they are less vital and able to save themselves (Siebeneck et al. 2015). Although the indicators in this dimension might be difficult to improve by spatial planning, it gives a good insight in the (lack of) resilience in a city.

The final dimension of flood resilience is the organisational capacity of a system. The definition is "The full range of interaction among stakeholders in flood risk management, functioning of organisations, information management, and public participation" (Joerin et al. 2014; Moench 2014). During a disaster, community networks must be able to survive and function under extreme conditions and therefore this organisational capacity is of main importance for resilience (Godschalk 2003).

These dimensions are the starting point for the development of the framework and for each of the dimensions, the 4-5 most frequently coded indicators were selected for the resilience framework. These indicators were coded at least 6 times in the review.

3.2 Indicators

In the review, I established a list of 107 indicators. From these, I selected the 18 which were mentioned most often in the reviewed articles and could be clustered according to the 5 dimensions. As explained in paragraph 2.2.4 of the methodology 18 indicators cover the content of resilience and ensure an uncluttered framework. Table 3.1 presents the 18 indicators clustered in the different dimensions.

Table 3.1. Dimensions and indicators of flood resilience

Dimensions	Indicators			
Recovery	Emergency management	Resourcefulness	Protection of critical infrastructures	
Resistance	Flood barriers	Absorption capacity	Strength of build environment	Building codes
Adaptability	Self-organization	Learning capacity	Preparedness	
Vulnerability of population	Population density	Population composition	Household assets	Income level
Organisational capacity	Stakeholder cooperation	Access to information	Institutional capacity	Public participation

The dimension recovery is divided in three indicators. Emergency management is defined as the full range of evacuation plans, warning systems and aid coordination procedures in a city (Hamilton 2009). Hospital services and the fire brigade are of main importance in the emergency management. The recovery of a city is also indicated with its resourcefulness. Andrew et al. 2016 defines resourcefulness: "The ability and capacity of organisations to identify, prioritise, and mobilise resources (that is, monetary, physical, technological, and human resources) to meet internal functional needs and the external demands of a local community". Just as resourcefulness, the protection of critical infrastructures also guarantees the continuing of a cities functioning. Critical infrastructures are a set of facilities ensuring necessary services for a city to operate (Barocca 2013). Examples are power-plants, subways, railways, water treatment plants, communication networks and airports. They can be protected by their elevation or the use flood barriers to prevent water to reach the critical infrastructures and cause damage to it.
Flood barriers are part of the dimension resistance. Aerts et al. (2013) explains that physical flood barriers (dikes, dams, sea walls) and natural barriers (e.g. mangrove forest) are measures to protect cities against flooding. However, when a city gets flooded, its absorption capacity determines to what extent the city can continue its functioning. Absorption capacity is the ability of a city to operate in a degraded mode, related to alternatives that can be offered by the system following the failure of one or more of its components (Lhomme 2013). The indicator 'strength of build environment' is the resistance of buildings to flooding caused by their material and building style. The stronger the buildings in an environment the higher its level of resilience (Chan et al. 2012). Next, building codes indicate the resistance of a city. Brown et al. (2012) states "Building codes are prescriptions and implementation on elevation or adaptation of buildings to make them flood-proof". According to Aerts et al. (2013) also choices in the siting and design of both housing and transport systems are part of building codes.

The adaptability of a city is partly determined by the self-organization of its residents. Self-organization is the degree to which individual persons are able to organise themselves or the system in fixing damage and cleaning up without waiting for external help (government or aid agencies) (Djordevic 2011; Liao 2012). Another indicator of adaptability is the learning capacity. According to Lu&Stead (2013): "Learning capacity is the ability to learn from previous floods in the city in order to deal with similar conditions in the future". Examples of learning capacity are educational plans or institutional adaptations related to climate change adaptation based on earlier floods. The preparedness of a city also indicates its adaptability to flooding.

Preparedness was often mentioned in the literature review as characteristic for resilience in general. Since a definition was lacking, preparedness is applied on climate change adaptation and based on assumption defined as the extent to which is prepared for climate change by taking future projections into account in the design of flood protection systems.

The population density indicates vulnerability since a higher population density in an area causes a higher vulnerability to experience harm or damage in case of flooding. The population density is expressed in the amount of people per km^2 (Farhan&Lim 2011). Kotzee&Reyers (2016) defined the population composition as the proportion of the city's population above the age of 65 and below the age of 14 as percentage of the total population in the city. There is assumed that kids and elderly are in general less self-reliant and more vulnerable than mature people.

The third term that indicates the vulnerability of the population is 'Household assets'. Joerin et al. (2014) defined household assets: "The access of households to television, radio, mobile telephone, motorised vehicle, non-motorised vehicle, basic furniture". The income level indicates a person's capacities to deal with the impacts of flooding. Households with greater wealth and features are generally abler to overcome disasters and recover their losses more quickly than poorer households (Joerin et al. 2014).

The dimension organisational capacity was divided in four associated indicators. Resilience is a broad concept and implementation of resilience is the responsibility of different parties. Therefore, stakeholder cooperation is of main importance. Borba et al. (2015) defines this indicator: "Stakeholder cooperation is the interaction among the main stakeholders affected by storm water drainage risks – policymakers and (local) government officials, safety organisations, engineers and NGO's". Access to information is another indicator of resilience. The access to and understanding of information about flooding for policymakers and scientists can help to develop policy and spatial interventions based on climate information (Moench 2014).

The indicator 'Institutional capacity' is defined by Godschalk (2003) as the formal and informal associations that operate in an urban area: schools, organizations, task forces. During a disaster, the community networks must be able to survive and function under extreme and unique conditions which enhances a city's resilience (Godschalk 2003; Joerin et al. 2014).

The last indicator is public participation. Lu & Stead (2013) stated: " Public participation is the ability to involve the public in policy decisions, both in terms of informing the public and responding to concerns from the public". Examples are online citizens' panels and communication of information from policy to residents (Lu&Stead 2013).

3.3 The resilience framework

I translated the five dimensions and 18 associated indicators into a framework to study resilience. I call the framework the Resilience Wheel (figure 3).

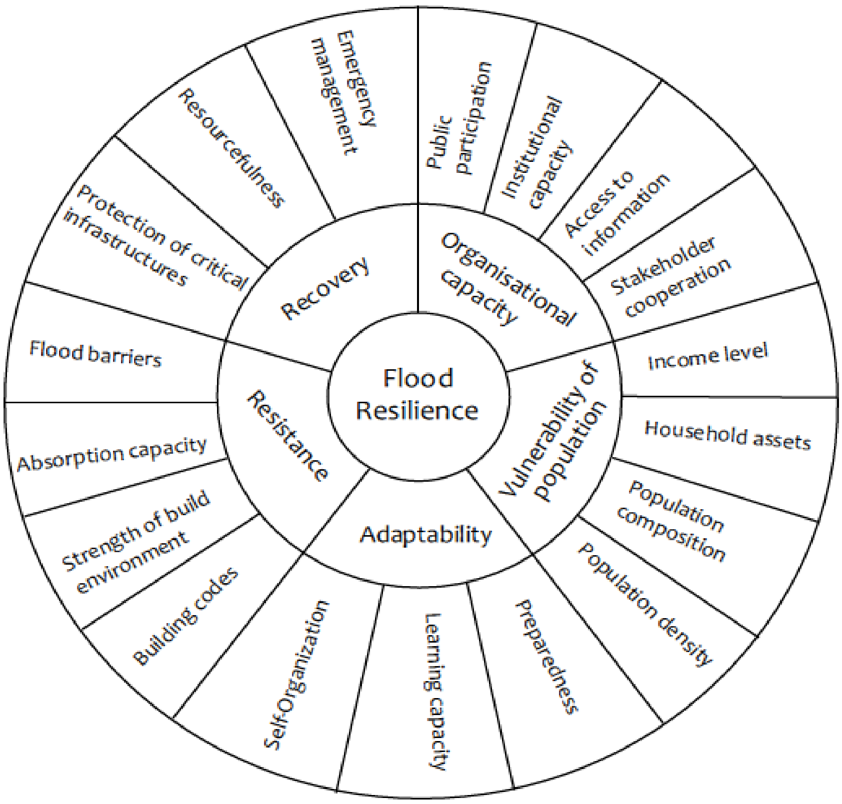

Figure 3 - Resilience Wheel

The form and structure of the Resilience Wheel were derived from the Adaptive Capacity Wheel (Gupta et al. 2010; Van den Brink et al. 2013). The Adaptive Capacity wheel is a tool to diagnose strengths and weaknesses in institutional systems in the capacity to adapt to climate change. It can help academics and social actors to assess if institutions stimulate the adaptive capacity of society and focus where and how institutions need to be redesigned (Gupta et al. 2010). The Adaptive Capacity Wheel also has a division of indicators in overarching dimensions. However, the dimensions and indicators of the Adaptive Capacity Wheel are different than the dimensions and indicators of the Resilience Wheel since the wheels do not present the same topic. Next, the Adaptive Capacity Wheel consists of 6 dimensions and 22 indicators and the Resilience Wheel consists of 5 dimensions and 18 indicators. The dimensions are presented in the first ring. Each dimension of resilience contains a set of criteria as indicators of that dimension listed in the outer ring. The functioning of the Resilience Wheel is also based on the functioning of the Adaptive Capacity Wheel since both wheels are used to diagnose strengths and weaknesses. The Resilience Wheel is not the first framework that presents resilience in different dimensions. An report of Batica and Gourbesville (2014) describes The Collaborative Research on Flood Resilience in Urban Areas (CORFU). This research led to the development of a Flood Resilience Index (FRI). This index consists of five dimensions (natural, physical, economic, social and institutional). One of the main objectives of the index was to evaluate whether an urban community is able to accept a certain disturbance and recover from it. However, this Flood Resilience Index is less suitable for operationalizing and monitoring resilience in delta cities since it does not present an overview of what resilience is. Next, it is a technical assessment tool that delivers scores for resilience based on calculations of weights of different scores. I decided to apply the same weights for each indicator since they all represent resilience to the same extent and equal weights will give most accurate outcomes for resilience measuring.

3.4 Scoring protocol

Monitoring can lead to data that can be used to score the indicators in the Resilience Wheel in the second ring. The Resilience Wheel can be used for the benefit of cities to communicate in what domains the strengths and weaknesses of the city are. Insights in the weak points presents the domains for improvement and insights in the strong points show the aspects of a city where can be built upon. The scoring of indicators will be done by a qualitative and quantitative analysis based on interviews and document studies to rate the indicators with a scale from 1 being absent to 5 being very high. The meaning of the scores and the associated colours that will be used to present the scores in the Resilience Wheel, can be seen (table 3.2).

Table 3.2 - Colour scheme to score the indicators of the Resilience Wheel

Score	Description
1	Absent
2	Low
3	Medium
4	High
5	Very high
	No data

Presenting and communicating the outcomes of resilience measuring is important since flood resilience of a city becomes transparent in a quickly way. Hence, I decided to use colours to communicate how well a dimension or indicator of resilience scores. This could be done with a grey tone but that might not be clear enough. According to Gupta et al. 2010 "Grey shades are non-judgemental and provide a more neutral evaluation". This is because of the less visible distinction in colours. "A traffic light system (where green represents a high score and red a low score) is visually recognizable and communicative" (Gupta et al. 2010). By applying colours to distinguish between low to high resilience, this wheel can be used to both measure resilience in cities and communicate where there may be room for discussion and reform (Van den Brink et al. 2013).

When the necessary data for scoring an indicator were lacking, the box will remain white which means: 'no data'. The particular indicator will neither be included in the average score of the dimension. The scale of 1 to 5 is chosen because of its clarity and its intelligibility by people from different countries. Other possibilities were formulating the questions as statements and let people agree or disagree, the use of different scales (-2 till +2) or the use of a larger scale (1 till 10). In the case of statements, the distinction between agree or disagree would be vaguer and more subjective than the use of numbers. A scale from -2 till +2 is more prone to writing mistakes and typos and a bigger scale (0-10) could make the distinction between scores smaller and less clear than an ordinal 5-point scale.

As described in paragraph 2.2.4, the definitions of the indicators were sharpened in a way it is clear what aspects of a city can be measured to score this indicator. Table 3.3 presents the operational definitions of the indicators and the meaning of the scores.

Table 3.3 - Operationalisation of the indicators based on ordinal scoring

Dimension	Indicator	Operational definition	Score
Recovery	Emergency management	Availability of warning systems, evacuation plans and aid coordination procedures (Hamilton 2009).	1= No availability - 5= Very high availability
	Resourcefulness	The budgeted financial reserves and backups in water & energy (Andrew et al. 2016).	1= No reserves - 5= Very large reserves
	Protection of critical infrastructures	Physical protection or elevation of energy network, traffic routs, water supply, airports (Aerts et al. 2013).	1= No protection - 5= Very high protection
Resistance	Flood barriers	Physical presence of dikes and mangrove forests (Albrito 2012).	1= No flood barriers - 5= Very high flood barriers
	Absorption capacity	Spatial dispersion of shopping centres, stations, water & energy supply sources through the city.	1= Central concentrated - 5= Extremely dispersed
	Strength of build environment	Physical material and design of buildings adapted to flood risk (Albrito 2012).	1= Low strength - 5= Very high strength
	Building codes	Building plans and building regulations adapted to flood risk (Aerts et al. 2013).	1= No building codes- 5= Very extensive building codes
Adapatability	Self-organization	The ability of residents to organize themselves in fixing damage and cleaning up after a flood (Liao 2012). Measurable in flood reports.	1= No self-organization - 5= Very high self-organization
	Learning capacity	Education plans and institutional adjustments to adapt to flooding (Liao 2012).	1= No plans and adjustments - 5= Very extensive plans and adjustments
	Preparedness	The use of future projections in policy and design plans of flood barriers.	1= No use of projections - 5= Very extensive use of projections
Vulnerability of population	Population density	Average residents/km2 in the city (Farhan&Lim 2011).	1= > 15000 pop./km^2 2= 5000-15000 pop./km^2 3= 1000-5000 pop./km^2 4= 500-1000 pop./km^2 5= 0-500 pop./km^2

	Population composition	Proportion of the city population above the age of 65 and below the age of 14 as percentage of the total population in the city (Joerin et al. 2014).	1= 60-75% above 65 or below 14 2= 45-60% above 65 or below 14 3= 30-45 % above 65 or below 14 4= 15-30% above 65 or below 14 5= 0-15% above 65 or below 14
	Household assets	Percentage of the city population owning a radio, mobile phone and car (Siebeneck 2015).	1= 0-20% of city population 2= 20-40% of city population 3= 40-60% of city population 4= 60-80% of city population 5= 80-100% of city population
	Income level	The average annual household disposable income in a city in $ (Kotzee&Reyers 2016).	1= $0-$5000 2= $5000-$10000 3= $10000-$20000 4= $20000-$30000 5= > $30000
Organisational capacity	Stakeholder cooperation	The amount of established collaborations between policymakers and (local) governments, safety organisations, engineers and NGO's (Joerin et al. 2014).	1= No collaborations - 5= Very high amount of collaborations
	Access to information	Availability of information (scientific climate information & risk assessments) to prepare risk reduction (Moench 2014)	1= No access to information - 5= Very high access to information
	Institutional capacity	The amount of formal and informal associations that currently operate in the city: schools, organizations, task forces (Godschalk 2003; Joerin et al. 2014).	1= No associations - 5= Very high amount of associations
	Public participation	The extent of public participation in flood risk reduction policy and measures (Lu&Stead 2013). This can be measured in amount of citizen panels, advisory groups and other participation methods in the city.	1= No participation - 5= Very high participation

3.5.2 Scoring procedure

The monitoring by means of scoring the indicators in table 3.3 can be based on at least three sources. First (in depth) interviews with experts in the field of spatial planning, flood risk management and governance can provide the required information to give a score per indicator. This can be done by asking them to characterize the indicators in their city and give the scores as researcher based on their arguments. Another possibility is to execute a survey and let the stakeholders rate the indicators. The third option is to perform a document study on the occurrence of the indicators in delta cities and give the scores based on the interpretation of information. However, since most of the indicators are qualitative, it remains an interpretative tool and the final score depends on the opinions of the interviewee or the researcher. Therefore, arguments that underpin the given scores are important to verify the scores.

Arguments for the given scores might enrich the discussion for resilience improvements since it is clear why a city has a low score on a particular indicator. The 'hard' indicators can be scored with statistical data (e.g. from the World Bank or OECD). The scores can be processed in the Resilience Wheel that presents with red, yellow and green colours the height of the scores which shows the resilience of the city on each dimension.

Although a part of the scores is quantified to explain what each number means, many of the indicators still have to be scored in a relative rating (low, medium, high). A logical question is: 'High compared to what?' The frame of reference for rating the indicators is international. One of the possibilities of this framework is to enable comparison of international delta cities on their flood resilience. By scoring the indicators with numbers, one should keep in mind that the score will be compared with other international delta cities. Therefore, one should not give a high score to an indicator because it is better than another city in the same country. Although the situation in other delta cities is not exactly known, this international context can guide the rating and improve the comparative function of the framework. Still, there might be a problem with different values within a delta city. For example, the protection of critical infrastructure might be very high in one district and limited in another district of the same delta city. In this case the districts can be compared and scored separately. To come to one score for the entire delta city, both district scores can be averaged.

4. Case study Rotterdam

The study of Rotterdam was conducted to test the usability of the Resilience Wheel. First, some background information on Rotterdam is given to understand the historical situation and the current state of climate adaptation in the city.

Outline of the situation
Rotterdam is located in the heart of the Dutch Delta that is formed by the rivers Rhine and Meuse. The city is developed along the western coastal side of the Netherlands where the river Rotte meets the Meuse. Water has always been of main importance for Rotterdam. Rotterdam has a long history as a harbour city and is still considered as the marine gateway to western Europe via the rivers Rhine and Meuse. Of all the Dutch cities, Rotterdam has the lowest position and for this reason it has been flooded many times throughout history. After the flood of 1953 in which over 1800 Dutch inhabitants drowned, the Delta Works were established. A complex system of dikes, storm, surge barriers and closure dams were all part of the Dutch Delta Plan. Governments and planners are aware of the risks of flooding for the city. Population growth and urbanization in the Netherlands led to an increasing population in Rotterdam. From 2009 onwards, around 10% of the Dutch population growth occurred in Rotterdam (CBS 2016). The Netherlands is a developed country and the strong economic situation facilitates multiple possibilities for climate change adaptation (Lu & Stead 2013). To turn the water challenges in Rotterdam into opportunities, the project Rotterdam Water City 2035 was developed. The main thought of this project is that water will make the city attractive for work, living and investment (Vonk 2006).

4.1 Scoring flood resilience of Rotterdam

The scores for Rotterdam are based on a document study and statistical data about Rotterdam. Below, I will discuss the scoring based on the indicators. The adjoining tables contain the sources that were used give the ratings.

4.1.1 Recovery

The dimension 'Recovery' is divided in the indicators 'Emergency management', 'Resourcefulness' and 'Protection of critical infrastructure'.

Emergency management
There is a Medical Emergency Assistance Organization in Rotterdam that is responsible for preparation, coordination and control of medical assistance. During a crisis, this organization controls the medical assistance (Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017). Rotterdam has 56 emergency plans that can be executed in times of crisis. However, these plans are barely tested in practice since hazards are not very common. In case of hazards, there is a Commando Place Incident (COPI) where municipal services, fire brigade, police and Medical Emergency Assistance Organization are represented for fast rescue and relief (Gemeente Rotterdam 2016). This extensiveness of emergency services was interpreted as high availability of emergency management and resulted in a four. The operation of emergency management during flooding is not proved and therefore the score is not five (very high).

Resourcefulness
According to the Sustainable Cities Water Index (2016), Rotterdam is amongst the highest cities in the world in water reserves. There have been heavy investments in the reservoir catchment system. However, the Delta Commission Report (2008) noticed that the fresh water supply is limited in The Netherlands. This resulted in a strategy to improve water supply. Energy supply is concentrated in the harbour area of Rotterdam where different sources of energy can be approached (coal, biomass, heat, steam). However, there are no backups of energy since the storage of energy is not achieved (Port of Rotterdam 2016). The

financial plans of Rotterdam for 2015 and 2016 contained small budgeted reserves for specific goals (e.g. spatial development, safety). The use of these reserves led to a shrink of the total reserves. Special budget for crisis management was not found but there is a small general reserve (€58 340) which is applicable and can be used in times of crisis. €4,5 million is budgeted for unforeseen costs. The province and the national government can also support Rotterdam in times of flooding but the own budgeted reserves for flooding are limited and therefore interpreted as small reserves leading to the score two (Conceptbegroting 2016 Gemeente Rotterdam; Programmabegroting Rotterdam 2015).

Protection of critical infrastructures
12,000 hectares of land in Rotterdam have been elevated several meters above sea level to protect Rotterdam from flooding. The essential harbour area was part of this elevation. The safety norm of the Dutch coastline is 1:10.000 which means the coastline can withstand a flood with a probability ('return period') of 1/10,000 years (Aerts et al. 2009). A policy document, 'Waterplan Rotterdam 2' states there is extra attention for protection of critical infrastructures as communication nodes and electricity supplies in the design of areas outside the dike. However, scenarios in the Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017 conclude that vital infrastructures like the electricity network would be damaged in case of flooding from the North Sea. Still, the policy documents described high protection methods and therefore the protection of critical infrastructures scores four. Table 4.1 summarizes the scores and the sources that were studied to quantity the indicators of the dimension 'Recovery'.

Table 4.1 - Quantification of indicators for recovery.

Dimension	Indicator	Score for Rotterdam	Source
Recovery	Emergency management	4= High availability	-Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017 -Website gemeente Rotterdam
	Resourcefulness	2= Small reserves	-Conceptbegroting 2016 Gemeente Rotterdam -Programmabegroting 2015 Gemeente Rotterdam -Sustainable Cities Water Index (2016)
	Protection of critical infrastructures	4= High protection	-Gemeente Rotterdam, Waterplan 2013 -Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017

4.1.2 Resistance
The dimension 'Resistance' is divided in the indicators 'Flood barriers', 'Absorption capacity', 'Strength of build environment' and 'Building codes'.

Flood barriers
The Maeslant Storm Surge Barrier protects Rotterdam in the case of an extreme flood event. This flood barrier was part of the Deltawerken that were developed to protect the south-western part of the Dutch coastline against flooding (Dircke et al. 2013). The other dikes along the coastal side of Rotterdam are more than 10 m in height (Aerts et al. 2013). The safety standards are maintained, thus it is expected that the strength and height of the dikes will be sustained. This information is interpreted as very high flood barriers resulting in a score of five in the Resilience Wheel of Rotterdam.

Absorption capacity

The spatial dispersion of essential functions in a city determines the absorption capacity. In Rotterdam, the shopping centres, railway and metro stations are dispersed along the entire city (Gemeente Rotterdam 2013). This division improves the flood resilience of Rotterdam. The energy supply is concentrated in the harbour area. However, since the harbour area is large, the essential functions are still fairly dispersed and therefore the risk of complete damage of essential functions is limited (Port of Rotterdam 2016) (figure 4.1). The dispersion of essential functions is interpreted as high and therefore the absorption capacity is rated with four. Because the concentration of essential functions in the harbour area, this indicator is not scored with five.

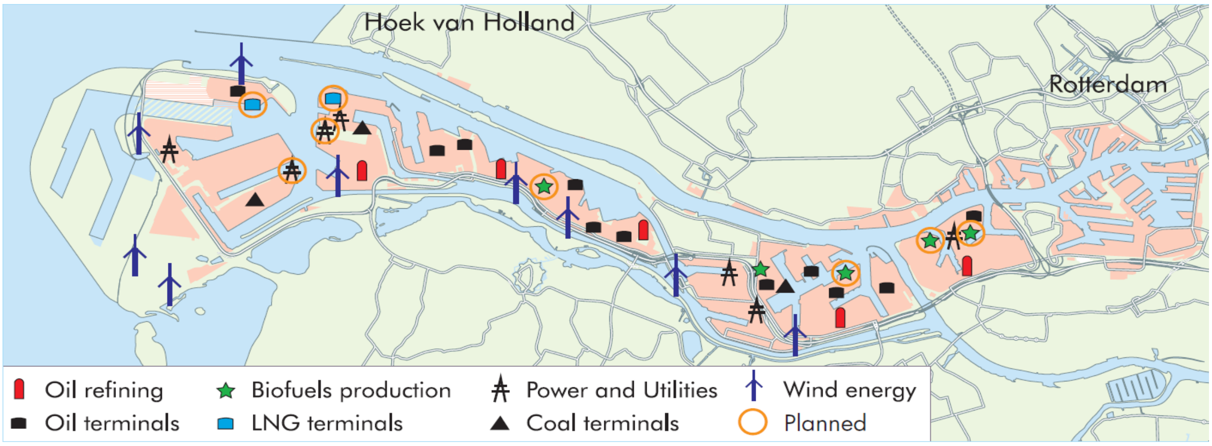

Figure 4.1 - Map with the essential functions in the Rotterdam harbour area which shows that the distribution of functions is dispersed.

Strength of build environment

According to the Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017, Rotterdam emphasises robust building. I assumed that Rotterdam has a strong build environment since its city centre is relative new because it was completely rebuilt after bombing during WW (Gemeente Rotterdam). Most buildings are made of strong materials as stone, concrete and steel. Due to building codes, buildings are developed robust and therefore the strength of the build environment scored four in Rotterdam. The assumption on the strong build environment because of the rebuilding after WWII could not be supported by literature and therefore the score is not five.

Building codes

According to the policy document 'Waterplan Rotterdam 2', there is an adaptive way of building in areas outside the dikes in Rotterdam. The municipality stimulates development of houses on stilts, designing of floating houses and flood-proof houses (Gemeente Rotterdam 2013). The protection system around Rotterdam is designed to withstand a storm estimated to occur once in every 10.000 years. The design surge level is determined at 4 meter. Both surge levels and breaking wave heights are taken into account in building of dikes and harbour buildings (Lu&Stead 2013). Because the strict building codes are mainly applied on dikes and less on housing, this indicator is not scored with 5 but with 4 meaning that building codes are extensive (Gemeente Rotterdam 2013). Table 4.2 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Resistance'.

Table 4.2 - Quantification of indicators for resistance

Dimension	Indicator	Score for Rotterdam	Source
Resistance	Flood barriers	5= Very high flood barriers	-Dircke et al. (2013) Connecting Delta Cities 1 p.20 -Aerts et al. (2013)
	Absorption capacity	4= Highly dispersed	-Gemeente Rotterdam (2013) -Port of Rotterdam (2016)
	Strength of build environment	4= High strenght	-Gemeente Rotterdam 2013 -Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017
	Building codes	4= Extensive building codes	-Lu&Stead (2013) -Gemeente Rotterdam 2013

4.1.3 Adaptability

The dimension 'Adaptability' is divided in the indicators 'Self-organization, 'Learning capacity', 'and 'Preparedness'.

Self-Organization

Authors of the Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017 state: "better risk communication will lead to a higher self-organization of residents". However, the high safety standards and good protection against flooding makes that resident disregard a serious risk of flooding and therefore highly depend on emergency services in times of flooding. The Beleidsplan cirisisbeheersing 2014-2017 emphasizes the necessity of increasing self-organization despite of the existing preventive measures against flooding. Although the self-organization might increase, the current state of self-organization is limited which means that the score is two.

Learning capacity

The flood of 1953 made clear that extensive flood protection was required in The Netherlands. The installation of a Delta Committee, a Delta Law and Delta Plan were actions to prevent such a disaster to happen again (Delta Commissie 2008). In addition, the high water levels in 1995 led to the program 'Ruimte voor de Rivier' since it was clear that the river should get more space instead of heightening the dikes (Lu&Stead 2013). Emergency services such as the fire brigade and hospital services evaluate their actions after a hazard with the objective to identify learning points (Beleidsplan Crisisbeheersing 2014-2017). The document study presented multiple ways of learning capacity in Rotterdam which is interpreted as a very extensive learning capacity resulting in a five.

Preparedness

Dircke et al. (2013, p. 12) stated "facing the future probability of flooding, reinforcing flood protection is an ongoing concern in Rotterdam and the Netherlands". Future projections also play an important role in the project Rotterdam Water City 2035. Spatial ambitions for 2035 are based on probabilities and scenarios for the (nearby) future (Vonk 2009). Next, several reports (e.g. Rotterdam Climate Proof 2009 and 2010) are forecasting on sea level rise for the development of dikes and flood protection. This large amount of future projections was interpreted as a very extensive preparedness and therefore results in a score of five for the Resilience Wheel of Rotterdam. Table 4.3 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Adaptability'.

Table 4.3 - Quantification of indicators for adaptability.

Dimension	Indicator	Score for Rotterdam	Source
Adaptability	Self-organization	2= Limited organization	-Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017 -Gemeente Rotterdam 2013 -Beleidsplan Crisisbeheersing 2014-2017
	Learning capacity	5= Very extensive plans and adjustments	-Lu&Stead (2013): A case study of Rotterdam -Delta Commission Report (2008) - -Beleidsplan Crisisbeheersing 2014-2017
	Preparedness	5= No use of projections	-Vonk (2009) Rotterdam Water city 2035 -Dircke et al. (2013): Connecting delta cities 1 -Lu&Stead (2013): A case study of Rotterdam

4.1.4 Vulnerability of Population

The dimension 'Vulnerability of Population' is divided in the indicators 'Population density', 'Population composition', 'Household assets' and 'Income level'. These are hard indicators which means that the scores can be classified in numbers instead of a relative scale from absent to very high.

Population density

The population density of the city Rotterdam is 2960/km^2. The data were retrieved from the Dutch Centre for Research and Statistics (CBS). This population density is high for Dutch terms but medium compared to other international delta cities. The associated score is three, which means that Rotterdam has a medium population intensity.

Population composition

The proportion of the population above the age of 65 and below 14 indicates the vulnerability of the population in case of a flood. Elderly and kids are generally less resilient against harsh conditions than mature people are (Kotzee & Reyers 2016). According to the Dutch Centre for Research and Statistics (CBS), the proportion of residents below 14 is 22% and the proportion of residents above 65 is 15%. Adding both percentages results in a percentage of 37% above 65 or below 14 score. This percentage is in the third category for the population composition. This means that Rotterdam has a medium population composition without extreme aging or rejuvenation.

Household assets

There were no specific data about the household assets of Rotterdam. The international database of World Bank provided information about financial household assets, but percentages of the population with a radio, mobile phone and car, were lacking. It was possible to do assumptions for the rating of this indicator based on the financial assets but this could not be underpinned with good arguments. Therefore, this indicator is not rated.

Income level

The income level is expressed as the annual disposable household income in $. This parameter indicates the vulnerability of households since it says how much money households can spend in dealing with flooding. The consulted sources for scoring this indicator in Rotterdam resulted into different values. A socio-demographic study on Rotterdam showed a disposable income of $33255 (rate of exchange Euro/USD 1,1174) (Feitenkaart Rotterdam 2010). The Dutch Centre for Research and Statistics (CBS) showed a disposable income of $34935 for Rotterdam in 2014. Statistics from OECD noticed an average disposable household income of $27759 but this was based on data from The Netherlands in general. Although these data differ, their average is still above $30000 which is interpreted as a very high income level leading to the score 5. Table 4.4 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Vulnerability of Population'.

Table 4.4 - Quantification of indicators for vulnerability of population.

Dimension	Indicator	Score for Rotterdam	Source
Vulnerability of population	Population density	3= 1000-5000 pop./km²	-Centre for Research and Statistics (COS) -http://www.oozo.nl/cijfers/rotterdam Population density: 2960 /Km²
	Population composition	3= 30-45% above 65 or below 14	-CBS.nl -Gemeente Rotterdam Bevolkingsprognose 0-14 = 22% 65> = 15% 22+15 = 37%
	Household assets		-No specific data
	Income level	5= >$30 0000	-OECD (2016) -Gemeente Rotterdam (2012) -CBS.nl

4.1.5. Organisational Capacity

The dimension 'Organisational capacity' is divided in the indicators 'Stakeholder cooperation', 'Access to information', 'Institutional capacity' and 'Public participation'.

Stakeholder cooperation

The Delta Commission Report (2008) highlights the importance of inter-sectoral collaboration for water management in the Netherlands. There are collaborations between politicians and scientist, and between local, regional and national governments (Raadgever 2013). In addition, the balance between spatial and technical measures in and around Rotterdam requires cooperation between planners, decision makers and engineers (Lu&Stead 2013). The 'Waterplan Rotterdam 2' (2013) states that stakeholder cooperation is high, but can be improved. Based on the aforementioned reports, the stakeholder cooperation is scored with four.

Access to information

Authors of the document 'Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017' address scientific studies of climate change and scenario making that can be used in in risk assessment and scientific scenarios. This is an example of accessible climate information that can inform policymakers for climate adaptive policy. The KNMI provides climate information for decision-making (KNMI 2016). The Knowledge for Climate programme is an important scientific initiative to provide information on climate impacts and ensure climate adaptability will be taken into account in governance decision-making (Lu&Stead 2013). The Beleidsplan Crisisbeheersing 2014-2017 describes the risk communication from government to residents. However, according to the same document, there is information management at the ministry of Infrastructure and Environment but it is too fragmented. This information is interpreted as a high access to information from different sources and therefore scores a four.

Institutional capacity

It proved impossible to score the institutional capacity with a document study since there was no specific data about the amount of active organisations in Rotterdam. Next, it was not defined what were high, low and medium amounts of organisations. Although experts of delta cities can estimate this indicator, the test case of Rotterdam revealed that rating the institutional capacity from literature was not possible and therefore this indicator is not scored.

Public participation

A best practice in Rotterdam is that it organises participatory processes in order to find solutions together with the public housing companies, projects developers, businesses/industries and inhabitants (Raadgever 2013). In the 'Beleidsplan Crisisbeheersing 2014-2017' the network management between all the participants is emphasized as participative element. The 'Waterplan Rotterdam 2' noticed the objective of public participation improvement what was interpreted as a current public participation that can be improved. Next, the report of OECD quantified the participation in Rotterdam (i.e. involvement in decisions, right to vote) with 6,3. Based on the information from aforementioned documents the public participation in Rotterdam scores three. Table 4.5 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Organisational capacity'.

Table 4.5 - Quantification of indicators for organisational capacity

Dimension	Indicator	Score for Rotterdam	Source
Organisational capacity	Stakeholder cooperation	4= High amount of collaboratoins	-Delta Commission Report (2008) -Raadgever (2013): Report on the European Climate Change Adaptation Conference -Gemeente Rotterdam, Waterplan 2013 p.44
	Access to information	4=High access to information	-KNMI 2016 -Lu&Stead (2013): A case study of Rotterdam -Beleidsplan Veiligheidsregio Rotterdam-Rijnmond 2013-2017
	Institutional capacity		No specific data
	Public participation	3= Medium participation	-Raadgever (2013): Report on the European Climate Change Adaptation Conference -Beleidsplan Crisisbeheersing 2014-2017 -Gemeente Rotterdam, Waterplan 2013 p.32

4.2 Conclusion

The case study on Rotterdam was conducted as a test for the framework and to give insights in the strengths and weaknesses of Rotterdam based on document studies.

4.2.1. Usability of the framework

The resilience framework with indicators proved successful in measuring flood resilience in Rotterdam. 16 of the 18 indicators could be scored using policy documents, assessment reports and statistical data. It succeeded to score them because these 16 indicators were formulated in a way it was clear how they can be measured. The other reason for this successful assessment was the availability of data on the 16 indicators in policy documents, assessment reports and statistical data. It succeeded to read information, interpret the data and convert it into a score. Next, the amount of indicators in the framework ensured a clear view on the flood resilience of Rotterdam and enabled an easy manageable instrument for measuring resilience. However, it is necessary to test the framework also in another context. This can deliver insights in the findability of data about indicators in other cities. Conversations with experts in the field of flood risk management can be used to check if the set of indicators covers the content of flood resilience according to them.

It appeared that household assets and institutional capacity of Rotterdam could not be scored. The problem with institutional capacity is that it has a very broad and vague definition. Godschalk (2003) and Joerin et al. (2014) defined institutional capacity as: '*The amount of formal and informal associations that currently operate in the city: schools, organizations, task forces etc.*'. It is not clear what is defined as an association and what is not. Next, informal associations might be unknown and therefore untraceable for the quantification. An iteration of testing this framework in Dhaka will reveal if the institutional capacity can be sharpened into a measurable indicator or if it is better to remove this indicator. Also the household assets of Rotterdam could not be found in this study. The wording of 'household assets' seems quite short and clear: '*The percentage of the city population owning a radio, mobile phone and car*' (Siebeneck 2015). It was defined in a quantified way enabling the researcher to find data and statistics about the city. However, it did not succeed to find the data to quantify this indicator. The combination of three forms of asset (radio, phone and car) into one indicator makes it difficult to find related data. The framework will not be changed based on one measurement moment where one method was used (document study). In the second case study, this framework will be reviewed by experts. The second case study will reveal if the indicator 'Household assets' can be changed or should be omitted in the final version of the Resilience Wheel.

4.2.2. Flood resilience of Rotterdam

Based on the method of Gupta et al. (2010), the scores of the indicators were added in the Resilience Wheel. The average score of the dimensions are determined by calculating the scores of the indicators and dividing it by the amount of indicators of that dimension. They are round off to two decimals to clarify the specific average for each dimension since these scores represent the score of several indicators. The two indicators without data (household assets and institutional capacity) were not scored and therefore, these indicators are neither included in counting the average scores. Figure 4.2 is the Resilience Wheel presenting the outcomes of the indicators for Rotterdam.

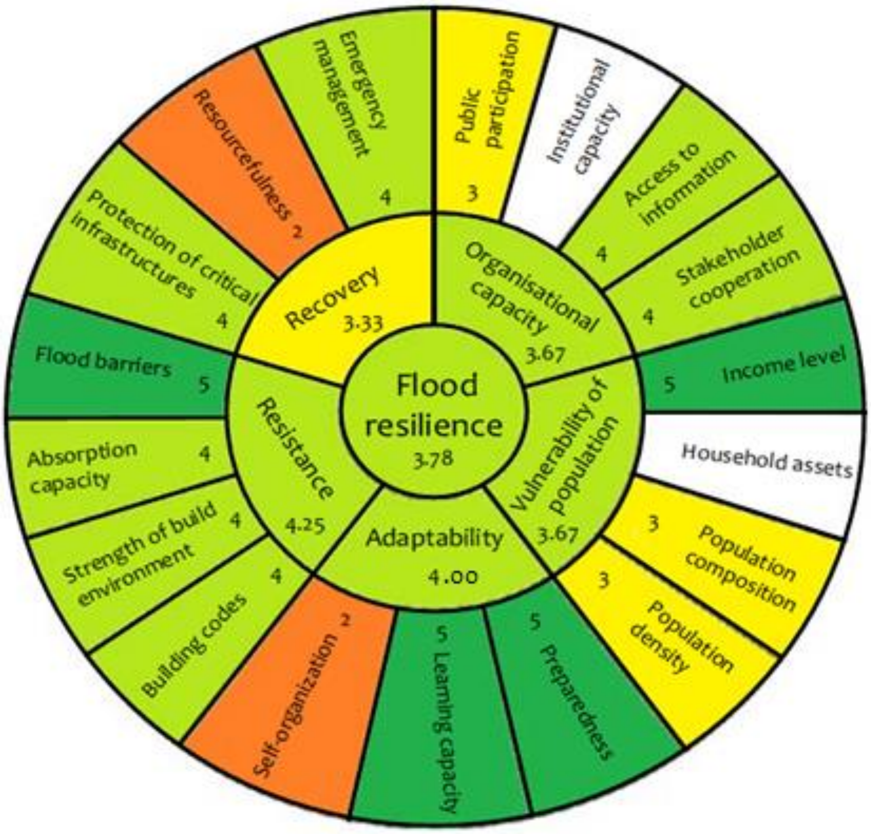

Figure 4.2 - Application of the Resilience Wheel to Rotterdam.

Rotterdam has an overall score of 3.78 for the city's flood resilience based on the document study on the indicators from the Resilience Wheel. A score of three was defined as medium and a score of four was defined as high, hence the score of 3.78 is a medium-high outcome for Rotterdam. The dimension 'Resistance' got the highest score (4.25). This reflects the emphasis of Rotterdam on physical protection against flooding. Flood protection in Rotterdam aims to lower or exclude the probability of a flood to happen. This is indicated by the high flood barriers and building codes. However, when a flood does appear in Rotterdam, the city can also adapt to it. Adaptability had the second highest score with an average of 4.00. This score was caused by high scores on learning capacity and preparedness. The low score on indicator self-organization (2), makes that adaptability does not have the highest score. Both the dimensions 'Organisational capacity' and 'Vulnerability of population' are scored with 3,67. There are high socio-economic standards in Rotterdam. Rotterdam's population has also a limited vulnerability since the city is not extremely dense populated, and the percentage of vulnerable people (above 65 and below 14) is medium. On an ordinal 5-point scale these scores are high. The score of 3.67 for organisational capacity indicates the importance of cooperation and participation in Rotterdam. The dimension 'Recovery' had the lowest scores (3.33). The lack of budgeted reserves resulted in this lower score for recovery compared to other dimensions. However, there might be financial resources that can be used for recovery after flooding but these were not found in budgeted funds in Rotterdam. The yellow and green colours represent an overall positive score for Rotterdam on its flood resilience. Although Rotterdam has a fairly high score on flood resilience, there are still lessons to be learned. These will be stated in the recommendations at the end of this thesis.

5. Case study Dhaka

The next iterative step in this research was a case study on Dhaka (Bangladesh). The goal of this case study was to refine the measurement of resilience and assess Dhaka on its flood resilience using the refined framework. First, background information on Dhaka is given to understand the physical and socio-economic situation of the city.

Outline of the situation

Dhaka is located in the delta of three rivers, the Meghna, the Padma (Ganges) and the Brahmaputra. This capital city of Bangladesh is one of the fastest growing megacities in the world. Due to the geography of Dhaka (6-8 meter above sea level), the city has always been susceptible to flooding (Walters 2015). Flooding is a threat for Dhaka and Bangladesh in general. National and local governments do not have governance structures or planning methods sufficient to deal with flooding. Most social welfare and poverty relief in Dhaka is carried out by large NGO's as BRAC and Grameen. International donors provide some basic relief after flooding where possible (Walters 2015). Because of poverty, there is a high migration from rural to urban areas, which leads to overcrowding in the cities. A high population pressure in Dhaka results in settlements into very low-lying areas eastern of Dhaka. The majority of these new arrivals are living in slums, which account for around 35% of Dhaka's housing (IGS 2012). Currently, Bangladesh is a rapidly developing country envisaging to become a middle-income country in 2021. In order to deal with the challenges in water safety, socio-economic development and food security, the Dutch and Bengalese government started a cooperation to create the Bangladesh Delta Plan 2100. The objective of this plan is to come to a long-term, integrated and holistic vision where different delta-related sectors are integrated. This Delta Plan describes how adaptive and dynamic planning can be achieved in Bangladesh by taking into account the uncertainties in future developments in climate change, population growth and socio-economic development (Bangladesh Delta Plan 2100).

5.1 Refinement of the framework

As described in chapter 2.5 of the methodology, a workshop with 18 experts from the Institute of Water Modelling was conducted in order to obtain feedback on the indicators of the Resilience Wheel. This chapter presents the results of the workshop and provides the analysis of how the feedback is processed into a new version of the Resilience Wheel.

5.1.1 New indicators of flood resilience

The experts on water management in Dhaka suggested to include the indicator 'Flood shelters' in the Resilience Wheel. Although the city might get flooded and material damage will occur, the availability of flood shelters can lower the amount of human victims during a flood. Flood shelters are defined as high concrete structures located near settlements where flood-affected communities can take refuge during extreme hydrological events (Sanyal&Lu 2009). According to De Bruijn (2005) flood shelters can be widened stretches of embanked roads or roofs of schools, shops or restaurants. Shelters are a typical form of flood resilience from a physical perspective. By means of flood shelters, people can physically resist and survive the flood. For these reasons 'Flood shelters' is included as indicator of resistance in the Resilience Wheel.

The second suggestion of the experts was to include the indicator 'Drainage systems' in the Resilience Wheel. According to the representatives at the workshop, the resilience of a city is partly determined by its constructed drainage system. It indicates the speed of water discharge and therefore the ability to withstand the flood without experiencing a lot of damage in the city. Drainage systems was also two times coded as indicator in the literature review. Two quotations were not enough to select this indicator in the first version of the framework. The indicators in the first framework were coded at least six times in literature. However, the occurrence in literature confirms the suggestion that drainage system is an indicator of flood resilience. Drainage systems are defined as: "All the constructed elements in a city through which water is discharged" (Booth 1991). Hamilton (2009) noticed pipes, ditches, sewerage, pumps and culverts as some examples of drainage systems. A well-functioning drainage system can prevent water logging. This is in line with the definition of flood resilience and fits best to the dimension 'Recovery' since drainage systems attribute to recovering from water logging. Therefore, 'Urban drainage systems' was included as new indicator for resistance.

5.1.2 Refining the measurability of indicators

Next, the measurability of the indicators was discussed at the workshop. The comments of the experts are presented in the tables 5.5 till 5.5. Based on two criteria (representation of flood resilience and improvement of measuring function) was decided if the comments were used for refinement of the framework. Elaborating on all the comments would be a very long digression and therefore the most relevant comments a shortly discussed. The comments are compared with the insights on measurability of the indicators based on the first case study and there is explained how these insights are used to refine the Resilience Wheel.

Recovery

The representatives at the workshop suggested to measure emergency management by means of voluntary services. Voluntary services are part of emergency management and therefore, it was added to the operational definition of emergency management. Next, the operational definition of resourcefulness is sharpened to: the *budgeted emergency fund, recovery funds and reserves in water and energy.* (all the new operational definitions are presented in table 5.1). A critical note of the experts was: '*How much resourcefulness is good?*' However, this cannot be answered because the Resilience Wheel is not a normative tool with good or bad values but a relative way of measuring. Experts in delta cities will have a notion if the funds are high, low or medium from an international perspective. Besides, the costs of emergency and recovery will differ per country and therefore cannot be quantified in fixed classifications in American dollars.

Resistance

The suggestion of the experts to specify 'Flood barriers' into 'Embankments' was incorporated. The argumentation of the representative was that 'Flood barriers' was a very broad concept and natural environmental protection was not used in cities. For measuring a city's flood resilience, the focus on embankments was more practical and better to assess than flood barriers general.

Another point of feedback was to include flood zoning and flood proving to measure the strength of build environment. These terms were already part of indicator 'Building codes' but were not yet stated in its operational definition. Building codes are about the prescriptions on elevation or adaptation, site (i.e. flood zoning) and design of buildings to make them flood-proof (i.e. flood proving) (Aerts et al. 2013). Strength of build environment is about the physical resistance of buildings to flood because of their building style and material. Therefore, flood zoning and flood proving are included in the operational definition of building codes.

Many comments on indicator 'building codes' emphasized the measurability of building codes in plans, laws and policy. This shows that 'Building codes' is an institutional aspect rather than a physical aspect of flood resilience. Zoning and flood-proof designing of buildings therefore

fits better to the dimension 'Adaptability' than to 'Resistance' since building codes are invented to adapt buildings to flooding. The indicator 'Building codes' was moved from the dimension 'Resistance' to the dimension 'Adaptability'.

Adaptability

The experts suggested to measure the education level, willingness an financial capacity of residents to determine the indicator 'Self-organization'. However, a measurement on these parameters cannot directly be translated into a score of their self-organization. The attendants at the workshop defined learning capacity as a relatively measurable indicator based on education, trainings and media attention. Trainings and media attention were added in the operational definition because these are aspects to measure learning capacity.

Vulnerability of Population

Related to the population composition was suggested to measure the capacity of the effective group (15-64) instead of the both parts below 14 and above 65. The suggestion indicated that it is better and easier to measure one resilient group (15-64) than two vulnerable groups (0-14, 65>). The name of the indicator remained the same but the way of measuring is framed in a different way. The proportion of the city population between the age of 15 and 64 was measured as percentage of the total population in the city.

The attendants at the workshop agreed that data on household assets are difficult to find and hard to estimate for experts in the city. Also the case study of Rotterdam revealed that data about the household assets were lacking. It did not succeed to define household assets in a way it indicated the vulnerability of households and was also measurable. Therefore, I decided to omit this indicator in the refined version of the Resilience Wheel.

Organisational capacity

According to the experts, measuring stakeholder cooperation could be performed by looking for coordination meetings among stakeholders and information exchange. These two suggestions are included in the new operational description of stakeholder cooperation. Meetings and exchange of information are indications of cooperation.

Based on the case study in Rotterdam, institutional capacity proved to be a difficult indicator to measure in practice. This indicator could not be scored because data on the amount of organizations in a city were not findable, partly for the reason that 'organizations' was not specified. The suggestions to measure institutional capacity by the number of institution involvement, is not very clear but gives reason for a search on how this indicator could be measured. Therefore, a literature study on institutions was performed to define the indicator 'Institutional capacity' in a measurable way. Zijderveld (2000) states that institutions are not equivalent to organizations, as institutions also refer to underlying norms and values. Gupta et al. (2010) states "Institutional capacity is the set of decision-making procedures, programs and system of rules that give rise to social practices, assign roles to the participants in these practices, and guide interactions among the occupants of the relevant roles". Using this definition for institutional capacity in the Resilience Wheel is possible when the 'decision-making procedures, programs and system of rules' are applied to flood risk management. This definition is adopted for the refined Resilience Wheel. Although the measuring of institutional capacity is still relative, experts can estimate this indicator better than the amount of organizations. Besides, document studies might provide more information on programs and rules related to flood risk management.

5.2 Resilience Wheel and indicators

The iterative step of the workshop resulted in a new version of the Resilience Wheel (figure 5.1) and renewal of the definitions of indicators (table 5.1).

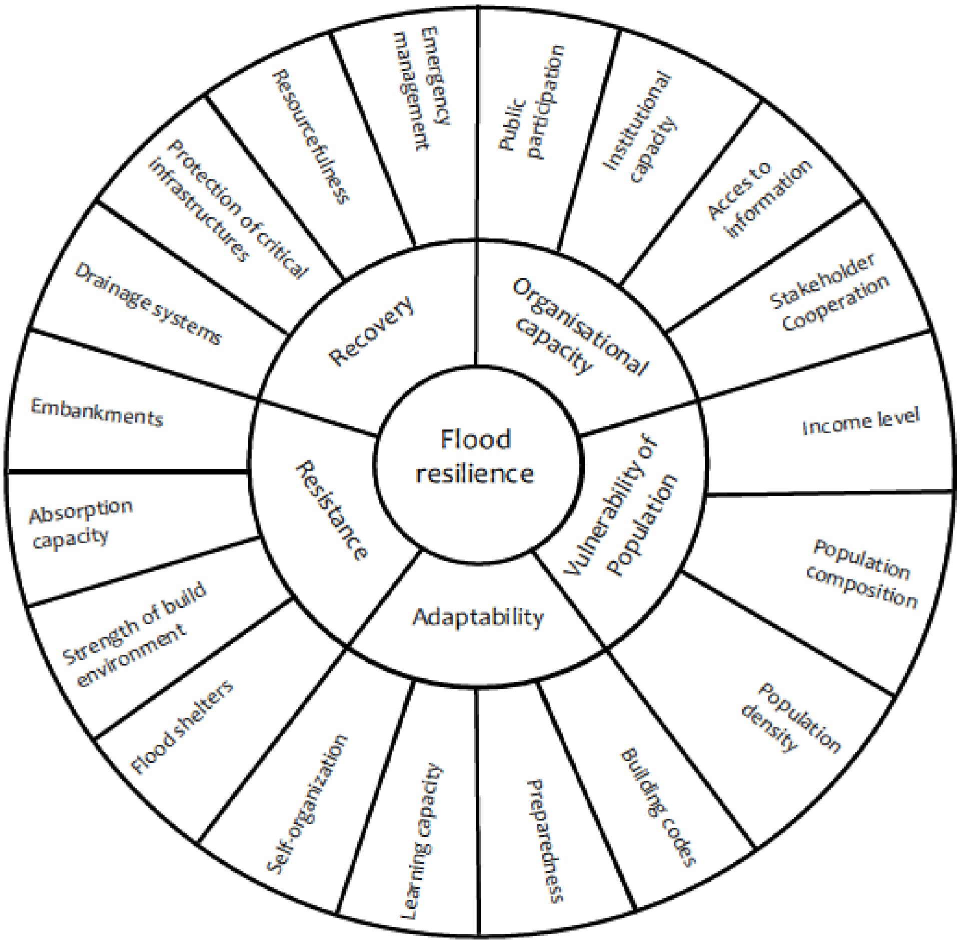

Figure 5.1 – Refined Resilience Wheel

This new version of the Resilience Wheel consists of 19 indicators instead of 18. The indicator 'Household assets' was removed because of its immeasurability. The indicator 'Drainage systems' was added to the dimension 'Recovery' and the indicator 'Flood shelters' was added to the dimension 'Resistance'. Further, the indicator 'Building codes' was moved to the dimension 'Adaptability'.

Table 5.1 - Definitions of flood resilience indicators

Indicator	Operational definition	Meaning of the scores
Emergency management	Availability of warning systems, evacuation plans, aid coordination procedures and voluntary services (Hamilton 2009).	1= No availability - 5= Very high availability
Resourcefulness	The budgeted emergency funds, recovery funds and reserves in water & energy (Andrew et al. 2016).	1= No reserves - 5= Very large reserves
Protection of critical infrastructures	Physical protection or elevation of energy network, traffic routes, water supply, airports (Aerts et al. 2013).	1= No protection - 5= Very high protection
Drainage systems	Availability and operation of drainage systems (pipes, ditches, sewerage, pumps and culverts) (Hamilton 2009).	1= No drainage system - 5= very extensive drainage system
Embankments	Physical presence and height of embankments (Albrito 2012).	1= No embankments - 5= Very high embankments
Absorption capacity	Spatial dispersion of shopping centres, stations, water & energy supply sources through the city.	1= Central concentrated - 5= Extremely dispersed
Strength of build environment	Physical material and design of buildings adapted to flood risk (Albrito 2012).	1= Low strength - 5= Very high strength
Flood shelters	The availability of flood shelters (widened stretches of embanked roads or roofs of schools, shops or restaurants) (De Bruijn 2005).	1= No availability - 5=Vey high availability
Self-organization	The ability of residents to organize themselves in fixing damage and cleaning up after a flood (Liao 2012) Measurable in flood reports.	1= No self-organization - 5= Very high self-organization
Learning capacity	Education plans, trainings, media attention and institutional adjustments to adapt to flooding (Liao 2012).	1= No plans and adjustments - 5= Very extensive plans and adjustments
Preparedness	The use of future projections in policy and design plans of flood barriers.	1= No use of projections - 5= Very extensive use of projections
Building codes	Regulations, plans and prescriptions about the design and zoning of buildings in order to adapt to flood risk (Aerts et al. 2013).	1= No building codes - 5= Very extensive building codes
Population density	Average residents/km2 in the city (Farhan&Lim 2011).	1= > 15000 pop./km^2 2= 5000-15000 pop./km^2 3= 1000-5000 pop./km^2 4= 500-1000 pop./km^2 5= 0-500 pop./km^2

Population composition	Proportion of the city population between 15 and 64 as percentage of the total population in the city (Joerin et al. 2014).	1= 0-20% between 15 and 64 2= 20-40% between 15 and 64 3= 40-60 % between 15 and 64 4= 60-80% between 15 and 64 5= 80-100% between 15 and 64
Income level	The average annual household disposable income in a city in $ (Kotzee&Reyers 2016).	1= $0-$5000 2= $5000-$10000 3= $10000-$20000 4= $20000-$30000 5= > $30000
Stakeholder cooperation	The degree of collaborations, meetings and information exchange between policymakers and (local) governments, safety organisations, engineers and NGO's (Joerin et al. 2014).	1= No collaborations - 5= Very high amount of collaborations
Access to information	The availability of scientific climate information & risk assessments for policymakers to prepare risk reduction by political and spatial interventions (Moench 2014).	1= No access to information - 5= Very high access to information
Institutional capacity	The availability and operation of decision-making procedures, programs and system of rules related to flood risk management (Gupta et al. 2010).	1= No associations - 5= Very high amount of associations
Public participation	The extent of public participation in flood risk reduction policy and measures (Lu&Stead 2013). This can be measured in amount of citizen panels, advisory groups and other participation methods in the city.	1= No participation methods - 5= Very high participation

5.3 Scoring flood resilience of Dhaka

The improved framework was used to score the flood resilience of Dhaka. Eleven survey respondents assessed the flood resilience of Dhaka. The scores of the indicators are further corroborated by a document study and an interview. In case of discrepancies between both sources, the scores were averaged. Based on the procedure of the Adaptive Capacity Wheel, the scores of indicators are round off to whole numbers in order to present the final score.

5.3.1 Recovery

The dimension 'Recovery' in the new Resilience Wheel is divided in the indicators 'Emergency management', 'Resourcefulness', Protection of critical infrastructure' and 'Drainage systems'.

Emergency management

The survey-respondents scored emergency management in Dhaka with an average of 2.6. This means a low to medium emergency management. Islam et al. (2013) states: "There is a large gap in coordination and management to reach disaster victims". Although the Bangladesh Emergency Response Preparedness Plan (2014) identified Minimum Preparedness Actions (MPA) to implement emergency management, most of these actions are still ongoing and residents are not aware of the warning signals and evacuation routes in Dhaka. This information is interpreted as a limited emergency management (score of 2). This gives as discrepancy of 0.6 with the score of the survey. The average of 2.6 and 2 is 2.3 which is rounded to two as the final score of emergency management.

Resourcefulness

The experts scored the budgeted monetary and material reserves in Dhaka as low to medium. An assessment report of Dhaka of Parvin & Shaw (2012) described the current situation of disaster management in Dhaka. There was stated that the recovery capacity was limited because funding lacked. However, due to investments of international NGOs, donors, governments and the UN, there are some funds available. Most of these funds are small but there are three large funds: The Bangladesh Climate Change Trust Fund, Bangladesh Climate Change Resilience Fund and the Pilot Program for Climate Resilience (Give2Asia 2016). However, resourcefulness is also about the reserves in water and energy. In Dhaka, four of five city dwellers lack access to drinking water within 1000 meters of their homes. In addition, energy supply is even in situations without flooding very changeable. Thus, there is assumed that the energy supply during floods is limited (Bangladesh Emergency Response Preparedness Plan 2014). The document study resulted in a score of two. The score of the experts was 2.5. This leads to an average score of 2.25 which is rounded to two for the resourcefulness in Dhaka.

Protection of critical infrastructures

The protection of critical infrastructures in Dhaka was scored medium in the survey. Based on a report of the flood in 1998 in Dhaka it appeared that there was a reactive way of critical infrastructure protection by the erection of protection walls around water supply pumps. In addition, electrical appliances were elevated above flood level (Huq & Alam 2003). As result of the flood in 1998, amongst others 37 km of road was elevated and the airport was protected by embankments. According to the Bangladesh Emergency Response Preparedness Plan (2014), flooding in Dhaka will still disrupt the infrastructure system, communication system and key supplies in electricity and gas. This information shows that protection of critical infrastructures is developed but still needs to be improved. These findings corroborate the score of the experts that Dhaka has a medium protection of critical infrastructures.

Drainage systems

Experts in Dhaka scored the drainage system as medium (3). According to Khan (2016), the drainage system of Dhaka is not operating very well: "due to a lack of maintenance the drainage system and pumps are functioning not as effective as they could". This is confirmed by the Dhaka structure plan (2015, p.283) that describes the drainage system in Dhaka as very poor. In times of water logging the drainage system often gets clogged, which hampers a quick discharge and causes water logging on the streets. Dhaka has a drainage system, but its operation if limited. The document study confirms the view experts so this indicator is scored with three.

Table 5.2 summarizes the scores and the sources that were studied to quantity the indicators of the dimension 'Recovery'.

Table 5.2 - Quantification of indicators for recovery.

Dimension	Indicator	Experts	Documents	Score for Dhaka	Source
Recovery	Emergency management	2.6	2	2= Low availability	-Survey -Islam et al. (2013) -Bangladesh Emergency Response Preparedness Plan (2014)
	Resourcefulness	2.5	2	2= Small reserves	-Survey -Bangladesh Emergency Response Preparedness Plan (2014) -Parvin & Shaw (2011)
	Protection of critical infrastructures	2.9	3	3= Medium protection	-Survey -Huq& Alam (2003) -Bangladesh Emergency Response Preparedness Plan (2014)
	Drainage systems	3	3	3= Medium drainage system	-Survey -Khan (2016) -Dhaka Structure Plan (2015)

5.3.2 Resistance

The dimension 'Resistance' in the new Resilience Wheel is divided in the indicators 'Embankments, 'Absorption capacity', 'Strength of build environment' and 'Flood shelters'.

Embankments

The survey came to an average score of 3.2 on the embankments of Dhaka. The document study revealed that the western half of the city has river embankments and the eastern part does not have embankments although there is risk of river floods (Brammer 2015, p.177). In addition, parts of the embankments failed due to geomorphologic transformation of rivers underneath the embankment. However, NGO's and the national government currently initiate projects of new embankments to protect a larger part of Dhaka against flooding (Dhaka structure Plan 2015, p. 211). The protection of half of Dhaka with embankments is interpreted as medium embankment and therefore scored with three.

Absorption capacity

The average score for absorption capacity in the survey was 2.5 meaning a low-medium dispersion of essential functions in Dhaka. Since Dhaka is increasing in terms of population and surface, the Dhaka Structure Plan (2015) evaluated the plans for dispersion of commercial activities and essential functions. It appeared that no specific policy was given and the planned dispersion was not implemented. According to the Dhaka Structure plan (2015), shopping centres, railway and bus stations are dispersed along the entire city of Dhaka. However, according to Khan (2016), the water and energy supply in Dhaka is very limited and dispersed in such a way that only a part of Dhaka has access to it. Comparing the information from the survey with the information from the document study resulted in the score of three. This score indicates the medium absorption capacity in Dhaka.

Strength of build environment

The experts rated the strength of the build environment in Dhaka with 2.9. According to a recent study, 78,000 out of 326,000 buildings in Dhaka were detected as risky (Dhaka Structure Plan 2015). The collapse of a garment factory in 2013 Dhaka was an example of the weakness of Dhaka's buildings. Other reasons for a low strength of the build environment are the use of sand to fill low lying and flood prone areas for constructing high-rise buildings. This weak foundation causes a high risk of buildings to collapse. Next, many old and dilapidated buildings are considered as heritage of Dhaka without considering retrofitting or strengthening the buildings (Dhaka Structure Plan p.285). According to the Bangladesh Emergency Response Preparedness Plan (2014 p.22) there is an improper construction of buildings in Dhaka. This information is interpreted as a low strength of build environment (score of 2). This gives a discrepancy of 0.9 with the score of 2.9 given by the experts. Averaging the scores of 2 and 2.9 gives a score of 2.45. This is rounded to two. This score presents a low strength of the build environment in Dhaka.

Flood shelters

The 11 experts in Dhaka who completed the survey assessed the availability of flood shelters as limited (2.2). According to Huq & Alam (2003) and the Bangladesh Emergency Response Preparedness Plan (2014) there are not enough flood shelters in Dhaka to offer protection in times of flooding. Next, the shelters are not designed according to a standard universal design and their accessibility is very low. A study of Masuya et al. (2015) presented that there are 5537 buildings in Dhaka city that can be used as flood shelters but they do not have the capacity to house the number of people who could potentially seek refuge there. The shortage of flood shelters for the residents in Dhaka is relatively increasing due to the increasing population in Dhaka. Since document study confirmed a limited availability of flood shelters, this indicator is scored with two. Table 5.3 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Resistance'.

Table 5.3 - Quantification of indicators for resistance

Dimension	Indicator	Experts	Documents	Score for Dhaka	Source
Resistance	Embankments	3.2	3	3= Medium embankments	- Survey -Dhaka Structure Plan (2015) -Brammer (2015)
	Absorption capacity	2.5	3	3= Medium dispersed	-Survey -Khan (2016)
	Strength of build environment	2.9	2	2= Limited strength	-Survey -Dhaka structure Plan (2015) -Bangladesh Emergency Response Preparedness Plan (2014)
	Flood shelters	2.2	2	2= Limited availability of flood shelters	-Survey -Masuya et al. (2015) -Bangladesh Emergency Response Preparedness Plan (2014)

5.3.3 Adaptability

The dimension 'Adaptability' is divided in the indicators 'Self-organization, 'Learning capacity', 'Preparedness' and 'Building codes'.

Self-Organization

According to the outcomes of the survey, the self-organizing capacity of Dhaka's residents is medium (3.1). Walters (2015) described the organization of communities in Dhaka: "there are strong and reliable ties between the people in the slums in Dhaka". These networks become important after a flood when people have to build up their lives again. However, due to the poverty, there is a limited access to monetary and material sources for redevelopment after a flood, which hampers a proper self-organization. Since the rainy season causes annual floods in Bangladesh, flooding became part of the culture of Bangladesh and the residents know how to rebuild their lives after a flood. Still, large-scale rescue and relief after a flood is conducted by aid organisations as Unicef and the Red Cross (Khan 2016). This information was interpreted as a medium self-organization and confirmed the outcomes of the survey resulting in a score of three.

Learning capacity

Respondents to the survey rated the learning capacity in Dhaka with an average of 2.5 meaning low-medium learning capacity. This score was confirmed by a document study. According to Walters (2015) "The experience of one severe flood provides no capacity for the poor to learn and prepare themselves better for the next flood. They must start their lives again after each flood". Although flooding became a usual occurrence in Bangladesh, people do not learn from the flooding and do not adapt to it. They just let the floods happen and recover afterwards. Though, there are efforts for institutional adjustments for climate change adaptation (Khan 2016). The Bangladesh Emergency Response Preparedness Plan (2014) tries to stimulate the learning capacity by advising evaluative reports and education on flooding but it is still not in operation. The document study presented a low learning capacity (score of 2). The discrepancy with the survey score (2.5) was 0.5. The average between both scores is 2.25 which is rounded to the score of two.

Preparedness

The preparedness to flooding by the use of flood projections was scored medium by Dhaka's experts in water management. A document study revealed that the use of projections is even higher than assessed by the experts. According to Islam et al. (2013): "the Union Disaster Management Committee disseminates flood forecasting information with risk and damage information in the pre-disaster phase". The national government constructed a satellite receiving station at the storm-warning centre in Dhaka that will help forecast and warn the city of flooding events (Give2Asia 2016). Next, there is a Flood Forecasting Centre in Dhaka that uses climate models and projection methods to predict the probability of flooding (DHI Water and Environment 2006). The high extent of flood forecasting in Bangladesh as described in documents was averaged with the score of the experts (3) resulting in an average score of 3.5 Rounding 3.5 to whole numbers leads to a score of four for the indicator preparedness.

Building codes

The surveys revealed that the experts rated the use of building codes as medium in Dhaka. RAJUK, the municipal body responsible for building and land use regulation, stated that the "Private Housing Project Land Development Rules" adopted in 2004 imposed building regulations and a minimum flood elevation for buildings built by private developers. However, these regulations are not widely enforced (Jahan 2011). According to the Dhaka Structure Plan p.295 (2015) "There is absence of urban design regulations and weak enforcement of development control regulations". General building codes are available but not used in practice, therefore this indicator is scored with three in the Resilience Wheel of Dhaka. Table 5.4 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Adaptability'.

Table 5.4 - Quantification of indicators for adaptability.

Dimension	Indicator	Experts	Documents	Score for Dhaka	Source
Adaptability	Self-organization	3.1	3	3 = Medium self-organization	-Survey -Khan (2016) -Walters (2015)
	Learning capacity	2.5	2	2 = Limited plans and adjustements	-Survey -Bangladesh Emergency Response Preparedness Plan (2014) -Walters (2015) -Khan (2016)
	Preparedness	3	4	4= Extensive use of projections	-Survey -Give2Asia (2016) -Islam (2013) -Flood forecasting centre
	Building codes	3	3	3= Medium building codes	-Survey -Jahan (2011) -Dhaka structure Plan (2015)

5.3.4 Vulnerability of Population

The dimension 'Vulnerability of Population' is divided in the indicators 'Population density', 'Population composition', and 'Income level'. These are hard indicators and therefore the scores are classified in numbers instead of a relative scale from absent to very high.

Population density

The experts agreed that the population density of Dhaka is very high. In the case of resilience, a high population density is a negative attribute since it contributes to a higher vulnerability. The average survey score was 1.1 meaning a population density of >15000 pop./km^2. This was verified by data about the population density in Bangladesh. The population density in the district of Dhaka was 8229 in 2011. However, this is for the district of Dhaka which is bigger than the city itself (Bangladesh Bureau for Statistics 2015 p.45). According to data from the Citylab (2016) Dhaka has a population density of 45000 people per square kilometre. Therefore, this indicator is scored with one meaning a population density higher than 15000 pop./km^2.

Population composition

The proportion of the population between 15 and 64 as percentage of the total population had an average score of 3.4 (medium-high). This means that around 70% of the population is in the age group of 15-64. Data from the World Bank reveals that 65.1% of the population of Bangladesh was between the age of 15 and 64 in 2015. Data on Dhaka were found in a report of the Bangladesh Bureau for Statistics (2015) that presents a percentage of 70.24% of the population in Dhaka between 15-64. This percentage is within the category 4 (60-80% between 15 and 64). The outcome of the survey (3.4) was averaged with the outcome of the document study (4). The result was a score of four for the indicator population composition.

Income level

Bangladesh is one of the poorest countries in the world. The experts scored the average income with 1.5 representing an income level between the categories 1 ant 2 meaning an income level between \$0 and \$10000. According to the Bangladesh Bureau of Statistics (2015) the average annual income level in Dhaka is \$1600. This is within category 1 (\$0-\$5000). The statistical data confirm the score of the experts and therefore the income level of Dhaka is scored with one in the Resilience Wheel.

Table 5.5 summarizes the scores and the sources that were studied to quantity the indicators of the dimension 'Vulnerability of Population'.

Table 5.5 - Quantification of indicators for vulnerability of population.

Dimension	Indicator	Experts	Documents	Score for Dhaka	Source
Vulnerability of population	Population density	1	1	1= 1000-5000 pop./km^2	-Survey -Bangladesh Bureau for -Statistics (2015) -Citylab (2016)
	Population composition	3.4	4	4= 60-80% between 15 and 64	-Survey -Bangladesh Bureau for Statistics (2015) -World Bank (2016)
	Income level	1.5	1	1= \$0-\$5000	-Survey -Bangladesh Bureau for Statistics (2015)

5.3.5. Organisational Capacity

The dimension 'Organisational Capacity' is divided in the indicators 'Stakeholder Cooperation', 'Access to Information', 'Institutional Capacity' and 'Public Participation'.

Stakeholder cooperation

According to the respondents to the survey, Dhaka scored 2.7 on its stakeholder cooperation related to flood risk management. Flood risk management in Dhaka is fragmented in multiple agencies. These agencies have a limited cooperation since they each have their own responsibilities within the field of flood risk management. Dhaka Water Supply and Sewerage Authority (DWASA) is responsible for drainage system, the Bangladesh Water Development Board (BWDB) arranges flood protection, the two city corporations are responsible for infrastructures (Khan 2016). Occasionally new roads are built without consideration of drainage routes and embankments. The lack of coordination in this diffused network of organisations hinders the development of structural solutions for flood risk management (Dhaka Structure Plan 2015). This information from documents is interpreted as low stakeholder cooperation (2). Averaged with the score of the experts, the score is 2.35 which is rounded to two.

Access to information

The survey revealed an average score of three for the access to information. The availability of scientific climate information and risk assessments with improved due to the involvement of NGO's and other international projects in Bangladesh (Bangladesh Delta Plan 2016). Climate models and scenarios are accessible in summary reports for policymakers made by IPCC. Next, the Flood Forecasting Centre in Dhaka uses climate data and (DHI Water and Environment 2006). Although risk and climate information is available, it is a bit fragmented and the translation into policy on climate change is lacking (Dhaka Structure Plan 2015). This information is interpreted as a medium access to information and therefore scored with three in the Resilience Wheel.

Institutional capacity

The institutional capacity related to flood risk management was scored as low-medium (2.6) in the survey. Professor Khan stated in the interview that the institutional capacity is one of the main problems in Dhaka. As stated in the assessment of the stakeholder cooperation, the responsibilities for flood risk management are fragmented amongst multiple parties. There are decision-making procedures and programs for flood risk management but they are not universal to all stakeholders in the field of flood risk management (Khan 2016). Dhaka is divided in a northern and southern city corporation and the water agencies in Dhaka (Water Development Board, Dhaka Water Supply and Sewerage Authority) are under the responsibility of different ministries. The institutional system is therefore very fragmented (Khan 2006). Since there are programs and decision-making structures, but their operation is very limited, the institutional capacity is rated with two. Averaged with the score of 2.6 from the experts this leads to a final score of two.

Public participation

The public participation is assessed low by the survey respondents (1.9). The Dhaka Structure Plan (2015) describes a lacking participation of local people in fields of flood risk management, waste management and infrastructure development. The development of Community Based Organizations and Ward Councillors should facilitate the participation that is currently lacking. Although the political system in Bangladesh is a parliamentary democracy, residents do not have a say in spatial and political decisions in Dhaka (Nahiduzzaman et al. 2006). According to Walters 2015, a large part of Dhaka's population lives in slums and these people are unreachable for participation. The preparation of the Dhaka Metropolitan Development Plan (DMDP) pretended to use public participation in the development of housing projects. However, a report of Nahiduzzaman et al. (2006) revealed that participation was absent in the development of housing. A document study resulted in the score of one, this is averaged with the score of 1.9 for the experts resulting in a score of 1.45 which is round off to one.

Table 5.6 summarizes the scores and the sources that were studied to quantify the indicators of the dimension 'Organisational capacity'.

Table 5.6 - Quantification of indicators for organisational capacity

Dimension	Indicator	Experts	Documents	Score for Dhaka	Source
Organisational capacity	Stakeholder cooperation	2.7	2	2= Limited amount of collaborations	-Survey -Khan 2016 -Dhaka Structure Plan (2015)
	Access to information	3	3	3 = Medium access to information	-Survey -Bangladesh Delta Plan (2016) -IPCC (2013) -(DHI Water and Environment 2006)
	Institutional capacity	2.6	2	2= Low amount of associations	-Survey -Khan (2016) -Khan (2006)
	Public participation	1.9	1	1= No participation methods	-Survey -Walters (2015) -Nahiduzzaman et al. 2006

5.4 Conclusion

The case study on Dhaka was conducted to test the improved framework and to give insights in the strengths and weaknesses of Dhaka based on a survey, interview and document studies.

5.4.1 Usability of the framework

The refined version of the Resilience Wheel with two new indicators and sharpened operational definitions was used for measuring the resilience of Dhaka. There can be concluded that this refined framework is useful for measuring resilience in delta cities. The consulted experts in Dhaka were able to complete all the questions in the survey. Also the triangulation with a document study provided the required information on all 19 indicators. I assumed that the descriptions of the indicators were clear and relatively measurable since no questions were left open and there were no additional comments on the second version of the framework. Besides, it succeeded to find information on all the 19 indicators which enabled a full assessment of the flood resilience in Dhaka by the Resilience Wheel. The case study in Dhaka has been a conscious choice to test if the application of the Resilience Wheel also works in a different ethnic culture and planning culture than the first case study in Rotterdam. However, the refinement of the framework is also based on context and cultural dependent issues. For example, the addition of the indicator 'Flood shelters' was based on the situation in Dhaka. Flooding became part of the culture in Bangladesh and their way planning is rather reactive than adaptive. The physical protection by embankments in Dhaka is low and therefore the flood shelters are important features to survive flooding and contribute to resilience. However, Rotterdam has a more adaptive way of planning and focuses on protection of and adaptation to flooding. Therefore, flood shelters are less important in well protected countries but important in countries that are often flooded. To improve the international comparison of delta cities the indicator 'Income level' was reconsidered. This indicator expresses the annual disposable household income in $ but the outcomes are very dependent on the context of the country. An annual disposable income level of €30000 is very high for African standards but moderate for European standards. The spending possibilities of households might give a more reliable view. However, also the spending limit of households is a context dependent indicator since there are large differences in costs of living taxes and other financial aspects that determine the spending possibilities. After a search on digital databases (World Bank, OECD and CBS) it appeared that data on spending limits were not findable. When it came to expenditure of household, the annual disposable income was the most common indicator and therefore is not decided to change this indicator. The differences in culture and the context dependency of the framework will remain and therefore the explanation of the scores is of main importance to put the scores in perspective. There is concluded that the assessment of Dhaka with the refined framework was successful and gave no clear indication for additional refinement of the framework. Therefore, I decided to not conduct an additional refinement of the Resilience Wheel.

5.4.2. Flood resilience of Dhaka

The scores of the indicators and the dimensions in Dhaka were added in the Resilience Wheel. Figure 5.2 presents the outcomes with colours symbolizing the height of the scores.

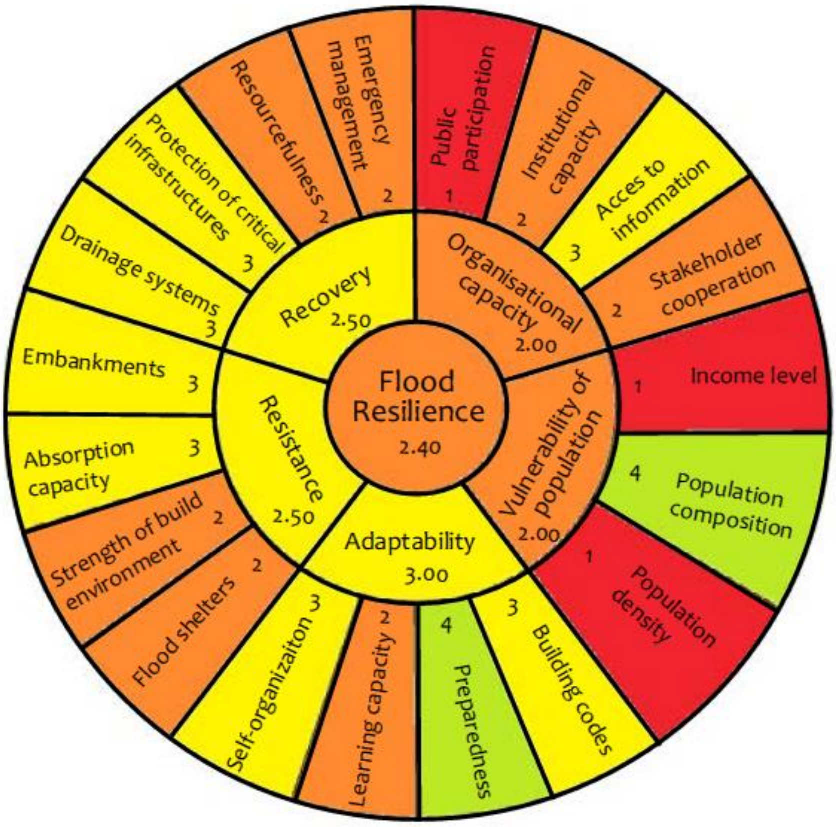

Figure 5.2 - Application of the Resilience Wheel to Dhaka

Dhaka has an overall score of 2.40 for the city's flood resilience based on the survey and the document study by the Resilience Wheel. A score of two was defined as low and a score of three was defined as medium hence the score of 2.40 presents a low to medium flood resilience for Dhaka. The dimension 'Adaptability' was scored highest (3) because there is climate adaptation to a certain extent by using climate future projections. Still, the score of three means a medium adaptability. The low learning capacity and medium self-organization and building codes led to a medium adaptability. Recovery and resistance were both rated with 2.50 meaning low to medium. The low emergency management and a medium protection of critical infrastructures and drainage systems shows that the recovering capacity of Dhaka is limited. The same applies to the resistance of Dhaka against flooding which is limited due to a low amount of flood shelters and a medium strength of the build environment. Both the dimensions 'Organisational Capacity' and 'Vulnerability of population' were scored lowest with two. Dhaka has a low organisational capacity partly because of the fragmented institutional and organisational system related to flood risk management and a lacking public participation. Although there is a high percentage of Dhaka's population in the 'resilient' age group of 15-64, their low income level and extreme high population density resulted in a high vulnerability of the population. The outcomes of Dhaka's flood resilience are analysed and compared with the outcomes of Rotterdam to come lessons for resilience improvement.

6. Comparative analysis

The application of the framework on two delta cities led to insights in the flood resilience of Rotterdam and Dhaka. Here I analyse the differences in outcomes and compare both cities on their flood resilience. Next, I mention the domains for resilience improvement in Rotterdam and Dhaka which will be further complemented in the recommendations at the end of this thesis. The way in which cultural differences between the cities affected the assessments will be shortly mentioned and further treated in the discussion.

6.1 Recovery

Rotterdam scored 3.33 on recovery and Dhaka scored 2.50. A remarkable outcome within this dimension was that the resourcefulness of Rotterdam and Dhaka were scored equal (low). This outcome needs to be put in perspective. Since Bangladesh is a developing country, they do not have the financial capacity to recover from flooding. Therefore, Dhaka still depends on international aid organizations for their recovery (Khan 2016). Although there are no fixed financial reserves for flood disasters, Rotterdam might have a higher financial capacity than Dhaka because the economic situation in the Netherlands is better than in Bangladesh (Programmabegroting Rotterdam 2015; Khan 2006). In both cities, experience with earlier floods led to the awareness of flood risk. However, in Rotterdam this resulted to a high protection of critical infrastructures and a high emergency management while these indicators scored respectively medium and low in Dhaka. This might be explained by the worse economic situation and a lacking decisive attitude of Dhaka's government. The awareness of flooding did not lead to resilience increasing measures as protection of critical infrastructures and emergency management. Dircke et al. (2013) state that Rotterdam has the objective to be an example for other cities in climate adaptation. The structured way of emergency management in Rotterdam where there is a central coordination could also be tried in Dhaka. Another domain for improvement in Dhaka is the implementation of infrastructure protection by elevation of roads, railways and other essential infrastructures.

6.2 Resistance

Resistance as the physical dimension of resilience, is significantly higher in Rotterdam as in Dhaka. An explanation for the high resistance to flooding in Rotterdam can be found in the flood of 1953. This flood catalysed a high resistance and emphasis on the need of physical protection against flooding from sea resulting in the current safety norm of 1:10.000 (Aerts et al. 2009). Where Rotterdam is protected from several sides, in Dhaka only the western part of the city is embanked because there was no money for a complete embankment of the city (Khan 2016). Reasons for the low resistance of buildings against flooding are moderate building codes and lack of financial resources (Parvin&Shaw 2011). An interesting outcome is the small difference between both cities regarding the absorption capacity. In Rotterdam, many essential industrial functions are concentrated in the harbour area but shopping centres and stations are dispersed along the city. In Dhaka, the water and energy supply functions are concentrated in the more developed parts of the city. Since there is lack of financial capacity, these facilities are concentrated on the richer districts and less on the slum areas. Other functions as shopping centres and railway stations are dispersed through Dhaka. Resilience in Dhaka can be increased by the implementation of physical flood protection. Inspired by Rotterdam, Dhaka can also apply a safety norm and translate that into design of embankments.

6.3 Adaptability

The adaptability was medium in Dhaka and high in Rotterdam. The medium adaptability in Dhaka was mainly caused by their high preparedness in the use of future projections. Still, Rotterdam scores very high on future projections since the availability, knowledge and expertise in climate change modelling and predicting is higher in the Netherlands than in Bangladesh (Lu&Stead 2013; Khan 2016). Where both cities have been confronted with flooding in the past, only in Rotterdam this results in a very high learning capacity. It is remarkable that Dhaka has a low learning capacity. According to Khan (2016), the knowledge and expertise to learn from disasters is available but it is not operated into institutions and physical interventions. Dhaka lacks the decisiveness in spatial planning that can lead to policy and spatial adjustments after a flood to prevent damage in case of another flood. An interesting outcome is the higher self-organization of Dhaka's residents compared to Rotterdam. Although one can doubt about the reliability of the information, a survey with experts and a document study revealed that citizens of Dhaka have a medium self-organization and Rotterdam has a low self-organization. This might be the result of the high flood-frequency in Dhaka making citizens experienced with flooding and able to organize themselves. Also the experience with frequent replacement of houses in the slum areas makes residents in Dhaka self-reliant and resilient against change. The low self-organization in Rotterdam is declared by their reliance on flood protection and a high emergency management. Residents might trust on the physical flood protection in Rotterdam and therefore nog adapt to the probability of flooding. It is a domain for improvement in Rotterdam to not only rely on physical protection but also educate their residents in self-organization.

6.4 Vulnerability of population

The vulnerability of the population in both cities determines their (lack of) resilience. There is a large difference in population characteristics between Rotterdam and Dhaka. The population density of Rotterdam is medium (2960 pop. /km^2) but the population density of Dhaka is extremely high (>15000) compared to international standards. This high population density makes Dhaka highly vulnerable to flooding and therefore less resilient than Rotterdam. The difference in population density is explained by the difference in the economic situation between Bangladesh and the Netherlands. Developing countries often face a higher urbanization than developed countries (Walters 2015). In Bangladesh, people move from the rural to the urban areas to seek for work and a better future while the Netherlands does not face this trend. Also the difference in income level is explained by the varying economic situation in both countries. Rotterdam has a very high average income level and Dhaka has a very low average income level which makes the city less resilient in overcoming hazards. The percentage of the population in the age group of 15-64 is comparable in both cities (63% in Rotterdam and 70% in Dhaka). This shows that the 'resilient' part of the population is high in both cities. It is difficult to change population characteristics by learning from other cities. There is lack of zoning in Dhaka while zoning can be used to become more resilient. When the government determines which areas are suitable as residential areas, they can develop housing space in that areas. In this way the government can steer urbanization and prevent the development of slums in vulnerable areas. Zoning is a way of adapting to a potential development (urbanization) and therefore increases the resilience of a city.

6.5 Organisational capacity

The organisational capacity in Dhaka was low (2.00) compared with a medium-high organisational capacity of Rotterdam (3.67). One of the main reasons for the low organisational capacity in Dhaka is the fragmented institutional system compared with the structured institutional system in Rotterdam. A low institutional capacity is combined with lacking public participation and a low stakeholder cooperation in Dhaka. Rotterdam has a medium public participation and a high stakeholder cooperation. This difference can be explained by the emphasis on participation in Dutch planning and water policy. A shift from top-down to bottom-up planning and decision making leads to a higher participation (Woltjer & Al 2007). The planning and decision making in Dhaka is mainly performed by local governments that do not involve citizens in their decisions. Next, each agency or organization related to flood risk management focuses on its own responsibilities which results in a low cooperation between agencies (Khan 2016). The domains for improvement of organisational capacity are mainly related to the institutional system. First, the flood risk management which is currently dispersed among several agencies and ministries can be central coordinated by one ministry and performed by one agency instead of five. Next, a changing mind-set of governments from top-down to bottom-up planning can lead to more involvement of stakeholders and residents in decision making. This bottom-up planning might increase the public participation and stakeholder cooperation. However, the difference in planning culture and ethnic culture makes this change of planning difficult. It is hard to change a way of planning that has been used for many years. Next, hierarchy plays an important role in the Bengal culture. As a remnant of the Indian caste system there are differences between people based on their origin, profession and age (Khan 2016). This hierarchy makes it difficult for governments, stakeholders and residents to act on an equal level.

7.Discussion

This chapter answers the research question by providing the indicators of flood resilience and the way they can be used for monitoring. The main findings are presented and the relation with existing literature is described. This chapter also discusses the methodology and the procedure for using the Resilience Wheel.

The research objective was to create a coherent framework with indicators that characterize flood resilience and are measurable through assessment of cities. The following research question was addressed in this thesis: *Which indicators of flood resilience offer a coherent framework for operationalizing and monitoring flood resilience of delta cities?*

7.1 Indicators of flood resilience

I converted the main research question into three sub questions. The first question was: *What indicators exist in the literature to measure flood resilience of delta cities?* The findings that answered this question are 5 dimensions and 18 indicators of resilience placed in a framework. Although many more indicators exist in resilience literature (e.g. communication capacity, peoples health status, accessibility of roads), I selected the most prevalent indicators since they were used most to represent resilience in scientific discourse. I clustered the indicators in 5 overarching dimensions and placed them in a first version of the framework which I called the Resilience Wheel. The use of indicators to make a theoretical concept measurable was adapted from the systematic approach developed for the Adaptive Capacity Wheel (Gupta et al. 2014). The 5 dimensions and 18 varying indicators show that resilience is a very broad concept indicated by technical and social characteristics. Resilience is not a purely technical concept expressible in numeric indicators. Therefore, selecting only indicators with absolute values (e.g. income level) that were easy measurable would not cover the meaning of resilience. The concept resilience was translated into both 'social' indicators (e.g. stakeholder cooperation) and 'technical indicators' (e.g. population density) and is therefore a mix of relative and absolute values. According to Wong (2003) there is a development of indicators as "involving a methodological process of moving from abstract concepts to more specific and concrete measures to yield policy intelligence". This research presented a 'methodological process' by using a literature review and two case studies to translate resilience as abstract concept into a framework with indicators.

Rae & Wong (2012) stated that indicators enable scientists and policymakers to measure abstract concepts when they are applied to systems. The findings of this research can be used to measure the abstract concept (flood resilience) applied to systems (delta cities). It is therefore an example of application of indicators to translate an abstract concept into an operational term. The chosen indicators are based on literature about varying countries (US, Thailand, Bangladesh, The Netherlands) and from different authors. By this selection the chance for a bias towards western cities is limited.

7.2 Testing the coherence of the framework

The second sub question was: *What insights for the coherence of the framework can be derived from measuring the flood resilience by rapid assessment?*

A rapid assessment of resilience in Rotterdam provided insights in the coherence of the framework derived from theory. The results of this question showed that 16 of the 18 indicators derived from theory could be measured in practice. An important finding was that indicators 'Household assets' and 'Institutional capacity' proved immeasurable due to respectively lacking data and an unclear definition. This finding means that the coherence and functioning of the framework could be improved. Further, the Resilience Wheel showed to be useful for a first indication of the resilience of Rotterdam. It remains, however, a first indication because the assessment of these cities was based on relative measuring of indicators and depended on the interpretation of the researcher. The findings on the flood resilience of Rotterdam corroborate the studies of Stead& Kok (2013) and Lu& Stead (2013) who studied resilience in spatial planning in Rotterdam and concluded that resilience to climate change was performed in spatial measures and adjustments of policy. Both studies revealed the focus on robustness against flooding in Rotterdam. This was confirmed by the assessment of Rotterdam in this research.

An interesting finding was that the Resilience Wheel exposes tensions between the dimensions. For example, a high resistance may lead to a lower recovery. When decision makers in a city focus on the prevention of flooding, it is assumed that a flood may not happen. Therefore, the recovery from a flood may receive less attention in policy and spatial measures. This was evident in the case study on Rotterdam where resistance got the highest score (4.25) and recovery got the lowest score (3.33). The division of indicators in different dimensions in the Resilience Wheel enables to focus on specific dimensions for flood resilience improvement. However, the literature review revealed that the essence of resilience is a combination of different elements that creates the ability to 'withstand or adapt to flooding' (Restemeyer, Woltjer & Van den Brink 2015). Strengthening flood resilience therefore works best when decision makers do not concentrate on the increase of one or two dimensions but attempt to combine the improvement of all dimensions.

7.3 Operationalization of resilience

The third sub question was: *What does a comparison of different applications offer for refining the procedure of measuring resilience?* A case study in Dhaka resulted in new findings about the functioning of the framework that were compared with the insights of the case study in Rotterdam. The findings confirmed the immeasurability of household assets due to lacking data. This indicator was omitted from the framework. The definition of institutional capacity was sharpened in a way institutional capacity could be measured. Next, I added the indicators 'Flood shelters' and 'Drainage systems' in the refined framework since they indicated resilience. I further refined the measuring procedure by sharpening the definitions of indicators Emergency management, Resourcefulness, Learning capacity, Population composition and Institutional capacity. A more specific definition of these indicators clarified how they can be measured in delta cities. Related to the main research question, this research offered 5 dimensions and 19 indicators of flood resilience in a coherent framework that operationalize resilience and can be used for monitoring resilience of delta cities. The innovation of the resilience framework aims to fill the debate on resilience in scientific planning literature with practical content. Previous research on resilience was about defining resilience (Davoudi et al. 2012; Folke et al. 2010; Leach 2008). This research extended and specified prior research because it focused on the operationalization of flood resilience for delta cities. The operationalization of the concept resilience in the Resilience Wheel contributes to the discussion on operationalization of resilience in scientific literature. Blackmore et al (2012) stated "In spite of 30 years of scientific debate and analysis, no consensus on how to operationalize resilience has been reached". Chelleri et al. (2015) argued that there is a poor understanding of how to operationalize resilience in the context of cities. In contrast to their conclusions, the findings of this research offer a way to operationalize resilience by defining and measuring it with 5 key dimensions and 19 measurable indicators. By testing the framework in the context of cities its functionality was corroborated and further improved. The outcomes of this research aim to fill the lack of operationalizing by offering not only a theoretical conceptualisation but also empirical evidence in addition to the literature. Thus, the scientific resilience discourse with mainly theoretical discussions on resilience are supplemented with a way to operationalize urban flood resilience for the benefit of resilience implementation in cities.

Next to the findings on the refinement of the resilience framework, the outcomes of the flood resilience in Dhaka confirm the resilience assessment of Dhaka by Parvin&Shaw (2011). They also concluded that the institutional flood protection in Dhaka is low and there is a high vulnerability of the population against climate disasters. The findings of this research related to the physical flood protection were divergent from

Parvin & Shaw (2011) since they concluded a medium to high physical protection while the assessment in this research revealed a low physical protection.

Monitoring resilience

The findings of this research on indicators that enable monitoring resilience complement the discussion of Rae & Wong (2012) about the value of monitoring. They stated that "Monitoring is deemed necessary to yield relevant and credible intelligence to inform the framing and effectiveness of spatial planning policies" (Rae & Wong 2012). Although in this research was only time to use the Resilience Wheel for rapid assessments, the tool can also be used for annual monitoring to inform spatial planning policies. The Resilience Wheel enables an understanding of flood resilience in delta cities and might lead to subsequent decision making based on that understanding. Resilience can be implemented since monitoring by means of the Resilience Wheel shows what aspects of the city are in need of adaptation to become flood resilient. The spatial planning policy can be based on the strength and weaknesses of the city.

7.4 Reflection on the used methods

Although the research approach was explained in chapter 2, reflection on the chosen methods is required. This paragraph reflects on how the limitations in the research approach might affect the results and which alternatives exist to improve the methodology.

Interpretation

There was a clear and structured research methodology but interpretation played an important role in the selection of articles and indicators. In the first round of selection, 124 articles where scanned on their abstracts to assess if they would contain indicators of flood resilience. Based on a short summary of the article, I included or omitted the article for indicator selection. However, this way of selecting articles highly depends on interpretation and is therefore subjective. The articles that were not selected might also contain useful information. This could be prevented when all the 124 articles were analysed, but there was no time to conduct a literature review of that extent and hence was focused on 40 articles. Interpretation was also important in the coding phase. Deciding if a notion of resilience could function as indicator of flood resilience was subject to interpretation. I had to make assumptions on the selection of indicators but I always tried to base these assumptions on the context of the indicators and to underpin the assumptions with arguments.

Another limitation of this research was the influence of interpretation of the researcher in the assessments of Rotterdam and Dhaka. The scoring of Rotterdam and Dhaka was dependent on the interpretation of data, policy documents, assessment reports, spatial plans and laws that contained information about the indicators. Although these ratings are 'coloured' by my perception, I tried to be as objectively as possible. If information on an indicator was lacking in literature, I did not score that indicator. This approach has been chosen to prevent a skewed view on the flood resilience by adding scores based on assumptions. One could assume that no information means no or low availability of the indicator, but that is doubtful since a lack of information on indicators does not always equal a low score.

Triangulation of sources was applied to increase the validity of the assessment of Dhaka. The role of interpretation can be restricted by also applying triangulation of researchers when the Resilience Wheel is used in practice. Monitoring conducted by several researchers increases the reliability of outcomes. Besides, the more experts are included in the survey to assess their city, the higher the reliability of the average outcomes.

Hard and soft indicators

The findings of the literature review were hard and soft indicators of resilience. The hard indicators are about data and statistics and can be expressed in universal values. For example, population density is a hard indicator since it can be expressed in residents/km2. This is measurable in existing data about the city. However, the most indicators of flood resilience as derived from literature are soft indicators which means that they are not expressible in numbers. That is why the Resilience Wheel is for the major part based on relative measuring instead of absolute measuring. A scale of 1 to 5 (from absent to very high) is a quantitative way of measuring but still depends on what the respondents of the surveys or the researcher define as low or high. The results of the assessments are therefore affected by the interpretation of information by the researcher and the experts. An alternative is to look for only numerically expressible indicators.

The possibility to quantify the meaning of the scores differed per indicator. The scoring tables could have been made even more quantitative e.g. by expressing all the numbers 1-5 into percentages of occurrence of the indicator (1=0-20%, 2=20-40%… 5=80-100%). In the current form, only the scores belonging to the dimension 'Vulnerability of population' (Population density, Population composition, and Income level) were classified in numbers. These indicators were about statistical data that could be easily found in the cases of this research. However, resilience is not a purely technical concept and therefore it will be difficult to find only numerically expressible indicators. The Resilience Wheel could also be changed in a way of merely qualitative measuring using soft indicators. However, this increases the dependency on the interpretation of researcher and experts and therefore the objectivity and accuracy of the outcomes might decrease. The indicators of four of five dimensions were not quantifiable and therefore I only gave a description of the scores without a quantification in numbers or percentages. This is done deliberately since the Resilience Wheel is not developed to let the experts do a long during, extensive study on indicators to come to absolute values. The objective of this research was create a coherent framework with indicators that characterize flood resilience and are measurable through assessment of cities. It should be an easily operating instrument that also serves a better comparison of the elements of resilience within a city and between delta cities.

Although the Resilience Wheel is mainly based on interpretation of information, applying triangulation (of sources and of researcher), will give a reliable insight in the flood resilience of the assessed delta city. The rating in this research is therefore very suitable for a provision of insights in strengths and weaknesses based on document study and expert knowledge.

Comparing delta cities

The Resilience Wheel can also function as a tool to compare delta cities on their flood resilience. However, different cultural, economic and natural circumstances might hamper a comparison between delta cities. In this thesis, two very different delta cities are chosen to test if the framework functions in different conditions. Rotterdam and Dhaka are far apart in terms of culture, socio-economic conditions and planning methods. Similarly, every delta city has its own ethnic culture (religion, rituals, practices) but also the governance culture and planning culture probably differs. For example, a flood protection plan in Myanmar might be well developed for local standards resulting in a high score for this indicator while this same flood protection plan would be low rated in the US. In addition, the institutional culture probably differs between countries. The importance of rules, laws and agreements will be different for delta cities from different countries. Therefore, there might be doubted about the possibility to apply the developed framework to delta cities in different countries. Most scores of indicators will be cultural determined and therefore an international comparison based on fixed indicators is difficult. Since the Resilience Wheel offers a way of relative measuring, the explanation of scores is very important to identify the context of the indicators and explain why the particular scores are given. The possibility for international comparison was facilitated by the classification of the scores on the dimension 'Vulnerability of population'. Since these indicators (e.g. income level) are statistical data, I developed scale that categorizes the scores in different values based on data from the World Bank. In this way the scale of low-high was categorized based on international standards which stimulates an international comparison. However, most of the indicators are relative and therefore need to be scored from low to high by the experts or researcher. To improve the comparative function there can be tried to also classify these scores into categories that represent the international occurring values.

The last limitation in this research is the amount of case studies to test the framework. In this research was time for an application of the framework on two delta cities since the literature review, the creation of the framework and the interviews for feedback on the framework were time consuming. It is important to continue with testing the Resilience Wheel in practice in order to refine it. Testing the framework on more delta cities would increase the insight in the applicability of the framework (i.e. how well the framework functions in delta cities with different circumstances).

8. Conclusion

This chapter contains the conclusions of this research. Possibilities for expansion of the developed framework are given and advice for resilience improvement in Rotterdam and Dhaka is provided. Next, I recommend options for further research.

8.1 Resilience Wheel

In the problem description was stated that there is lack of an applicable framework with indicators that operationalizes the concept of resilience and enables monitoring of resilience in cities. The research focused on flood resilience which is defined as "the ability of a system to withstand or adapt to flooding without being harmed in its functionality" (Restemeyer, Woltjer & Van den Brink 2015). The research question was: *Which indicators of flood resilience offer a coherent framework for operationalizing and monitoring flood resilience of delta cities?* There can be concluded that it was possible to develop a framework with indicators of flood resilience based on a systematic literature review. This study identified 5 dimensions and 19 indicators of flood resilience that operationalized the concept of resilience and were placed in a framework called the Resilience Wheel. This framework can be used to monitor flood resilience since it is known which indicators should be measured to get an insight in the flood resilience of delta cities. Two case studies led to the refinement of the framework and the indicators proved measurable in the delta cities Rotterdam and Dhaka. I conclude that the Resilience Wheel offers an understandable way of measuring resilience for the respondents in the cities. The associated colour scale is a communicative way of presenting information about the city. The outcomes of using the Resilience Wheel are quantitative results on flood resilience. These results can be used to rank, for example, which delta cities score better and which worse on a flood resilience scale. The Resilience wheel further offers a comprehensive diagnostic tool enabling to compress large amounts of information in a concise and communicative overview. It helps to diagnose strengths and weaknesses of delta cities that can respectively be built upon or improved. Keeping resilience as a guideline for policy facilitates a lowering vulnerability in future development (Folke et al. 2010). This study makes clear that the notion resilience can be helpful from a planning perspective in understanding and analysing urban systems. After monitoring of cities, the coloured Resilience Wheel can be used to stimulate discussion with planners and policymakers involved in landscape adaptation to climate change for flood-prone cities.

8.2 Recommendations for expansion of resilience monitoring

The use of the Resilience Wheel is a way of measuring flood resilience in delta cities. However, the Resilience Wheel can be adapted for measuring other types of resilience.

Expanding the Resilience Wheel

Although the focus on flood resilience made the research more specific, it fulfilled just a part of resilience measuring. However, it is possible to expand the Resilience Wheel to a method for monitoring resilience in general. An equal model as the Resilience Wheel can be used and also the procedure of measuring (document study, surveys and empirical observation) can be applied. Though, monitoring resilience in the wider sense requires to find indicators that represent resilience in its broadest meaning. The Resilience Wheel already contained a few general resilience indicators (e.g. learning capacity, institutional capacity, and preparedness) but they were applied to flooding by their operational definitions in this research. Using general definitions of these indicators makes them appropriate for a general resilience monitor.

However, the attempt to expand the Resilience Wheel for monitoring resilience its broadest sense might lead to the vagueness that was stated as problematic feature of the concept resilience in the introduction. This research showed that resilience is a very broad concept applicable on many topics. Therefore it might be better to focus resilience monitoring on the specific 'resilience issue' (e.g. drought, pollution, earthquakes) to prevent vagueness and ambiguity about resilience in general. In this research, the motivation for research on resilience was climate change which leads to sea level rise and requires the implementation of flood resilience. Expansion of the Resilience Wheel should also focus on a specific problem or question. This enables the applicability of resilience to a specific topic and makes the concept more clear. For a larger Delta Monitor, it is important that the chosen indicators should be clear and simple enough to show the development progress in resilience since that is essential for monitoring.

Absolute and relative measuring

The Resilience Wheel did not include border values of indicators. Each indicator could be scored from 1 (being absent or low) to 5 (being very high or very extensive). In this research, I chose for an intermediate form of 'hard' and 'soft' measuring. The Resilience Wheel could be changed into a framework with only 'hard', numeric indicators which requires a lot of available data, very specific knowledge and an intensive study on the cities. However, when experts do not know the exact rate (which is likely) they might not rate this indicator at all. The procedure for scoring hard indicators could be changed into a detailed data study by the researcher. Another alternative is to change the Resilience Wheel into a 'light version'. This could be a framework with only 'soft' indicators that need to be scored without argumentation. This enables a quick assessment but decreases the objectivity and accuracy of the outcomes since it depends more on the interpretation of the researcher and experts. With the Resilience Wheel I chose to take both elements (easy measuring and objectivity) into account. This way of monitoring requires numerical data and relative data/estimations.

Monitoring

The Resilience Wheel is developed in a way it can be used for resilience monitoring. The operational definitions of the indicators show what information should be found to score the flood resilience of delta cities. This research presented document study and expert surveys as the information collection methods for monitoring of flood resilience in cities. However, the measurements of flood resilience in this study were single measurement moments and therefore resembled assessment rather than monitoring. Still, the Resilience Wheel is a useful tool for monitoring when it is yearly applied and converted into series of measurements. An annual update of the scores of indicators can show the progression or decrease of flood resilience in cities over time. This way of monitoring can be done by an annual recurrence of the document study, expert interviews and observation of delta cities. Another way of monitoring is to establish an annual meeting with experts in flood risk, management and spatial planning of different delta cities. The meetings are the measurement moments where the flood resilience of delta cities can be scored by means of the Resilience Wheel. This series of measurement enables to keep track on the flood resilience of delta cities and compare the outcomes of different delta cities.

8.3 Flood resilience in Rotterdam and Dhaka

The main goal of the case studies was to test the Resilience Wheel on its functioning. However, the outcomes of the assessments also gave insight in the domains for flood resilience improvement by spatial planning in the cities. Monitoring by means of the Resilience Wheel is a preparing step towards resilience improvement. Therefore, this paragraph shortly notices the domains for improvement of flood resilience based on the assessments of both delta cities.

Rotterdam

Although Rotterdam scored fairly high on flood resilience (3.78), there is still room for improvement. Rotterdam has a high ability to withstand flooding. Though, relying on technical prevention measures might be risky in the case these measures like the Maeslantkering fail. The recovering capacity and adaptability of Rotterdam could be increased to strengthen their flood resilience. Resourcefulness, self-organization and public participation scored low compared to other indicators. The resourcefulness can be improved by the development of a 'flooding fund'. A predetermined budget for the payment of response to flooding enables a quicker and clearer expenditure of money than the situation when there is no budget for recovery as in the case of Dhaka. Next, the flood resilience could be improved by the strengthening of citizens' self-organization that was higher in Dhaka than in Rotterdam. Resilience is not only determined by physical and institutional elements but also has a large social component. Citizens could be educated and trained in how to organize themselves in times of flooding. This would increase the adaptive capacity of cities to flooding. The population characteristics of Rotterdam are difficult to change by spatial planning but the organisational capacity can be improved. The moderate public participation in Rotterdam can be increased by the application of participation methods in decision making related to flood risk management. Local knowledge and expertise can be utilized by citizen panels, consultation evenings and advisory groups to involve the citizens in decision making and increase the organisational capacity of Rotterdam.

Dhaka

Overpopulation is considered as the main problem in Dhaka which makes the city very vulnerable to flooding. Overpopulation automatically causes city expansion. Although an undirected city expansion is difficult to steer, it would be best to use zoning for developing new residential space in the higher located areas around Dhaka. The current city expansion started eastwards of Dhaka but this is a low lying area (IGS 2012). Based on a study of maps that show the height of Dhaka and surrounding, the northern part would be more appropriate for city expansion (Walters 2015).

Next, the fragmented institutional system in Dhaka prevents an effective operation of flood risk management. According to Khan (2016), the knowledge and expertise on flood protection are available in Dhaka but the practical implementation is not made. Five government agencies, Bangladesh Water Development Board (BWDB), DWASA, Dhaka City Corporation (DCC), Roads and Highways Department (RHD and The Capital Improvement Authority (RAJUK) are directly or indirectly related to flood mitigation and water drainage in Dhaka. In addition, these agencies are under the responsibility of different ministries. Dhaka can learn a lesson from Rotterdam by changing this institutional 'spider web' into a central coordinated system enabling a clear and effective flood risk management in Dhaka. This could be facilitated by bringing the different flood related agencies under one ministry. It is also possible to assign the responsibility for flood mitigating policy and implementation of this policy to one agency. This results in a better overview of urban flood risk management and prevents working at cross-purposes. It also leads to a higher organisational capacity which contributes to resilience enhancement. However, cultural aspects can hinder a change in flood risk management. Rotterdam has an adaptive planning culture were innovations and changes are common (Dircke et al. 2013). In Dhaka there is a more traditional planning culture and changes are not implemented unless highly necessary (Khan 2016). This traditional culture might hamper a change in flood risk management. One of the reasons for water logging in Dhaka is the ineffective functioning of the drainage systems. Most drainages at the sides of the streets are full of waste. This prevents a quick water discharge. Since the city is too crowded and there are no open spaces, the dirt is just removed from the drainage but deposited next to the drainage. As a result of this, the dirt flows into the drainage again when it starts raining. This is an example of a temporary solution for problems that require a structural solution. A structural solution could be the development of a dredging and maintenance process where the mud from the drainage systems can be used for the elevation of low lying areas.

8.4 Recommendations for further research

Further research is required to find more ways for operationalizing resilience since it is a concept conceived to use in practice. Although this research operationalized resilience, the literature study in this research revealed that there is still a need to fill the gap of practical approaches for assessing, applying and operationalizing resilience. Articles about a specific resilience issue (e.g. resilience to terrorism) could be selected by Scopus and analysed by Atlas.ti to operationalize the concept and clarify its usability in practice.

Another recommendation for further research is to investigate the possibility to transform ‘soft’ indicators of resilience into ‘hard’ measurable parameters. Although resilience is not a purely technical concept, the formulation of quantitative indicators increases the objectivity of resilience measuring since it can be scored by absolute values instead of relative values. This requires in depth study on the indicators of resilience and how they could be expressed in quantifiable terms without losing their meaning as indicators of flood resilience.

This thesis applied resilience on delta cities resulting in indicators that were findable in cities. Another specification was the focus on flood resilience. It is recommended to also research the usefulness of the concept of resilience to other systems such as rural areas or natural systems or to other topics of resilience such as drought, earthquakes or refugees.

This research mainly focused on the monitoring of flood resilience but also touched upon the improvement of flood resilience based on the insights after the monitoring. However, this domain requires further research: How can the indicators of flood resilience be converted into specific measures to improve flood resilience? The implementation of flood resilience measures is context dependent and therefore it requires situation specific research on how to implement measures based on the strengths and weaknesses of delta cities.

A research that continues on the identification of measures is the investigation of the costs and benefits of resilience measures. What are the costs of robust, adaptive and recovery measures? This research can be conducted with a cost-benefit analysis of specific resilience measures.

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Figure 1 - Global average sea level rise for the SRES scenario. Intergovernmental Panel on Climate Change. (2013).

Figure 2.1 - Documents by year. Generated by http://www.scopus.com (Accessed February 10, 2016)

Figure 2.2 - Categories of irrelevant articles. Generated by Microsoft Excell.

Figure 3. - Resilience Wheel. Generated by Adobe Indesign.

Figure 4.1 - Essential functions in the Rotterdam harbour area. From Port of Rotterdam. (2016). Available at: https://www.portofrotterdam.com/nl/lading-industrie/energie-industrie/fossiele-energie. (Accessed May 11th, 2016).

Figure 4.2. - Application of the Resilience Wheel to Rotterdam. Generated by Adobe Indesign.

Figure 5.1 – Refined Version of Resilience Wheel. Generated by Adobe Indesign.

Figure 5.2 - Application of the Resilience Wheel to Dhaka. Generated by Adobe Indesign.

Appendix 1 – Full list of articles for systematic literature review

	Authors	Title	Year	Source title	Volume	Issue	Relevance	Category
1	Acharjee, S.	Urban land use and g	2015	Geological Sc	419	1	Irrelevant	Technical studies
2	Adewole, I.F., Agbola, S.B	Building resilience tc	2015	Environment	27	1	Relevant	
3	Aerts, J.C.J.H., Botzen, W..	Cost estimates for flc	2013	Annals of the	1294	1	Relevant	
4	Agudelo-Vera, C.M., Ledu	Harvesting urban res	2012	Resources, C	64		Irrelevant	Energy
5	Ajibade, I., McBean, G., Be	Urban flooding in Lag	2013	Global Envirc	23	6	Irrelevant	Human studies
6	Albrito, P.	Making cities resilier	2012	Journal of bu	5	4	Relevant	
7	Andrew, S., Arlikatti, S., Si	Sources of organisati	2016	Disasters	40	1	Relevant	
8	Balsells, M., Barroca, B., B	Making urban flood r	2015	Proceedings	168	2	Relevant	
9	Balsells, M., Barroca, B., A	Analysing urban resil	2013	Water Scienc	68	11	Relevant	
10	Barroca, B., Serre, D.	Behind the barriers:	2013	Sapiens	6	1	Relevant	
11	Barthel, S., Isendahl, C.	Urban gardens, Agric	2013	Ecological Ec	86		Irrelevant	Food
12	Blackmore, J.M., Plant, R.A	Risk and resilience tc	2008	Journal of Wa	134	3	Relevant	
13	Booher, D.E., Innes, J.E.	Governance for Resil	2010	Ecology and S	15	3	Irrelevant	Technical studies
14	Borba, M.L., Warner, J.F., I	Urban stormwater flc	2015	Journal of Flood Risk Manag			Relevant	
15	Bristow, D.N., Kennedy, C	Urban metabolism ar	2013	Journal of Inc	17	5	Irrelevant	Energy
16	Brown, A., Dayal, A., Rumt	From practice to thec	2012	Environment	24	2	Relevant	
17	Carpenter, S.R., Cottingha	Resilience and restor	1997	Ecology and S	1	1	Irrelevant	Biology
18	Cashman, A.C.	Case study of institut	2011	Journal of Flc	4	1	Relevant	
19	Chan, S.-L., Wey, W.-M., C	Establishing Disaster	2014	Social Indicat	115	1	Relevant	
20	Chang, S.E., Mcdaniels, T.,	Toward disaster-resil	2014	Risk Analysis	34	3	Irrelevant	Technical studies
21	Chelleri, L., Schuetze, T., S	Integrating resilience	2015	Habitat Inter	48		Irrelevant	Technical studies
22	Chelleri, L., Waters, J.J., O	Resilience trade-offs	2015	Environment	27	1	Relevant	
23	Cheshire, L.	'Know your neighbou	2015	Environment	47	5	Irrelevant	Human studies
24	Chiang, Y.-C., Tsai, F.-F., C	Adaptive society in a	2014	Land Use Poli	36		Irrelevant	Rest category
25	Chirisa, I., Bandauko, E.	African Cities and the	2015	Urban Forum	26	4	Irrelevant	Energy
26	Collier, F., Hambling, J., Ke	Tomorrow's cities: A	2014	Proceedings	167	2	Relevant	
27	Comboul, M., Ghanem, R.	Value of information	2013	Journal of Wa	139	4	Irrelevant	Technical studies
28	Cuppens, A., Smets, I., Wy	Definition of realistic	2012	Water Scienc	65	8	Irrelevant	Water quality
29	D'Aragon, J.	Disaster risk reductic	2013	Regional Dev	34	1	Irrelevant	Rest category
30	Deatrick, J.F.	Flood-resilient redev	2015	Proceedings	168	2	Irrelevant	Technical studies
31	del Mar Alguacil, M., Torre	Long-Term Effects of	2012	PLoS ONE	7	10	Irrelevant	Water quality
32	Dieleman, H.	Organizational learni	2013	Journal of Cle	50		Relevant	
33	Djordjević, S., Butler, D., G	New policies to deal	2011	Environment	14	7	Relevant	
34	Dosh, P.	Tactical innovation, c	2009	Latin Americ	51	1	Irrelevant	Rest category
35	Duh, J.-D., Shandas, V., Ch	Rates of urbanisatior	2008	Science of th	400	42430	Irrelevant	Water quality
36	Farhan, A.R., Lim, S.	Resilience assessme	2011	Ocean and Cc	54	5	Relevant	
37	Ferguson, B.C., Brown, R.F	A diagnostic procedu	2013	Ecology and S	18	4	Irrelevant	Water quality
38	Festing, H.	Getting ready for the	2015	Planning Adv	2015	MAY-J	Relevant	
39	Fu, X., Tang, Z.	Planning for drought	2013	Cities	32		Irrelevant	Technical studies
40	García-Armisen, T., Inceoğ	Seasonal variations a	2014	PLoS ONE	9	3	Irrelevant	Water quality
41	Giovinazzi, S., Wilson, T., I	Lifelines performanc	2011	Bulletin of th	44	4	Irrelevant	Rest category
42	Godschalk, D.R.	Urban hazard mitigat	2003	Natural Haza	4	3	Relevant	
43	Gupta, K.	Urban flood resilienc	2007	Urban Water	4	3	Irrelevant	Technical studies
44	Hamilton, W.A.H.	Resilience and the ci	2009	Proceedings	162	3	Relevant	
45	Head, L., Muir, P.	Suburban life and the	2006	Transactions	31	4	Irrelevant	Rest category
46	Hettiarachchi, M., Athukoi	Urban wetlands and	2014	International	5	1	Irrelevant	Water quality
47	Hooli, L.J.	Resilience of the poc	2015	Regional Environmental Cha			Irrelevant	Technical studies
48	Hordijk, M., Sara, L.M., Sut	Resilience, transitior	2014	Environment	26	1	Irrelevant	Water quality
49	Jacobi, J., Drescher, A.W.,	Diversity strengthen	2010	Appropriate	37	1	Irrelevant	Food
50	Joerin, J., Shaw, R., Takeu	The adoption of a clir	2014	Disasters	38	3	Relevant	
51	Johannessen, A., Rosemar	Strategies for buildir	2014	International	10	PA	Irrelevant	Water quality
52	Keck, M., Etzold, B.	Resilience refused w	2013	Erdkunde	67	1	Irrelevant	Food
53	Khailani, D.K., Perera, R.	Mainstreaming disas	2013	Land Use Poli	30	1	Irrelevant	Technical studies
54	Kollin, C.	Planting resiliency	2008	American Foi	113	4	Irrelevant	Biology
55	Kotzee, I., Reyers, B.	Piloting a social-ecol	2016	Ecological Inc	60		Relevant	
56	Krupa, M.B., Stuart Chapir	Robustness or resilie	2014	Ecology and S	19	2	Irrelevant	Technical studies
57	Lamond, J.E., Rose, C.B., B	Evidence for improve	2015	Proceedings	168	2	Irrelevant	Technical studies
58	Lamond, J.E., Proverbs, D.	Resilience to floodin	2009	Proceedings	162	2	Relevant	
59	Lassa, J.A., Nugraha, E.	From shared learning	2015	Environment	27	1	Irrelevant	Rest category
60	Lhomme, S., Serre, D., Dia	Analyzing resilience	2013	Natural Haza	13	2	Relevant	
61	Li, Y., Li, Y., Wu, W.	Threshold and resilie	2015	Environmental Pollution			Irrelevant	Water quality
62	Li, Y., Shi, Y., Qureshi, S., E	Applying the concep	2014	Ecological Inc	42		Irrelevant	Water quality

63	Liao, K.-H.	A theory on urban	2012	Ecology ar	17	4	Relevant	
64	Lu, P., Stead, D.	Understanding the	2013	Cities	35		Relevant	
65	Malan, N.	Urban farmers and	2015	Agrekon	54	2	Irrelevant	Food
66	Marafa, L.M.	Effects and resilier	2002	Geograph	87	4	Irrelevant	Technical studies
67	McDaniels, T.L., Cha	Towards disaster-r	2015	Environm	35	2	Irrelevant	Technical studies
68	McNally, A., Magee	Hydropower and s	2009	Journal of	90	SUPPL. 3	Irrelevant	Energy
69	McPhearson, T., Ha	Urban ecosystem s	2014	Ambio	43	4	Irrelevant	Technical studies
70	Mebarki, A., Valenc	Flood hazards and	2012	Natural Ha	12	5	Irrelevant	Technical studies
71	Mehmood, A.	Of resilient places	2016	European	24	2	Relevant	
72	Milman, A., Short, A	Incorporating resil	2008	Global Env	18	4	Irrelevant	Rest category
73	Moench, M.	Experiences apply	2014	Developm	24	4	Relevant	
74	Mugume, S.N., Gon	A global analysis a	2015	Water Res	81		Irrelevant	Technical studies
75	Muller, M.	Adapting to climat	2007	Environm	19	1	Irrelevant	Water quality
76	Myers, M.R.	A student and teac	2012	Journal of	50	4	Irrelevant	Water quality
77	Ni, Z., van Gaans, P.	Combination of aq	2015	Applied Microbiology and Biot			Irrelevant	Energy
78	Ning, X., Liu, Y., Che	Sustainability of ur	2013	Frontiers	7	5	Irrelevant	Water quality
79	Noor, N.B.M., Nor,	Geospatial techno	2014	Planning N	12		Irrelevant	Human studies
80	Odemerho, F.O.	Building climate ch	2015	Environm	27	1	Irrelevant	Rest category
81	Padgham, J., Jabbou	Managing change a	2015	Urban Clir	12		Irrelevant	Food
82	Parthasarathy, D.	Informality, resilie	2015	Pacific Aff	88	3	Irrelevant	Rest category
83	Pearson, A.L., Pearc	Deprived yet healt	2013	Social Scie	91		Irrelevant	Rest category
84	Perkol-Finkel, S., A	Loss and recovery	2010	PLoS ONE	5	5	Irrelevant	Biology
85	Pilav, A.	Before the war, wa	2012	Internatio	3	1	Irrelevant	Human studies
86	Porio, E.	Vulnerability, adap	2011	Asian Jour	39	4	Irrelevant	Rest category
87	Prashar, S., Shaw, R	Community action	2013	Mitigation	18	4	Irrelevant	Technical studies
88	Prashar, S.K., Shaw,	Urbanization and h	2012	Internatio	3	1	Relevant	
89	Rachlin, J.W., Wark	An evaluation of th	2007	Northeast	14	4	Irrelevant	Biology
90	Ratick, S., Meacham	Locating backup fa	2008	Growth ar	39	4	Irrelevant	Technical studies
91	Razzaghmanesh, M	Developing resilie	2014	Science of	490		Irrelevant	Technical studies
92	Restemeyer, B., Wo	A strategy-based f	2015	Planning T	16	1	Relevant	
93	Rijke, J., Farrelly, M	Configuring transf	2013	Environm	25		Irrelevant	Technical studies
94	Rinne, P., Nygren, A	From Resistance to	2016	Journal of	18	1	Irrelevant	Rest category
95	Roberts, D.	Prioritizing climate	2010	Environm	22	2	Irrelevant	Technical studies
96	Rothwell, A., Ridou	Environmental per	2014	Journal of Cleaner Production			Irrelevant	Food
97	Schuetze, T., Chelle	Integrating decent	2013	Water (Sw	5	2	Irrelevant	Technical studies
98	Sciulli, N., D'Onza, (	Building a resilient	2015	Internatio	28	6	Relevant	
99	Scott, C.A., Vicuña,	Irrigation efficienc	2014	Hydrology	18	4	Irrelevant	Food
100	Seelig, S.	A master plan for l	2011	Cities	28	6	Irrelevant	Technical studies
101	Shale, M.T.	Can burial societie	2014	Climate ar	6	3	Irrelevant	Technical studies
102	Siebeneck, L., Arlik	Using provincial ba	2015	Natural Ha	79	2	Relevant	
103	Siekmann, T., Siekn	Resilient urban dra	2015	Urban Wa	12	1	Irrelevant	Technical studies
104	Sjöman, H., Hirons,	Urban forest resili	2015	Urban For	14	4	Irrelevant	Biology
105	Smith, J.G., DuBois,	Framing for resilie	2015	Sustainability Science			Irrelevant	Human studies
106	Smith, K., Lawrence	The resilience of lo	2016	Agricultur	33	1	Irrelevant	Food
107	Smith, T.F., Daffara	A method for builc	2011	Futures	43	7	Irrelevant	Rest category
108	Spence, S., Ross, J.,	Snagging funding f	2010	Journal / A	102	10	Irrelevant	Technical studies
109	Srivastava, N., Shaw	Occupational resili	2015	Internatio	12		Irrelevant	Rest category
110	Stead, D.	Urban planning, wa	2014	Internatio	21	1	Relevant	
111	Stokeld, D., Hamer,	Factors influencing	2014	Wildlife R	41	2	Irrelevant	Biology
112	Sudmeier, K.I., Jabo	Operationalizing "	2013	Disaster P	22	4	Relevant	
113	Sunarharum, T.M., S	Re-framing plannin	2014	Internatio	5	3	Relevant	
114	Surjan, A., Shaw, R.	Enhancing disaster	2009	Disaster P	18	4	Irrelevant	Rest category
115	Toubin, M., Laganie	Improving the con	2015	Journal of	141	4	Relevant	
116	Uy, N., Shaw, R.	Ecosystem resilien	2013	Journal of	8	1	Irrelevant	Biology
117	Van Veelen, P.C., S	Planning resilient	2015	Proceedin	168	2	Relevant	
118	Vedeld, T., Coly, A.	Climate adaptation	2015	Natural Hazards			Relevant	
119	Wabnitz, C.C.C., Bal	Ecosystem structur	2010	Marine Ec	420		Irrelevant	Biology
120	Wagner, I., Breil, P.	The role of ecohyd	2013	Ecohydrol	13	2	Irrelevant	Water quality
121	Walters, P.	The problem of co	2015	Habitat In	50		Relevant	
122	Wickes, R., Zahnow	Neighborhood Stru	2015	Social Scie	96	2	Relevant	
123	Yazdani, A., Otoo, R	Resilience enhanc	2011	Environm	26	12	Irrelevant	Water quality
124	[No author name av	Perceptions of con	2014	Communi	15		Irrelevant	Water quality

Appendix 2 - List of attendants at the workshop

Name	Function
Prof. Dr. M. Monowar Hossain	Executive director
Dr. A F M Afzal Hossain	Deputy executive director
Coast, Port & Estuary Division (CPE)	
Zahirul Haque Khan	Director
Shumi Aktar	Associate specialist
Flood Management Division (FMG)	
Md. Sohel Masud	Director
Dr. Sardar Mohammad Shah-Newaz	Principal specialist
Md. Abdulla Hel Kafi	Associate specialist
Aasadul Kabir Chowdhury	Associate specialist
Shahadat Hossain	Junior specialist
Irrigation Management Division (IRM)	
Sardar M Shah-Newaz	Director
Md. Shamsuddin	Environmental specialist
River Engineering Division (REN)	
Imran Khan	Junior engineer
Fahmida Noor	Associate specialist
Asmot Ara Alam	Junior specialist
Survey & Data Division (SDT)	
Pankaj Kumar Maitra	Associate specialist
Kh. Shafiqul Islam	Junior speciliast
Water Resources Planning Division (WRP)	
David Mohammed Khan	Senior specialist
Ismat Ara Pervin	Associate specialist

Appendix 3 – Survey questions

Below are the questions that were part of the digital survey. These questions were also asked to professor Khan during the semi-structured interview.

<u>Quantification of flood resilience in Dhaka</u>

Dear respondent. This survey is part of my master thesis about flood resilience. I developed a model to measure the flood resilience of delta cities with help of 19 indicators divided over 5 dimensions. Flood resilience is defined as the ability of a city to withstand or adapt to a flood without being harmed in its functionality. You're kindly asked to rate the indicators of flood resilience in Dhaka from 1-5. Each question contains a description of the indicator after which the respondent should estimate the height of this indicator for Dhaka and give a score from 1-5. It does not matter when you do not know the exact data, try to estimate the value of the indicator for Dhaka. It is important to provide a short argumentation for the score you gave at each question. Except for the dimension vulnerability of population (since these are data) you can provide your arguments at the option: 'Arguments'. At the end of this survey you are asked to provide your recommendations to improve the flood resilience of Dhaka. Good luck!

Recovery

Question 1. Emergency Management. How would you rate the availability of warning systems, evacuation plans, aid coordination procedures and voluntary services in Dhaka?

1. No availability.
2. Low availability.
3. Medium availability.
4. High availability.
5. Very high availability.

Arguments….

Question 2. Resourcefulness. How would rate the budgeted emergency funds, recovery funds and reserves in water & energy in Dhaka?

1. No reserves.
2. Small reserves.
3. Medium reserves.
4. Large reserves.
5. Very large reserves.

Arguments…

Question 3. Protection of critical infrastructures. How would you rate the physical protection or elevation of energy network, traffic routes, water supply & airports in Dhaka?

1. No protection.
2. Low protection.
3. Medium protection.
4. High protection.
5. Very high protection.

Arguments…

Question 4. Drainage systems. How would you rate the availability and operation of drainage systems in Dhaka? (e.g. pipes, ditches, sewerage, pumps and culverts).

1. No drainage system.
2. Limited drainage system.
3. Medium drainage system.
4. Extensive drainage system.
5. Very extensive drainage system.
Arguments…

Resistance

Question 5. Embankment. How would you rate the physical presence and height of embankments in Dhaka?

1. No embankments.
2. Limited embankments.
3. Medium emankments.
4. High embankments.
5. Very high embankments.
Arguments...

Question 6. Absorption capacity. How would you rate the spatial dispersion of shopping centers, stations, water & energy supply sources in Dhaka?

1. Central concentrated.
2. Limited dispersed.
3. Medium dispersed.
4. Highly dispersed.
5. Extremely dispered.
Arguments…

Question 7. Strength of build environment. How would you rate the strength of buildings in Dhaka to flooding caused by their material and building style?

1. Low strength.
2. Limited strength.
3. Medium strength.
4. High strength.
5. Very high strength
Arguments…

Question 8. Flood shelters. How would you rate the availability of flood shelters in Dhaka? (e.g. widened stretches of embanked roads or roofs of schools, shops or restaurants).

1. No flood shelters.
2. Limited availability of flood shelters.
3. Medium availability of flood shelters.
4. High availability of flood shelters.
5. Very high availability of flood shelters.
Arguments…

Adaptability

Question 9. Self-organization. How would you rate the ability of residents to organize themselves in fixing damage and cleaning up after a flood in Dhaka?

1. No self-organization.
2. Low self-organization.
3. Medium self-organization.
4. High self-organization.

5. Very high self-organization.
Arguments…

Question 10. Learning capacity. How would you rate the ability to learn from previous floods in Dhaka? Measurable in education plans, trainings, media attention and institutional adjustments adapted to flooding.

1. No learning capacity in plans and adjustments.
2. Limited learning capacity in plans and adjustments.
3. Medium learning capacity in plans and adjustments.
4. Extensive learning capacity in plans and adjustments.
5. Very extensive learning capacity in plans and adjustments.

Arguments…

Question 11. Preparedness. How would you rate the preparedness of Dhaka by the use of future projections in policy and design plans of flood barriers?

1. No use of projections.
2. Limited use of projections.
3. Medium use of projections.
4. Extensive use of projections.
5. Very extensive use of projections.

Arguments…

Question 12. Building codes. How would you rate the availability of regulations, plans and prescriptions in Dhaka about the design and zoning of buildings in order to adapt to flood risk?

1. No building codes.
2. Limited building codes.
3. Medium building codes.
4. Extensive building codes.
5. Very extensive building codes.

Arguments…

Vulnerability of population

Question 13. Population density. How would you rate the population density in residents/km2 in Dhaka?

1. > 15000 pop./km2.
2. 5000-15000 pop./km2
3. 1000-5000 pop./km2
4. 500-1000 pop./km2
5. 0-500 pop./km2

Question 14. Population composition. How would you rate the proportion of the city population between the age of 15 and 64 as percentage of the total population in Dhaka?

1. 0-20% between 15 and 64.
2. 20-40% between 15 and 64.
3. 40-60% between 15 and 64.
4. 60-80% between 15 and 64.
5. 80-100% between 15 and 64

Question 15. Income level. How would you rate the average annual household disposable income in Dhaka in $?

1. $0-5000.
2. $5000-15000.
3. $15000-30000.
4. $30000-45000.
5. >$45000.

Organizational capacity

Question 16. Stakeholder cooperation. How would you rate the degree of collaborations, meetings and information exchange between policymakers, (local) governments, safety organizations, engineers and NGO's in Dhaka?

1. No collaborations.
2. Low amount of collaborations.
3. Medium amount of collaborations.
4. High amount of collaborations.
5. Very high amount of collaborations.

Arguments…

Question 17. Access to information. How would you rate the availability of scientific climate information & risk assessments for policymakers to prepare risk reduction by political and spatial interventions in Dhaka?

1. No access to information.
2. Low access to information.
3. Medium access to information.
4. High extensive access to information.
5. Very high access to information.

Question 18. Institutional capacity. How would you rate the availability and operation of decision-making procedures, programs and system of rules related to flood risk management in Dhaka?

1. No availability.
2. Low availability.
3. Medium availability.
4. High availability.
5. Very high availability.

Question 19. Public participation. How would you rate the extent of public participation in flood risk reduction policy and measures in Dhaka? This can be measured in amount of citizen panels, advisory groups and other participation methods in the city.

1. No participation methods.
2. Low participation methods.
3. Medium participation methods.
4. Extensive participation methods.
5. Very extensive participation methods.

Question 20. What are in your opinion required spatial and political interventions to increase the flood resilience in Dhaka?