The effects of floods on residential property values

Thesis

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ARCADIS

The effects of floods on residential property values

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”I believe water will be the defining crisis of our century — from droughts, storms, and floods to degrading water quality. We’ll see major conflicts over water and the proliferation of water refugees. We inhabit a water planet, and unless we protect, manage, and restore that resource, the future will be a very different place from the one we imagine today.”

- Alexandra Cousteau

Preface

Integrating different topics and domains has always been of interest to me. Therefore, the freedom of choosing a thesis topic was challenging but an advantageous opportunity. Combing my interest in the built environment, sustainability, and economy, has been an intriguing opportunity. Originating from the faculty of Architecture and the Built environment, I was wired to think in concepts and designs. Moreover, the field of research was quite new to me. Combing this state of mind with research and conducting different types of analyses was very interesting. Throughout the research, I developed an enhanced understanding of the complexity involved in the effects of floods on our built environment and the importance of an integral perspective and approach in developing effective solutions. Hopefully, this understanding can be applied throughout my professional career when encountering similar or completely different challenges.

First of all, I would like to thank my supervisors from the Delft University of Technology, Ellen van Bueren, Martine van den Boomen, and Zac Taylor. Your subset of expertise allowed me to leverage a variety of methods and still feel supported in each and every part. Your guidance and critical notes throughout the process have challenged and stimulated me to enhance my work. The interesting discussions resulting from your sincere interest and involvement in the subjects and the interfaces of the built environment and climate change during our meetings have inspired me and triggered me to pursue topics and methods beyond my initial understanding of the challenge of flooding and the built environment.

Second, I would like to thank both Marjolijn Versteegden and Michiel Mees for allowing me the opportunity to conduct my research while being surrounded by an inspiring environment such as Arcadis. Additionally, I would like to thank you for your constant support and guidance throughout the project. Through weekly conversations with you, I was given a glimpse of the subjects you are working on and how you strive to enhance the built environment. Through your guidance, I was able to understand the link between research and practice, and why this link is so essential.

Third, I would like to thank everyone I interviewed, this provided an extremely interesting perspective on how the topic is relevant in practice and how we consider flood risks at this moment. It showed how different stakeholders perceive and experience flood challenges in different ways, and why it is so important to understand what drives different stakeholders. Moreover, everyone was very helpful and sincerely interested in the subject, greatly motivating me. Fourth, I am incredibly grateful for all my friends and family who supported me throughout the entire process, provided me with critical remarks, and inspired me during discussions about the subject. Lastly, I would like to thank my fellow graduate interns and the employees at Arcadis, as they motivated me and made my thesis time especially great.

I hope you enjoy reading this report!

Linde van der Ven
Delft, April 2023

Executive Summary

Large-scale climate change trends, such as sea level rise, are increasingly observed worldwide. As approximately 10% of the population in the world is living in low-lying coastal areas, sea-level rise is deemed to be one of the biggest threats to human beings in the future (Haasnoot et al., 2020). The Netherlands is a low-lying delta known for its remarkable position and subsequent water expertise, as a quarter of the country is below sea level.

However, the area situated under sea level is the most densely populated and the economic heart of the country (Mulder et al., 2011). Moreover, the Netherlands has one of the most significant mortgage-to-debt-to-GDP ratios in the world (Hochstenbach & Aalbers, 2023). As a result, the Dutch economy is vulnerable to damages to real estate as this could lead to large-scale householder default and ultimately destabilize their economy. Alleviating flood risks and reducing their subsequent adverse effect on real estate values can thus be considered crucial for stakeholders operating within the Netherlands. Subsequently, the country's approach to adopting flood-alleviating measures both on a public and private level can therefore be viewed as vital for its welfare.

Notwithstanding, a generic and widely adopted tool to assess flood risks and their subsequent effect on real estate values in practice is yet to be constructed. In addition, the social implications of a flood appear not to be fully incorporated within the definition of flood vulnerability in Dutch practice. Therefore, the main question of this research is formulated as follows:

How can the impact of flood vulnerability on real estate values be assessed, and how can stakeholders contribute to maintaining the stability of residential property values?

Methodology

A combination of quantitative and qualitative methods was employed throughout this study to answer the primary research question. Additionally, a case study was used to enable the quantification of the constructed framework of flood vulnerability (Maastricht in the Netherlands).

First, employing a literature review, the state-of-the-art models were explained. Second, based on academic literature, a vulnerability framework was constructed and applied to the case study. The software program QGIS was employed for the data analysis. The framework consisted of socio-economic, disaster-bearing capabilities, and flood exposure indicators. The data analysis provided insight into the impact of including a divergent set of indicators in the definition of vulnerability. The steps of the vulnerability assessment consisted of (1) Retrieving and treating data, (2) Re-scaling, (3) Weighting, (4) Aggregation, and (5) Robustness checks.

Third, qualitative methods in the form of a literature review and exploratory semi-structured interviews with stakeholders were utilized. Through the qualitative methods, stakeholders' barriers, stimuli, and enablers were analyzed. A framework by (Graaskamp, 1992) was adopted to enable the analysis. Subsequently, a stakeholder analysis was conducted to retrieve the implications of the encountered barriers and the subsequent opportunities. This analysis was executed by comparing the barriers, stimuli, and enablers from the literature with the exploratory interviews. The exploratory interviews were analyzed through the following steps: (1) Analyzing the transcripts, (2) Marking relevant quotes, (3) Constructing open codes, (4) Grouping the open codes within axial codes, (5) Linking the axial quotes to the category "barrier," "stimuli" or "enabler." By linking the experienced barriers to enablers of stakeholders, opportunities could ultimately be identified.

Results

The results of the conducted study were two-fold. The first results consisted of quantitative research on the flood vulnerability of the case study and its implications. The second part covered the qualitative research on the relevant stakeholders and the main implications and opportunities in alleviating flood risks and their potential subsequent effect on real estate values.

Vulnerability assessment
First, state-of-the-art models for examining the effect of floods were explained. Numerous economic models exist to assess these potential effects. The Hedonic Pricing Model and Spatial Regression Model were deemed most effective for future flood risks due to their ability to estimate hypothetical events in their price structure and extrapolate the effect of specific property characteristics. Additionally, the difference-in-difference model was deemed most suitable for past flood events, as it enables identifying the impact of a single attribute (i.e., treatment) over time. An essential implication within this conclusion was that the most appropriate model depends on the desired parameter being measured as well as the granularity of the available dataset.

Subsequently, a framework was constructed to define flood vulnerability and enable an assessment of the flood vulnerability of the case study. The framework entailed social status, economic status, population area, disaster-bearing capabilities, and flood exposure. Thereafter, 16 indicators were defined to utilize and quantify the constructed framework.

The quantitative study showed clustered flood vulnerability when solely considering flood exposure. However, the flood vulnerability was dispersed throughout the case study when applying the complete framework, indicating significant effects of including a variety of indicators when assessing flood vulnerability. The current definition of the application of flood vulnerability may thus be too narrow, lacking full consideration of the social impact of a flood event. It was discussed that enhancing social cohesion and micro-adaptation could be applied to prevent enlarging social injustice such as climate gentrification.

Stakeholder Analysis
The barriers, stimuli, and enablers of seven stakeholders were assessed through a literature review and semi-structured exploratory interviews. The assessed stakeholders are insurers, financial institutions, investors, developers, residents, the government, and municipalities. The main barriers can be summarized as: Lack of awareness, Lack of uniformity, Limiting regulation, Lack of priority, Lack of responsibility, Limited capabilities, and Complicating conditions.

Similarly, the main enablers of the assessed stakeholders were concluded to be: Enhance awareness, Diminish risk, Regulation, Collaboration, Economic (dis)incentives, and Discourage. Subsequently, the perceived barriers were linked to the observed enablers to extrapolate stakeholder opportunities and implications. The analysis indicated the ensuing findings:

- **Enhancing Awareness** The awareness of the possible effects of flood risks on real estate (values) is seemingly low. Stakeholders primarily experiencing a lack of awareness as a barrier were concluded to be developers and residents. Enhancing awareness could be achieved through enablers such as new regulations or economic incentives; an example is the water label, in which all real estate receives a flood risk score. Stakeholders vital in enabling incentives to alleviate this barrier were considered to be the government, municipalities, insurers, and financial institutions.
- **Collaborate and Uniformize** Communication around flood risks displays implications of complexities. This phenomenon could potentially be reduced through a collective understanding of risk levels. Moreover, barriers due to the complex systems and regulations within the Netherlands might be alleviated through collaboration and open communication, after which consensus can be reached. Stakeholders experiencing limiting regulation as a barrier were concluded to be investors and developers whereas financial institutions felt uniformity was currently lacking. To reduce these barriers, all stakeholders are relevant through collaboration, in which the government may have a central role.
- **Knowledge as a common good** Knowledge around flood risks is seemingly experienced as a commercial commodity, whereas flood risks are undeniably a collective issue. Moreover, within the knowledge of flood risks, uncertaintainties, and interdependencies exist, leading developers, residents, and municipalities to feel dependent on the government. Enhanced knowledge sharing can contribute to reducing the lack of capabilities stakeholders experience. Limited capabilities were found to be experienced as a barrier for all stakeholders. Economic incentives may contribute to limited financial funds, to which investors, the government, or municipalities could contribute.
- **Divide and Conquer** Finally, ambiguity in task divisions and organized irresponsibility appear to result in limited responsibility toward flood risks. This can act as a barrier, seemingly present

for investors, developers, the government, and municipalities. Clarity within the division and taking ownership of the existing risks might reduce this barrier. Moreover, partially dividing the responsibility for flood risks may result in greater engagement of non-public stakeholders. The stakeholder most critical in the reduction of this barrier was found to be the government through regulation. In addition, financial institutions and insurers could contribute by influencing the public opinion.

In conclusion, although the potential devaluation of real estate can significantly impact the Netherlands, the measures to quantify the risks and their subsequent impact are seemingly still in their infancy for many stakeholders. Within the state-of-the-art economic models to assess the effects of flood risks on residential real estate values, the definition and usage of the parameters appeared to be vital. When constructing a more accessible tool for all stakeholders, employing a more integral definition of flood vulnerability may thus be more socially just.

Additionally, stakeholders may contribute to the stability of real estate values by actively adapting and incentivizing each other to similar behavior. In addition, within the collective approach of the Netherlands, organized irresponsibility and pillarization appear to be embedded within the system. Through cooperation, division of responsibilities, and taking ownership (e.g., the stick and carrot), devaluation risks may be diminished and the phenomenon of organized irresponsibility reduced. Moreover, by prolonged engagement of initiating stakeholders (e.g., developers), the goal of real estate might be moved from short-term profit to long-term real estate values, potentially contributing to the prevention of enlarged social injustice due to flood risks. Within the shift towards organized responsibility, this research hints towards a vital role for both the government and insurers.

Future research could consider validating and applying the vulnerability framework in other places, potentially focusing on areas with greater social and flood vulnerabilities. Additionally, future research may assess the current definition of flood vulnerability in practice and its role within flood management strategies. In addition, future research could assess the relation between transactional data and flood vulnerability of properties. Besides, future research could validate the barriers, stimuli, and enablers from the literature and the exploratory interviews. Furthermore, future research may delve into the practical implications of the opportunities within Dutch practice. Finally, future research could explore the differences in models and data sources of the stakeholder to understand the complexity and requirements for an integral, accessible model.

Table of Contents

List of Figures

List of Tables

1

Introduction

This chapter highlights the impact of floods on real estate values and their scientific and practical importance. Moreover, the research questions that have been answered throughout this thesis are discussed. First, in section 1.1, the relevant background information on the research topic is discussed. Second, in section 1.2, the identified problem description will be discussed. Subsequently, in section 1.3, the research questions of this study will be presented. Finally, the research relevance, including the scientific as well as practical relevance, will be discussed in section 1.4.

1.1. Background Information

> "Many individuals are doing what they can. But real success can only come if there is a change in our societies and in our economics and in our politics." - David Attenborough

Climate change is one of the major challenges ahead in this century. The world is highly dependent on how our climate and environment will evolve in the upcoming 50-100 years. Global warming will likely result in a significant increase in the overall temperature of the world, associated with altered rainfall patterns (Pour et al., 2020). Throughout the world, large-scale trends (e.g., droughts, sea level rise, extreme precipitation) of global warming occur, most likely driven by human impact. These trends are anticipated to continue or even accelerate in the future (Bubeck et al., 2019).

However, within the different predictions of the changes in our climate, high levels of ambiguity regarding the exact effects of climate change on our environment occur. This can be attributed to imperfections in our models, inherent fluctuations, and the use of different emission outcomes (Liang et al., 2020).

Although various scientists delineate divergent future predictions, the vast majority of scientists agree that climate change will radically shape and change the world we are living in. Predominantly in urban areas, the effects of climate change are likely to be more severe (Pour et al., 2020). Moreover, recent studies have developed possible explanations for mechanisms leading to significant sea level rise (Haasnoot et al., 2020). The global sea level is estimated to rise between 0.52 and 0.98 meters in 2100 (Grases et al., 2020). As 10% of the world's population lives in low-lying coastal areas, sea level rise is one of the biggest climate change threats for human beings (Haasnoot et al., 2020).

The Netherlands is a country that is especially exposed to this threat. The Netherlands is a low-lying delta, known for its remarkable location, as 26% of the country is below sea level. In this area, 60% of the residents live, and 70% of the gross domestic product is currently being earned (Mulder et al., 2011). Next to the fact that the Netherlands is a coastal area, three large rivers flow through the Netherlands: the Meuse, Rhine, and Scheld (Gerritsen, 2005) resulting in 60% of the country being susceptible to large-scale flooding from rivers and the sea (Haasnoot et al., 2020). The Netherlands is highly reliant on dikes and other flood protection measures (Gerritsen, 2005).

In addition to the risks resulting from sea-level rise, the amount and intensity of precipitation have increased over the past century. Between 1910 and 2013, there has been a 26% increase in annual precipitation within the Netherlands. According to the climate scenarios of the KNMI, climate change can lead to an additional increase of approximately 7-14% in hourly extremes of daily precipitation, leading to more extreme weather events. These extreme weather events will increase the chance of flooding (van den Hurk et al., 2014). Thus, although the country is known for its water expertise, extreme impact of climate change can be a major concern for the existence of the Netherlands.

These growing concerns are especially relevant to the government, municipalities, property owners, insurers, and investors (Daniel et al., 2009b). Municipalities are responsible for adaptation measures to climate change on a community and regional level. For the government, it is essential to incorporate

the potential economic consequences of environmental risk when investing in protective infrastructures (Reisinger et al., 2011). For property owners, these changes in extreme variability in weather patterns, rising mean temperatures, and rising sea levels can lead to damages resulting in write-offs and depreciation of their assets (TCFD, 2017). To conform to EU Taxonomy regulations, investors must ensure that projects are climate-proof to lend money. Hence, the effects of climate change on real estate hold significant importance for investors as well (European Parliament, 2020).

1.2. Problem Description

Approximately 15% of the world population faces flood risks due to river-flooding, sea-level rise, urbanization, and changing weather patterns (Koop et al., 2018). Flood risks in urban areas rapidly escalate due to increased impermeable surfaces and expanded floodplain (i.e., bordering a river) construction (O'Donnell & Thorne, 2020).

These challenges are highly complex and interrelated, requiring integration between different sectors and effective governance (Driessen et al., 2016). Floods can heavily impact and damage real estate; however, it remains unclear what the exact implications will be to the inherent complexity of this challenge. Adapting to climate change's impact and aligning public and private parties on the subject requires understanding people's behavior in response to (changing) flood risks (De Koning & Filatova, 2020).

Moreover, many stakeholders can be impacted by the affected values of real estate. For example, many institutional investors have substantial exposure to real estate in their portfolios, and knowing the potential impact of climate change on real estate is therefore very important (Clayton et al., 2021). Insurance, subsidy, and government tax policies may impact certain real estate development by encouraging or discouraging them (Bagstad et al., 2007).

This research aims to contribute to the existing knowledge on the effect of climate change on our built environment, specifically on residential real estate. Although numerous studies have been conducted to assess the effects of past floods and the impact of living in a future flood zone on (residential) real estate values, the results have been very divergent.

In addition, past studies have focused on risk levels associated with living in a flood zone, frequently neglecting the potential impact of socio-economic vulnerability of local residents. However, precisely the socio-economic vulnerabilities of the residents may be crucial in recovering from a flood event. Moreover, the insufficient understanding of the effects of floods on real estate values limits relevant actors in reducing these effects and complicates decision-making. To further explore the effect of flooding on real estate values, the remainder of the thesis will explore the flood risk impact assessment in Maastricht, the Netherlands.

1.3. Research Questions

The main research question leading this research is:

How can the impact of flood vulnerability on residential real estate values be assessed, and how can stakeholders contribute to maintaining the stability of residential property values?

The sub-questions are:

1. *What are the state-of-the-art models that describe the relationship between flood risk and real estate value?*
2. *What is the most appropriate model to evaluate flood risk impact for the case study Maastricht?*
3. *How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?*
4. *How can relevant stakeholders contribute to preserving residential property values?*

1.4. Research Relevance

This research has aimed at assessing the potential impact of floods on residential real estate and has focused on the drivers, barriers, and enablers of stakeholders and flood vulnerabilities. Thereby, it can

contribute to the question: can we maintain the stability of real estate values in the future? Thus, this research has aspired to understand flood vulnerability and the subsequent role of stakeholders.

First, a literature review has assessed existing studies on past floods and flood risk effects on real estate values. Second, the applied economic models within the academic literature to assess the effects of floods on real estate values were explained. Third, flood vulnerability was defined and applied to the case study. Fourth, potential connections between the barriers and enablers of different stakeholders have been identified to enable the identification of opportunities.

This could contribute to our knowledge of the effects of climate change on real estate and its related costs if the network of real estate actors does not take sufficient measures. Subsequently, this research can add to our understanding of the effects on homeowners whose property is prone to floods and within areas considered more vulnerable. This will allow for a better understanding of several actors' choices in the real estate and construction industry. Thus, it can help homeowners, municipalities, and the government in their decision-making concerning climate adaptive measures and how to invest wisely. By assessing the perspectives of relevant actors, this research contributed to understanding the current barriers for stakeholders and what could be done to alleviate these barriers.

1.4.1. Scientific Relevance

This research adds to the existing body of knowledge in predicting the impact of flood events. Research on the impact of flood risk on residential property values within the Netherlands is scarce but essential due to its relative climate-prone location. This research has therefore endeavored to reduce the gap between the current knowledge on the effects of climate change on residential real estate property and its importance for stakeholders such as municipalities, investors, and property owners.

In addition, little research has been executed to assess the impact of risks on property values posed by climate change in the future, most likely as this is hard to measure due to the high level of uncertainty in future climate scenarios. Moreover, markets are dependent on how potential buyers view risk, as described widely in literature (Baldauf et al., 2020, Zhang et al., 2010, Brilly and Polic, 2005, O'Neill et al., 2016). Areas might be hazardous, but if the market has a different view, this may not affect housing prices. Therefore, this research will contribute to our knowledge of assessing the impact of future risks and the importance of valid information and effective communication.

Finally, although some studies focus on the effect of floods on real estate values, these studies frequently apply a straightforward definition of flood risks (i.e., chances that an area will flood). In contrast, flood vulnerability might entail more complexity, such as socio-economic vulnerability and the subsequent resilience of residents. Therefore, this research aims to contribute to understanding flood vulnerability and its relation with existing economic models to assess the effects of flood risks on real estate values.

1.4.2. Practical Relevance

The results of this research will give enhanced clarity for all stakeholders (e.g., property owners, investors, and decision-makers) on the impact of flood risk on property values. Thus, it can contribute to urging stakeholders to adapt to climate change actively. Moreover, it can contribute to creating awareness of the impacts of climate change on an individual level so that one can take preventive measures accordingly.

This research aimed to assess how stakeholders and governance can be involved in protecting housing prices. Should perception be used to discourage actors from developing and purchasing housing in climate-prone areas?

Within the Netherlands, risks to areas outside of dikes are relatively high. Although most residents, policy reformers, investors, and other involved actors are (partly) aware of these risks, real estate is continued to be built within the prone areas ('polders') within the Netherlands. As visualized in Figure 1.1, large areas within the Netherlands are below sea level and are, moreover, the most densely populated areas. By understanding and reflecting on the risk of flooding in real estate prices and the role of stakeholders within this process, the government and other stakeholders can consider this within their decision-making regarding flood safety.

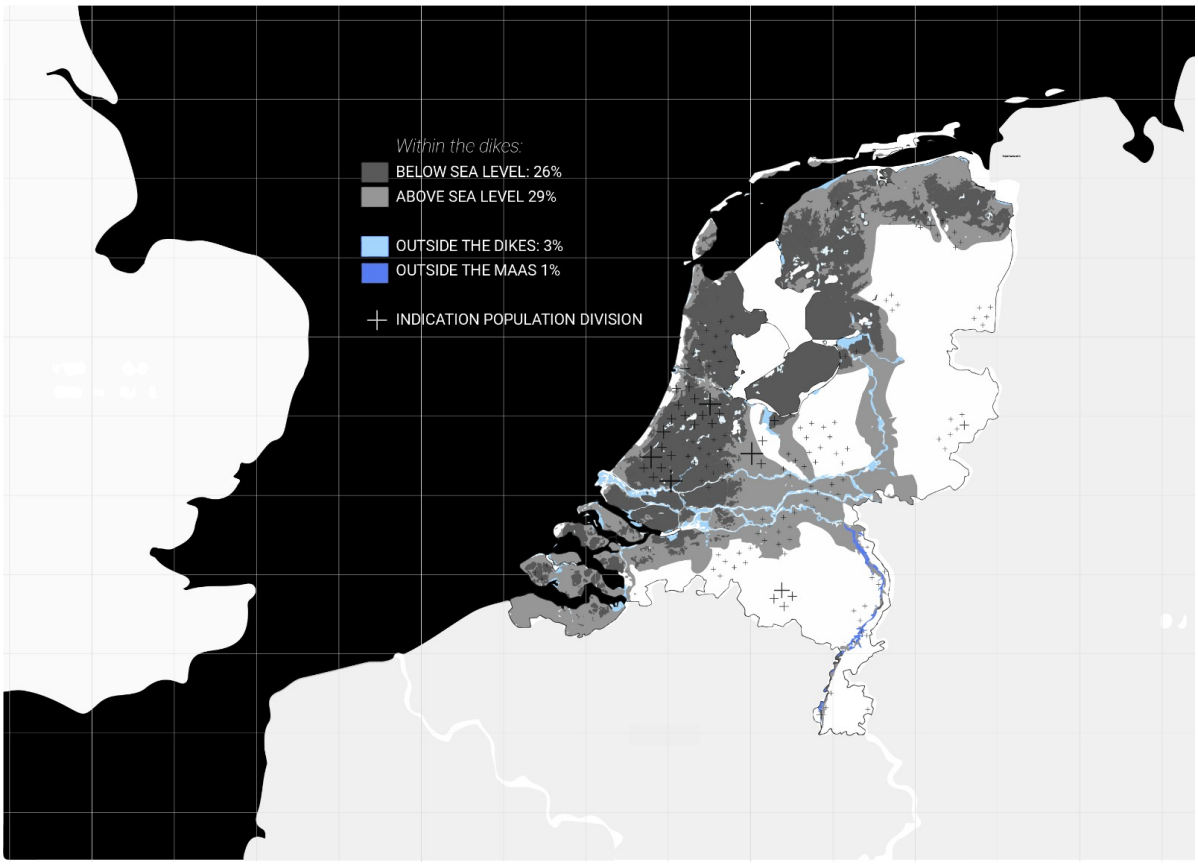


Figure 1.1: Elevation and population in the Netherlands (Author's image)

2

Research Design

Multiple perspectives can be applied while assessing the relationship between flood (risk) and real estate values. Within this chapter, the structure and chosen perspective of this study will be explained. In addition, the scope and methodology of this study are elaborated upon. First, within section 2.1, the research scope is discussed, defining the boundaries of the study. Second, in section 2.2 the research setting and methodology are elaborated upon, in which the methods leveraged for this research will be presented. Finally, the research outline will be presented in section 2.3

2.1. Research Scope

This research has aimed to assess the impact of climate change on real estate. In order to make the research feasible within the appointed time, the scope of the research has been limited, and boundaries have been set. Within this section, the set boundaries for this research are explained.

As mentioned in chapter 1, climate change, in general, can have large consequences on the built environment. The first boundary of this research is that it will solely focus on the effects of floods. This implies that other natural disasters (e.g., urban heat island effect or droughts) were not assessed within this research. The second boundary is that within the assessment of floods on real estate, this research has focused exclusively on residential housing. This was done, as the housing market has a significant influence on the financial stability of a country's private and public sectors and is thus relevant to assess (Beltrán et al., 2018).

The third boundary is that although numerous cities could have been chosen and assessed, flood vulnerability is assessed through a single, illustrative study case that has been chosen to assess the influence of floods and flood risks on residential real estate. The final boundary is that for the stakeholder analysis, seven stakeholders have been chosen to illustrate the effects of stakeholders on real estate values and the potential mitigation measures to alleviate flood risks.

In summary, this research focuses on the potential devaluation of residential real estate due to vulnerability to floods and the impact of seven relevant stakeholders, assessed through a case study.

2.2. Research Setting and Methodology

Within this section, the applied methodologies and setting in which the research was executed are elaborated upon. The research can be divided into three main phases. The research was conducted for the Delft University of Technology with the support of Arcadis. The contribution of Arcadis has been in the form of guidance and professional experience. Arcadis is a Dutch consulting and engineering firm that aims to deliver sustainable design, engineering, and consultancy solutions for natural and built assets. The company has over 33.000 employees in over 70 countries.

Within the first phase, a literature review was conducted to understand the gaps in the existing academic literature on the effects of floods on real estate values. Moreover, the existing methods to quantify the impact of flood risks on real estate values were studied. Within the second phase, the research fields on flood risk and (social) vulnerability have been studied in order to define vulnerability to floods. Additionally, in this phase, through quantitative analysis, the study case has been assessed on its vulnerability to floods.

Finally, in the third phase, the practical implications of the findings of phase one and phase two were analyzed through a qualitative analysis by conducting exploratory semi-structured interviews and a literature review. This allowed for researching the identified challenge of the two previous phases by gathering empirical evidence. The findings of the combined phases finally led to answering the main

research question. The structure and phases of the research are summarized in Figure 2.1 in which the interplay between methods and sub-questions is visualized.

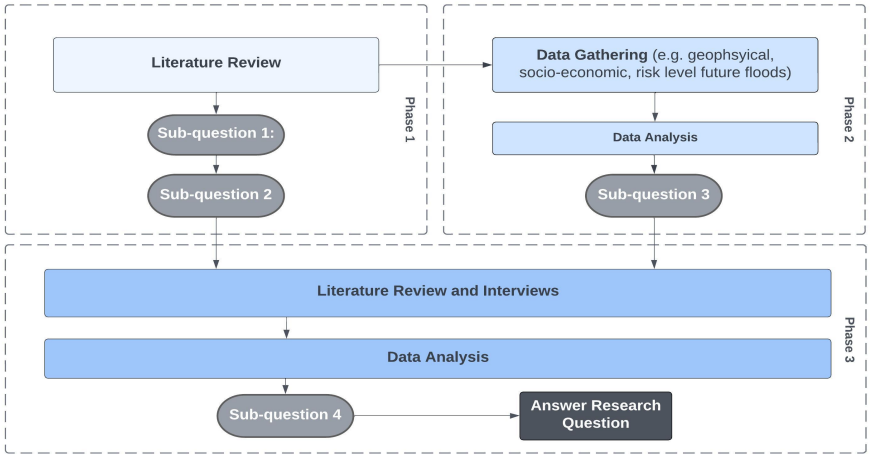


Figure 2.1: Research Structure (Author's image)

2.2.1. Literature Review

The first method selected was conducting a literature review. As described by Snyder (2019), literature is an extremely important method nowadays, as the field of research is accelerating and growing at an incredible speed. For this research, the existing literature on the effect of past floods, perception of floods, and future flood risks on real estate values was assessed. Subsequently, the academic literature on vulnerability to floods and flood risk governance was reviewed.

To allow for answering the first research sub-question: *"What are the state-of-the-art models that describe the relationship between flood risk and real estate value?"*, the existing models for assessing the effect of floods or flood risks were studied. The fundamentals of the economic models have been studied. Additionally, the models were reviewed to understand the strengths and limitations of the economic models and evaluate which economic model would be most appropriate for the case study of this research. Additionally, to answer the second research sub-question: "*How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?*", a literature review was used to define indicators that determine the vulnerability to flooding. Subsequently, the chosen indicators have formed the basis to construct the vulnerability framework that was applied within this research.

Finally, a literature review has contributed to answering the sub-question: "*How can relevant stakeholders contribute to preserving residential property values?*". The literature review has served as an effective method to distinguish relevant actors and to understand the different perspectives of these involved stakeholders and how these can synergize or conflict with one another. This qualitative research has supported the understanding of the barriers, stimuli, and enablers of the stakeholders within the literature.

2.2.2. Semi-structured Interviews

By means of semi-structured interviews with relevant actors, the linkage between common methods and barriers in practice and within theory has been made. Through the RED&BLUE project and Arcadis, stakeholders such as investors, financial institutions, government, and insurers were leveraged. The main aim of these interviews was to obtain enhanced insights into the recognition of flood risks in practice. The data retrieved from the interviews contributed to answering the sub-question: "*How can relevant stakeholders contribute to preserving residential property values?*".

In order to identify the most important actors, the steps as described by Lindenberg and Crosby (1981) were used; these steps included inventorying all relevant actors, examining their importance, and mapping the stakeholders. An invitation was sent to fourteen practitioners from numerous institutions or

companies, of which eight responded and were willing/had the time to conduct an interview. The eight practitioners covered all seven of the selected stakeholder groups.

Hence, to understand the barriers, drivers, and enablers of involved stakeholders within the impacts of flood risk on real estate values, eight interviews were conducted with insurance companies, the government, real estate developers, investors, financial institutions, municipalities, and local residents. To allow for comprehension of the implications of the findings within the first phase of the research, the interviews were conducted within the final phase of the research, providing additional data. Moreover, the interviews were conducted to increase understanding of the conflicting interests of different stakeholders as well as identify potential drivers complementary to the literature. Additionally, through the interviews, the stakeholders could elaborate on the available instruments they have that are valuable in addressing the challenge of flood risks. An overview of the interviewees is given in Table 2.1

Interview	Company/Institution	Function	Date of interview	Duration of interview
1	Municipality	Policy Officer Cultural Heritage and Spatial Quality	11th of January	01:01:24
2	Real Estate Investor	Director / Investor / Advisor	18th of January	00:41:54
3	Developer	Director	20th of January	00:40:44
4	Insurer	Senior Manager Actuarial - Climate Change	25th of January	01:05:35
5	Financial Institution	Senior Advisor Sustainable living	16th of February	00:52:20
6	Insurer	Medior Policy Advisor Climate Change	16th of February	00:39:23
7	Developer	Chief Operating Officer	22nd of February	00:35:15
8	Government	Senior Policy Officer Climate Adaptation	24th of February	01:00:26

Table 2.1: Semi-structured Interviews

2.2.3. Data-analysis

In order to answer the sub-question: "*How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?*", this study has examined the socio-economic vulnerability, the disaster-bearing capabilities, and the flood exposure in Maastricht. This has allowed for an analysis of the degree of vulnerability to future flooding in the different neighborhoods of the residential real estate values within them. Software program QGIS facilitated the conducted analysis. Publications by ENW (2021), publications on the floods by Asselman et al. (2022), ArcGis files from the klimaatatlas (Gemeente Maastricht, 2022), data from the Centraal Bureau Statistiek (2022), LIWO (2022), Stichting Climate Adaption Services (2022), PDOK, and IPCC reports have been leveraged to conduct the analysis to enable answering the research sub-question.

Second, the data obtained from the interviews have been analyzed. First, the interviews were recorded and transcribed with the help of Microsoft Teams to allow for the analysis. Then, Qualitative Content Analysis was used; within this method, data is categorized in an inductive way (i.e., derived from the data) through close reading (Forman & Damschroder, 2007). This form of inductive content analysis is widely used and can help provide meaningful insights from the derived data (Kyngäs et al., 2019). The topic of this research study has not been fully covered in the existing academic literature. Therefore, making use of this form of content analysis is suitable. The basic steps of the methodology entail data reduction, data grouping, and, lastly, forming the concepts that can be used to answer the research questions. A risk that should be mitigated within this method is the potential subjectivity of the researchers while interpreting the data. Subjectivity may lead to a mismatch between the constructed codes and the data. This can be mitigated by reassessing the raw data for each open code within the analysis after it is identified (Kyngäs et al., 2019). The assessment was done through the software program ATLAS.ti.

2.2.4. Case Study

In order to assess the altered proposition of flood vulnerability and its subsequent effect on real estate values, a case study has been leveraged. Case studies have the advantage that they allow for the measurement of qualitative variables and allow for the incorporation of complex relations (Bennett, 2004). Moreover, Cronin (2014) praises case study research as a very legitimate research method that enables dealing with interconnected difficulties. The results of analyzing the case study have supported answering sub-questions: *How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?*.

A quarter of the Netherlands is situated below sea level. Therefore, the Netherlands has a long track record of applying water adaptation structures. A good example of Dutch expertise in water management is the drainage of the province of Flevoland, which was done by the Dutch between 1959 and 1967 in order to acquire more land. The pumping of the polder created a 5% increase in land for the Netherlands (Hoeksema, 2007). Even though a significant part of the Netherlands is situated below sea level, relatively few floods have been recorded. The flood event with the biggest impact occurred in the province of Zeeland in 1953, with extreme damages to infrastructures and many casualties. The Netherlands was highly impacted due to its position below sea level (Gerritsen, 2005). After this disastrous flood, the Delta Works have been constructed, successfully protecting the Netherlands from the North Sea since 1953 (Hall, 2013).

The flood events after 1953 have primarily occurred in the province Limburg (Van Baars & Van Kempen, 2009). In 1993, the Meuse River in Limburg overflowed its banks, which led to extensive flooding, resulting in 17,000 hectares being flooded and damages to 5580 private homes (Wind et al., 1999). Two years later, in 1995, the water reached extreme levels again. Levels of 16,69 meters above sea level in Lobith were recorded, and 45,71 meters at Borgharen. Due to uncertainty if the dikes would persevere this led to 200.000 residents being evacuated from threatened areas and €125 million of damages (Anonymus, 1995).

After almost 30 years, in July 2021, the province of Limburg in the Netherlands suffered from extreme rainfall and floods again (Figure 2.2). In addition, large parts of neighboring countries Germany and Belgium were flooded, leading to serious damages and hundreds of casualties. Within the Netherlands, more than 2500 houses and 5000 habitats were affected, and the damages were estimated in the order of €350-600 million euro, significantly higher than the two earlier floods (Hoogwater et al., 2021).

a) Drone image floods Limburg (MAX Vandaag, 2021)

b) Flood in the streets (Jeugdjournaal, 2021)

Figure 2.2: Flooding in Limburg in July 2021

Next to its unique position relative to the sea, the Netherlands is a well-organized country with large data availability. Therefore, the Netherlands makes for an interesting case to study while analyzing future flood risks. This research has selected a city within the province of Limburg, namely Maastricht, due to its unique history of flooding and extensive data availability. The location of the study case can be seen in perspective to the province Limburg and the Netherlands in Figure 2.3

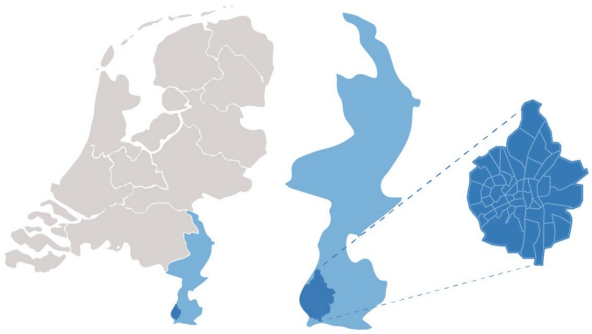


Figure 2.3: Position study case relative to the Netherlands (Author's image)

2.3. Outline Research

Finally, the outline of this research has been summarized in Figure 2.4 in which the different stages of this study can be seen. In the following chapters, first, in the reviewing part, the existing literature and state-of-the-art models are studied. Next, in the assessment part, the vulnerability assessment and stakeholder analysis are executed, succeeding the data gathering. Subsequently, in the reflective part, the implications of this research are discussed as well as the limitations of this study. Finally, in the conclusive part, the research questions are answered, after which recommendations for future research are given.

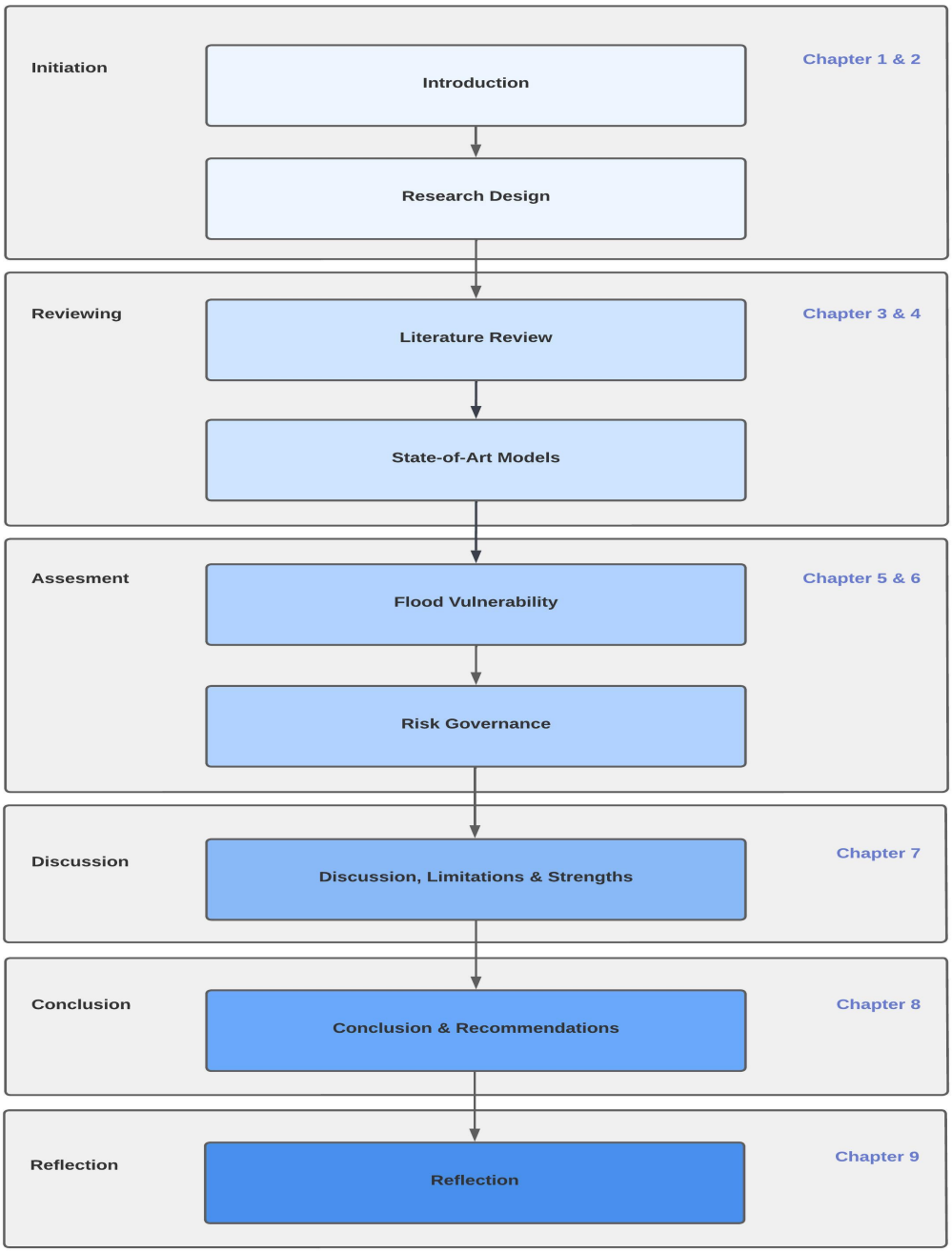


Figure 2.4: Research Outline (Author's image)

3

Literature Study

Understanding literature is essential in research. Therefore, this chapter reviews existing research on the effects of flooding on real estate values. First, the literature review on past floods will be discussed in section 3.1. Hereafter, within section 3.2, the reviewed literature on the effect of future flood risks on real estate values will be discussed. Third, the literature on the effects and implications of perception of risks on real estate values will be elaborated on in section 3.3. Fourth, the literature on flood vulnerability is described. Fifth, studies on the governance of flood risks are discussed. Finally, the conclusion of the literature review is given in section 3.4, and the knowledge gap is identified.

3.1. Past Floods

Several studies investigated the relationship between flooding and residential real estate values. When assessing this relation, researchers have attempted to quantify and define the impact of past floods on real estate. In addition, researchers have assessed if real estate is currently being discounted for future flood risks. Although many studies have been done within this area, their methodologies and outcomes have been wildly divergent. However, when reviewing the literature on the effect of past flooding on property values, many studies have concluded a correlation between floods and decreasing housing prices.

For example, McKenzie and Levendis (2010) investigated the effects of Hurricane Katrina on willingness to pay for certain aspects of housing. They concluded that the willingness to pay for the elevation of the location of houses had increased due to hurricane Katrina, with 4.6% per foot in flood-prone areas. Moreover, Hallstrom and Smith (2005) investigated the effects of hurricanes on the US market and found through a difference-and-difference (DND) framework that the property values declined by at least 19% after the hurricanes. In addition, Beltrán et al. (2019) used a repeat-sales approach to assess the effects of flooding in England between 1995 and 2014 and found that for inland flooding, the price of an entirely inundated property was, on average 24.9% lower than unaffected houses.

In addition, Atreya et al. (2013) investigated the effect on property prices of flood risk after a significant flood event through a difference-in-difference model and concluded that the short-term impact is between -25 and -44%. However, they also concluded that this effect diminished after four to nine years after the flood and even became positive. Moreover, Gharbia et al. (2016) researched the effects of being in a flood zone and having a history of flood events in Dublin through a hedonic regression and concluded that houses in the 1% risk zone have a similar market value than equivalent houses. However, being subject to historical flood events had a 3.4% negative price effect. In addition, Gibson and Mullins (2020) researched the effects of three flood risk signals: an insurance reform act (increasing premiums), a hurricane, and a new floodplain map through a difference-in-difference framework. Although all estimates were pessimistic, the most significant impact was on houses located in the new floodplain that escaped recent hurricane sandy, namely -11%.

Interestingly, numerous studies compared the immediate effect of a flood and the long-term impact and found that the prices tempted to rebound after a couple of years because people forget about the floods. For example, Miller and Pinter (2022) examined three US counties before and after flooding through a difference-in-difference model and found for Boulder County, prices fell by 6.26% in the 100-year floodplain until they rebounded after 2-3 years. A post-flood price effect was not detected for the second county, Benton. However, throughout the study period, the houses in the 100-year floodplain had 9.4% lower prices than houses outside the floodplain. Finally, a price effect for the third county (Cass) was not detected for the 100-year floodplain. Interestingly, a large flood control project had been discussed after a flood event here, which may have prevented price discounting.

Moreover, Inoue and Hatori (2021) investigated the effects of historical and more recent floods in Japan. They concluded that historical floods significantly impacted property values, but recent floods did not. They concluded that this might be because people already had a strong awareness of the flood risks due to the historical floods and had already fully incorporated the risks within housing prices.

Within The Netherlands, little research has been done so far on the impact of flooding on real estate values. However, Daniel et al. (2009b) researched the effects of the flooding in 1993 and 1995 on the residential prices in Maastricht and found a decrease of 9% in the affected houses. However, the research authors also found countervailing effects related to water, namely an upward effect on the property values of 3%. Moreover, as can be seen within the results of the paper of Daniel et al. (2009b), being situated along the coast or near water is considered as a highly valued amenity, making it harder to analyze the effects of flood risks on coastal areas. For example, Bin et al. (2008) investigate amenities accompanied by living nearby water and conclude that these result in high price premiums, substantially higher than the willingness-to-pay for lower flood risks within this study area. Moreover, Atreya and Czajkowski (2019) investigated the effects of flood risks and amenities in Texas and concluded that properties in the highest-risk flood area controversially command a price premium. These authors, location case study, applied method, and subsequent outcome of the researches can be summarized as in Table 3.1.

When reviewing the aforementioned studies, no clear relation between the employed method and outcome can be derived. Interestingly, studies applying the same method yield very divergent results when assessing similar phenomena, which seems to hint towards the possibility that another reason for the price losses in areas could be present. Moreover, the varying results might challenge the robustness of the results.

Authors	Location	Method	Outcome
Miller and Pinter, 2022	United States	Difference-in-Difference	-6.26%
Inoue and Hatori, 2021	Japan	Linear regression model	Limited recent price effects
Gibson and Mullins, 2020	United States	Difference-in-Difference model	-11%
Atreya and Czajkowski, 2019	United States	Difference-in-Difference model	-22-44%
Beltrán et al., 2019	United States	Repeat-sales model	-24.9%
Gharbia et al., 2016	Ireland	Hedonic Pricing Function	-3.4%
Daniel et al., 2009a	The Netherlands	Hedonic pricing model	-6%
Atreya et al., 2013	United States	Difference-in-Difference model	Price premium
McKenzie and Levendis, 2010	United States	Willingness-to-pay model	3.4% increase for elevation
Hallstrom and Smith, 2005	United States	Difference-in-Difference model	-19%

Table 3.1: Studies on past floods and property values

3.2. Future Floods

To assess if (future) flood risk is capitalized into housing prices, researchers have tried to measure the relation between the risk level of a property and its prices. For example, Wei and Zhao (2022) investigated whether flood risk is capitalized into the prices in China and found that plots with a high flood risk suffer a price discount of 8.62%. Likewise, Bernstein et al. (2019) have leveraged a database of home transactions in the United States from 2007-2016 and found that properties that the authors disclosed as perceived as vulnerable had a 7 percent discount. In addition, Bernstein et al. (2019) concluded that in areas where inhabitants are more concerned about climate change, housing prices are associated with more considerable penalties in the form of property devaluation than in areas that are less concerned about this subject.

Moreover, Beck and Lin (2020) investigated the effects of vulnerability to inundation from sea level rise in Georgia through a hedonic pricing model and found a price discount of 3.1% for houses that are most at risk from sea level rise. In addition, within the Netherlands, Bosker et al. (2019) assessed the willingness to pay to avoid flood risk using a border discontinuity design. They found that house prices are, on average, 1% lower when at risk of flooding.

However, as mentioned before, the literature is not unanimous on the adverse effects of flood risk and housing prices. Maddison, Elliott, et al. (2018) found in their meta-analysis across studies on the effect

of flooding that the price discount for properties located in flood zones lies between -75.7% to a +61% price premium. Moreover, Murfin and Spiegel (2020) compared house prices based on their threshold for inundation, based on under sea-level rise projection. They found estimated null results through a regression, suggesting limited price effects. Moreover, Walsh et al. (2019) investigated the effects of structures that help alleviate risks as a result of sea level rise on property values through a hedonic property value model and found that adaption structures can have a significant positive effect on house prices at the waterfront. For example, a bulkhead or a riprap can increase prices by 8-14%.

In addition, Cupal (2015) mapped flood risk on an ordinal scale of n-year water, i.e., flood zones 1 to 4 in which 4 is the highest risk and tested if there is a correlation between housing prices and flood risk through a multiple linear regression model and found limited price effects. Furthermore, Fuerst and Warren-Myers (2021) assessed if housing prices reflect the flood vulnerability of properties in Australia and found no effects. They argued that this may be because there is no clear information on the risks available to home purchasers, myopic buyer behavior, that homeowners do not have to contribute to adaptation costs currently, or that the insurance premiums are still relatively affordable in areas that are not affected yet.

These studies can be summarized as in Table 3.2. Similarly to the observed studies on the effects of past floods on real estate values, similar methods yield divergent results. Moreover, when reviewing the results of studies that have attempted to quantify the effects of future flood risk on real estate values, extreme differences (i.e., between -75,7% and + 61%) can be observed. The significant discrepancies and ambiguous results may be attributed to the large uncertainties intertwined with future flood risks. Moreover, within studies that attempt to understand the effect of flood risks, the amenity of being located in the proximity of water seems hard to extrapolate.

Name	Location	Method	Outcome
Wei and Zhao, 2022	China	Spatial Autocorrelation Analysis	-8.62%
Fuerst and Warren-Myers, 2021	Australia	Hedonic Framework	No effect
Beck and Lin, 2020	United States	Hedonic Pricing model	-3.1%
Murfin and Spiegel, 2020	United States	Hedonic Pricing model	Limited price effects
Bosker et al., 2019	The Netherlands	Willingness-to-pay model	-1%
Walsh et al., 2019	United States	Hedonic Pricing Model	+8 to 14% due to adaption measures
Bernstein et al., 2019	United States	Hedonic Pricing model	-6-8%
Maddison, Elliott, et al., 2018	United States	Meta-analysis	Between -75,5% - +61,0%
Cupal, 2015	Czech republic	Multiple Linear Regression	Limited price effects

Table 3.2: Studies on future flood risk and property values

3.3. Perception

Several studies have been conducted on the effects of perception on risks. When flooding occurs, damaged houses will most likely decrease in value. But eventually, how the future risks on a property are perceived will define the value of the location of a property. For example, Pryce et al. (2011) discuss that if prospective home-buyers have perfect information about the hazard risks and behave accordingly, natural disasters should not affect property values. They argue that the hazards should have already been capitalized into the market price. Therefore, it can be discussed that post-hazard price discounting indicates that there was no complete awareness of the natural hazard.

In addition, Botzen et al. (2009) assessed the factors determining risk perception of flood risk. They concluded that this is generally low and dependent on consistency with actual risk levels. In addition, they concluded that individuals not protected by dikes underestimate their risk level, individuals with lower risk knowledge have a lower risk perception, and older and highly educated individuals have a lower risk perception. Moreover, Zhang et al. (2010) investigated the relationship between hazard proximity, risk perception, and the effect on housing values and concluded that risk perception could mediate between hazard proximity and property value. This might have implications for effective governance to protect property values.

Besides, Bakkensen and Barrage (2022) provided empirical and theoretical evidence that climate risk beliefs affect coastal housing markets. They presented a model in which they assessed how housing markets would be expected to react to climate risk beliefs and tested what the number of optimists

buying coastal homes would have as an impact. To verify their theories, they executed a field survey among residents. They found that flood zone residents generally have a lower flood risk perception and a higher waterfront amenity valuation. Moreover, they found that coastal houses are overvalued by 13%, indicating that optimists who would like to purchase an overvalued coastal home would gain from immediate policy reform.

Furthermore, Baldauf et al. (2020) investigated the impact of belief heterogeneity on long-run climate change on the valuation of real estate within the United States. Through data on the beliefs of the U.S. population on climate change, home transaction prices, and future inundation projections, they apply a hedonic pricing model. They found that homes in areas marked as 'believer neighborhoods' sell for 7% less than homes in 'denier neighborhoods.' Additionally, Hino and Burke (2021) assessed the effect of floodplain maps on residential property values in the United States through a panel, difference-in-difference, and cross-section method to find little evidence that housing markets fully price the information on flood risks. However, they concluded that the price penalty is more significant when buyers are more risk aware, suggesting that policies to improve communication could influence the market outcomes.

Additionally, Wachinger et al. (2013) reviewed the main insights from the literature on risk perception concerning natural hazards. They found that the level of trust in authorities and experts, and personal experiences substantially impact people's risk perception. In addition, they found a paradox in those most risk-aware people who do not act accordingly by preparing themselves. They concluded that future governance and communication should consider creating awareness, enhancing trust in authorities, and encouraging personal responsibility for protection. Within the Netherlands, Centraal Bureau Statistiek (2021) investigated the view of the Dutch on climate change, and that although 94% of the Dutch agree that the climate is changing, only 11% think this can still be put to a halt. This might have an influence on residential property values in climate-prone areas. For example, through survey data, Mol et al. (2020) analyzed the possible flood risk misconceptions of floodplain residents within the Netherlands and found that although residents overestimate the possibility of a flood, they underestimate the maximum expected water level of a flood.

Moreover, Forrest et al. (2021) assessed the emerging role of citizens in local pluvial flood risk management in the Netherlands and found that creative and dialogical approaches are shaping this into citizen engagement, citizen-initiated contributions, and traditional authority-led interactions. Finally, Terpstra and Gutteling (2008) discussed the shift from prevention towards risk management in flood risk management within the Netherlands and explored how households within the Netherlands view their responsibilities for taking private protection measures through a survey. They found that 75% of the respondents saw the government as mainly responsible for flood protection, but 50% viewed disaster preparedness as an equal responsibility between the households and the governments.

Thus, the effects, causes, and subsequent behavior of residents due to risk perception seems complex and ambiguous. However, the existing academic literature hints towards significant implications of risk perception on real estate values.

3.4. Flood Vulnerability

When considering flood risks, how to define an area's vulnerability should be considered as the effects of climate change can result in increased environmental and social vulnerabilities (Zanetti et al., 2016). Numerous studies have therefore tried to define neighborhoods' social and flood vulnerability. For example, Fekete (2010) assessed the flood vulnerability of areas along river channels in Germany. They confirm that social groups as the financially weak and elderly, are susceptible groups. Moreover, they attempt to integrate as well social as infrastructure vulnerability.

In addition, Tewari, Bhowmick, et al. (2014) constructed a livelihood vulnerability index and stated that floods affect households depending on their livelihood choices. Furthermore, Cutter et al. (2003) constructed an index of social vulnerability to environmental hazards, reduced the 42 assessed variables to 11, and concluded that social vulnerability has an interactive nature. Additionally, Li and Li (2011) analyze the vulnerability factors to storm surges in a coastal area in China through a social-economic, land use, eco-environmental, coastal construction, and disaster-bearing capability index to assess the most vulnerable areas and suggest this study can be used for scientific advice for prevention and mitigation

of storm surge disasters. Likewise, Zanetti et al. (2016) develop a social-environmental vulnerability index for coastal areas. Their study highlights the vulnerability susceptibility of their study case Santos to hazards posed by climate change. This study aimed to support local decision-makers in preparing adaptation plans.

Within calculating vulnerability scores, researchers should carefully check the robustness of the study. For example, Aroca-Jiménez et al. (2020) have developed an Integrated Socio-Economic Vulnerability Index and found high stability in the chosen variability categories and that the conservation state of buildings is causing more significant variability in the index scores. In addition, several studies have attempted to understand the broader and social impact of the relationship between flood risk and housing. For example, De Koning and Filatova (2020) discussed the effects of repetitive floods on out-migration and concluded that this could lead to increased climate gentrification. Furthermore, Ann Conyers et al. (2019) compiled an inventory of all adaptation and mitigation measures and leveraged this data to measure exposure and readiness and develop a city vulnerability index. They concluded that the most vulnerable regions are frequently characterized by high income and apparent unresponsive to sea level rise.

In conclusion, even though there are numerous studies on the price effects of flood risks, few studies have considered hidden issues, like social vulnerability, within their considerations of flood risk levels. Moreover, studies executed are often fragmented and not validated (Aroca-Jiménez et al., 2020). Moreover, studies have not yet coupled the vulnerability index scores to quantifying real estate values.

3.5. Flood Risk Governance

Piccininni (2014) investigated the role and emergence of environmental insurance and explored the risk management of real estate owners that experience changing climate risks. They concluded that real estate owners are at risk of enormous financial losses and public relations disasters due to environmental risks, the impact of climate change in combination with increasingly strict regulations might increase the impact and occurrence of loss events, and that insurers would be well-suited to promote as well adaption as mitigation measures by the use of green infrastructure (Piccininni, 2014). Moreover, Warren-Myers et al. (2018) investigated the implications of sea level rise and aim at understanding the potential risks that follow, and stated the considerations and planning with regards to the impact of a flood event is underestimated concerning as well financial as social costs, as non-direct losses should also be considered which is not always accurate as only direct losses are tracked. For example, buildings that are not inundated themselves but may experience limited access by being cut off from infrastructure.

Thompson et al. (2022) investigated climate gentrification and its key drivers and stated that tools that can quantify the impact of resilience measures can help support policy measures and benefit all stakeholders. Insurers could provide information on flood forecasts and ways to make homes less vulnerable. In addition, Thompson et al. (2022) stated that property price changes pose a risk to several stakeholders such as insurers, homeowners, mortgage industries, banks, and, thereby, the financial systems. Likewise, Hirsch et al. (2015) developed a tool to assess the effects and results of a risk assessment tool within their study and stress the fact that information on small-scale data applicable to the housing and real estate industry is necessary, as medium-sized enterprises and private homeowners currently experience difficulties as their site and properties are fixed. Finally, Beierle (2002) studied the effects of quality of decisions concerning the stakeholder-based processes and emphasizes that involving all relevant stakeholders within environmental decisions enhances the effects.

3.6. Conclusion

The literature review has focused on five essential topics concerning the effects of floods on real estate values. First, studies on the effects of past floods on real estate values were discussed. Second, studies that tried to measure the impact of future flood risks on real estate values were discussed. Third, the impact of the perception of flood risks and its influence on real estate values were discussed, as well as inside and outside the Netherlands. Fourth, studies that investigated the vulnerability of cities were discussed, and finally, studies that investigated how flood risk can be governed and who is impacted were discussed. The key findings of these five topics are discussed within this subsection.

Within the assessment of studies on the effect of past floods on real estate values, it can be concluded that the observed results exhibit significant heterogeneity between studies. Although the majority of the studies conclude a negative relation between past floods and real estate values, the effects of the assessed studies employing similar methods vary from limited price effects to a decrease in value of 44%. This observation might hint towards limited robustness of the results. Studies on the effects of future flood risk and real estate values have even more significant variability in outcomes due to limitations like uncertainty, limited information sharing, and hard-to-predict behavior of residents. The effects of future flood risks vary from -75,5% to +61,0% in the United States alone.

Studies on the perception of risk have indicated a between human behavior and market functioning. Studies hint towards an important role of perception in the stability of property values. For example, within areas where people believe in climate change, the houses sold for 7% less. Moreover, studies showed that ambiguities exist regarding the perception of risk levels and flood responsibilities. Literature examining flood vulnerability shows that the definition of flood vulnerability is broad and often fragmented within papers. However, they show the potential importance of both social and physical vulnerability in assessing flood risks in study cases. Moreover, the literature suggests future flood risks can have significant social implications, such as increasing inequalities within cities. Finally, studies on flood risk governance emphasize the importance of flood risk for the stakeholders involved as they have enormous potential losses. Moreover, studies conclude that the position and actions of stakeholders can help prevent potential losses, although there are still numerous barriers.

3.6.1. Knowledge Gap

Numerous studies have been conducted on the effects of floods on real estate (values). Different methods have yielded divergent results concerning future and past risks. When assessing the existing economic models to assess the effects between flooding and real estate values, literature frequently applies the definition of vulnerability if the assessed houses are in a flood zone and thus have a chance to be inundated. However, in the additional literature review, the complexity of flood became apparent, thus highlighting a potential challenge in flood vulnerability that should be further assessed. Subsequently, the definition of vulnerability that studies have applied remains different and fragmented and has yet to be combined with valuation methods. Finally, floods could have a significant impact on real estate and, thereby, a lot of stakeholders, but the connection between methods, vulnerability, and the stakeholders is ambiguous.

To add to the existing knowledge on the effects of flood risks on real estate value, this study aims to understand what methods are available for assessing the impact of flood risk on residential real estate values and what defines flood vulnerability. Finally, through the exploration of involved actors, this study will contribute to knowledge on the governance of (de)valuation of real estate due to flooding. The core of the added value of this research is the integration of divergent topics on flood risks and vulnerabilities, emphasizing potential mismatches between economic theories, vulnerability, and stakeholders in theory and practice. The theoretical framework that summarizes the outcomes of the literature review can be seen in Figure 3.1

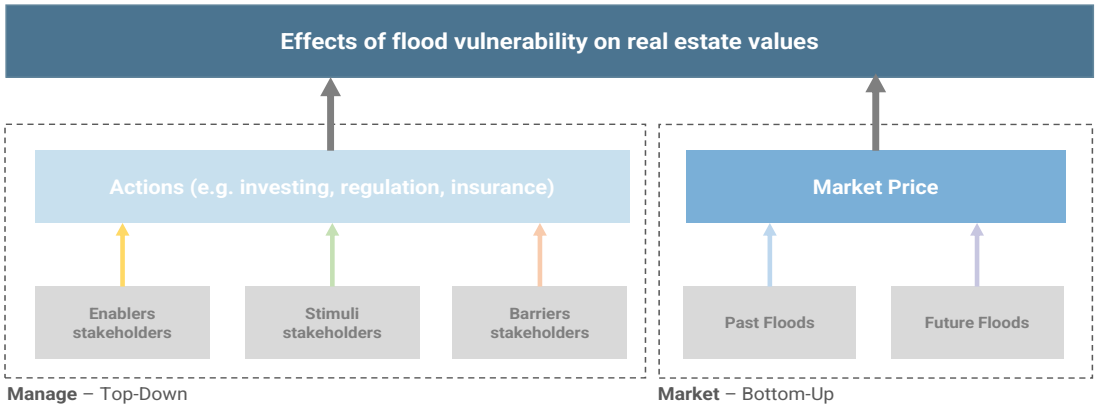


Figure 3.1: Theoretical framework based on academic literature (Author's Image)

4

State-of-the-art models

Different models exist to assess the relationship between climate change and real estate values while assessing flood risks. Within this chapter, the two mainstream types of methodologies: stated preferences and revealed preferences, are elaborated upon, describing potential advantages and disadvantages. In addition, the methods most widely used in literature to assess the effects of flood risks on real estate waters are discussed, namely: hedonic pricing, difference-in-difference, repeat sales, willingness-to-pay, regression discontinuity, and spatial regression models. Finally, based on the review of the existing methods the research sub-questions: *What are the state-of-the-art models that describe the relationship between flood risk and real estate value?* and *What is the most appropriate model to evaluate flood risk impact for the case study Maastricht?* are answered.

4.1. Stated and perceived preference

Stated preferences are methods that leverage the stated preference of individuals (for example, through interviews or surveys) to assess the willingness to pay for reduced flood risk of an individual. However, this method also has disadvantages. For example, as this is the stated preference of an individual, within this method, the correspondence between their stated preferences and actual behavior remains indeterminate (Gharbia et al., 2016, List and Gallet, 2001).

Perceived preference observes the actual behavior of individuals within markets. This allows for analyzing the revealed impact of a phenomenon. For the perceived preference method, market prices are frequently utilized. Market prices are praised for the perceived evaluation of property value due to their apparent objectivity. The value of a property is described as the perceived value by the buyer. French and Gabrielli (2018) describe market value as the amount an asset can be exchanged on the valuation date based on a transaction between a willing buyer and seller. A disadvantage of this method is that it is limited in assessing the future willingness to pay of individuals in different scenarios. Moreover, it is difficult to assess how communication and risk perception influence actual behavior within this method of an individual (De Blaeij and van Vuuren, 2003 Florax et al., 2005).

4.2. Hedonic Pricing Model

The hedonic pricing model is widely used within the academic literature. The hedonic pricing model can be used to assess floods' effects on housing values. On the basis of this model, the structures (e.g., the number of rooms, square feet, etc.), the location, and environmental aspects are considered within the housing price to explain the effect of the different factors (Rosen, 1974). The hedonic pricing model is a revealed preference method that allows for estimating the monetary value of the characteristics of a good. Therefore, it makes it possible to break down the several characteristics of a house and gather approximations on the monetary value of each character and the diversity of external factors. This method makes it possible to test whether variables influence housing prices. Using this method, the effect of measures that enhance flood safety on a property, such as elevation or storm-water management measures nearby, could be assessed.

The method should be adjusted to the specific characteristics the researcher aims to investigate. The model's functional form to explain the property model is as follows: Price = f(Physical Characteristics, Other Factors).

$$\mathrm{P} = f(LOC, STR, NGH) \tag{4.1}$$

Within this equation, LOC, STR and NGH represent location, structures, and neighborhood, respec-

tively. Additionally, complementary factors like earthquakes or floods can be added to assess if these factors have influenced housing prices.

As the relationship between selling price and time-on-the-market is difficult to specify (Sirmans et al., 2006), an Ordinary Least Squares (OLS) model, is applied in many cases within the literature. The OLS model can minimize the sum of square errors, in which the error represents the difference between the predicted and actual value of the outcome. It is a method that uses a linear least squared model to find the parameters in a linear regression model (Zdaniuk, 2014). This formula is as follows:

$$SellingPrice = \alpha_0 + \beta_i * X_i + \epsilon \tag{4.2}$$

In this equation, ϵ is the independent error, β is the vector of marginal prices, and X_i is the examined characteristic.

4.2.1. Advantages and Limitations

The HPM method is widely used in research. It allows the researcher to analyze the possible effect of every single attribute of a property. However, this method has certain limitations. First, only the perceived danger can be considered, and tax and interest rates are not considered within this model. Moreover, it requires detailed data (e.g., all structures) (Hargrave, 2021). In addition, when using a hedonic pricing model, the variables should be selected with care. To choose the best variables for research, a meta-analysis of this method by, for example, Sirmans et al. (2005) should be further reviewed. Lastly, bias may be present in the estimates due to the misspecification of the function. The more independent variables are included, the higher the chances of misspecification (Chau & Chin, 2002).

4.3. Difference-in-difference

The Difference-in-Difference (DiD) approach compares certain groups that are exposed to different treatments and are often leveraged to estimate the effects of a certain intervention (Fazal et al., 2020). Two different groups can be observed within two periods, receiving equal treatment in the first period. In the second period, one group is exposed to a certain treatment, and the other is not. By analyzing this difference, one can study the effects of the treatment. This method assumes that the groups would have been identical in the absence of the treatment (Schwerdt & Woessmann, 2020). It has the aim of imitating the design of a natural experiment (Card & Krueger, 1993).

A DiD can be used to estimate the influence of a change (for example flooding), in which y_{it} is the difference. The group could consist of individuals i=1..., N, and the time frame could run from t=1..., T. In which δ_{it} indicates the same outcome if the change was operative in time period t for individual i. Group members that experience the change react accordingly to parameter γ could be formulated as:

$$y_{it} = \gamma * \delta_{it} + \eta_i + m_t + \epsilon_{it} \tag{4.3}$$

In which η_i is a time-variant effect that is unique for i, m_t is a time effect that is equal for all individuals in period t, and ϵ_{it} is an individual time-varying error that is distributed across the individuals independently. In the case of Maastricht, this would mean that factor m_t would be all residential property in Maastricht and for the η_i, only the residential areas that were inundated would be selected.

4.3.1. Advantages and Limitations

The Difference-in-Difference approach has the underlying assumption that in absence of the treatment, the outcomes of the different groups would have been equal (Fazal et al., 2020) which can not always be controlled for. Another limitation of this method is that it assumes spatial independence, which could lead to cumbersome approximations of the parameters as the neighborhoods often share equivalent characteristics (e.g., structures, features) (Atreya & Ferreira, 2015). However, an advantage of this method is that it allows for isolating the effects that can be attributed to a specific flood from other simultaneous variables (e.g., changing markets or housing) (Atreya & Czajkowski, 2019).

4.4. Repeat Sales Method

Another method that may be used is the repeat sales method. The method includes an analysis of units that have been sold at least two times during a certain time period. This method can be useful to assess the annual percentage growth over time (Malpezzi & Stephen, 2003). Therefore this method could effectively assess the floods in Maastricht in 1993 and 1995. The formula that explains this method is:

$$\log P = X * \beta + \beta_1 * T_1 + \beta_2 * T_2 + \beta_3 * T_3 + \beta_4 * T_4 \tag{4.4}$$

In which P indicates the value/price/rent, X is used for relevant characteristics (e.g. list of housing and neighborhood characteristics), and T_i are the time dummies, representing the time under consideration. The time under consideration can (relying on the available data) be considered in months, quarters, or years (Malpezzi & Stephen, 2003).

4.4.1. Advantages and Limitations

An advantage of this method is that no specific information on the characteristics of the unit is needed. However, as a consequence, the method is limited as it solely yields price changes (Malpezzi & Stephen, 2003). Another limitation of the repeat sales method is that the types or locations of homes might change over time which might bias the index (Clapp & Giaccotto, 1998). To alleviate these shortcomings, combining the repeat-sales method with the hedonic pricing method could prove to be very valuable. Even though the repeat-sales method can be considered less comprehensive, it can confirm the results of the hedonic pricing model. It, therefore, can reduce the presence of bias.

4.5. Willingness-to-pay

The willingness-to-pay method assesses the willingness to pay for something of an individual. In this particular case, following Bosker et al. (2019), the willingness to pay to avoid flood risk can be assessed by calculating the log difference between two otherwise equal homes of which one faces flood risk. The formula to assess this can be described as:

$$\alpha \approx \frac{1}{K} \sum_k * \left[\rho^k(\tau)[1 - b^k(\bar{s} - \tau)] \left(\frac{\sum_1 U_h^H * h_i}{U_X^X} \right) / P(H, 0) \right] \tag{4.5}$$

Within this equation, α indicates the difference in willingness to pay, $P(H, 0)$ denotes the price of a house where H is a vector of housing attributes, and s is the water-depth in centimeters that would inundate a house in case of a flood. In addition, K is the sample size of the population, X denotes non-housing consumption, and h_i denotes the $i_t h$ housing attribute. Furthermore, perception is integrated into the formula by $\rho^k(\tau)$ denoting the perceived flood risks, and $1 - b^k(\bar{s} - \tau)$ denoting the perceived flood damages.

Subsequently, the willingness to pay depends positively on the perception of the likelihood of a flood, and negatively on the total tax income τ that a government invests in flood defense. Moreover, the willingness to pay depends negatively on the perception of residents of what share of the housing attributed will not be damaged by a flood ($b^k(\bar{s} - \tau)$). Finally, it can thus be concluded that a negligible outcome in of Equation 4.5 on a case study can be explained by either a high level of trust in the flood defense structures, a high level of trust that the government will cover flood damages or a belief that the houses will not be damaged in case of a flood.

4.5.1. Advantages and Limitations

A limitation of the willingness-to-pay method is that it is incapable of assessing new products for which there is no data yet. Moreover, it requires necessary price variations. An advantage of assessing flood risk could be that through a willingness-to-pay method, one can assess what people are willing to pay for their flood protection, which can have important implications for governance.

4.6. Regression Discontinuity

Although regression discontinuity has not been widely employed within existing academic literature as a method to evaluate the effect of floods on real estate values, the method could potentially be leveraged for assessing the effect of floods on real estate values.

Regression discontinuity analysis is a quasi-experimental design that can be used to estimate the impacts of an event in which objects or people are selected for a 'treatment' based on an arbitrary threshold (Jacob et al., 2012). Within this case, time could be used as the running variable, and 'treatment' could be assessed as inundated or non-inundated houses.

Van Der Klaauw (2010) describes a general case in which a (binary) treatment's outcome must be assessed. Within this case, they take random samples i that are observed for an outcome of y_i and the treatment indicator if t_i. This formula of regression discontinuity, while comparing the effect of t and y in which $y_i(0)$ is the outcome given the treatment (e.g. flood), can be described as:

$$y_i = \beta + \alpha_i * t_i + u_i \tag{4.6}$$

In which $\alpha_i = y_i(1) - y_i(0)$ and $y_i(0) = E[Y_i(0)] + u_i = \beta + u_i$.

4.6.1. Advantages and Limitations

The regression discontinuity method may not fully capture the connection between residential property prices and flooding. However, quasi-experimental designs are becoming widely known and used in studies examining the causative relationship between property values and environmental attributes. In particular, the regression discontinuity model can be used as it has plausible casual implications of an event (Hidano et al., 2015).

Moreover, regression discontinuity requires fewer assumptions compared to other non-experimental approaches, and the data used does not have to be as detailed. However, due to its nature, the density of the variable measured needs to be continuous for each individual (Lee & Lemieux, 2010). Second, regression discontinuity has weak statistical power (Tang et al., 2015). Third, regression discontinuity only allows for the recognition of the mean effects on objects nearby the threshold (Battistin & Rettore, 2008).

4.7. Spatial Regression Model

A spatial regression analysis model adds a spatial weighting matrix to a general linear model. Using GIS to observe data could be beneficial, as real estate markets tempt to have similar behavior in the same neighborhoods and could therefore improve consistency. Within this process, spatial weight analysis could be used to define relevant neighborhoods to observe (SAKAMOTO et al., 2022).

$$lnY = \alpha + \sum_i \beta_i x_i + \varepsilon \tag{4.7}$$

In which $\varepsilon = \lambda W\varepsilon + u$. In this formula, Y is the transactional price, X_i constitutes this ith housing attribute, W is the spatial weighting matrix, ε represents the vector of error terms, u is the vector of distributed random error terms, and finally λ denotes the spatial autoregressive coefficient.

Hereafter, a spatial-lag hedonic model could be used that assumes the spatially weighted sum of neighborhood housing prices and explanatory variable (Bin et al., 2008).

$$H = \lambda WH + S\beta + N\gamma + E\psi + R\varphi + \varepsilon_2 \tag{4.8}$$

In this equation, λ is a spatial autoregressive parameter, WH is, for the weights matrix w the vector of spatially lagged dependent variables. Additionally, the regression coefficient are described as $\beta, \gamma, \psi, \varphi$. Finally, the ε denotes the random error term.

Spatial Analysis

Spatial Correlation analysis considers the distribution of mapped variables. It refers to the presence of systematic spatial variation (Haining, 2001). It uses a null hypothesis and aims to assess if certain events cluster in space or are randomly distributed (Wei & Zhao, 2022).

Wei and Zhao (2022) use global Moran's I to describe the distribution between residential land prices and to assess if there are clusters in space within their paper following:

$$I_{\mathrm{G}} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \left(x_i - \bar{x}\right) \left(x_j - \bar{x}\right)}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \tag{4.9}$$

In this formula, $S^2 = \frac{1}{n} \sum i = 1^n (x_i - x)^2$, $x = \frac{1}{n} \sum j = 1^2$, x_1, x_i, x_j are the observed values of points i and j. N is the number of samples, and $w_i j$ is the spatial weight matrix. Within this analysis, Moran's I has a range of -1,1 relating to the distribution. A positive spatial correlation exists if the value is larger than 0. The larger the value is between 0 and 1, the more significant the spatial correlation. Near 0, the outcome indicates random distribution (Wei & Zhao, 2022).

4.7.1. Advantages and Limitations

The spatial correlation analysis can help solve complex problems and provides improved identification of the location of what is happening. It is not a method that can potentially assess the impacts of a flood itself. Using a spatial correlation method can solve a limitation hedonic models possess since hedonic models usually assume independent observations although the observation may be spatially auto-correlated (Kim & Kim, 2016). Combining spatial auto-correlation methods with hedonic methods (e.g., spatial regression) is, therefore, a useful method.

One limitation of the spatial regression model is that it forces a continuous pattern onto the spatial arrangement of an area, meaning it may oversimplify aspects of the spatial arrangement of areas, not fully reflecting the accurate spatial structure. (Bitter et al., 2007). Another limitation of spatial regression models can be observed in the fact the data set utilized should be complete to prevent ”holes” in the spatial observation to yield valid results (Anselin, 2002).

Finally, the assessed state-of-the-art-models and their respective limitations and advantages can be explained as in Table 4.1

Method	Explanation	Advantage	Limitation
Hedonic Price Models	- Break down characteristics and estimate monetary value of each characteristic	- Extrapolate effect of every attribute on value - Widely used in literature	- Non-inclusion tax and interest rates - Definition many variables - Detailed data required - Chance of misspecification
Difference-in-Difference	- Compare certain groups that are exposed to different treatments (e.g. control group and intervention group)	- Extrapolate single attribute	- Assumes spatial independence - Assumes groups to be equal without treatment
Repeat-sales Method	- Comparing different sales on same property	- Less specific characteristics data required	- Only yields price ranges - Property needs to be sold twice since event
Willingness-to-pay	- Assess the additional amount an individual would pay for something	- Quantify impact of preventive measures	- Requires price variations - No possibility to assess new products
Regression Discontinuity	- Analyze candidate/object for a treatment on the basis of arbitrary threshold value	- Requires less assumptions - No detailed data required	- Possible endogenous problems - Difficult to distinguish characteristics - Weak statistical power - Can only assess mean effects on object around threshold
Spatial Regression Model	- Spatial weighted matrix to assess the presence of systematic spatial distribution	- Improves consistency - Does not assume independent observations	- Forces a continuous pattern onto the spatial arrangement of an area - Requires complete, detailed data set

Table 4.1: State-of-the-art models review

4.8. Conclusion

Within the literature, different methods have been applied in order to assess the effects of floods in the past and flood risks in the future. Some researchers make use of stated preference methods, to take the view of residents into account. Other studies use perceived preference methods to focus on people's actual behavior. Within the perceived preference method, most studies use a hedonic pricing

model, meaning using a model to identify the influence of a non-market external characteristic. Hedonic pricing, thus, appears to be the current most widely accepted and applied method.

Other methods frequently used within the literature are difference-in-difference, repeat-sales, and willingness-to-pay methods. Difference-in-difference and repeat-sales attempt to measure the difference of an external factor, for example, a flood, on housing prices. Willingness-to-pay aims to assess what residents would be willing to pay for a house with fewer flood risks (e.g., elevation). For assessing the effects of recent floods on real estate values, the repeat-sales method is most likely not capable of capturing the effect of a recent flood, as the property should be sold at minimum twice since a flood event. In addition, the willingness-to-pay method would not be suitable for capturing the potential adverse effects of future flood risks on real estate values.

Although regression discontinuity has not been frequently mentioned within the literature on flood risk, it could prove valuable. In contrast to the other methods discussed, regression discontinuity takes an event as a threshold. The advantages of this method are that it requires fewer data and assumptions. On the other hand, the variables need to be continuous for each individual data point. This may pose a limitation in gathering the data. Regression discontinuity could therefore be used as a robustness check but is itself not adequate to isolate the effects of floods from other simultaneous changes (e.g., changes in the housing market or macroeconomic shocks).

Finally, spatial auto-regressive models have been discussed in this chapter. Utilizing a spatial auto-correlation analysis, the distribution of variables can be mapped within this method. This enables recognizing spatial patterns within a dataset. This can be interesting when defining relevant neighborhoods within a research case. Nonetheless, relying solely on this method does not suffice to describe the effects of floods on real estate, which is why it is often used in combination with a regression model. Spatial auto-regression could be leveraged as an addition to a hedonic model. An example of this combination is the spatial regression model. Spatial regression models have the advantage they do not assume independence between observations. However, they force a continuous pattern on the spatial arrangement of an area and require complete and detailed datasets, forming potential limitations.

In conclusion, considering the advantages and disadvantages of the different methods, the difference-in-difference method seems to be most suited for assessing the effects of past floods, as it allows for extrapolating a single attribute and is suitable for comparing groups that received different treatment in time (e.g., inundated or not inundated). For assessing the effects of future flood risk, Hedonic Price Model and Spatial Regression Model seem to be the most suitable method if detailed data is at hand and the variables are selected carefully, as these methods allow for estimating the effect of different property characteristics and can therefore measure hypothetical events.

The first research sub-question, "*What state-of-the-art models describe the relationship between flood risk and real estate value?*" can be answered with the fact that derived from literature, numerous methods to assess the effects of floods on real estate values exist. The most frequently used methods are hedonic price, difference-in-difference, repeat-sales, willingness-to-pay, regression discontinuity, and spatial regression. Reviewing all methods, it can be concluded that it is helpful to include empirical analysis by conducting a case study for research. All described methods are theoretical frameworks that have to be applied to practical example cases. As projections of more extreme effects of sea level rise on more vulnerable places in the world have diverse outcomes, taking a study case that has experienced actual floods can effectively put the future outcomes and implications in a certain perspective.

The second research sub-question *What is the most appropriate model to evaluate flood risk impact for the case study Maastricht?* can be answered by concluding that hedonic pricing models, spatial regression models, and difference-in-difference are currently most suitable and widely used for assessing the effects of environmental disasters on real estate values. When a case study has experienced previous floods and has chances of flooding in the future, difference-in-difference is the most suitable method for assessing past floods. A hedonic pricing model or spatial regression model may be the most suitable for evaluating the effects of future flood risks. Additionally, utilizing different methods can help provide robustness, as the different methods have different strengths and weaknesses. Finally, it should be noted that the optimal method is depended on the aim of the research and the level of detail within the dataset the researcher has obtained.

5

Flood Vulnerability

Several important aspects of an area can be assessed when assessing future risks. Due to climate change, an increasing number of houses are exposed to flood risks. However, the geography and location of different areas, including the chances of flooding and the depth of flooding, lead them to have different risk levels. Moreover, the broader vulnerability of a house can be dependent on numerous factors. For example, do the residents have a large financial buffer to cover potential damage costs? Can the residents quickly flee in case of a significant flood event? In order to assess vulnerability to future floods, the case study Maastricht is assessed in geophysical and socioeconomic factors within this chapter. Through data-analysis of the vulnerability levels of residential properties within Maastricht, the third sub-question *How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?* will be answered.

5.1. Vulnerability

Within this section, the common methods and included indicators to assess flood risks will be reviewed. Subsequently, the framework for vulnerability for this study is constructed, and the indicators that will be assessed in this study are subsequently defined.

Decisions on flood alleviation measures that are solely based on avoidance of material damage may be too limited, as the social impact of a flood is not considered within this decision-making (Coninx & Bachus, 2007). Social impact is considered to be change in the way people live, work, and organize themselves to address their needs and cope within society (Committee on Guidelines Principles for Social Impact Assessment (SIA), 1995). Studies on floods frequently focus on tangible risks, as these can be quantified. Currently, within the standard practices within the Netherlands, flood risks are calculated with the input of three factors: scenarios, scenario probabilities, and consequences per scenario as can be seen in Equation 5.1:

$$R = \{\text{Scen}_i, P_{\text{Scen},i}, q_{\text{Scen},i}\} \tag{5.1}$$

In this equation, R is the risk, $Scen_i$ is the identification of scenario i, $P_{\text{Scen},i}$ is the probability of scenario i and $q_{\text{Scen},i}$ is the expected consequences of scenario i, expressed in fatalities and economic damages (Jongejan & Maaskant, 2015).

However, studies like Werritty et al. (2007) explore the social impact of a flood and conclude that this intangible impact may sometimes be even more severe than the economic impact. Therefore, socio-economic factors may determine an area's vulnerability next to physical risks resulting from geographical factors. This is noteworthy as people with better financial situations can better prepare for a disaster in advance. Moreover, they can generally access resources more easily during a disaster and recover after disasters.

To assess the vulnerability of a place, the definition of vulnerability should first be understood. Within this research, the definition: 'the degree to which a person or place is susceptible or unable to cope with adverse effects of climate change' will be adapted (McCarthy et al., 2001). Therefore, within this research, data on social vulnerability and the local buildings will be combined with flood risk maps to assess the vulnerability of the case study Maastricht.

Where you are located and who you are can significantly influence how you experience and recuperate from natural disasters like a flood (Morrow, 1999). Namely, a disastrous event might have divergent

short and long-term impacts on people with different “socioeconomic and geographic gradients” (Spielman et al., 2020). Vulnerability can be seen as a function of exposure (i.e., what assets and people are at risk), sensitivity (i.e., what is the impact on those people and assets at risk?), and resilience (i.e., how can a system adapt and recover from the impact?). Therefore, to analyze the vulnerability of a city, all components, and the most influential dimensions should be assessed.

To effectively study the vulnerability of a specific place, the compilation of factors influencing this should thus be combined. Within academic literature, several studies have been done to identify the vulnerability of cities. Different studies have used different variables to measure vulnerability. A number of these studies have been summarized in Table 5.1. Derived from these studies, it appears that next to the social aspects, the disaster-bearing capability should be understood by assessing the property and its characteristics. Finally, following the traditional definition of flood vulnerability (Equation 5.1), the chances that a property will flood and the inundation depth should be determined to understand the scenarios, probability of floods, and consequential damages.

Vulnerability Concept	Variables	Reference
Social	Wealth, Age, Density, Economic Dependence, Housing Stock, Ethnicity, Occupation, Infrastructure dependence	Cutter et al., 2003
Social	Age, gender, ethnicity, employment rate, income, persons per housing unit	Spielman et al., 2020
Socio Economic	Social Exposure, Economic Exposure, Social Sensitivity, Economic Sensitivity, Social Resilience, Economic Resilience	Aroca-Jiménez et al., 2020
Social-Environmental	Social Economic, Land Use, Eco-environmental, Coastal construction, Disaster-bearing capability	Li and Li, 2011
Socio-Environmental	Flooding, Landslides, Coastal Erosion, Wave Exposition. Socioeconomic Status. Population Density, Land Use	Zanetti et al., 2016
Socio-Environmental	Population Density, Flood Prone Area, Altitude, Gender, Mortality rate, Dependency ratio, Lack of access to drinking water an sanitation, Unemployment, Agricultural land, Literacy rate, Number of hospitals, Length of asphalt roads, Forest cover, Income, Flood management measures.	Nazeer and Bork, 2019
Socio-Environmental	Age, Gender, School, Income, Job, Unemployment, Persons per household, Ownership, Urbanity	Fekete, 2010
Socio-economic and physical	Mean tidal range, Coastal slope, Relative Sea level rise, Mean wave height, Geomorphology, Poverty, Age, Density, Ethnicity, Gender, Income, Employment	Boruff et al., 2005

Table 5.1: Academic literature on vulnerability

To analyze the vulnerability of neighborhoods, indicators from the papers of Fekete (2010), Zanetti et al. (2016), Cutter et al. (2003), Li and Li (2011), and Aroca-Jiménez et al. (2020) are adapted within this research. The adapted indicators can subsequently be divided into five categories: flood exposure, disaster-bearing capability, social status, economic status, and population, as illustrated in Figure 5.1.

Social status, economic status, and population are combined within the category ’Socio-Economic’. Thus, we distinguish three main categories within this research: Socio-Economic status (including social status, economic status, and demographics), Disaster-bearing capability, and Flood Exposure. Hereafter, for all indicators, the sub-indicators have been adapted from the literature to assess the vulnerability of the case study of this research, Maastricht.

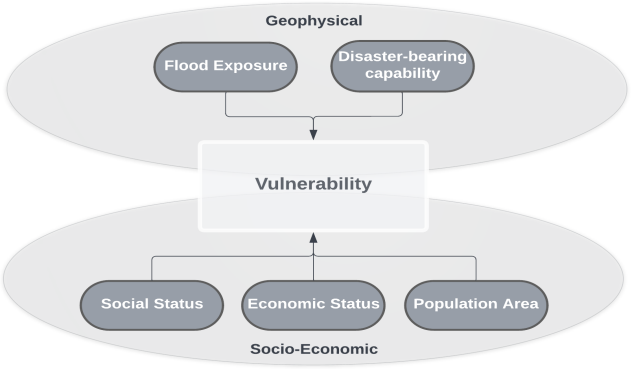


Figure 5.1: Vulnerability framework, (Author’s image)

5.1.1. Socio-Economic Vulnerability

The first vulnerability assessed is the socio-economic vulnerability. In literature, there is consensus on certain aspects of socio-economic vulnerability like gender, age, and race (Cutter et al., 2003). The socio-economic status of residents is important, as having a low socio-economic status is frequently accompanied by having less education, lower well-being, more dependency on social services, and limited access to resources (Krokstad, 2004). Within this section, there is elaborated upon the adapted socio-economic indicators.

Density

Several studies have concluded that urban areas with a high population density can be more vulnerable to floods. For example, Cutter et al. (2003) conclude that evacuating densely populated areas can be more convoluted and lead to more complex and high costs recoveries. Therefore, the average density per km^2 in every neighborhood was assessed.

Age

When looking at the demographics of an area, it is important to consider the distribution of ages because certain age groups are considered more vulnerable than others. Specifically, areas are considered to be more vulnerable if they consist of a high percentage of people between 0-15 years and 65 years and older (Cutter et al., 2003). For this reason, the proportion of people between 0-15 and 65+ was assessed in all the different neighborhoods.

Dependent people

When assessing the social vulnerability of an area, it is important to consider the health status of the residents, as this impacts the vulnerability and resilience of an area. Namely, residents with health conditions are more susceptible to problems related to the evacuation but also the protection and recovery after a flood event (Defra & Flood, 2003). In addition, Cutter et al. (2003) state that people dependent on social services and economically/socially marginalized will need extra support in the recovery period. Therefore, the number of people that require health aid, defined as youngsters in the youth services and adults in the Social Support Act (WMO) were considered in the vulnerability analysis.

Financial Aid

Areas that have a high number of people around or under the social minimum in the Netherlands and a high number of people receiving financial aid are considered vulnerable, as residents have fewer means to recover after a disaster and are economically dependent on the government (Aroca-Jiménez et al., 2020, Holand et al., 2011). Financial aid was assessed for this research by the number of people eligible for social assistance (de bijstand), meaning they are eligible for financial aid from the government in the Netherlands.

Income

Households with a lower income have fewer means to protect themselves during and recover from a disaster (Fekete, 2010). Moreover, according to Cutter et al. (2003), a higher income allows residents to recover from losses due to social safety nets and entitlement programs. Residents with a lower income were assessed through the number of households around or under the social minimum as defined by the government of the Netherlands (CBS, 2022).

Unemployment

Lack of employment can cause minimal economic capacity (Aroca-Jiménez et al., 2020). Moreover, poverty is considered an essential indicator of vulnerability as it limits access to resources (Fatemi et al., 2017). In addition, higher unemployment rates are frequently observed in conjunction with higher levels of vulnerability after disasters (Fatemi et al., 2017). For this study, the percentage of the population of the neighborhoods that are unemployed was therefore assessed.

Education

Education is linked to socioeconomic status, as higher education often results in greater lifetime earnings. In addition, lower education can lead to a lower level of understanding of the warning information and less access to recovery information (Cutter et al., 2003). Therefore, the number of people with lower education is determined, which was assessed through the percentage of the total residents that

have received lower education within this research. Lower education is defined as elementary school, vmbo, the first three years of havo/vwo and mbo-1 (Statistiek, 2022).

Gender
Women may experience a more difficult recovery process as they are frequently responsible for care for families and have lower wages (Cutter et al., 2003). Moreover, according to Fekete (2010) females are generally observed to be financially dependent with greater frequency. Therefore, the percentage of women per neighborhood was assessed.

Foreign Population
Language differences might impact the reception of flood warning signals, and cultural differences can exacerbate the impact of floods (Defra & Flood, 2003). Moreover, foreigners may be less included in flood preparedness institutions (Fekete, 2010). Therefore, the percentage of non-native people was assessed.

Rental Housing
According to Cutter et al. (2003), people rent, in general, because they lack financial resources. In addition, they often lack information about financial aid when they experience a disaster. Moreover, in extreme cases, renters can lack shelter options if rent becomes too expensive or uninhabitable. Therefore, the amount of rental housing per neighborhood was considered in this research.

5.1.2. Disaster-bearing Capability Vulnerability
In addition, the disaster-bearing capabilities of a neighborhood and house are very important in assessing vulnerability, as they determine the actual economic and social impact of a flood. If houses are older or only consist of one story, for example, this can heavily impact the effects of a flood on that property. Within this section, the disaster-bearing capability indicators are discussed.

Soil Capacity
Properties accessible during floods are less vulnerable than properties locked in during a flood. Moreover, the water-bearing capability of soil within a neighborhood will define how much water the ground can absorb before becoming saturated. Areas with a low saturation level (e.g., hardened surfaces) will therefore experience more intense and long-lasting floods as the land available for infiltration is limited and more surface runoff is created, which can result in floods (Al-Bassam et al., 2014). Thus, the soil capacity of the neighborhoods was assessed.

Building Year
The building year of properties can have implications on the construction and how well it can cope with disasters and floods specifically. Therefore, the building year of a property was considered within this study (Usman Kaoje et al., 2021). The definition of 'old' adopted within this study is after 1992. This was done in 1992, the Building Decree (Bouwbesluit) was adopted within the Netherlands, guaranteeing certain standards and qualities of all buildings.

Property Type
The property type is important in assessing the impact of a flood, both economic and social, will be. For example, Tapsell et al. (1999) clarified that single-story properties are more vulnerable to disruption, more significant losses, and more extended evacuation periods. Therefore, the proportion of single-story properties was assessed in this study.

5.1.3. Flood Exposure Vulnerability
Flood exposure is expressed by the expectation of areas being flooded in 2050 and the inundation depth. Within this prognosis, LIWO (2022) has taken essential factors regarding the vulnerability to flood into account, such as proximity to a water body, slope, and height (Zanetti et al., 2016). Within this section, the adapted flood exposure indicators are discussed.

Flood risk
The risk of flood can be described as the probability that an area will flood. The neighborhoods were rated on their local flood risk with a large chance (>1/30 per year), large-average chance (1/30 to 1/300 per year), and smaller than 1/3000 (small chance to extreme small chance) to flood with at least 20 cm.

Inundation Depth

The depth of inundation has an influence on the amount of damage and, subsequently, on the social impact when heavily disrupted. The Institute of Environment Research (1986) concluded in their research that 80% of the respondents felt that they would be greatly affected by floodwaters of 0.1 meters. Moreover, Dinh et al. (2012) elaborate on the importance of flood depth and argue that most studies on flood hazard have flood depth as a key indicator. Therefore, the inundation depth is considered in this study. The inundation depth was defined (following Stichting Climate Adaption Services (2022) as areas with a water depth smaller than 0.5 meters, between 0,5 and 1 meters, between 1 and 1.5 meters, between 1.5 and 2 meters, between 2 and 5 meters, and larger than 5 meters.

Extreme Flood risk

Following Pant et al. (2018), a distinction has been made between all areas that were marked with a flood risk (from the large chance to extremely small chance) and areas that received the mark of large chance to flood (>1/30 per year) as increased likelihood to a flood makes an area more vulnerable. Areas with an annual flooding chance of 3.3% or more are defined as areas with a large chance (Pant et al., 2018).

Extreme Inundation Depth

A distinction has been made between the percentage of a neighborhood that has expected inundation and high inundation depth, as this will not only cause greater damages to the real estate but is also threatening to the residents and human life. The percentage of the neighborhoods that could flood over 2 meters (Dinh et al., 2012) was therefore considered.

Finally, the adapted indicators, methods used for their measurement, sources, and references have been consolidated in Table 5.2

Categories	Parameters	Measured in	Source	Reference
Socio-Economic	Population Density (DENS)	#/km	CBS	3,
	Age (A) 65+ or 15-	%	CBS	1, 2
	Dependent people (DP)	%	CBS	1, 2, 4
	Financial Aid (FA)	%	CBS	1, 2, 5
	Income (I)	%	CBS	1, 2, 5
	Unemployment (U)	%	CBS	1, 2, 4
	Education (E)	%	CBS	2, 5
	Gender (G)	%	CBS	1, 2
	Foreign Population (FP)	%	CBS	1, 2
	Rental Housing (RH)	%	CBS	1
Disaster-bearing capability	Soil Capacity (SC)	mm	Atlas Leefomgeving	4
	Building year (BY)	%	Kadaster	1, 2, 4,
	Property Type (PT)	%	LIWO	4
Flood Exposure	Flood Risk (FR)	Probability in years	LIWO / RWS	3
	Inundation Depth (ID)		LIWO / RWS	3
	Extreme Flood Risk (EFR)	Probability in years	LIWO / RWS	3
	Extreme Inundation Depth (EID)	M	LIWO / RWS	3

Table 5.2: Vulnerability Measuring Factors - Referenced studies: 1 = Cutter et al. (2003), 2=Fekete (2010), 3=Zanetti et al. (2016), 4=Aroca-Jiménez et al. (2020), 5=Li and Li (2011)

5.2. Vulnerability Scores

Within this section elaboration is given on how the data was obtained, treated, re-scaled, weighted, aggregated, and what robustness checks were executed to arrive at the final vulnerability scores. The assessment was done both for the three categories separately as well as combined.

5.2.1. Data and Data Treatment

Data on the socio-economic sub-indicators was retrieved from Centraal Bureau Statistiek (CBS), data on the disaster-bearing capabilities from Kadaster and the Landelijk Informatiesysteem Water en Overstromingen (LIWO). Finally, data on flood exposure was retrieved from LIWO, Klimaateffectatlas and

Rijkswaterstaat (RWS). The software program QGIS was leveraged to assess and obtain information on the flood risk maps, inundation depth maps, properties, and permeability maps. GIS is a well-known tool that has been used by many researchers to map the spatial distribution of the built environment and exposure to risks, such as floods (Karmakar et al., 2010). The QGIS maps were first polygonized in order to assess them as shapefiles, after which they were clipped to all different neighborhoods of Maastricht to be able to compare the different neighborhoods to each other within the data analysis.

The level granularity of neighborhoods has been chosen. This is because that information on smaller scales (postal codes) was limited due to privacy concerns. However, some neighborhoods were still difficult to assess, as data suppression is common within small-scale observation when the population does not reach the threshold of 50 residents. Similarly, if neighborhoods did not reach the threshold of 200 residents, sensitive data (e.g., income) may be coded classified (Kirby et al., 2019).

In case of missing data, three methods can be applied. The first method is deleting the case. However, this approach simply ignores the possibility that there can be systematic differences between the different incomplete and complete samples. Therefore, this method can produce biased results. This method should only be applied in cases where the deleted records are random sub-samples or in cases where the missing variables are less than 5% of the total records. Moreover, the standard error will increase due to missing information when deleting the classified cases. The other two methods, single imputations or multiple imputations, try to replace the missing data through single imputation (e.g., mean/median or mode), regression, or other methods. To minimize bias, data imputation is thought to be effective. However, data imputation is always associated with assumptions (The Joint Research Centre-European Commission, 2008).

Following The Joint Research Centre-European Commission (2008), for this research, a single imputation method is chosen: an unconditional mean. Within this imputation, x_q is the random variable of an indicator q and x_q, n the value for the neighborhood n. If m_q is the number of non-missing values, the unconditional mean can be calculated with Equation 5.2. An important implication within this method is the fact that the true variance is underestimated by substituting the missing values with the mean and is, therefore, moderately biased.

$$\bar{x}_q = \frac{1}{m_q} \sum_{\text{recorded}} x_{q,n} \tag{5.2}$$

In conclusion, the neighborhoods missing specific information in the retrieved data set therefore received the average score of the other neighborhoods. Although this might lead to more or less extreme vulnerability scores for certain neighborhoods, this allows for a fair comparison between the neighborhoods. Maastricht consists of 43 neighborhoods (see Figure 5.2), which were assessed on their different vulnerabilities.

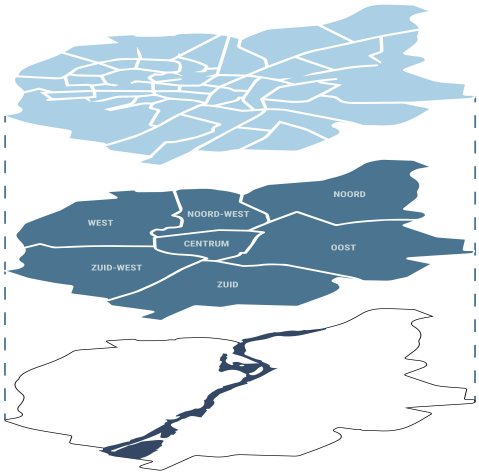


Figure 5.2: The Maas, Districts and the Neighborhoods (Author's Image)

5.2.2. Data Rescaling

The data was transformed into a single scale to make it feasible to aggregate and compare the different indicators. Normalizing the data can be done through, for example, ranking, standardization, or the min-max method (The Joint Research Centre-European Commission, 2008). The ranking technique divides the data on a scale following its magnitude. Ranking has the advantage of not being affected by outliers in the data. However, within this transformation, the information on the numerical values of the data is lost. Moreover, this method is sensitive to missing data, as the missing data points can not be ranked. Standardization transforms the data to a common scale (e.g., measured on the same scale) with a standard deviation of one and a mean of zero. This method can thus prove valuable when data have different scales. Standardization is susceptible to outliers. Finally, the min-max method normalizes all the indicators to range between [0,1] (The Joint Research Centre-European Commission, 2008).

The min-max method was applied as this method widens the range of indicators within a small interval, and the numerous neighborhoods have values around the same percentage for certain indicators. In addition, all indicators have been defined (meaning for some indicators inverted) in such a way that a higher score would mean a higher vulnerability (Stathatou et al., 2016, Tewari, Bhowmick, et al., 2014). A sensitivity analysis was conducted to avoid a strong effect of outliers within the data (as explained in subsection 5.2.5). Thus, the dimensions of vulnerability were assessed on a scale from 0 to 1 with an equal weighting to all sub-components following (5.3).

$$\mathsf{X_i} = \frac{X_a - X_{\mathsf{Min}}}{X_{\mathsf{Max}} - X_{\mathsf{Min}}} \tag{5.3}$$

In this equation, X_i is the normalized value for sub-component i (DENS, A, DP, I, U, E, G, FP, RH, SC, BY, PT, FR, ID, EFR, EID), X_a is the actual value, X_{min} and S_{max} are the minimum and maximum values for the indicator i—resulting in all normalized values from the data for all neighborhoods with the highest value being 1 and the lowest being 0.

5.2.3. Weighting

The weights of all indicators are relevant as they can substantially affect a neighborhood's overall vulnerability score. Equal weighting can be assumed when there is insufficient understanding of the relationship between an indicator and the vulnerability of an area (Nazeer & Bork, 2019). An unequal weighting can be applied in three ways: through a normative approach (e.g., expert opinion, public opinion), a data-driven approach (e.g., statistical), or hybrid (Baptista, 2014). Statistically, derived weights are considered to be more defensible within the academic literature. However, weighting generally introduces the complexity of subjectivity within vulnerability analysis (Fekete, 2010). An equal weighting was compared with a statistical method for robustness (Nazeer & Bork, 2019) to avoid subjectivity or skewed outcomes within this research.

The first and most straightforward approach applied is equal weighting (EW), assigning equal weight to all indicators. This method can be justified without clear grounds for an unequal weighting of the indicators. The second applied weighting scheme, the statistical method, was adopted from Nazeer and Bork (2019) and is called the Iyenger and Sudarshan's method. Within this method, all the weights are assumed to vary inversely in their respective indicator over the neighborhoods. This method is thought to be effective as it ensures that a significant variation in one of the indicators can not dominate the contribution compared to other indicators (Nazeer & Bork, 2019).

First, the normalized constant (K) was calculated using (5.4), in which n is the number of indicators of the normalized value of the indicator X_i.

$$\mathsf{K} = \left[\sum_{i=1}^{n} \frac{1}{\sqrt{\mathsf{Var}\, X_i}}\right]^{-1} \tag{5.4}$$

Then, the weights for the different indicators were calculated through Equation 5.6, for each indicator subject to W_i ($\sum_{i=1}^{n} W_i = 1$ and $0 \leq W_i \leq 1$).

$$\mathsf{W_i} = \frac{K}{\sqrt{\mathsf{Var}\, X_i}} \tag{5.5}$$

5.2.4. Aggregation

In order to compare the different neighborhoods on the complete set of their sub-indicators, the different data points had to be aggregated. The arithmetic mean was calculated for the first method (equal weighting) to combine the set of variables for assessing the vulnerability of different neighborhoods. This was done by dividing the sum of the index values of all separate variables by the number of variables (n) taken into account, as can be seen in (5.6), in which SVI is the sub-vulnerability index.

$$\mathsf{SVI} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{5.6}$$

When standardized in this manner, all Vulnerability Index variables range from 0 to 1 and are not influenced by the number of variables included. When a neighborhood received a higher score, this meant that it was more vulnerable (The Joint Research Centre-European Commission, 2008).

For the statistical method, since the weighting has to be considered, the aggregation of weighted normalized factors was calculated through (5.3).

$$\mathsf{SVI} = \sum_{i=1}^{n} W_i X_i \tag{5.7}$$

In this equation, SVI is the sub-vulnerability index of a category and the weights are indicated by W_i and the sub-indicators by X_i.

Finally, the total flood vulnerability index (TVI) per neighborhood can then be calculated by multiplying the sub-vulnerability indexes (SVI) with each other as in Equation 5.8.

$$\mathsf{VI} = \frac{1}{3}(SVI1 + SVI2 + SVI3) \tag{5.8}$$

In this equation, SVI1 is the socio-economic vulnerability, SVI2 is the disaster-bearing capability, and SVI3 is the flood exposure.

5.2.5. Robustness Checks

Within this section, the robustness of the conducted assessment will be checked. First, in order to verify if indicators are not too highly correlated, the correlation of the indicators was assessed. This is important as a high correlation between coefficients can lead to double counting within an assessment. Second, the choice of vulnerability indicators was verified. Third, to assess whether the total flood vulnerability index was not highly influenced by one of the indicators, a sensitivity analysis was conducted.

Indicator Correlations

Although variables will never be fully independent if they aim at measuring the same phenomena, it is generally deemed necessary to discard a certain indicator when highly correlated (The Joint Research Centre-European Commission, 2008). Following (Nazeer & Bork, 2019) in order to assess the correlation between indicators, Pearson's correlation is applied as can be seen in Equation 5.9:

$$\mathsf{r} = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\Sigma x^2 - \left(\sum x\right)^2\right]\left[n\Sigma y^2 - \left(\sum y\right)^2\right]}} \tag{5.9}$$

In this equation, r is Pearson's correlation, n is the number of observed values (neighborhoods), and x and y are indicators for assessing the relation. Existing literature is not unanimous about the threshold for highly correlated (varying for example between 0.65 and 0.9). Within this research, the definition of

highly correlated is adapted from Hagenlocher et al. (2016), who defined highly correlated as defined a Pearson's correlation (r) that is above 0.9.

The different socio-economic indicators have either positive or negative correlations (Table 5.3). The correlation between education and dependent people is relatively high, as well as the number of unemployed people and rental housing. Another high correlation value is found between rental housing and income, with a value of 0.783. The highest correlation value is found between people receiving financial aid and those with a low income; their correlation is 0.91. As this exceeds the threshold value of 0.9, the percentage of people receiving financial aid was excluded from the indicators.

With regard to the flood indicators, the correlations with the socio-economic factors are all relatively low. Similarly, the correlations between disaster-bearing capabilities and socio-economic vulnerabilities are low. A stronger correlation is found between the disaster-bearing capabilities and flood exposure. Especially the correlation between the water storage capacity and flood risk is high (0.784). Moreover, the correlation between the total water depth and the areas with high flood chance or extreme water depth is very high (0.898 and 0.930, respectively). As the relation between water depth and high water depth is above the defined threshold, extreme water depth was not considered within the vulnerability assessment.

Pearson Correlation	**I**	**A**	**DP**	**E**	**G**	**FP**	**RH**	**U**	**DENS**	**FA**	**FR**	**ID**	**BY**	**PT**	**SC**	**EFR**	**EID**
I	1,00	-0,26	0,25	0,56	-0,01	0,48	0,78	0,48	0,32	**0,92**	0,02	-0,16	0,19	-0,17	0,12	-0,11	-0,11
A	-0,26	1,00	0,42	0,13	0,18	-0,67	-0,39	0,01	-0,21	-0,11	-0,07	0,16	0,01	-0,21	-0,36	0,10	0,10
DP	0,25	0,42	1,00	0,59	0,37	-0,33	0,23	0,18	0,19	0,47	0,07	0,09	-0,29	-0,41	-0,06	0,21	0,20
E	0,56	0,13	0,59	1,00	-0,09	-0,04	0,31	0,13	0,02	0,77	0,15	0,08	-0,16	-0,04	0,10	0,13	0,14
G	-0,01	0,18	0,37	-0,09	1,00	-0,04	0,08	0,24	0,39	-0,04	-0,23	-0,34	-0,08	-0,67	-0,19	0,08	-0,07
FP	0,48	-0,67	-0,33	-0,04	-0,04	1,00	0,59	0,21	0,40	0,31	-0,21	-0,39	0,14	-0,09	0,13	-0,33	-0,31
RH	0,78	-0,39	0,23	0,31	0,08	0,59	1,00	0,63	0,40	0,69	0,07	-0,24	0,15	-0,21	0,23	-0,20	-0,22
U	0,48	0,01	0,18	0,13	0,24	0,21	0,63	1,00	0,54	0,39	0,04	-0,07	0,24	-0,25	-0,11	-0,10	-0,09
DENS	0,32	-0,21	0,19	0,02	0,39	0,40	0,56	0,54	1,00	0,23	-0,12	-0,30	0,08	-0,17	-0,07	-0,24	-0,23
FA	**0,92**	-0,11	0,47	0,77	-0,04	0,31	0,69	0,39	0,23	1,00	0,02	-0,16	0,19	-0,17	0,12	-0,11	-0,11
FR	0,02	-0,07	0,07	0,15	-0,23	-0,21	0,07	0,04	-0,12	0,02	1,00	0,61	0,05	0,32	0,78	0,53	0,54
ID	-0,16	0,16	0,09	0,08	-0,34	-0,39	-0,24	-0,07	-0,30	-0,16	0,61	1,00	0,07	0,39	0,41	0,90	0,93
BY	0,19	0,01	-0,29	-0,16	-0,08	0,14	0,15	0,24	0,08	0,19	0,05	0,07	1,00	0,21	0,08	-0,04	-0,05
PT	-0,17	-0,21	-0,41	-0,04	-0,67	-0,09	-0,21	-0,25	-0,17	-0,17	0,32	0,39	0,21	1,00	0,28	0,23	0,21
SC	0,12	-0,36	-0,06	0,10	-0,19	0,13	0,23	-0,11	-0,07	0,12	0,78	0,41	0,08	0,28	1,00	0,44	0,42
EFR	-0,11	0,10	0,21	0,13	0,08	-0,33	-0,20	-0,10	-0,24	-0,11	0,53	0,90	-0,04	0,23	0,42	1,00	0,98
EID	-0,11	0,10	0,20	0,14	-0,07	-0,31	-0,18	-0,09	-0,23	-0,11	0,54	**0,93**	-0,05	0,21	0,44	**0,98**	1,00

Table 5.3: Pearons Correlations

Indicator Selection

The selection of indicators is a complex step within the vulnerability analysis that can be perceived as ambiguous. To test the robustness of the indicators, through conversations with experts within the internship company Arcadis within different fields, different indicators and their importance were discussed to verify an effective choice of indicators across the vulnerability categories (i.e., Global Shelter Program Manager, Sr. Project Lead Resilience, Principal Advisor Urban Water Management, and Climate Adaptation, Senior Planeconoom).

Sensitivity Analysis

In addition, a sensitivity analysis was carried out by excluding certain indicators. The indicators tested in exclusion were the indicators that had the largest variances, as they would be expected to have the largest influence on the total flood vulnerability index rates. The tested indicators when excluding were: age, gender, employment rate, soil, total water depth, and extreme flood chance, as can be observed in Table 5.4. The sensitivity analysis indicated that the tested indicators had a maximum difference of 0.038 and were thus negligibly low (Damm, 2010).

Excluded Variable	**Mean with Statistical Weighing**	**Mean with Equal Weighing**
None	*0,445586*	*0,369742*
Age	0,433179	0,348512
Gender	0,407093	0,340032
Employment Rate	0,423485	0,345412
Soil	0,449359	0,330879
Total Waterdepth	0,477789	0,361149
Extreme Flood Chance	0,478713	0,362784

Table 5.4: Sensitivity Analysis

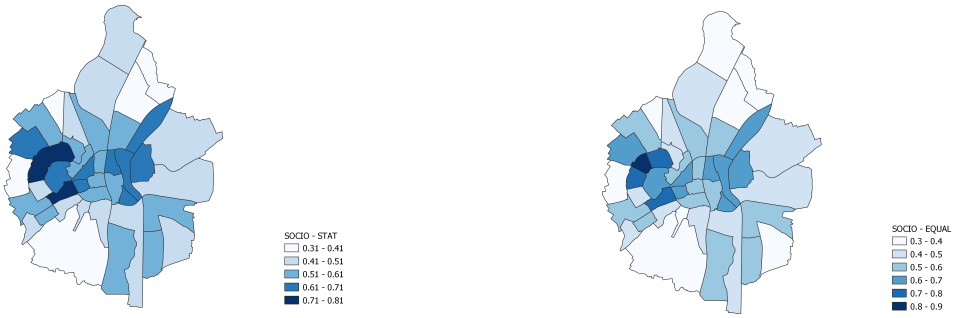
5.3. Vulnerability Outcome

The socio-economic, disaster-bearing, and flood exposure vulnerability indices and their combined vulnerability index can finally be mapped per neighborhood. Within this section, the socio-economic, disaster-bearing, and flood exposure vulnerabilities will be elaborated on by comparing the statistical and equal weighing and assessing potential explanations for the division of vulnerabilities. In addition, the combined vulnerability of the different neighborhoods of Maastricht is presented and assessed. Finally, the outcomes of the indexes are compared and discussed. The overview of the total flood vulnerability assessment executed through the data analysis can be seen in Appendix D.

5.3.1. Socio-Economic Vulnerability Index

The socio-economic vulnerability based on the statistical weighing of the different neighborhoods can be mapped as in Figure 5.3, in which can be seen that although the socio-economic vulnerabilities are generally well-distributed over Maastricht, the neighborhoods in the district Maastricht-West and Maastricht-Oost have a relatively high socio-economic vulnerability.

The indicators in which these neighborhoods score relatively high are education, dependency, employment rate, and income. The neighborhoods that are identified as the most vulnerable are observed to have an accumulation of these factors. This observation may suggest a relation between these socio-economic indicators, resulting in an enlarged socio-economic vulnerability of these neighborhoods.



a) Socio-Economic vulnerability scores with statistical weighing

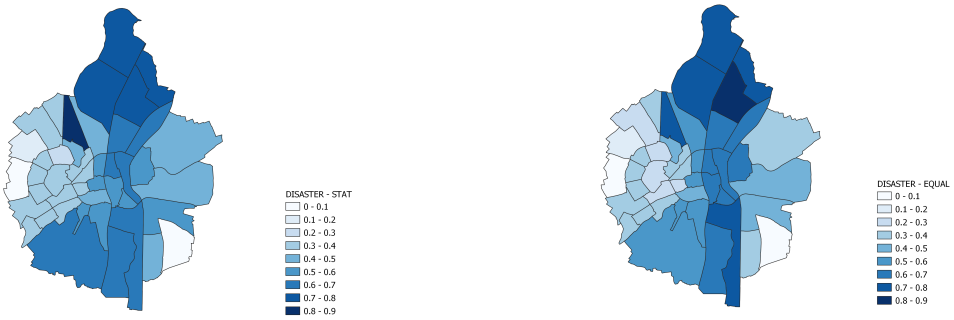
b) Socio-Economic vulnerability scores with equal weighing

Figure 5.3: Socio-Economic vulnerability scores (Author's image)

5.3.2. Disaster-bearing Vulnerability Index

The disaster-bearing vulnerability of the different neighborhoods can be mapped as in Figure 5.4, in which it can be seen that relatively many neighborhoods score both within a statistical as an equal weighing high, compared to the socio-economic scores. This can be attributed to the relatively low differences between the number of houses within the neighborhoods with an extra floor (property type), with many neighborhoods receiving a higher normalized value.

In contrast to the socio-economic vulnerabilities, the Maastricht-west district has relatively low vulnerabilities regarding disaster-bearing vulnerabilities. This can mainly be attributed to the fact that relatively few old properties are situated, and the soil capacity is relatively high. Neighborhoods near the city center have a relatively high number of older buildings. Moreover, the neighborhoods adjacent to the river naturally have a lower soil capacity, enlarging their vulnerability. Finally, the districts with the largest number of properties without a dry floor were Maastricht-Noord and Maastricht-Zuidwest.



Disaster-bearing vulnerability scores with statistical weighing

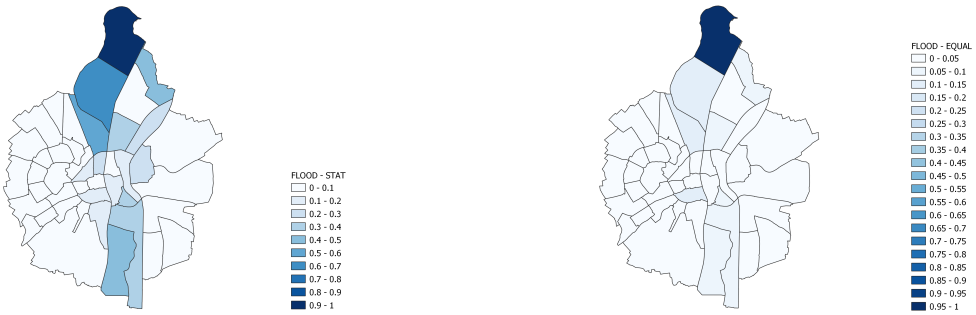
Disaster-bearing vulnerability scores with equal weighing

Figure 5.4: Disaster-bearing vulnerability scores (Author's image)

5.3.3. Flood Exposure Vulnerability Index

The disaster-bearing vulnerability of the different neighborhoods can be mapped as in Figure 5.5, in which can be seen that the differences in flood risk vulnerabilities are more significantly divided between the neighborhoods. This can be attributed to the fact that there is a large difference between the flood exposure that the neighborhoods have due to their location nearby the river and the elevation of the different areas. In addition, neighborhoods with the largest flood chance naturally have the largest areas with a high inundation depth.

To ensure this correlation between flood risk and inundation depth was not too big, this was tested as discussed in subsection 5.2.5. The neighborhoods adjacent to the river de Meuse thus have the largest flood exposure.



Flood exposure vulnerability scores with statistical weighing

Flood exposure vulnerability scores with equal weighing

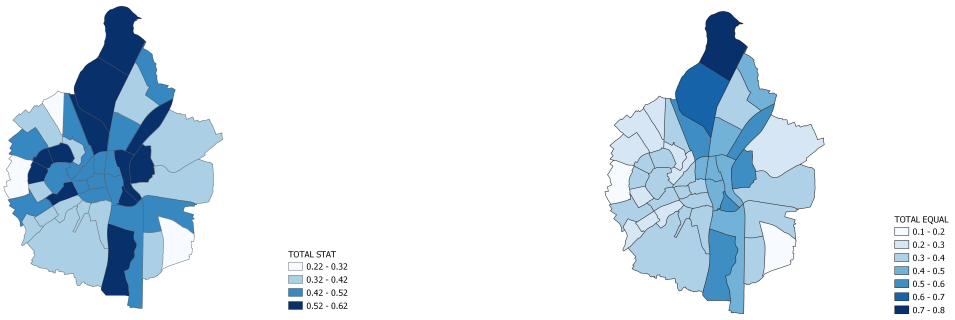
Figure 5.5: Flood exposure vulnerability scores (Author's image)

5.3.4. Total Flood Vulnerability Index

Finally, the total flood vulnerability of the different neighborhoods can be mapped as in Figure 5.6, Within the equal weighting, the three different vulnerability indexes all got a contribution of one-third to the total flood vulnerability index, as considering an equal weight divided amongst all different indicators could lead to skewed results to the higher amount of indicators in the socio-econonomic vulnerability. Within the statistical weighing, we see a more dispersed pattern, due to the inclusion of the normalized constant within the definition of weighting.

Unlike the flood exposure vulnerability, disaster-bearing capabilities and socio-economic indicators have a more segregated vulnerability pattern. The implication can be discussed as that those areas

more prone to the chances of flooding are not, per definition, the only areas that should be considered while assessing flood exposures. Disaster-bearing capabilities and socio-economic indicators significantly influence the total flood vulnerability of an area, presumably not only for floods but also for other natural disasters. The areas where socio-economic, disaster-bearing capabilities, and flood vulnerability overlap are considered the most vulnerable areas, which would need to be most considered within flood defense systems and measures. For example, neighborhoods in the district Maastricht-Oost are areas where all the vulnerabilities indices assessed aggregate. Not only are these areas more prone to flooding, but the residents are also more vulnerable and less resilient.



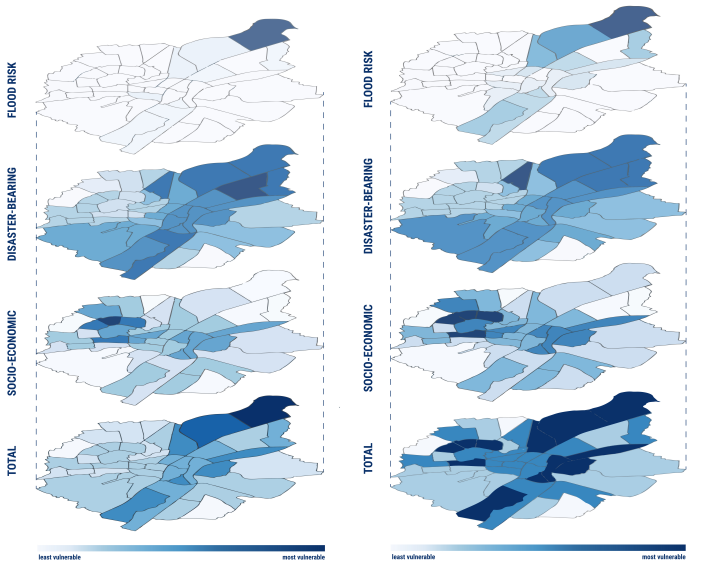
Total flood vulnerability scores with statistical weighing

Total flood vulnerability scores with equal weighing

Figure 5.6: Total flood vulnerability scores (Author's image)

5.3.5. Combining the Indices

As a final step toward the implications of flood vulnerability, the different indices have been compared to identify potential overlapping vulnerabilities. Within Figure 5.7 an axonometry of the area has been constructed with the total flood vulnerability, socio-economic, diaster-bearing capabilities, and flood exposure. Observing this axonometry, there does not seem to be a high overlap for the different vulnerability indexes for specific neighborhoods. The most significant overlap is seen between the disaster-bearing capabilities and flood exposure of the neighborhoods adjacent to the river.



Axonometry vulnerability indices with statistical weighing

Axonometry vulnerability indices with equal weighing

Figure 5.7: Axonometry vulnerability indices (Author's image)

5.4. Conclusion

This chapter assessed the socio-economic, disaster-bearing, and flood-exposure vulnerability of the case study. For all vulnerability indices, sub-indicators were defined based on the literature. The following socio-economic sub-indicators were adopted: age, density, dependent people, education, gender, foreign residents, financial aid, income, and rental housing. For the disaster-bearing capabilities, the sub-indicators were property type, building year, and soil capacity. Finally, for flood exposure, the sub-indicators were defined as flood exposure, extreme flood risk, extreme inundation depth, and inundation depth.

The neighborhoods with a relatively high socio-economic vulnerability were primarily positioned in the district Maastricht-West and Maastricht-Oost. The relatively high socio-economic vulnerability of these districts can be attributed to education, dependency, employment rate, and income indicators. The higher disaster-bearing capability vulnerabilities are positioned adjacent to the river the Meuse due to the low capacity of the soil for water and the relatively high number of older houses. The flood risk vulnerability of the case study is centered adjacent to the river as well due to the combination of the flood chance and water-depth projections within these neighborhoods.

Finally, the third sub-question *How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?* can be answered by concluding that although defining vulnerability is a complex challenge in which numerous indicators could be chosen and considered, a well-constructed definition of vulnerability can be considered crucial for the right implementation of flood-alleviating measures. By taking vulnerability indicators such as disaster-bearing capabilities and socio-economic vulnerability into account, a more integral consideration of flood risk and its implications on cities emerges. Interestingly, when solely considering the flood exposure (i.e., flood chance and inundation depth), the vulnerable neighborhoods were concentrated adjacent to the riverside in Maastricht. However, when including other vulnerability indicators besides flood chances (i.e., disaster-bearing capabilities and socio-economic vulnerability) the division of vulnerability of the case study was substantially affected, resulting in a more dispersed vulnerability pattern.

The current practice maintains the norm of defining flood risk as the probability that an area will flood and the damages that will occur due to this flood (fatalities and economic damages). However, the total vulnerability index constructed in this chapter highlights the impact of considering other factors, such as the type of buildings located within the neighborhoods and the socio-economic status of its residents. Subsequently. the outcome of the total vulnerability index shows high vulnerability adjacent to the river but also in neighborhoods defined as more socially vulnerable districts, namely Maastricht-West and Maastricht-Oost.

6

Risk Governance

Stakeholders play a fundamental role in real estate valuation, as mentioned in chapter 3. But how do the stimuli, barriers, and enablers of relevant actors, such as investors, insurers, financial institutions, and the government, relate? Do the different actors have a similar view and approach within decision-making around investing in areas that are prone to flooding, or do they have conflicting interests? What methods do these different actors use, and what timelines do they consider? To understand the implications of risks on residential real estate and what different actors can do to alleviate these challenges, the current state of practice and interrelations between the actors should be understood. Employing literature review and exploratory interviews, the research sub-question *How can relevant stakeholders contribute to preserving residential property values?* is answered in this chapter.

6.1. Background Information

The Netherlands has one of the highest mortgage-to-debt-to-GDP ratios in the entire world. The owner-occupied market is highly financialised (Hochstenbach & Aalbers, 2023). These mortgage debts have been used as an instrument to facilitate home ownership and have created the illusion of wealth for groups of homeowners and the financial sector (Hochstenbach & Aalbers, 2023). During the last two years, the Dutch government has implemented measures to reduce the significant differences in wealth dynamics that influenced the housing market to increase fairness and allow more households to be able to afford a place to live. The Dutch government has attempted to limit the growth of mortgage debts (Hochstenbach & Aalbers, 2023). Climate change poses a high risk to mortgage lenders, as they face increased risk due to householder default in case of a disaster (e.g., flood). Therefore, financial institutions may abstain from securitizing loans to real estate at high risk of climate change (Ouazad & Kahn, 2019).

Caloia and Jansen (2021) applied a stress test framework to quantify the effects of flood events on real estate in the Netherlands. Their results show that floods can have a significant financial impact that could damage the stakeholders and potentially affect the entire financial stability of the Netherlands. Likewise, Mandel et al. (2021) assessed the risks that floods pose on global financial soundness and conclude that high-income countries are exposed to financial shocks due to climate change. Moreover, the adaption policy of these countries might be an essential driver that defines the future risks of high-income countries. Therefore, while defining the adaptation policy, the protection of the financial security of a country should therefore be considered (Mandel et al., 2021).

The Netherlands has a financial system that is very much intertwined with real estate. New policies might alleviate the pressure on the financial system. However, it might not be as straightforward as adopting new policies. Namely, Loucks et al. (2008) argued that in current systems, developers are attracted by large profits in floodplain areas, as the time they are exposed to risks is relatively short. Moreover, local institutions frequently encourage these developments, as they depend on tax incomes. Neither of these stakeholders has to pay the damages if a flood occurs. The benefits may outweigh the higher risks for the homeowners, as the government might provide partial insurance (based on taxes). Thus, the incentive to benefit from the space for as long as possible increases for all the stakeholders.

The Netherlands has a collective approach that divides and allocates responsibilities to different parties. Namely, the Netherlands has 37 waterboards (i.e., governmental bodies responsible for flood protection, water management, and urban wastewater treatment). As these waterboards work autonomously, different rules and taxes are applied throughout the country (Filatova, 2014). All flood protection measures are funded through taxes, and many Dutch people feel safe and experience the risk resulting from 26% of the country being below sea level as “business as usual” (Havekes et al., 2004).

However, Suykens et al. (2019) argued that a disadvantage of the water management structure of the Netherlands is citizens' lack of awareness due to their limited responsibilities. This can be attributed to the fact that solely the citizens that reside outside the dikes have a responsibility, there is a lot of expertise on water management in the Netherlands, and there has been little public debate on flood risk management. Another difficulty is the large number of uncertainties in the current compensation system within the Netherlands. For example, minor flood events cannot be covered under the governmental disaster act (Suykens et al., 2019). Subsequently, Mehryar and Surminski (2021) stated that within the Netherlands, flood risk governance is currently the sole responsibility of the national government and public sectors. However, they argue that multi-actor engagement is considered vital for effective flood risk governance.

While looking at policies on insurance for damages caused by floods, the government will cover a part of the flood damages in case of a disaster. However, as stated in Article 1 of the Safety Regions Act, the damages due to floods are "uninsurable, unavoidable and non-recoverable," and therefore, the damages will never be fully covered (Veiligheid & Justitie, 2013). Moreover, private flood insurance is currently not possible within the Netherlands. The only financial safety net in place is known as the Calamities and Compensation Act (WTS) which can be applied after a destabilizing disaster (Aerts & Botzen, 2011). Verbond van Verzekeraars (2020) has therefore investigated what should be done with the residual risk of floods and concluded that more public-private collaboration, considering mandatory insurance and defining how much is insured in the law, could help. Although the Netherlands is a front-runner in water-safety measures, the insurance policies and risk coverage are falling behind as there are gaps within the coverage (Verbond van Verzekeraars, 2020).

If the infrastructures were to fail, different stakeholders would face high costs. Monnin (2018) argued that climate costs could be divided into physical costs and transition costs. Physical costs entail the actual damages due to, for example, extreme weather events such as storms and floods. Physical risks can be acute (e.g., climate event) or chronic (e.g., sea level rise), and they can have direct damages, for example, to properties, and indirect, for example, through market disruption. Transition costs consist of investments in alleviating measures to the physical risks and the write-offs of polluting assets in use. The transition costs comprised changes in market preferences, policies, and technologies (Monnin, 2018).

Likewise, Sakhel (2017) argued that there are three main categories of climate risks: physical, regulatory, and market risks. Physical risks are defined as the direct consequence of changes within the climate and form a risk of financial losses - due to damages or disturbance of processes. Regulatory risks follow due to changes in regulations that were applied to diminish the effects of climate change. Subsequently, this leads to potential financial risks as investments have to be made or operating costs can increase. Lastly, market risks can occur due to changing financial markets as consumers' attitudes and demand for products alter.

An important question remains, how can these climate risks be assessed? Although numerous stakeholders attempt to quantify these risks, these attempts have barely scratched the surface. Monnin (2018) described that the methodologies used by market participants could be separated into three steps. The first step is defining the different scenarios caused by climate risks. The second is estimating the economic and financial impacts. Finally, these financial impacts have to be translated into credit risk measures. However, within the methodologies, common challenges can be found. Monnin (2018) described these challenges as the constraints in historical data, developing the limit of current credit risk models, the correct level of detail in data, climate risks vulnerability indicators, and the switch between monetary impact and financial risks.

6.2. Stakeholder Selection

When attempting to put the potential problem of real estate devaluation into perspective, understanding and accounting for its relevant stakeholders is essential. According to Isa et al. (2019), stakeholders should be considered if they have information that the researcher would not be able to receive otherwise or if they are needed for the successful implementation of actions derived from the analysis. Based on a literature review, a first list was constructed with relevant stakeholders. The snowball sampling method was applied within the semi-structured interviews, which can identify stakeholders that could otherwise be overlooked or missed (Giordano et al., 2020).

For selecting the stakeholders, the time life-cycle of an asset and the shifting responsibilities throughout its cycle were considered. The shifting interests can lead to stakeholders lacking long-term commitment, as seen in Figure 6.1. Moreover, Hertin et al. (2003) stated that there is a paradox in the fact actors at the beginning of the supply chain (e.g., developers) will have a high power on the potential exposure of housing stock but will experience limited damages (e.g., only for warranties). In contrast, actors towards the end of the supply chain are more exposed to the effects of climate change on housing stock, even though they have limited influence on the characteristics that will define their vulnerability. Therefore, both actors at the supply chain's beginning and end were considered.

Eventually, from the complete list, seven identified stakeholders were chosen to assess further, which tried to cover public and private parties, parties with a short-term and long-term interest in real estate, and parties that could be highly impacted by floods (e.g., residents and insurers). Consulting and asset managers were other relevant perspectives that could have been included but were not due to scope limitations. The aim of the stakeholder selection has been to cover actors of all the different cycles of an asset, as visualized in Figure 6.1.

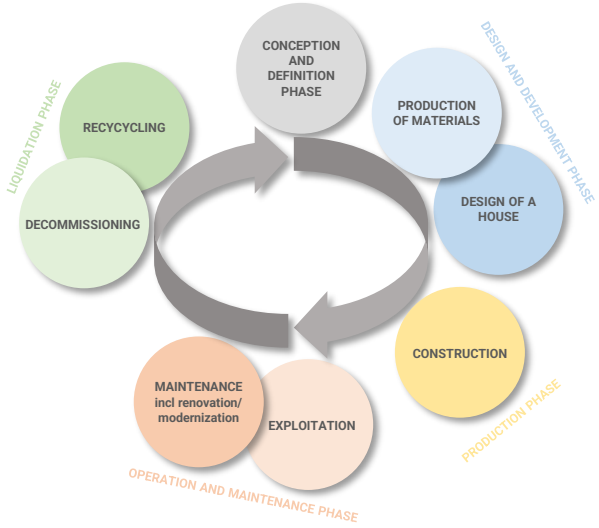


Figure 6.1: Lifecycle Asset (Author's image on basis of Podwórna (2022))

6.3. Framework

Next, to understand and assess the selected stakeholders' interests, barriers, and enablers, the framework "the real estate process" by Graaskamp, 1992 has been adopted and altered for this research. Within this framework, the three defined groups are constantly interacting (space users, space producers, and public infrastructure providers).

The first group, space users, consists of future, collective, and space users. Space users aim to buy or rent a house that accommodates their specific requirements; they aim at sustaining and optimizing and looking for assurance given their means. They base their choices on balancing costs and characteristics (e.g., space or location), which will impact their choices. Collective users are local users who leverage the public space and the space created throughout the real estate. In addition, they can leverage political systems that regulate space production (e.g., lobbying). Future users are presented by interest groups or developers who anticipate their future demands (Graaskamp, 1992).

Second, the space producers are the actors that assemble the necessary materials, capital, and skills. This entails the design, material assembly, and preparation of the materials. The space production group includes everyone knowledgeable in both creating and managing spaces for space users within the market (Graaskamp, 1992).

Third, the public infrastructure providers are the actors within the real estate processes that supply both the physical and the immaterial off-site systems required for the space consumers (e.g., education, physical assets such as sewer, institutional regulation, and all other forms of economic activity that imply

joint off-site action). The most considerable difference between the public infrastructure providers and the space producers is that the public infrastructure providers can be leveraged through joint action (Graaskamp, 1992).

The groups are interrelated, as they provide services, tax, and rent/purchases to one another. Every actor has a driver and an enabler for his involvement in the site. The groups within the original framework are not distinguished by being either public or private. However, this framework was artificially adapted to accommodate the specific analysis of this study. The chosen stakeholders (e.g., residents, municipality, government, insurer, developer, investor, and financial institution) are divided into the three groups and placed within the framework.

Within this artificial alteration, the residents (space users & future users) and developers (collective users) present the space consumers. The space producers are represented by investors (material), developers (skills), and financial institutions (capital). Finally, the public infrastructure providers are presented by insurers (security systems), municipalities (utilities), and the government (services). The original content “site + replacement” was replaced by “real estate at risk of devaluing due to floods.” As visualized in Figure 6.2, the barriers (i.e., what complications do the stakeholders experience?), stimuli (i.e., what drivers the stakeholders to contribute?), and enablers (i.e., how can the stakeholders contribute?) are linked to the real estate at risk of devaluation due to floods and can be assessed to complete the framework. This has been done through a literature review and exploratory interviews. Lastly, “regulation” was added as a relation between the public infrastructure providers and the space producers.

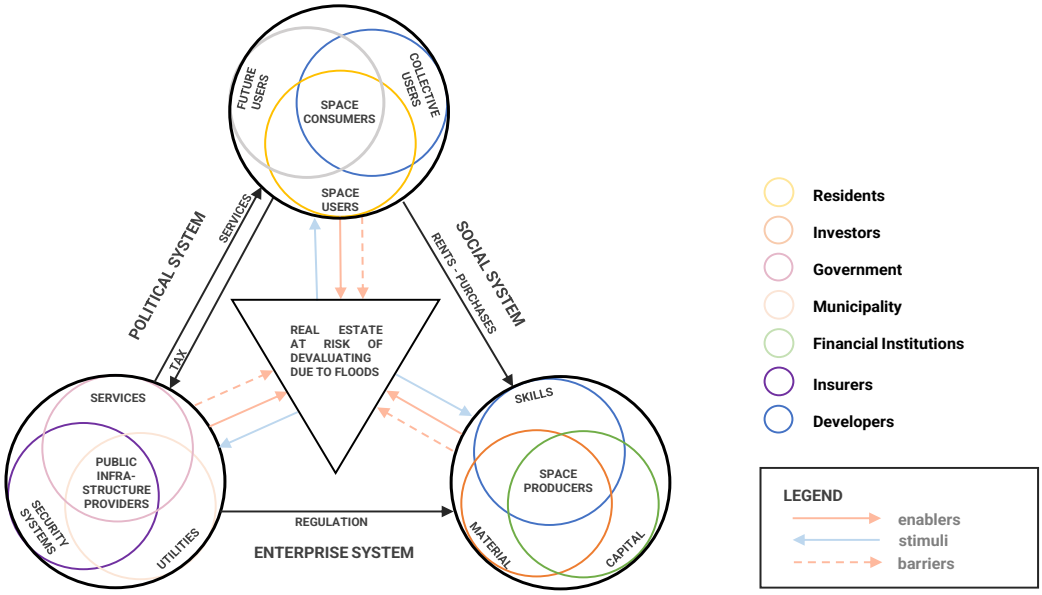


Figure 6.2: Framework Interviews (Author’s image, altered from (Graaskamp, 1992))

6.4. Literature Review Stakeholders

Within this section, the literature on the selected stakeholders and their drivers, barriers, and enablers is elaborated on. This was done before the explanatory interviews to allow for enough expertise and perspective and formed the basis for establishing the interview guide.

Insurers

As floods and heavy storms will become more frequent, insurers have to think about what they can and want to insure. After the floodings in Zeeland in the Netherlands in 1953, it was prohibited to insure buildings against floods. This ban has only been lifted since 1998. However, some residents now desire flood insurance on their properties. Currently, this is not a very attractive market for insurers. Precipitation, nonetheless, has become insurable (Verbond van Verzekeraars, 2022). In 2016, Dutch insurers were surprised by the impact of a major hailstorm in the south of the country, which led to

losses and exceeded their disaster models. Due to climate change, extreme weather is becoming more difficult to estimate adequately for insurers. (De Nederlandsche Bank, 2017).

Although investors have a more prolonged holding of properties, insurance coverage must be renewed yearly. This may lead to climate risks and costs for investors (Urban Land Institute, 2019). Currently, within the Netherlands, properties are insured for local rain, and most properties for overflow of local waters (e.g., canals). However, properties are not insured for the failure of a primary water structure (Verbond van Verzekeraars, 2022). For insurers, an issue with long-term flood insurance is defining the premium, as the flood risk projects are fairly uncertain (Aerts & Botzen, 2011).

Individual insurers are, in most cases, unable to bear extreme losses due to climate change on their own, which is why in numerous cases, they share a part of the risk with re-insurers, which can also occur internationally. Johannsdottir (2014) conclude that insurance companies that are lagging behind should be incentivized and aided by insurance associations as studies have shown that they are at risk of becoming insolvent due to climate risks otherwise.

In their position paper, Verbond van Verzekeraars (2020) argue that individual insurance against floods in the Netherlands has not been feasible up until now due to “lack of awareness, cumulative risks (accumulation of damages), anti-selection (highly divided risks amongst the Netherlands) and the presence of governmental compensations.” Moreover, they argue that attempts by the entire insurance sector did not succeed due to a lack of governmental support and complexities within the system. They propose more clarity in the Calamities Compensation Act to alleviate these barriers. In addition, they propose considering a system with obligatory insurance, and finally, they propose a public-private pool for environmental catastrophes.

In addition, during a conference in November 2022 by Resilient Delta: “Insuring the Dutch Delta,” insurers, the government, and academics discussed the future of insurance against flood damages within the Netherlands. Four important implications were identified. First of all, not enough knowledge is available for the insurers and residents to understand the impact of natural disasters on asset values to establish actuarial models. Second, it was discussed that the general awareness of climate risks is lacking and should be enhanced. Third, the importance of public-private partnerships to foster positive synergies was stressed. Fourth, it was discussed how prevention of disasters could be established, and the role of insurers within this could be. For example, an insurer emphasized the opportunities for insurers to support this by differentiating premiums on flood risk.

Relevant and actual questions for insurers are what risks and disaster levels they will remain able to insure. Another interesting discussion identified is on the physiological impact of natural disasters on residents and how insurers should incorporate this. As physical risks become more severe and frequent, the financial solvency of insurers is threatened, leading to a decrease in the ability to pay the claims of policyholders (E. Mills, 2009). Although insurers are expected to be a leading sector in climate adaptation, they might not be proactive enough yet (Johannsdottir, 2014).

Financial Institutions

Financial institutions are interested in assessing climate risks, as climate-related costs can occur. If they underestimate these risks, they could face financial losses and hold assets with inadequate credit quality. For Central Banks, relying on low-risk investments is imperative, as they serve as vital support for the economy. Central banks, therefore, use credit risk assessments across their operations; thus, when climate risks are fully incorporated, some real estate assets may become unqualified as an investment.

For financial institutions, physical risks pose a threat as damages and losses can occur through natural phenomena (e.g., flooding, precipitation, storms). These losses and damages are either covered by insurance (leading the insurance business to be affected), or the losses have to be borne by businesses, households, and/or the government. Although the impact is not directly on financial institutions, through loans, shares, bonds, or mortgages, the financial institutions are exposed nonetheless (De Nederlandsche Bank, 2017). Banks are also interested in the effects of climate change on real estate, as a sudden risk re-pricing of the properties lenders could be financially destabilizing (Becketti, 2021) and floods could lead to deteriorating economic conditions and downward revaluation of Dutch sovereign bonds (De Nederlandsche Bank, 2017).

To abate these potential effects, green finance is growing rapidly. Green finance entails investments in renewable energy, which has increased more than tenfold from 2004 to 2016. Moreover, financial institutions do not solely feel an ethical responsibility to contribute to the energy transition, but their customers' demand is also shifting towards green energy projects and investments (De Nederlandsche Bank, 2017). Not only are private parties a customer of financial institutions through loans or insurance, but governments are also customers through insurance or loans on their assets (e.g., infrastructures, schools, hospitals) (Anne-Marie Bor & Hertog, 2021).

According to a report by de Nederlandsche Bank (DNB), the impact of future flood risk on financial institutions within the Netherlands heavily depends on the Dutch government's design and implementation of policies. Moreover, DNB stresses that financial institutions should assess if they have clustered exposures in flood risk areas (De Nederlandsche Bank, 2017). Currently, banks face the challenge of assessing a loan's climate-related risks. Moreover, the right level of detailed data is hard to access for financial institutions; thus, the risks are currently primarily estimated on higher levels (Monnin, 2018).

Financial institutions have tools to analyze risks (e.g., AON, Bluelabel, RMS), tools to stimulate (e.g., discounts in premiums, rent discount, financial compensations), and they can choose to finance innovatively (e.g., green finance, invest in projects, discounts), they can notify their customers on the risks (e.g., insurability/prevention tips) and actively participate and contribute to discussions or decisions (Anne-Marie Bor & Hertog, 2021).

In response to the potential flood damages, which can be up to 60 billion euros according to the De Nederlandsche Bank - DNB, the DNB, and institutions in the financial sector within the Netherlands are promoting the knowledge on physical climate risks and studying what options there are to manage the consequences (Bruin et al., 2019). Moreover, the DNB is developing stress tests for both physical and transition-related risks. Financial institutions within the Netherlands are working on the assessment of climate risks for their portfolios, for example, through data from the Dutch Climate Impact Atlas (Attoh et al., 2022).

Investors

Due to the increase of climate-related disasters and increasing recovery costs, investors are forced to consider climate change (Buckman & Sobhaninia, 2022). Understanding and managing climate risk is essential for real estate investment managers as it can impact their portfolios. It could be argued that less real estate should be built in areas under significant risk to decrease the potential damages.

Investors are increasingly working on getting insight into climate-induced risks in their portfolios. For example, in their annual report, Vesteda, a Dutch residential investor, published that it has built an in-house tool to have insight into its portfolio's physical climate risks and how they try to reduce its CO2 footprint (Vesteda, 2021). Likewise, another Dutch Investor (Bouwinvest) leverages this tool. Similarly, pension investors have to be able to explain their investment decisions, as clients want a responsible risk profile. In their annual reports, both APG (2018) and PGGM (2021) stress the fact that within their investments, "climate risk" is taken into account and that they avoid risks.

Consequently, Bunten and Kahn (2017) explain the paradox of investors that face choices of investing in the maintenance and protection of existing stock and constructing new houses. If investors choose to invest less in existing stock in risky areas, this will depreciate faster and might attract lower-income households. In addition, if investors decide not to finance additional buildings in risky areas, fewer people will live in areas prone to flood risks. The decisions of investors are, therefore, fundamental to how we are able to adapt to the upcoming climate change challenge. In addition, Attoh et al. (2022) describe barriers for investors as "tailored climate risk information, conversion of climate models to actual risks for their assets, inadequate human and financial resources, and lack of in-house expertise."

Additionally, Jackson and Orr (2021) researched the drivers and barriers for investors to adopt sustainability and describe that for investors, the following are considered as drivers: "competitive advantage, reputation, evidence responsibility, protection of asset value, future-proofing against tightening legislation as uncertainty".

Krueger et al. (2020) interviewed numerous institutional investors on climate risks and conclude that, in general, the majority of respondents think climate risks will have substantial financial implications on their portfolios, that climate risks have already started to actualize, and that there will be a significant

rise in global temperature by the end of this century. Less than half of the respondents have used analysis of carbon footprints and stranded assets risks (i.e., assets that have lost value or turned into liabilities prematurely), even though that are the most common approaches. In addition, the average respondent does not think equity evaluations fully embody climate risks.

Bruin et al. (2019), identified eight available methods of which investors make use to analyze climate risks. Namely: "acclimatize, Moody's investor's service, WRI, four twenty-seven, Carbone 4, Carbon Delta, Mercer and Ecoloab, Trucost & Microsoft," of which only WRI and Trustcosts are available for free and focus solely on water scarcity. Within these approaches, all but Acclimatise, Moody's, and WRI have investors as main targets. Acclimatize can be used as a pre-screening tool for risk managers or development banks before financing. WRI provides an analysis of portfolio exposure to climate risks for financial institutions (Bruin et al., 2019).

Developers

Developers can be vulnerable to the effects of floods during the construction phase, as real estate is their liability at the start of the asset cycle. In addition, housing associations (rather than commercial developers) could be vulnerable to the direct impacts of climate change as housing associations maintain their stock and are thus responsible for repairing damages and potentially increasing maintenance costs (Hertin et al., 2003).

Moreover, indirect damages will likely be more significant than direct impacts on building developers. This is because customer demand and regulations are vulnerable to changes caused by climate change. In the past, many houses were developed within floodplains, for example. Nonetheless, as awareness about flood risks increases, local residents, environmental agencies, planners, and non-governmental organizations might perceive this as an issue. If customer demand drops, building within these areas might become unfeasible. Several developers expressed the role of financial institutions and insurers in this process. The unwillingness of these parties to finance areas within floodplains will enlarge customers' reluctance to buy within these areas (Hertin et al., 2003).

Although housing developers are faced with the risks of climate change, they do not always (yet) act accordingly. For example, Ruppert and Deady (2017) investigated the impact of climate change on Law and Policy in Florida and conclude that the oversight of Florida's local planning decisions and actions has been reduced, leading to more flexibility concerning development. Therefore, the long-term resilience of ongoing development in exposed areas can be questioned. In addition, Mary Le (2021) investigated the patterns between climate risks and commercial real estate development and conclude that although the Miami metro has one of the highest percentages of assets under flood risk, it increased the most in its assets (from 2015 to 2019). Moreover, Buckman and Sobhaninia (2022) stated that commercial developers are slow to acknowledge the impact and risk due to climate change. Moreover, they conclude that although respondents agree that developers should do more, they deem this the government's responsibility to ensure areas are safe for development.

On an individual level, building developers have a restricted ability to enhance technological adaptation measures when considering flood risk. In the past, within the United States, these risks have been mainly borne by insurers, but if they refused to insure these risks in the future, they would be shifted to homeowners. Interference by the government by making flood insurance obligated could shift the risks to all taxpayers. Another factor that needs to be taken into account is perception. If the perception of involved parties changes and affects the perceived and actual values, this might impact banks and other parties offering mortgages (Hertin et al., 2003). Moreover, economic incentives such as subsidies can be used for developers to adopt flood preventive measures (Henstra & Thistlethwaite, 2017).

Residents

Property owners and residents are stakeholders which are highly impacted by floods and the potential devaluation of residential real estate. Many residents are highly dependent on the insurance of their properties. Moreover, if floods lead to the devaluation of properties, property owners and residents will likely face the largest impact.

Abebe et al. (2020) made use of a coupled agent-based flood model to evaluate decision-making and adaptive behavior of measures that reduce the effects of floods in Germany. They argued that residents have limited power in influencing decision-making around measures reducing the effects of floods.

Opportunities to help diminish the exposure of properties are: “elevating houses, retrofitting, dry or wet flood, insurance and subsidies.” Authorities could offer the funds, but still, the choice to adopt the measures has to be made by the resident. Thus, eventually, residents can significantly contribute to flooding adaptation as the implementation of measures can reduce the financial damage enormously, it can solve issues such as governmental capacity and public funding, and they are the only ones that can decide upon changes to their property (Abebe et al., 2020).

In addition, Abebe et al. (2020) concluded that it is essential to raise continuous awareness to ensure households do not forget to implement temporary measures. Moreover, they conclude that simple measures should be emphasized upon as this can avoid millions of euros in terms of damages. However, Thistlethwaite et al. (2020) studied the public opinion on flood risks and found that Canadians generally possess insufficient knowledge of the flood insurance system. Canadians have a limited willingness to pay for measures on their own property and flood insurance. Moreover, they anticipate the government will reimburse the financial damages if a flood occurs.

Snel et al. (2021) studied residents’ perspectives on responsibilities for flood risk adaption in England. They emphasize that the importance of residents in managing flood risk is recognized increasingly. Moreover, Snel et al. (2020) investigated the changing position of property owners in the flood risk debate and argued that a possible gap exists since the macro-level (e.g., duty in climate shifts) and micro-level (e.g., reducing flood risk on the property) arguments are fragmented. They conclude that integrating the role of homeowners more directly in climate adaptation plans could contribute to homeowners’ awareness of their responsibilities.

Moreover, Lo and Chan (2017) stated that low-risk (perceived) awareness of floods is a critical issue that could be alleviated by better informing residents that live in flood-prone areas. In addition, they stated that residents do not consistently make sensible decisions, as they can be impacted by cultural context and subjectivity. Finally, they concluded that households experiencing unease due to flood risks do not, per definition, act accordingly by managing these flood risks.

Within the Netherlands, Suykens et al. (2019) argued that a protection paradox exists. Citizens within the Netherlands feel safe due to flood protection measures which may increase vulnerability, and other interests sometimes dominate over flood defense. Suykens et al. (2019) argue that better post-event reimbursement systems should be in place. Individual flood defense is nearly infeasible in the Netherlands due to its location and conditions (Suykens et al., 2019).

Government

According to economists, it is the role of the government to act if there is a presence of market failures to provide for collective goods. Due to the location of the Netherlands, flood safety has always been an important topic, thus the government has prioritized flood-risk projects. However, the government has to deal with budgetary limitations (Jorissen et al., 2016). Thus, endless enforcement of the protection systems within the Netherlands might not be feasible.

Peter Glas, deltacommissaris within the Netherlands, urged the Dutch government to think about how investments and populations could be shifted to safer areas within the country instead of the low-lying west that is currently highly urbanized. In addition, he suggests that the current regulations concerning building outside the dikes should be sharpened (Programme, 2021).

An additional driver for governments to provide a safe environment could be investors. According to Urban Land Institute (2019), investors seek markets and areas with a government capable of funding measures against climate risks, prudence, and authority. Either at a regional or national level through, for example, policies. In investors’ opinion, governments should have “alleviation plans, make investments in protective infrastructures, and have accurate vulnerability scans for rainfall or flooding.” However, this is not as straightforward as it may seem, as the costs of these measures need to be funded somehow, which can influence the investment climate within the area as the taxes may become higher (Urban Land Institute, 2019).

In their recent letter Ministry of Infrastructure and Water Management (2022), emphasized the importance of the balance of water in the Netherlands to prevent both droughts as floods and poor water quality. The governance can raise awareness of issues like floods using such signaling documents.

Within the letter, they emphasize the importance of taking responsibility, integral strategies, safety at multiple levels, and considering all climate extremes.

In addition, a study is currently being conducted to assess if new houses within the Netherlands should receive a “water label,” equivalent to the energy labels that houses currently receive. This should enhance the awareness of buyers on the flood risks on potential houses (Arjen Schreuder, 2022). By leveraging tools like such, the government can raise awareness of the risks and potentially steer residents in their choices for safer areas. In general, governments are moving towards mandatory disclosure of climate risks.

Although the government is neither expected nor obligated to compensate all of the potential damages by floods, as they are relatively free in determining the level of compensation, a significant part of damages if a flood occurs will probably be carried by the government through the existing Calamities Compensation Act (De Nederlandsche Bank, 2017).

Thaler and Levin-Keitel (2016) described the task of a national authority in flood risk management to initiate projects and manage and lead them. The most critical instruments they stated for the government are “communicator, technical expertise, networker, managerial skills, and analyzer/problem solver.”

The government has several tools it can leverage to alleviate the potential effects of floods/flood risks. Through stress tests, the government can map vulnerable areas. In addition, through communication, the government can stress specific topics or issues. Moreover, through financial stimulation (e.g., subsidies or taxes), the government can encourage the construction of climate adaptive measures. Furthermore, through investments, the government can lead in preventing flood disasters. Lastly, through regulations, the government can steer the environment in which buildings and infrastructures are built and dictate which demands the real estate must comply with (Anne-Marie Bor & Hertog, 2021).

Punt et al. (2022) studied the governance of flood resilience at the Port of Rotterdam in the Netherlands and concludes on several institutional challenges. First, the institutional structure for flood resilience in the Netherlands is complex, resulting in institutional fragmentation. Moreover, they identified a “lack of vertical information exchange, an unclear division of responsibilities, and gaps in government expertise on flood resilience” as barriers to successful flood measures. In addition, as mentioned within section 6.4, institutional authorities can, in principle, only decide upon measures within the public space, limiting their actions.

Municipalities

Municipalities naturally are interested in protecting their citizens. In the Netherlands, for the Deltaprogramme of Spatial Adaptation (Deltaprogramma Ruimtelijke Adaptatie), municipalities execute “stress tests,” in which they assess potential floods due to heavy precipitation.

Runhaar et al. (2012) studied the stimuli and barriers for municipalities to adopt preventive measures for climate change and find the main barriers they observed were as follows: “ignorance of the issue either due to unawareness, the complexity or uncertainties, lack of political priority, and a lack of incentive (in terms of regulations or perceived benefits), uncertainties about scenarios, institutional fragmentation, inflexibility of current structures/plans and the lack of resources and high costs.”

In addition, the municipalities indicated that due to the reluctance of property owners to adapt actively, there was also a lack of measures on the more minor scales (building level). Within the same study, the primary stimuli observed were: “a sense of urgency, the ambition to be leaders, public pressure, attractiveness for companies and political support” (Runhaar et al., 2012).

To alleviate these barriers, Runhaar et al. (2012) concluded that there is a need for more clarity on the responsibilities and division between public and private actors and that currently, the municipalities depend on the government for flood avoidance in their strategies. Moreover, they state that as private actors are only moderately engaged in flood measures, the general awareness of the citizens is low.

Likewise, Uittenbroek et al. (2014) studied the willingness of municipalities in the Netherlands to contribute to structures or measures that reduce the effects of climate change by using a Q methodology and taking three big cities in the Netherlands as study cases (Rotterdam, Amsterdam, and The Hague) and concluded on three main barriers, namely: “lack of political commitment, undefined allocation of responsibilities and limited resources.”

In addition, Wihlborg et al. (2019) studied the barriers and drivers for municipalities in Sweden to implement flood alleviating measures and conclude on drivers and barriers. The drivers they found were: improvement in ecosystem services, awareness, and new knowledge. The barriers found within this study were: “budget, lack of knowledge, division in responsibility, limitations due to legislation, municipal systems, prioritization, political support, and resources.”

Finally, Thistlethwaite and Henstra (2017) studied the tools municipalities have to alleviate flood risks and conclude that “stakeholders engagement, public engagement, hazard disclosure, private insurance, subsidies/taxes, land use planning, and integrated stormwater management” are tools that can be leveraged.

The barriers, drivers, and enablers derived from literature can finally be summarized as in Table 6.1. Within the table, it is noticeable that certain barriers such as “limited resources”, “low-risk awareness,” and “granular knowledge” are common for multiple actors. In contrast, “raising public awareness” and “stress tests” are common enablers.

Stakeholder	Stimuli	Barriers	Enablers
Insurers	Risk of becoming insolvent	No granular knowledge Anti-selection Governmental Compensation Cumulative Risks Complexity	Stress tests Promote knowledge Price premiums Public-Private Partnerships Mandatory Insurance
Financial Institutions	Risk of inadequate credit quality Financial Regulation Ethical Responsibility Changing customer demands	No granular knowledge Dependency on policies	Raise public awareness Green finance Premium/Rent discount Financial compensation Participate in discussions Stress tests
Investors	Potential damages in portfolio’s Reputation Competitive advantage Future proofing against regulation	No tool to quantify climate risks Lack of financial and human resources No granular knowledge	Investments Risk assessment
Developers	Changing demands of customers Liability	Limited resources Limited responsibility feeling	
Property Owners	Risk of devaluation of property	Limited resources Low-risk awareness Limited responsibility feeling	Preventive measures in property
Government	Responsibility flood safety Healthy economy Attractive investment market	Lack of vertical information exchange Knowledge gaps Lack of clarity in responsibilities Dependencies Limited capabilities	Stress tests Regulation Subsidies/Taxes Raise public awareness Investments
Municipality	Ambition to be leader Public Pressure Attractiveness companies Political support Sense of urgency/Awareness Ecosystem services Knowledge	Lack of incentive Lack of political priority Complexity/System Lack of resources Inflexibility in plans Lack of clarity of responsibilities Legalisation Unawareness	Stakeholder/public engagement Hazard disclosure Subsidies/Taxes Land use planning

Table 6.1: Stakeholder analysis based on literature review

6.5. Interviews Stakeholders

To assess the barriers, drivers, and enablers of the stakeholders in practice, in addition to the literature review, in-depth semi-structured exploratory interviews were conducted. The participants of the interviews were invited through the invitation letter in Appendix B. Before the interviews, it was ensured that the participants signed Appendix C to use the interview data. The general questions and protocol list can be seen in Appendix A. The questions were set up to ensure that the interviews remained comparable and to serve as a guide; the content of the interviews was free for other topics as the set-up of the interviews was semi-structured. After the interviews, the interviewees received the transcripts to rectify or exclude parts. It was chosen to exclude the group “residents” from the interviews due to ethical considerations and subsequent complexities.

6.5.1. Interview Guide

Within this section, the constructed interview guide based on the literature review as discussed in section 6.4 is discussed, after which the results of the interviews will be elaborated upon.

1. Company and related function: this question was asked to understand the interviewee's past experiences and current position.
2. Building projects and inclusion of flood risk: this question was asked to acquire knowledge on how the interviewee experiences the problem of potential devaluation in practice.
3. Building projects and inclusion of flood risk methods: this question was asked to understand the methods that are used in practice compared to the academic literature
4. Responsibility flood protection: this question was asked to assess the viewpoint of the interviewee on the responsibility of flood protection and who identified themselves as accountable or viewed other parties as responsible
5. Responsibility flood insurance: this question was asked to assess and understand how the interviewee considered flood insurance and its feasibility
6. Barriers in taking flood risk into account: this question was asked to identify the main barriers the interviewee experienced in practice to alleviate flood risks
7. Conflict of interest now/later: this question was asked to understand the interplay between stakeholders and were there might be friction between the set of stakeholders.
8. Stakeholder mainly accountable for stopping devaluation: this question was asked to see where the stakeholder considers the responsibility for preventing devaluation would lie within the adopted framework.
9. Drivers for diminishing devaluation effects: this question was asked to see the drivers and motivations for the stakeholder to prevent devaluation and assess if these were financial or had different roots.
10. Potential collaborations with other stakeholders now/future: this question was asked to see if stakeholders have ambitions or see opportunities to join forces with other stakeholders
11. Role of the company in diminishing devaluation effects: this question was asked to see was the interviewee would put themselves within the framework and see themselves as a part of the solution.
12. Enablers company to influence valuation: this question was asked to see which tools the interviewee used or could use in the future to assess if this was similar to the identified enablers within literature.
13. Timelines: this question was asked to see if the different stakeholders have similar timelines or if large variations in timelines might enlarge barriers
14. Opinion on the involvement of flood risks in projects: this question was asked to see if the interviewee was of the opinion that flood risks are currently taken into account enough or if he/she would like to see changes in the future
15. Potential additions: this question was asked to give the interviewee the space and opportunity for potential additions which the questions did not cover yet, which could be valuable for the research.

6.6. Findings Interviews

Within this section, the findings of the conducted interviews will be discussed. Due to scope limitations, a limited number of selected stakeholders was interviewed, and the assessment of the interviews focused on commonalities and common barriers, stimuli, and enablers. Consequently, the findings have been integrated with the findings from the literature to assess the overlap or differences between the interviews and literature.

6.6.1. Barriers

When considering the barriers that the different stakeholders experience when taking flood risks on real estate values into account, the interviewees indicated that they experience several barriers. This

subsection explains the assessed barriers, followed by proof quotes deducted from the interview transcripts.

Differing interpretations

The first identified barrier is differing interpretations. A member of a financial institution mentioned that flood risks are defined and assessed in different ways by different stakeholders currently, leading to a different vision of flood risks, making communication and agreement on flood risks more difficult:

> *"There is a need for something objective, which could help in the conversation with the customer about flood risk, whether that is a value label or something else. That is something I perceive as a barrier to integrating flood risk into our customer service." - Financial Institution*

> *"If a general definition of flood risk would be used that is based on models that everyone uses, and everyone would have more or less the same vision of how the climate is developing, a general definition of what is the threshold after which it is no longer justified could be applied."- Financial Institution*

Knowledge gaps

When assessing flood risks, multiple actors indicated that currently, knowledge gaps exist between different actors, making it more difficult to communicate and agree on flood risks:

> *"All of that kind of data is there, of course, and the damage insurers will have all sorts of data, but the asset manager will not." - Investor*

> *"It is going to be very difficult for us to convince a customer that we have some kind of knowledge that he does not have and that we make decisions based on that with respect to the customer's loan because that conversation is very difficult and certainly if the outcome is negative." - Financial Institution*

Perception

Interviewees anointed the perception as a barrier to flood risks being accounted for and reflected within the prices of homes, as they believed that perception is connected to the potential devaluation of real estate values:

> *"I think when you have seen what it means to be inundated, only then a water label will most likely become something important." - Developer*

> *"In case the government always covers damages, then you do not take risks into account, and I think that is what is going on right now." - Developer*

Lack of awareness

In addition, interviewees indicated that currently, a lack of awareness is a barrier when taking flood risk into account in projects and within general flood safety:

> *"It is both information and awareness of project developers and other governments as well as having the tools with which it is an easy process. There are still quite a few things that are missing within this." - Government*

> *"Project developers often have interests in building homes as cheaply as possible and thereby not always taking the climate into account. And sometimes with some extra measures we could make a house climate-adaptive or in case of a flood the effect can be diminished but currently due to the lack of awareness there is not so much demand." - Insurer*

> *"I think there is a lot to be gained from the inhabitants of the Netherlands becoming more aware, as being well prepared, as this is just always beneficial." - Government*

> *"Awareness has grown enormously in recent years that we have to do something. But that does not mean that is also where we are; I think a lot of energy has to be put into getting everyone to understand it." - Municipality*

Differing timelines

Due to the different timelines of stakeholders, the interests and visions of the different stakeholders do not always align, which can be perceived as a barrier. Moreover, early engagement could help in preventing certain situations that may eventually lead to the devaluation of flood risks, as indicated by the interviewees:

> *"The developer has a short-term interest the municipality should have a long-term interest, but the question is whether that penetrates sufficiently. Our perspective is long-term because we have financing that can last 30 years. So within the difference of perspectives, there can obviously be tensions, because why is it relevant to a developer that there is a flood probability if the municipality has agreed." - Financial Institution*

> *"Appraisals are actually just way too late because then the customer already knows that he really wants the property. And then there are also just incentives in the market to make the appraisal feasible, then the reality if not fully reflected in the appraisal I am afraid." - Financial Institution*

Uncertainty

Uncertainty was indicated as a barrier, as taking risks into account that will happen in the future are hard to predict, and there is nobody who has the ability or knowledge to achieve this:

> *"It is very tricky as you can never be completely sure if it is the right choice for 100 years from now. The world also looked very different 100 years ago, but you have to acknowledge that the choices you make now do affect the future, so given the uncertainty, you have to look at what we know now and how can we use this to make a choice."- Government*

> *"Pension funds work very much with valuations, which is not backward-looking. This is looking forward, so there is nobody that actually knows what the impact on value will be; therefore people are speculating about it." - Investor*

Dependency

Dependency on other stakeholders due to limitations in, for example, human resources or force majeure was indicated as a barrier:

> *"You can not help but trust that information on flood risk and water levels is at least correct, as you do not have that capacity to investigate it yourself." - Developer*

> *"And within flood risk, we can not actually think of an effective way for their client to mitigate the risks. It could be a kind of housing development, where no expensive objects are situated on the ground floor or property that floats a little or something in that direction, but basically, those kinds of risks are actually not preventable by clients." - Financial Institution*

> *"If a developer is not likely to help pay for flood protection, then you also look very strongly to other governments, and the ministries agree that it is not the task for such a developer to ensure that that dike is built and then he is right too, is he not? Because that is not his task, but on the other hand, as a developer, you would want the people who are going to live there to be protected from flooding. I can imagine that this does add up." - Municipality*

Complexity

Furthermore, the complexity of flood risk and the measures concerning flood risks were indicated as a barrier due to the fact that the interrelations and impact of these measures make it complex to achieve the measures:

> *"It is always a very complex game that you play, so when you start working on river widening and dikes, you are dependent on parties such as the ministry, the Department of Public Works, the Water Board, and the municipality. And the world of water is very complicated, and it is all very complexly regulated, so you have to go through all sorts of different stages to arrive at an approach in which you are dependent to a fairly large extent on the financing of other parties." - Municipality*

"So I do find it very tricky. If we apply the water label, this would be good for awareness. However, how do we offer a perspective for action so that it remains somewhat fair that you can do something to improve, or is it just a permanent judgment on, after all, one of the very important aspects for people owning a house." - Government

"How can you have flood insurance and roll it out and then also look at if the person who, for example, also lives in the Veluwe pays equally much as the person who lives very close to the water very nicely? Then again, it is also not possible that the person who lives very high and dry pays zero, as those who are in a high-risk area would be getting extreme premiums that they can not actually pay, so you want to balance that." - Insurer

"We set those values based on an appraisal, and we assume that an appraiser already takes into account future expectations about flooding, whereas we actually do know that is probably not happening so that in the market the flood risk is not yet priced into the transactions and that also gives the feeling that we are a little bit more at risk there than in a perfectly functioning market." - Financial Institution

Data availability

Although the interviewees generally agreed that there is a lot of data on climate change within the Netherlands, data on short-term risks and sharing data amongst actors were perceived as barriers:

"I think sustainability is open source, it should not be a commercial tool. And we are a long way from thinking that way, but we need to help each other avoid making it worse, so we need to share our knowledge instead of keeping commercial forms." - Investor

"We need to know more about what is going to happen in the future, and for this group of insurers, it is important to also know what is going to happen in the short term and what the risks are." - Insurer

Granular data

Moreover, the granularity of the data that is needed for the different stakeholders to apply climate risks within their work was indicated as a barrier as it was not detailed enough:

"We use fairly rough data for that, but the moment we want to use it in a customer situation, those kinds of maps available on the internet are very abstract, I think, for a customer. Therefore, that will not be very workable in a customer relationship, so it would be better if there would be real data available at property level that a customer also is aware of when he is considering buying a property." - Financial Institution

"We want to know a little bit more about what is coming up in the relatively short term, as the impact for us is greater right now than what is going to happen in 2100." - Insurer

Lack of tools

Several interviewees indicated that there is a need for a general tool or instrument to process flood risks feasibly by default:

"There is not a tool for flood-proofing measures right now, which presents the flood risk in a simple way, and there is also not really a methodology to include that properly in construction projects by default." - Government

"Well, the information is actually there, but we are now also working to put that information into an instrument to present it both in a comprehensible way and process for, how do you make a decision?" - Government

"I think there are far too few possibilities to combining all kinds of relevant data sources." - Investor

Financial resources

Financial resources were indicated to be a barrier for multiple stakeholders, as they are limited to measures that are financially feasible for them:

"Developers are fine to invest in whatever is needed, but there are limits to what the land revenue from housing can have in terms of cost. That is where the problem is." - Developer

"Despite the fact that the municipality is, of course, pushing to get projects to alleviate flood risks on a municipal scale started, it is an impossible task for the municipality to cough up that amount of money. So we are constantly in discussion with these other parties to allow for funds." - Municipality

Differing interests

Although many interviewees agreed that the devaluation of real estate should be prevented, the different stakeholders have different interests, which can be making a profit or having liabilities:

"What you also see with property developers. They often have an interest in building homes as cheaply as possible and not always fully considering the climate. And sometimes with some extra measures, we can make a house climate-adaptive and if it inundates the effect can be smaller, but now due to the lack of awareness there is not so much demand." - Insurer

"There are an awful lot of conflicting interests. In the ordinary market, let alone worry about flooding" - Investor

"But you do see examples where, for example, construction takes place in river floodplains where you really see that this is simply not possible. The risk there is too great and is not intended for that. So, I would not say conflicts, but different interests, certainly that come into play with that." - Insurer

Divided-responsibility

In addition to the fragmentation and ambiguity within responsibilities concerning flood risks, a barrier can be non-responsibility, in which stakeholders look at other stakeholders to alleviate and own the flood risks, moreover who is responsible can be ambiguous and every stakeholder is responsible for its own piece in the puzzle, leading to fragmentation in responsibilities:

"To actively go out and find another rule yourself that you have to comply with that is not in the nature of developers. Not that they do not want to make something good, but if you are allowed to build, it is okay; apparently. I think it is up to the government to make us alert of this and to come up with the first measures that might transcend projects." - Developer

"For the private individual, it is force majeure and a private individual can not do that much about flood risks." - Investor

"Sometimes it is discussed that if insurers ever really start to inspect what they no longer find acceptable, maybe that will have more effect than a lot of spatial policy from the national government and prevent discussions about what would be nice, because if it is just not financed, then it is just not financed anymore, so it will not be built." - Government

"You can contemplate who should, in case the risk is present, bear the financial loss? Should the government step in there as it does now, or should the customers insure themselves? I think that is another issue, but that is more an issue after the prevention." - Financial Institution

Building regulations

Within the Netherlands, there are building regulations that the stakeholders have to comply with. The interviewees indicated that these regulations can in some cases form barriers, as they, for example, prevent building on a higher or lower level.

"Well, it is difficult to do anything complicated here in an over-regulated system like the Netherlands." - Investor

"We have to continuously substantiate with all kinds of studies, if you present an acquisition somewhere it has to be able to withstand these kinds of risks and certainly how you manage that, so it is going to be very important. Fear for policies and interventions are going

to dominate whether the real estate market in the Netherlands is going to continue to be invested in." - Investor

"You always need approval, you can not do anything in this world without the congregation giving you approval." - Developer

Industrial regulations

Being situated in the Netherlands, the interviewees indicated they experience barriers in the system that they have to comply with:

"Because if you make something like flood insurance mandatory, it would normally not be allowed as you make an agreement between insurers to introduce a certain coverage to everybody" - Insurer

"We thought after the flood in Limburg, that was the opportunity to build back better, but insurers are just bound by the current building code to which extent they can reimburse to build back homes. The current building code does not say anything about flood risk so they can not compensate for it either, so you can not build back without putting your own money in a better way when of course that is the time to do it. Let us solve that kind of thing first. that is where the priority should be and then you also have part of the insurance proposal." - Government

Non-incentived

Lack of incentive to apply preventive measures for flood risks can lead to reduced actions by the stakeholders, as they indicated that all stakeholders need enough drivers to be actionable:

"In the end, if it is not a hard requirement and a developer is going to do it, then they make themselves more expensive, so this will only work if all developers have to do it." - Government

"If I start saying to people, you also have to dig 8 cubic meters to store rainwater, they think; but that only costs me money and does not provide anything at all." - Municipality

"Developers and builders are generally short-term driven, so you make a product and you sell it, and there is not so much motivation in that to think about what happens next. And of course, you have to make good products, you have to be compliant. It has to be good because otherwise people or investors will not buy it." - Developer

Non-priority

Although the vast majority of the interviewees agreed that flood risk is an important topic within the Netherlands, they indicated the barriers of having the prioritize, and therefore losing the urgency to apply flood alleviating measures:

"You are already solving so many problems as a project developer or area developer that you are happy when you are allowed to build." - Developer

"And it has to be an answer to the housing shortage as well, where do most people want to live and where does it usually pay off best, just apart from the situation of the last year with rising construction costs, inflation and so on. Even before then, it was already incredibly difficult to make profitable projects. But where there is the most demand, in the Randstad, there is also the most risk around your issue." - Investor

"Looking at what is the remaining risk and how to do we best deal with that by maybe just building somewhere else or building in a modified way. In itself, most people are in favor of that, but once it starts costing a lot of time or a lot of money, it just often runs low on the list of interests" - Government

6.6.2. Stimuli

The identified stimuli are discussed in this section, followed by proof quotes from the transcripts.

Increasing awareness

Within the Netherlands, the interviewees indicated that the awareness about climate change and flood risks is increasing, which can be a stimulus for the stakeholders to take action.

> *"People are becoming more and more aware of the fact that all kinds of changes in the environment are going to play a role in determining the value of a home." - Municipality*

> *"I think that the awareness of the government is very high and therefore also policy-wise it is going to be very important for the whole sector." - Investor*

Ambition

Ambitions, as optimizing systems within the sector, were also indicated to be a stimulant for interviewees:

> *"We have to look more at the spatial planning of the Netherlands again, and the changing climate and the risks that go with it. There is now an integral look at risk and also an integral look at responsibility. And we try, and that is not always easy, but then not to put everything down geographically, but more integral to the whole system" - Government*

> *"Still looking well, but what is the risk that is still there and how do we best deal with that by maybe just building somewhere else or building in a modified way." - Government*

Responsibility

As experts on different topics, interviewees deemed themselves as (partly) responsible for preventing flood risks by, for example, informing citizens or contributing to alleviating the risks:

> *"Look as a citizen you obviously can not do much, everybody needs a home or an office, and you rent or buy a home or office. In that respect, you have relatively little influence. But as professional parties in spatial planning, you should pay attention to flood risks and raise the issue if it is present, ultimately I do think this is very much a collective and therefore a governmental task." - Developer*

> *"Should we allow that customer to live in that house that has an inundation risk? Because if we are financing, then we are exposing them to a situation that maybe they do not fully oversee, whose risks they may opportunistically underestimate because they want that house so badly." - Financial Institution*

> *"The water boards are responsible for flood prevention, so a good water design is of course very important. The knowledge institute that calculates this, Deltares, is also working on this. But municipalities and real estate investors as well are responsible for where they are going to build and what measures they are going to take and finally also the homeowner who can also take preventive measures into account and who can also do a lot themselves" - Insurer*

Financial regulations

Regulations are a stimulant for interviewees, as many stakeholders have to comply with current regulations but also change in regulations within the future by, for example, reducing the climate risks on portfolios or becoming net zero:

> *"They are steering towards a kind of risk reduction in bank portfolios, they are now asking us more and more emphatically to indicate what part of our portfolio is exposed to chronic or acute climate risk " - Financial Institution*

> *"European rules, are certainly one driver for a lot of insurers. They also have to achieve net zero, for example. So they have also signed a commitment that they want to be net zero not only in their investments but also in their portfolio, so they have to ask themselves, what do you still insure?" - Insurer*

Building regulations

Building regulations can drive developers or investors to make certain decisions or comply with rules about safety, which can therefore be a stimulant in alleviating flood risks:

"I think from the central government's point of view that the building code would be a good way to implement climate adaptive measures to homes." - Insurer

"I hope that we can raise awareness to such an extent and also by means of government regulations or in such a way that project developers are obliged to take this into account when designing homes."- Insurer

Damage prevention

Being commercial, different stakeholders have the aim of maximizing profit and therefore preventing damages, as this would have a negative influence on their balance:

"For insurers, the risk is mounting damage, so we have the climate damage monitor where we track annually what the damage is due to extreme weather and we see that is increasing and we also see those peaks getting higher and higher, so countering damage is a driver and the potential decrease in value of investments that are attached to that by for example an increase in extreme weather or an increase in the risk of flooding" - Insurer

Credit risk

For financial institutions, it is important to minimize credit risks, as damages can indirectly affect their profitability:

"The damage the customer suffers affects us indirectly in our credit risks, so the house has €20,000 damage the customer will then have to go and finance that himself and can also take out a loan with us unless he does not have the money and is forced to move with a residual debt. And then we have a loss on our portfolio. So the customers' losses can be our credit risks." - Financial Institution

6.6.3. Enablers

Within this subsection, the enablers that were discussed throughout the interviews are elaborated upon, followed by proof quotes that have been derived from the interviews.

Flexibility in development

In contrast to having fixed assets, developers have a choice to build (or not built) in certain places, if they deem it too dangerous. Flexibility can therefore be used as an instrument to prevent floods risks:

"Not investing or not developing if it is going to be a problem somewhere. That flexibility is actually our instrument in that sense." - Developer

Preventive measures

Preventive measures can be leveraged to reduce flood risks and can therefore be used as an enabler, as indicated by the interviewees:

"I think it would also be good for the government to build in places where there is a chance of flooding in such a way that you would not have much damage." - Insurer

"Now it is not insured, so now the risk is for the owner and therefore for the banks as they often have provided the mortgages, so if by flooding the value of the home decreases and actually the owners are going to be unable to pay then they may not be able to repay the mortgage either. So that is a risk for banks and that can be solved by insurance because then the risk is less." - Insurer

Collaboration

Several interviewees indicated that collaboration can be an enabler for reducing individual and collective risks for the stakeholders:

"There is certainly a greater role for insurers and financiers, but that has to happen in cooperation with each other, so also from us in the national government." - Government

"If we all behave in a consistent way with respect to such a qualification or uniform indication, it works better than if everybody is going to do something different." - Financial Institution

Engagement

Engagement of stakeholders can be leveraged to diminish risks upfront, or alleviate the existing risks as indicated by interviewees:

> *"I think it would be very good if just early on in the process of new homes or other new buildings in an area, the risks and potential solutions are critically assessed. Because if you have a large planning area where you want to place new homes, and you still have the choice to put them on the one side where it is elevated, it would make it easier to keep them safe in the event of very heavy rainfall or maybe a regional breach." - Government*

> *"If you are aware that there is insurance coverage in place, then the consequences of a water label for the value of the home again are probably less, as you then know I am insured for it, so in terms of timing, I would recommend doing that first and then only a month later introduce the water label." - Insurer*

> *"We could perhaps in the future look more at how we can make municipalities, for example, feel a bit more responsible to also take more account, and the same goes for the safety regions. Additionally, the same goes for the central government, just include all ministries a little bit more, I think." - Government*

Lobbying and Exlusion

Financial institutions, as well as companies or individuals, can use lobbying as an enabler to influence politics:

> *"We can exclude with conditions, and we can play with the price and lobbying, we try to influence the municipality or the or politics in a way that everything remains fundable." - Financial Institution*

Promote awareness

Having a large reach and being in touch with a lot of citizens, the interviewees indicated that they can help promote awareness to enable enhanced awareness to for example prevent people from living in un-insurable properties:

> *"Mainly for awareness, there is a climate damage monitor that we share annually. We work a lot with science, so also convey the latest insight into that and we also try to indicate certain things in the media, for example, last year that building in flood plains and building in low-lying areas can ultimately lead to un-insurability." - Insurer*

> *"From my perspective of the national government, that is obviously just on the one hand some more signaling vision documents, policy documents, so the water and soil letter (Water en Bodem sturend) is a good example of that." - Government*

Knowledge sharing

Different stakeholders obtain different sorts of knowledge and indicated that by sharing the knowledge amongst stakeholders the risks of devaluation of real estate due to floods could be reduced:

> *"There are many similar issues around this theme among the various financial parties, so we can also help each other well and where we also have input from, for example, knowledge questions from Deltares or from the Delta Commissioner's staff." - Insurer*

> *"But if you talk about climate, I mean, you should also make this kind of data available free of charge to developers and investors to people who ultimately have to decide what is wise to do." - Investor*

> *"We are also happy with maps, for example, the climate effect atlas and other maps where you can just see well. What a current risk is, but also what a future risk is. And many insurers calculate that themselves, certainly large insurers have a lot of knowledge about this." - Insurer*

Discount

Using economic incentives can support in steering citizens or companies towards the adaptation of flood preventive measures, for example by discounting, subsidizing, or using price premiums:

> *"We have lending standards in which we can apply lower wage to income of lower loan to value rates, so the customer still has some borrowing capacity for climate measures for example." - Financial Institution*

Subsidies

> *"Very often area developments are not feasible on their own, so the additional subsidy is needed for them. Well, that can start to be the case for flooding as well" - Developer*

Price premiums

> *"It could be that if we introduce flood insurance, we would introduce some premium differentiation and perhaps also make adaptive measures mandatory, but due to the low risk in many areas, it might not make sense to introduce these measures. However, for areas outside of dikes it might be very beneficial." - Insurer*

Finally, the **additional** barriers, stimuli, and enablers can be summarised:Table 6.2

Stakeholders	Additional Stimuli	Additional Barriers	Additional Enablers
Insurers	Financial Regulations Damage prevention	Data availability Differing Interests	Preventive measures Engagement Collaboration Knowledge sharing amongst stakeholders
Financial Institutions		Knowledge gaps Differing Interpretations in Flood Risks Uncertainty Industrial Regulation Differing Timelines Divided-Responsibility	Lobbying Collaboration
Investors		Knowledge gaps Uncertainty Data availability Differing Interests Priority Regulations	
Developers	Responsibility Building Regulation	Lack of Awareness Perception Quantifying Tool Dependency Priority Differing Interests Lack of Incentive Regulations	Flexibility
Resident	Increasing Awareness	Perception Dependency Divided-responsibility Lack of incentive	
Government	Increasing Awareness Ambition	Lack of Awareness Uncertainty Complexity Differing Timelines Quantifying Tool	Preventive measures Engagement Collaboration
Municipality		Dependency Granular Data	Engagement

Table 6.2: Additional barriers, stimuli and enablers based on interviews

6.6.4. Combining and coding literature review and interviews

As a next step, the barriers, stimuli, and enablers from the academic literature and the exploratory interviews were coded. This was done to enable the step from developing open codes into axial codes, to connect the barriers to the enablers, and derive implications for real estate practice in the Netherlands. The following steps were conducted: (1) The different barriers, stimuli, and enablers were grouped, (2) The different sets of barriers, stimuli, and enablers were labeled in axial codes (3) The axial codes were connected to the categories "enabler," "barrier," and "stimuli".

Coding barriers

First of all, the derived barriers from the interviews and the academic literature were grouped. This can be observed in the open codes in Figure 6.3. Next, the open codes were used to define axial codes, and finally, the axial codes were linked to the category barrier. When looking at the barriers to the different stakeholder experiences, new barriers derived solely from the interviews were: *Differing interpretations, Perception, Differing timelines, Data availability, Differing interests, and Building regulations* as can be seen in Figure 6.3. The majority of the reviewed literature focused on a single stakeholder, within the conversations with multiple stakeholders in practice, a lot of differences between the stakeholders (e.g., differing interpretations, interests, and timelines) were noted as barriers. On the other hand, *Governmental compensation, Inflexibility, Cumulative risks, Anti-selection, Knowledge resources, and Institutional fragmentation* were derived solely from literature.

Next, as shown in Figure 6.3, the barriers were labeled in axial codes, This was done to deduct the main barriers from the stakeholders to be able to couple them to the enablers the stakeholders have. The complete process of coding the barriers can be seen in Figure 6.3:

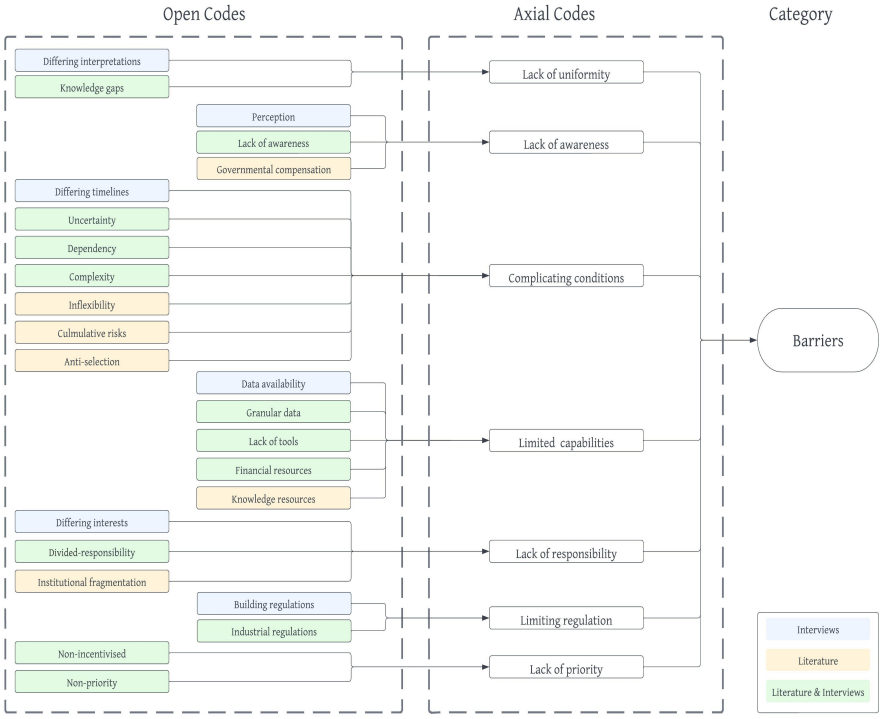


Figure 6.3: Barriers Coding (Author's image)

Finally, the axial codes of the barriers can be summarised as in Table 6.3 in which the barriers are explained:

Barriers	***Explanation***
Lack of uniformity	Knowledge gaps and differing interpretations of data can be experienced as a barrier for the stakeholders, as it leads to different definitions and makes communicating and subsequently agreeing more difficult
Lack of awareness	A lack of awareness and low-risk perception can lead to a missing sense of urgency for stakeholders, therefore, acting as a barrier to preventive measures
Complicating conditions	The interdependencies, uncertainties, and complexities in future scenarios act as a barrier for stakeholders as it makes achieving measures and supporting the reasoning for their urgency difficult
Lack of capabilities	A lack of financial and (granular) knowledge resources as well as a lack of tools are barriers for stakeholders to both assess flood risks as incorporate preventive measures
Lack of responsibility	Ambiguity and fragmentation of responsibilities result in stakeholders looking at other stakeholders for the appropriation of issues and leadership in diminishing the flood risks acts as a barrier to actions
Lack of priority	A lack of incentive and the need to prioritize other issues are barriers for the stakeholders as it often leads to flooding risk being lower on the list of interests within projects
Limiting regulation	Regulations are experienced as a barrier for certain stakeholders, as it limits their possibilities to alleviate flood risks

Table 6.3: Overview final barriers

Coding stimuli

Limited similarities between the existing academic literature and the conducted interviews were observed within the stimuli. Moreover, the interviewees talked less about the stimuli than the barriers they perceived. The reason for this might be that within the interviews, the stakeholders seemed to feel devaluation of real estate due to floods was not happening yet, and therefore limited stimuli were discussed.

The stimuli within the literature have been summarised as in Table 6.1 the stimuli *Flood prevention, Public pressure, Sense of urgency, Liabilities, Future proofing against regulation, Political support, Reputation, Devaluation of property, Becoming insolvent, Competitive advantage, Healthy economy, Changing demand, and Attractiveness companies* were not explicitly named within the interviews. The stimulant *Increased awareness* was an interesting addition to the reviewed literature, as within the literature, awareness was mainly concluded to be a barrier.

Similar to the coding methodology applied to the barriers described in the previous section, first, the stimuli were grouped and subsequently labeled within axial codes. Finally, the axial codes were linked to the category “stimuli” the process of the analysis can be seen in Figure 6.4

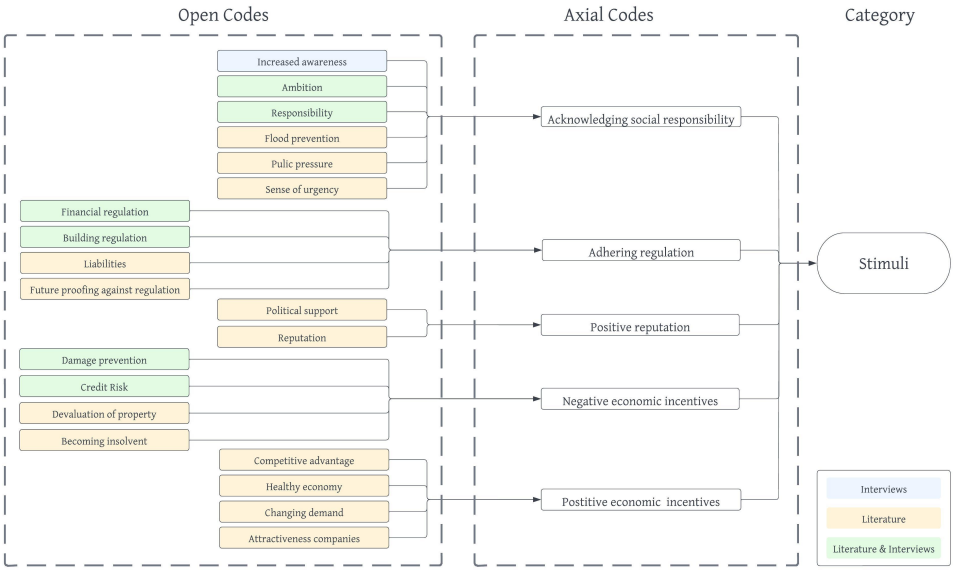


Figure 6.4: Stimuli Coding (Author’s image)

Finally, after the analysis, the stimuli are summarized within five axial codes and can be explained as in Table 6.4:

Enablers	***Explanation***
Acknowledging social responsibility	Due to factors such as ambitions, increased awareness, public pressure, flood prevention, and a sense of urgency, stakeholders experience social responsibility as a driver to diminish the effects of flood risks
Adhering regulation	Financial and building regulations and the prospect of future regulations as well as liabilities oblige stakeholders to follow certain rules which can be a driver for including flood alleviating measures
Positive reputation	Reputation and the desire for political support can drive stakeholders to make choices that are beneficial for the environment or alleviating flood risks
Negative economic incentives	Negative economic incentives as preventing devaluation, credit risk, damages, or becoming insolvent can drive stakeholders to adopt preventive measures
Positive economic incentives	Positive economic incentives such as a healthy economy, a competitive advantage, changing demands, or attracting companies can drive stakeholders to certain adaptations as well as being innovative and prioritizing flood safety

Table 6.4: Overview final stimuli

Coding enablers

After the completion of the process of coding the barriers and the stimuli, as a last category, the stakeholders’ enablers observed within the literature review and the exploratory interviews were coded. Com-

pared to the literature, *Collaboration, Exclusion, and Lobbying* were additional enablers. Both exclusion and lobbying are negative non-economic incentives, which were not found within the literature review.

Additionally, collaboration was named by multiple actors, which might be attributed to the fact that the questions of the exploratory interviews were focused on the different stakeholders and the barriers/-drivers between them.

On the contrary, within the exploratory interviews, *Stress tests, Building regulation, Land use planning, Participate in discussions, Public-Private Partnerships, Hazard disclosure, Investments, Green finance, and Taxes* were not explicitly discussed.

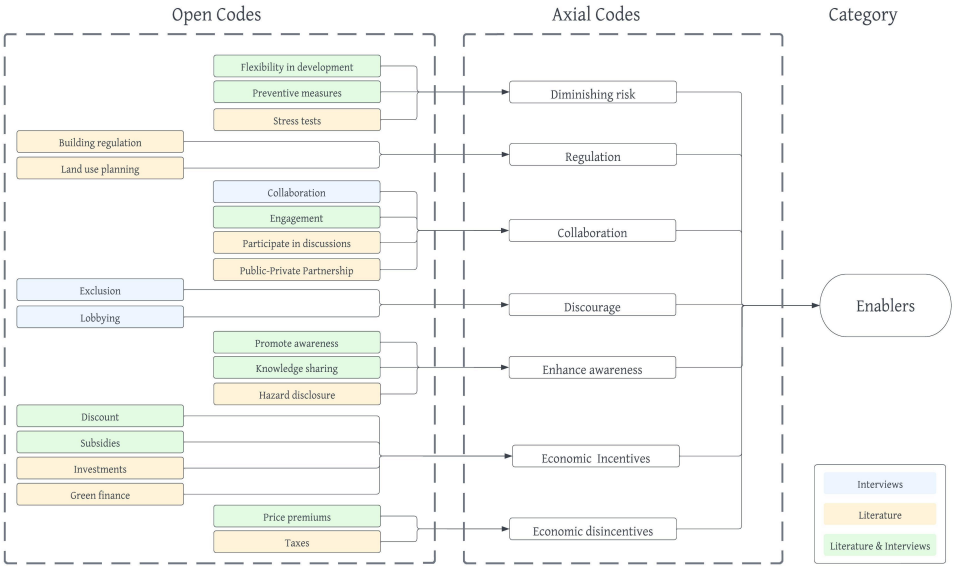


Figure 6.5: Enablers Coding (Author's image)

Next, the enablers were grouped and linked to the axial code and finally connected to the category enablers, as can be seen in Figure 6.5.

Enablers	***Explanation***
Diminishing Risks	By choosing where to develop, applying preventive measures, or executing stress tests, diminishing risks can be leveraged as an enabler to prevent real estate from devaluating due to flood risk
Regulation	Regulations, as well as land use planning, can be used as a tool to steer different stakeholders and create an incentive for stakeholders to contribute to diminishing the flood risks
Collaboration	By Public-Private partnerships, participating in discussions, engagement of different stakeholders and by collaborating with each other, stakeholders can help prevent risks upfront or diminish existing risks
Discourage	Lobbying and exclusion can be leveraged as tools to oppose regulations or discourage certain developments
Enhance Awareness	By promoting awareness or sharing knowledge, the stakeholders can help alleviate barriers as lack of awareness or gaps in knowledge among stakeholders
Economic Incentives	By using economic incentives such as discounts, subsidies, or investments to incentivize stakeholders to certain actions to promote flood preventive measures
Economic Disincentive	By the use of economic disincentives as taxes or price premiums, the government or other stakeholder can discourage choices

Table 6.5: Overview final enablers

6.6.5. Interrelations

The previous sections have shown how the axial codes for the barriers, stimuli, and enablers were constructed. Within this section, the barriers will first be connected to the enablers to assess if there are potential implications for the stakeholders to alleviate the barriers that are currently experienced.

This was done by first defining how the barriers could be overcome and subsequently assessing which enabler could contribute to this. Finally, the owner of the barrier and enabler was defined to deduce the

significance for the stakeholders. The overview of the barriers that have been coupled to the enablers can be seen in Figure 6.6.

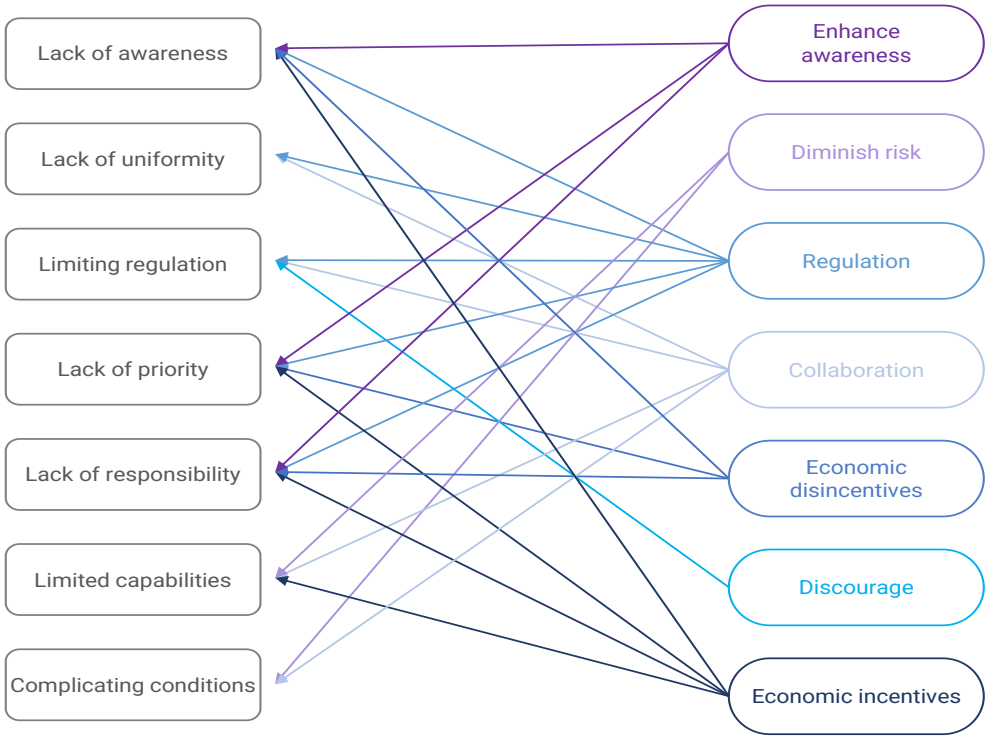


Figure 6.6: Connecting barriers and enablers (Author's image)

Barrier: Lack of uniformity

Lack of uniformity in leveraged methodologies, knowledge, and definition of flood risks can cause communication barriers and potential stakeholder disagreement. This hinders effective adaptation, and can therefore be experienced as a barrier. These barriers could be resolved by defining a general definition and source of flood risk, for example, through regulation or collaboration amongst the stakeholders to agree on an acceptable risk level.

Based on the assessed stakeholders, namely the financial institutions, investors, and the government, experience having a lack of uniformity as a barrier. Relevant stakeholders that have the ability to conduce in creating uniformity are the government through regulation and the remaining stakeholders in harmonizing the knowledge and reaching a consensus on general flood risk definitions.

Barrier: Lack of awareness

The second identified barrier is the lack of awareness. A lack of awareness of flood danger within the built environment leads to a missing sense of urgency and, therefore, a missing incentive for stakeholders to adapt actively. This barrier may be alleviated by means of enhancing awareness through, for example, policies or regulations. An example is the previously mentioned "waterlabel" in which all houses receive a label regarding their water safety or by public campaigns. Moreover, the stakeholders could be notified of the importance of water safety through economic (dis)incentives; awareness could thereby be enhanced.

Stakeholders that were primarily identified as having a lack of awareness were developers and residents. Important stakeholders that can contribute to mitigating this barrier through the aforementioned enablers are insurers, financial institutions, investors, the government, and municipalities.

Barrier: Complicating conditions
As discussed in section 6.1, there are a lot of interdependencies and complexities in the systems in the Netherlands, for example, the differing timelines of stakeholders, the complexities within the Dutch system, and uncertainties in future scenarios. This has proven to be a barrier for insurers, financial institutions, developers, residents, the government, and municipalities. Interdependencies exist between developers, residents, and municipalities dependent on the government for resources or regulations. However, the government reciprocally relies on its residents to adopt flood-alleviating measures.

By diminishing the potential risks and collaboration between the stakeholders, the stakeholders can help each other alleviate barriers they perceive due to uncertainties, dependencies, and differing timelines. Essential stakeholders in minimizing the barrier of complexity are the government by diminishing risks, residents by securing private properties, and insurers by resolving uncertainties through knowledge sharing.

Barrier: Limited capabilities
A common barrier to alleviating flood risks is limited capabilities either in financial, human, time, or knowledge resources. Limited capabilities can pose a barrier when stakeholders have the ambition to contribute but not the means. Stakeholders experiencing this barrier are investors, developers, residents, the government, and municipalities.

To alleviate the barriers of limited financial resources, investments or subsidies by, for example, the government, municipalities, or investors could be used as an economic incentive (e.g., investments) to adopt flood preventive measures in projects or own properties by developers or residents. Moreover, by diminishing the flood risks, such as conducting stress tests, preventative measures, or not building in vulnerable areas, the need for capabilities could be reduced. Finally, by collaboration amongst the stakeholders, tools and (granular) knowledge could be shared, further alleviating the issue of limited capabilities.

Barrier: Lack of responsibility
Stakeholders seem somewhat reluctant to adhere to the risks of floods due to differing interests or the division of tasks, resulting in a lack of responsibility. Lack of responsibility can result in stakeholders experiencing little encouragement to alleviate flood risks and their subsequent adverse effects on real estate values. A clear division of responsibilities, an enlarged sense of urgency, and more stringent regulations could help decrease this barrier. Within this study, investors, developers, residents, and municipalities appeared to feel (partly) a lack of responsibility. The observations suggest that stakeholders tend to look at other stakeholders to take the lead in alleviating flood risks (i.e., the bystander effect).

The stakeholder that could contribute to overcoming this barrier is the government. The government can leverage economic (dis)incentives or regulations to either solve the ambiguity in the division of responsibilities or to share the risk among the stakeholders. For example, by including stricter rules for flood safety in the Building Decree (Bouwbesluit), the government could force developers to include flood protection measures within their projects (e.g., through multi-actor engagement). In addition, enhancing awareness may help enlarge the sense of responsibility in the different actors.

Barrier: Limiting regulation
Regulations as building and industrial regulations can be experienced as a barrier within including flood alleviating measures within real estate projects, as regulations limit the possibilities of how and where we can build. Moreover, industrial regulation can result in limitations, such as restrictions on insurance structures or restraints on how we can build back after a disaster. Through consultation, the aspirations of stakeholders experiencing this barrier could be defined, and potential compromises could be made.

Primarily developers and investors seem to experience regulations as a barrier. Investors and developers could either discourage (e.g., lobbying) certain regulations or collaborate with the government to come to an agreement. On the other hand, the government could monitor and re-evaluate regulations. Subsequently, the government might adjust regulations perceived as constraining by developers and investors.

Barrier: Lack of priority
A lack of priority and a lack of incentives in alleviating flood risks in real estate is present among investors, developers, the government, and municipalities. The lack of priority can result in the omission of flood risks within existing and new real estate. Although a lack of priority can be anticipated due to the many aspects these stakeholders have to consider within their decisions, the importance of preventing the devaluation of real estate is not to be neglected. Real estate is vital for the Dutch economy due to the country's high mortgage-to-debt-to-GDP ratios (Caloia & Jansen, 2021). Emphasizing the importance of flood risk could help overcome this barrier.

This could be done by using economic (dis) incentivizes or regulation by the government or the municipality to steer private parties to prioritize this issue. Additionally, the awareness could be enhanced through, for example, position papers by insurers or financial institutions. Policies of the government could also enhance awareness.

6.7. Conclusion

Due to high mortgage-to-debt-to-GDP rates, the Netherlands' financial market is intertwined with real estate. The adaptation policies that help to alleviate the effects of climate change are, therefore, indispensable to the Dutch economy. However, the majority of the involved stakeholders in the real estate environment are not financially responsible for the direct damages in case of the occurrence of a flood. This provides these stakeholders with the incentive to make use of the vulnerable areas for as long as possible. The Netherlands is well-known for its expertise in water management. This has resulted in a high level of trust in the system by the residents of vulnerable areas. Nonetheless, the current system possesses certain flaws. Gaps exist in the damage coverage in case of minor flood events or floods because of the primary dikes. At the moment, such events cannot be insured. Furthermore, the government would not be able to bear the high costs in case of a flood.

Through alteration and application of the Graaskamp (1992) framework, within this chapter, the drivers, barriers, and enablers of the selected stakeholders (insurers, financial institutions, investors, developers, property owners, the government, and municipalities) were assessed. The assessment included conducting a literature review and exploratory interviews. The barriers, stimuli, and enablers were identified, coded, and linked to their subsequent category. In the next step, the enablers were linked as potential alleviating solutions to the perceived barriers. The following section discusses the main conclusions and implications for flood risks on real estate in the Netherlands. While analyzing the blockers or missed opportunities within stakeholders' interrelations, several important conclusions can be derived.

First, due to a (partial) lack of awareness, numerous stakeholders do not consider flood risk a priority per definition. Developers and residents were concluded to experience a lack of awareness as a barrier. Flood risks do not necessarily have to receive the highest priority within projects as the Netherlands is well-prepared against floods. However, it is deemed necessary that all stakeholders are aware of the flood risks in the Netherlands and the associated risks. Stakeholders could thereby be encouraged to look for integrative flood-alleviating solutions. The general level of flood risk awareness in the Netherlands can be improved by actively enhancing awareness. This could be achieved by introducing new regulations (e.g., water labels) or economic incentives (e.g., subsidies on property level). Stakeholders that were identified as having the capacity to mitigate the barrier were the government, municipalities, insurers, and financial institutions.

Second, the Netherlands has many regulations and evidently challenging regulatory processes for the construction or alterations of real estate. Although these regulations all serve a purpose, the stakeholders experiencing regulations as a barrier can be transparent and communicate the limiting effects they encounter. The stakeholders that experienced limiting regulation as a barrier were identified as investors and developers, whereas the government can contribute to alleviating this barrier. Stakeholders ought to collaborate (through potentially re-framing regulation) and try to work to a solution to alleviate these barriers. Moreover, by defining and agreeing upon uniform definitions of risks, the stakeholders can more easily cooperate, and conflicts might be avoided. The stakeholders that encountered a lack of uniformity were financial institutions, investors, and the government. To resolve this barrier, essentially all involved stakeholders should cooperate, in which the government could take charge.

Third, several assessed stakeholders (e.g., insurers, financial institutions, investors, developers, property owners, and municipalities) struggle with limited resources to assess and account for flood risks. For example, stakeholders face limited capabilities and a lack of access to granular data. Moreover, the presence of uncertainties and interdependencies accompanying flood risks make it challenging to assess the risks. Developers, residents, and municipalities experience dependencies on the government. Reciprocally, the government is dependent on the residents to alleviate flood risks on property level. Looking forward, the different stakeholders could focus on their potential contribution to diminishing flood risks. This could incentivize collectively working towards knowledge sharing, increased engagement, and collaboration. Flood risks can not be solved individually and should thus be addressed collectively. The government, municipalities, and investors were considered relevant in enabling and reducing the barrier of limited capabilities.

Fourth, as a result of levels of ambiguity in task divisions and reluctance to possess risks, stakeholders appear to possess limited responsibility feeling toward flood risks. Stakeholders encountering this barrier were assessed to be investors, developers, residents, and municipalities. By enhancing awareness, more stringent regulations, and economic (dis)incentives, the stakeholders can stimulate each other to incorporate and integrate flood risks in existing real estate and new projects. This may lead to stakeholders exhibiting stronger indications of responsibility toward flood risks and thus applying flood-alleviating measures. An important stakeholder in enabling the solution of this barrier was concluded to be the government.

Based on literature reviews and conducting exploratory interviews, this research has aimed at identifying barriers to flooding alleviating measures and protecting real estate values. Therefore, the fourth subquestion of this research: *How can relevant stakeholders contribute to preserving residential property values?* can be answered by concluding that although the interrelations and interests of the stakeholders have a complex nature, stakeholders are advised to incentivize each other through collaboration actively, economic (dis)incentives, diminishing risks, enhancing awareness, imposing regulations, and encouragement to prevent flood risks that might influence Dutch real estate. Neglecting the importance and impact of potential floodings in the future could result in severe damage to the Dutch economy and society. In this respect, cooperation and transparency are key. Within the conducted analysis, the government appears to have a central role in providing enablers to the barriers of stakeholders.

7

Discussion and Limitations

Within this research, the state-of-the-art models to describe the relation between flood risks and real estate values have been assessed. In addition, the definition of vulnerability has been evaluated. Finally, it was assessed how this complex issue relates to the real estate system and its involved actors. This study has tried to highlight the importance of vulnerability and derive steps toward a solution that can help alleviate the potential devaluing of real estate due to floods. The following chapter will demonstrate the reflection upon the assessments conducted and deliberates on the practical implications of the findings. First, within section 7.1, the connection to vulnerability in theory, the implications of the vulnerability assessment in practice, and its connection to the economic models will be debated. Second, in section 7.2, the potential root causes of the barriers within risk governance are discussed. Third, the implications of the discussion of both aforementioned sections will be explored in section 7.3. This chapter concludes by presenting the limitations and strengths of this research in section 7.4.

7.1. Flood Vulnerability in practice

Flooding events can have a significant impact on the built environment. Moreover, within the academic literature, it is debated that a gap between vulnerability in theory and practice might persist. Whereas this research has primarily focused on the impact of floods on the value of residential real estate, flood vulnerability may have more consequential implications. Additionally, within this research, economic models to quantify the impact of floods on real estate values were assessed, but would we be able to apply these existing economic models with a reassessed definition of flood vulnerability? This section discusses the application and integration of the constructed flood vulnerability with economic models from academic literature. Hereafter, both a potential consequence and solution to the divergent vulnerability levels assessed within this study are considered. Additionally, the repercussions of flood vulnerability on a larger scale are debated.

7.1.1. Flood Vulnerability Assessment

The academic literature offers a range of economic tools to quantify the potential correlation between flood risks and real estate values. However, the tools are often complex and require a lot of data, which is not always available for the stakeholders for whom the implications are so important. Moreover, if a tool were available to assess the relationship between flood vulnerability and real estate values, how do we account for vulnerability? Should we assess which areas will flood, the structures of the local housing, or who lives there; what defines vulnerability?

Although a resident's vulnerability does not directly relate to flood chances in an area, it does have implications for the recovery after a flood. However, how do we consider a flood's social impact, and can we rationalize and quantify this? Currently, the risk of floods is defined in the Netherlands by assessing the probability that an area will flood and the damages (e.g., economic and fatalities) it could result in.

This current definition of damages might be too narrow, as it could neglect the local socio-economic vulnerabilities. By inclusion of the socio-economic vulnerability indicators of the residents living in the assessed areas, the approach to flood management could thus exhibit a greater degree of integration. This does not necessarily entail enhancing the flood measures for areas where more vulnerable people reside. However, it could entail considering the socio-economic vulnerability of cities and how to reduce this phenomenon within flood assessments and subsequent flood-alleviating measures. For instance, micro-adoption by placing emergency garages that provide free gear to reduce flood risks on the property level (e.g., sandbags) to assist in areas where more socially vulnerable residents live could be considered.

7.1.2. Economic Models and Flood Vulnerability

The assessed economic models are primarily applied within the academic literature, with flood exposure as the determining parameter. However, as aforementioned, flood exposure might be too straightforward when defining the impact of flood vulnerability on real estate values. To explore the usage of a more integral approach to flood vulnerability within the economic assessments, this study constructed and applied a flood vulnerability framework, including the socio-economic vulnerability.

When looking at the connection between the assessed economic models and the constructed vulnerability framework of this research, two models are considered suitable for integrating the effects of flood vulnerability on real estate values. Namely, Hedonic Pricing Model and Spatial Regression Model. These models allow for the assessment of a hypothetical event while separating the effect of all different housing characteristics. Alternatively, the willingness-to-pay method can be applied to forward-looking scenarios; however, it focuses on assessing the premium residents are willing to pay, thus considering a different phenomenon.

The other three models reviewed within this research (repeat sales, difference-in-difference, and regression discontinuity) are considered less suitable, as they are frequently applied to backward-looking events. A forward-looking approach through which the different vulnerability levels of residential properties are compared is deemed more suitable. Moreover, the difference-in-difference method would be less suitable, as changes in the exposure of different neighborhoods would likely be ambiguous and complex to define separate “treatments.” Likewise, within regression discontinuity, an arbitrary threshold for treatment would be complex to decide upon. Similarly, repeat sales focus on a changed factor throughout past transactions which is more easily applied to a binary event as inundated or not-inundated within the past.

In addition, the assessed methods seem to primarily inform researchers. However, the implications of the studies and their subsequent importance (e.g., incentivizing adaptive behavior) may be predominantly important for stakeholders working in practice. Tools exist to calculate the risks for portfolios but are often not available for free. Moreover, many methods exist which can lead to different outcomes and, thus, a lack of uniformity.

Although actors appear to primarily use similar data sources within the Netherlands for understanding the climate scenarios, a general tool to assess risks and their subsequent adverse effects on real estate values seems lacking. Every stakeholder attempts to solve this deficiency independently, and large inequalities appear to be present between the methods at hand for the different stakeholders. It could therefore be argued that moving forward, an accessible tool to quantify and understand the effects of flood risks on real estate values for all stakeholders is deemed necessary.

A complicating factor within providing a general tool is that introducing an accessible tool available for everyone would introduce transparency in the potentially adverse effects of flooding on residential real estate values. Subsequently, if the adverse effects of floods would indeed impact real estate values, a degree of intricateness may be thus be involved as stakeholders with limited control over the risks (e.g., residents) would be vastly affected.

7.1.3. Climate Gentrification

This study concluded that socio-economic indicators influenced the division of flood-vulnerable neighborhoods within the case study. However, this socio-economic vulnerability may have additional implications for flood adaptation measures’ placement and focus areas. A significant challenge remains regarding which actions should be considered based on the knowledge that certain areas are more vulnerable than others. In addition, the question of how to reduce vulnerabilities and prevent more significant social inequalities remains unresolved. This section thus explores the adverse effects of flood-vulnerable areas.

Climate gentrification entails the phenomenon in which climate adaptation measures cause new or enlarge existing inequities within cities (Taylor & Aalbers, 2022). The absence of consideration of socio-economic vulnerability in flood alleviating measures and strategies may thus amplify this phenomenon. Taylor and Aalbers (2022) argued that plans to diminish climate risks should be reconsidered, in which social justice and housing fairness should be focal points. Moreover, it is argued that attention should be given to constructing integrative and inclusive strategies to prevent spatial inequality within risk

management.

Furthermore, Shokry et al. (2020) studied the effects of green, resilient infrastructure on residents and assessed if the interventions contribute to reducing the vulnerability of social groups most at risk or if the initiatives have dysfunctional effects enlarging the exposure of the groups at risk. This research found that within the case study, the vulnerable groups shifted into situations with an intensified vulnerability.

Additionally, Anguelovski et al. (2019) revealed that green infrastructure has unintended adverse effects. The most vulnerable citizens will likely have the most negligible benefit from climate-enhancing initiatives, enlarging social and spatial inequality. This research concluded with the paradox that green infrastructure initiatives meant to enhance the neighborhoods may lead the most vulnerable residents to lose their neighborhoods entirely. Thus, the strategies should consider social effects to alleviate flood risks and protect social justice.

7.1.4. Social Cohesion

Next to methods to assess the vulnerability of areas, measures to reduce vulnerabilities might be considered. Social cohesion could lessen the impact of divergent socio-economic vulnerabilities. Namely, Greene et al. (2015) studied the effects of social cohesion in relation to vulnerability and physiological endurance in the case of a flood event and discovered that reinforcing social cohesion can contribute to safeguarding the physiological health and well-being of residents.

In addition, Townshend et al. (2015) studied the correlations between social cohesion and resilience of areas and concluded that policies should acknowledge the connection between social cohesion and resilience and therefore stimulate community-based activities to promote physiological health and well-being. Moreover, they argue that neglecting social cohesion in programs may work counterproductive.

Within the Netherlands, Kaufmann (2018) argued that abundant resources, regulatory frameworks, and laws exist. However, they argued that the issue of justice is only slightly a topic of discussion, even though the increasing flood risks result in uneven burdens. Moreover, they argue that a discussion on justice and effective and fair flood risk management is therefore needed.

Acknowledging the importance of socio-economic vulnerabilities may thus help in flood preparedness and resilience. Ultimately the acknowledgment and integration of socio-economic vulnerabilities within flood prevention management might contribute to reducing the vulnerability of neighborhoods.

7.1.5. Flood Vulnerability on a larger scale

For this research, the case study of Maastricht was chosen due to its unique flooding history within the Netherlands. However, the flood risk levels in areas in Maastricht are somewhat limited. Looking at a larger scale (Figure 7.1), the areas below sea level naturally have a more significant flood risk level. Applying the vulnerability framework in other areas in the Netherlands could provide an enhanced understanding of flood vulnerability throughout the Netherlands and the subsequent implication for flood prevention management.

However, the Netherlands is known for its expertise in water, limiting the flood risks of the country in general. But applying the framework to countries with significantly higher flood risks and social vulnerability could assist in understanding where flood alleviating measures are most needed and what is the best method to implement them.

An example of a country more susceptible due to its high population density, socio-economic status, and flood exposure is Bangladesh, situated within the floodplain of three major rivers. Within Bangladesh, poverty has been amplified by flood events (Adnan et al., 2020). Elucidating what indicators cause underlying susceptibility to floods within these areas might contribute to applying flood-alleviating measures in a socially just way.

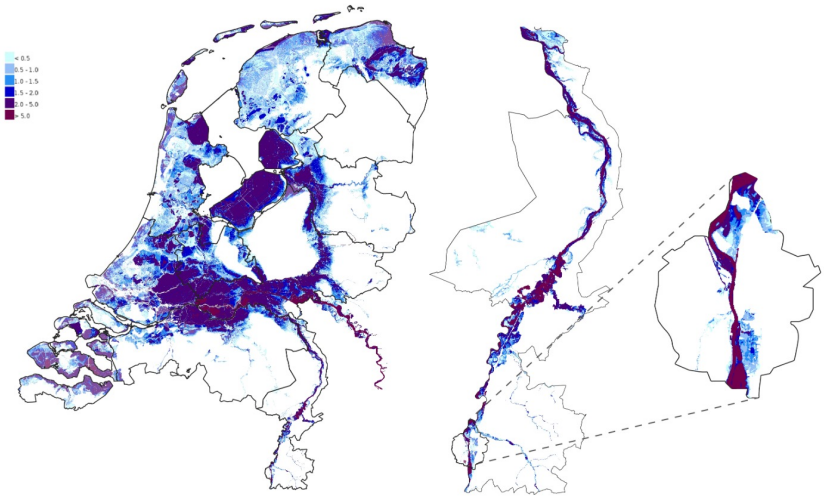


Figure 7.1: Flood Risk “middle-large” chance in the Netherlands (Author’s Image based on Stichting Climate Adaption Services, 2022)

7.2. Flood Risk Governance

This research examined the impact of risk governance on preserving the values of residential real estate. Lack of incentive and limited feeling of responsibility were barriers for numerous involved stakeholders. This section discusses processes that might underlie these specific barriers and debates potential alleviating solutions.

7.2.1. Organized Irresponsibility

Every actor has a direct or implicit interest in diminishing flood risks and their effect on real estate values, each with their drivers (e.g., financial, liabilities, social). As discussed in chapter 6, the Dutch financial system is intertwined with real estate and could thus be impacted if real estate values significantly deteriorate. Moreover, investors could choose to invest in other markets if they deem the Dutch market not safe enough or if the Dutch market is not attractive enough (e.g., due to cumbersome regulations). In addition, developers could retain from developing in the Dutch market, enlarging the existing political issues and challenges (e.g., the housing crisis) already embedded in the system. Flood risks might become, or already are, not insurable in the Netherlands, as the potential damages would be immensely high if our structures were to break.

This high level of exposure results from the position of the Netherlands relative to the sea level and our dependence on protective systems (e.g., dikes). Although everyone is aware of the aforementioned risks at some level, nobody appears ready to fully own the risk. This might be attributed to the fact that if flood risks would significantly rise, there might not be anything we could do on an individual level (i.e., force majeure). Likewise, J. Mills (2020) argued that the global bystander effect occurs within the climate change challenge. Although everyone is aware of climate change, relatively little is done to mitigate this, in which denial and renouncing one’s social responsibility are central. Moreover, fear might negatively impact the tendency of stakeholders to accept accountability.

Cooperation and all actors taking responsibility may contribute to diminishing the flood risks and impact on the Dutch Delta. However, it could be argued that every actor is (partly) looking at other actors for answers or taking the lead concerning alleviating flood risks? The concept of “organized irresponsibility” by Ulrich Beck that entails a system with social interactions in which all the different actors produce and distribute risks together but manage to avoid being held accountable (Galantino, 2022) might be

relevant. Solutions to flooding risks require actions by many actors, and instead, risks seem to be frequently downgraded, and thus more uncomplicated solutions may be in cases preferred over more promising ones (Tennberg et al., 2018).

Within the Dutch system, the sole responsibility for flood risk management is currently defined by the public sector, although the application of multi-actor governance might be vital (Mehryar & Surminski, 2021). Multi-actor governance entails the establishment of novel partnerships and networks involving many stakeholders (Bulmer & del Prado-Higuera, 2021). Ultimately, preventing floods comes at a cost, but acknowledging that, next to the government, we can all contribute to this is a concept that mandates a greater degree of internalization. Neglecting this responsibility may result in a reluctance to the adoption of this responsibility as currently, adopting flood alleviating measures will most likely only result in costs within our system.

7.2.2. Pillarization

Although the implementation of flood safety measures might be seen as a burden due to the correlated costs, it is also an opportunity for integrative potential in which multiple societal challenges can be addressed. The challenges can be interconnected through, for example, land utilization with multiple functions (Warbroek et al., 2023). An example of this is, for example, water squares, where a recreation place is created while alleviating flood risks simultaneously. Another way to attain integrative potential is connecting value chains when solutions may not be economically alluring. However, to be able to achieve this potential, integrative collaboration is vital.

A comparison of barriers to implementing sustainable energy measures can be made, in which many parallels with flood risk measures barriers can be observed. Warbroek et al. (2023) studied the bottlenecks to effective implementation of sustainable energy and identified the bottlenecks as “policy mismatches, institutional complexities, inconsistencies, lack of financial support, and uncertainty in cost/benefit allocation, and fragmentation in organizational boundaries” (Warbroek et al., 2023). Moreover, Warbroek et al. (2023) concluded that these barriers are fundamentally all caused by the inadequate appropriate institutional arrangement to facilitate integration. Similarly, Spijkerboer (2021) argued that the pillarization of the institutions in the Netherlands impedes integrative approaches.

In addition, Vaandrager (2020) argued that institutions must acknowledge new information from outside to rejuvenate old-fashioned routines to prevent institutional lock-in. Moreover, Vaandrager (2020) states that within bureaucratic organizations, the issue arises that the responsibility is divided over numerous departments. When a new issue arises, it has to comply with the internal structure and fit within one of the departments; otherwise, it does not exist in the existing theory. Therefore, Vaandrager (2020) argued that the bureaucratic scope defines the issue instead of its core. Moreover, this focus on organization has led to limited flexibility in institutional organizations to apply integrative solutions in which value chains can be connected. Similarly, integrative solutions to flood risks may be hampered if the issue is too complex and does not fit into one of our artificial boxes within our institutions.

7.2.3. Stick and Carrot

Next to incentivizing involved stakeholders to prevent organized irresponsibility, academic literature argues that the stakeholders should be steered to reduce their contribution to climate change (e.g., emissions). The building sector was responsible for approximately 28% of the greenhouse gas emissions in 2015 (Heffernan et al., 2021), which enlarges the climate change issues. Stimulating stakeholders to contribute to alleviating the effects of flood risks and reducing their contribution to climate change is complex, as every participant aims to benefit. A solution to alleviate the pressure of flood risks might be achieved by combining the ’stick (regulatory or economical with holders) and the carrot (enablers or incentives).’ Both steer toward more stringent building requirements and stimulate stakeholders to contribute voluntarily.

More stringent building requirements would be feasible within the Netherlands due to its advanced legal framework, well-developed policy frameworks, long-term planning, and knowledgeable institutes that establish pioneering (nature-based) solutions (Suykens et al., 2019). Implementing more stringent building requirements could help incentive stakeholders to build consciously and resolve the issue that originates from competitive markets leading developers to build as cheaply as possible. Moreover, building requirements provide more room for insurers to “build back better,” as the building requirements

in their coverage currently limit them.

However, the solution may not be found in solely strengthening the regulations. For example, Heffernan et al. (2021) investigated policy pathways to steer toward more sustainable rental housing and highlighted the need to include both carrot and stick policies, triggering both the desire to contribute and the need to avoid (Heffernan et al., 2021). Likewise, OECD (2018) argue that governments can take a step towards alleviating climate risks by supporting and steering the private sector in ”spatial planning frameworks, infrastructure projects, and policy appraisals, regulatory and economic standards.” One could thus argue that to incentivize stakeholders towards specific behavior, both sticks and carrots should be utilized.

7.2.4. The role of Insurers

Insurers can have an essential role in retaining the value of real estate in the Netherlands. Currently, as discussed in chapter 6, ensuring a primary dike breach is impossible and not deemed possible under present circumstances. However, the alliance of insurers proposes a solution to alleviate current barriers. The solution includes obligatory insurance for the Netherlands. Still, the fact remains that flood risks are significantly different between the western and eastern parts of the Netherlands (Figure 6.1). If only the flood-prone areas of the country were willing to take out flood insurance, the premiums would be very high. However, the government cannot reimburse damages in every event, shifting the risk to citizens, who are, in most cases, unaware of this.

Perazzini (2020) reviewed the role of public-private partnerships in managing natural disasters and concluded that public-private partnerships can direct and harmonize governments’ and private sectors’ goals and endeavors when responsibilities are clearly determined. It could, therefore, be argued that involving insurers in the governance of flood risk is believed to be vital, and public-private partnerships might support the feasibility of flood insurance in the Netherlands, enabling the preservation of real estate values.

7.3. Implications

Within this section, the implications of the discussion on flood vulnerability in practice and flood risk governance are debated, after which the three main recommendations derived from the discussion and input of the research are given.

Within this research, flood vulnerability appears to be convoluted, in which flood alleviating measures can have large social implications. In order to acknowledge the potential adverse effects on the social justice of flooding, flood vulnerability in the broader sense may thus have to be incorporated into the economic models applied to understand the integral effects of floods on real estate values. Subsequently, how and who is informed by the existing economic models may accordingly need to be revised.

The socio-economic vulnerability of residents may be reduced by providing them with the necessary tools and knowledge and supplying them with safer located or constructed real estate. Through micro-adaptation (e.g., knowledge and tools) and social cohesion programs, the residents’ socio-economic vulnerability could be reduced, which can help alleviate or prevent issues such as climate gentrification. Conversely, residents should be aware of the risks of residing in climate-prone areas and might shift their demands accordingly.

In addition, flood risk management was found to be complex and a collective issue, thus assumably requiring collective input. For the government, working towards integrative solutions and overcoming pillarization through cross-links may be crucial. In addition, market parties should be further incentivized as currently organized irresponsibility is seemingly occurring within the issue of flood risks on real estate.

Through sticks and carrots, the market parties could both be obliged and rewarded for incorporating flood risks within their pursuits. It could thus be argued that market players should profit from alleviating flood risks and social vulnerabilities instead of only having to bear costs. The concept of “sticks and carrots” could prove beneficial by regulating and withholding the players from certain development as well as enabling them to build more safely and profitably. The total system might subsequently move towards organized responsibility.

The implications of the discussion can be summarized in Figure 7.2, in which the government has a central role in creating organized responsibility by equipping its residents with knowledge and tools and incentivizing the market with the "Stick and Carrot." In addition, the market and residents should trigger each other to take responsibility through supply and demand. Ultimately, this study hints towards a more spread division of responsibilities, as multi-actor governance may be vital within the Netherlands.

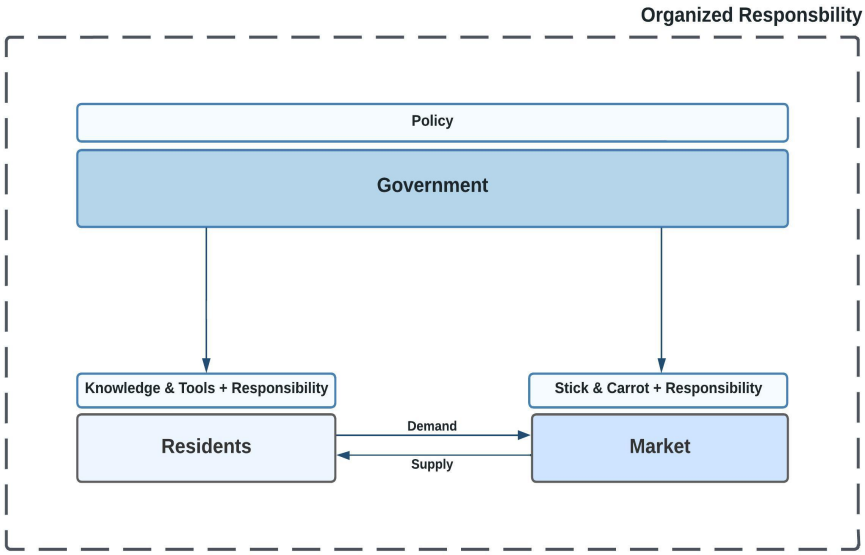


Figure 7.2: Towards Organized Responsibility (Author's Image)

7.3.1. Dogma of Growth

The focus of the Netherlands has always been on preventing floods. The importance of this is indisputable, as failure would have enormous consequences. Nonetheless, the strong flood risk alleviating capabilities in the Netherlands has led to a protection paradox which has caused essential stakeholders to lack the incentive to pay attention to flood safety and disaster preparedness on a smaller scale. It is argued that there is a dogma within growth in the Netherlands, as the areas with the lowest elevation are the most densely populated. This area is known as the Randstad, consisting of 25% of the space, where 60% of the residents live. Moreover, the ongoing aspiration is to persist with increasing the number of houses within the low-lying areas of the Netherlands.

Perhaps, we should rethink the use of land within the Netherlands and seize additional buildings in flood plains to focus on how to protect the existing real estate. This contradicts other problems within the Netherlands, such as the housing shortage Netherlands (Verheul & Hobma, 2022); however, perhaps this should be alleviated by rethinking how we live and use space (e.g.,co-living), potentially thereby even enhancing the social cohesion (Corfe, 2019). Moreover, growth in itself can be observed as a dogma, as the Netherlands continuously wants to grow its economy, which requires more people and emissions, further enlarging flood risks (Stoddard et al., 2021). It could thus be argued that in order to alleviate flood risks, it is time to seize or reduce the endless ambition of economic growth.

> "No country in the world would build 9 meters below sea level" (Redactie Waterform, 2021)

Awareness that the climate is changing and increasing flood risks is settling in. However, when choices between the current housing crisis or potential future flood risks have to be made, flood risks are not yet prioritized. An example is the Zuidplaspolder, located 9 meters below sea level, where an entirely new village of 8000 homes is planned (Redactie Waterform, 2021). Should we continue to build in the low-lying areas of the Netherlands, as this construction is a solution to other (currently more urgent) issues within the Netherlands, or should we decide not to risk it? Is the Zuidplaspolder chosen because it is safe or to solve a more urgent crisis for the government right now?

7.3.2. From profit to value

A mismatch was noted in the timelines and responsibilities within the real estate industry, leading to organized irresponsibility. The initiators of projects do not have to bear the risks of constructing something within a floodplain and therefore have a short-term focus. Maybe we should shift from making short-term profits to creating value by obligating the initiator that reaps the profit to bear responsibility in the next fifty years so they are incentivized to develop in such a way that the real estate has long-term value.

Moreover, as mentioned earlier, in current practice within the Netherlands, risks are defined by the scenario, the probability, and the damages (Jongejan & Maaskant, 2015). To shift from profit toward value, perhaps our definition of damage should incorporate the socio-economic vulnerabilities assessed within this research, potentially enhancing social cohesion and preventing climate gentrification in the future. Social values could subsequently be improved within the shift from profit to value, and organized irresponsibility may be reduced.

7.3.3. Taking charge

Organized irresponsibility and high levels of trust in the existing infrastructures seemingly have led people not to prioritize water safety in projects. Moreover, stakeholders appear to be inclined to look at others to alleviate potential risks within the Netherlands. Even though the future is full of uncertainties, the well-established institutional framework of the Netherlands may be leveraged to reduce the devaluation of real estate due to flood risks. A new insurance tool could prove beneficial. However, many pitfalls and drawbacks exist before arriving at a new product. Although all stakeholders are needed to successfully alleviate the risk of real estate devaluation due to floods, to incentivize each stakeholder, a leader seems to be required. The results of this research allude to the fact that it may be crucial for the government to take charge.

Maybe, for now, the focus should be on enhancing awareness of both our definition of vulnerability and the consciousness of every Dutch person. Additionally, the government could implement the carrot and stick policies, in which we are both steered towards and rewarded for taking responsibility, even if this entails that everybody has to give in a little bit. Lastly, the responsibilities for alleviating flood risks are currently the sole responsibility of public authorities. This study hints toward adopting a multi-actor governance system, as the current system has led to limited contributions by other stakeholders.

7.4. Limitations & Strengths

When reflecting on the used research design, methods, and completeness of this research, both limitations and strengths can be debated. In this section, first, the limitations will be elucidated. Subsequently, the strengths and added value to existing literature are highlighted.

7.4.1. Limitations

Like all studies, this research has limitations. Due to time restrictions, the scope of this study had to be defined, and aspects had to be deliberately excluded from the scope.

First, the chosen indicators for vulnerability are neither subjective nor comprehensive. The author has chosen indicators to define vulnerability and facilitate assessing the study case but is aware that other indicators could have been included. Specific indicators used throughout this study might have been neglected in other studies. Second, although the weighting of the indicators was checked for robustness, many additional methods exist within the literature to conduct the weighting in a statistical way, which may have led to different outcomes and vulnerability index rates. Third, as the leveraged CBS data was not exhaustive, the unconditional mean was used for missing data points. This might have influenced the socio-economic vulnerability scores as well as the total vulnerability scores.

Fourth, the number of exploratory interviews does not allow for validating the barriers, stimuli, and enablers. However, the interviews allowed for identifying common barriers, stimuli, and enablers in practice and enabled the author to place the real estate devaluation problem in the complex perspective of the real estate world. Fifth, in addition to the previous limitation, by including diversity in the interviewed stakeholders (e.g., small vs. large municipalities, different government departments), their differing views might have led to different input and, therefore, different outcomes for the stakeholder

analysis. Sixth, the selected stakeholders are not exhaustive; other stakeholders could have been included. If other stakeholders had been included, other barriers, stimuli, and enablers might have been identified, leading to potential alterations in the analysis and the subsequent conclusion.

Seventh, the method leveraged for identifying the barriers, stimuli, and enablers within the interviews (Qualitative Content Analysis) has the embedded risk that the researcher can influence the results due to the choice of codes which may result in bias in the outcomes. In addition to the previous limitation, the researcher was already of the opinion that flood risk is an important matter that should be incorporated more into practice due to previous experiences, studies, and background. The results may therefore be biased and could have been different if the analysis was conducted by someone more skeptical towards climate change and its subsequent impact.

Finally, within the interview part of the stakeholder analysis, it was chosen to exclude residents. This can possible have resulted in neglecting experienced barriers, stimuli, and enablers of residents in the Dutch practice. In future research, the stakeholder 'resident' should be attempted to be included in the interviews. This category is complex as one resident does not necessarily reflect an entire stakeholder group, and ethically conducting an interview with a resident is more complex.

7.4.2. Strengths

In contrast to its limitations, this research has characteristics that can be considered strengths and subsequently as an added value to the existing literature.

First, this research has applied and considered both a market as the managing side of the devaluation of real estate, thus trying to recognize the complexity of real estate depreciation due to floods. Assuming only the market or the managing side of the topic, either the impact of perception and vulnerability or the influence of stakeholders on retaining the value of real estate may have been neglected. This could have resulted in an incomplete understanding of the issue's complexity.

Second, this research has attempted to acknowledge the elaborateness of defining flood vulnerability and the need to look at different scales when evaluating flood vulnerability. Thus, this research has aimed to contribute to understanding flood vulnerability. Moreover, this research had the objective to enhance our understanding of how we can combine flood vulnerability with existing economic models that aim at understanding the relationship between floods and real estate values. In addition to other studies, this research has attempted to apply and construct an integrative approach, combining the subset of knowledge on vulnerability in the academic literature.

Third, by applying mixed methods (i.e., quantitative and qualitative), this research intended to highlight the need for approaches and understanding of the subject that integrate the different levels of detail. Through exploring the scales of economic models, the usage of parameters within these models (i.e., vulnerability), and the larger scale management of the risks, this study may have contributed to existing knowledge by exploring potential mismatches between the current application of the subset of the layers of economic models, flood vulnerability and risk governance.

8

Conclusions & Recommendations

Due to climate change, the global sea level is rising, and weather patterns are becoming more extreme. A country vulnerable to these changes is the Netherlands, a low-lying delta. Moreover, the significant mortgage-to-debt-to-GDP in the Netherlands leads to exposure of householder default in case of a large-scale flood event. Effective water management to prevent floods is thus vital for the Netherlands. The main aim of this research was to understand the impact of floods on residential real estate values and the actions that can contribute to protecting their stability. Moreover, as this is a complex and sensitive subject, this research tried to acknowledge the variety of factors affecting flood vulnerability. This chapter will answer the primary research question and associated sub-questions guiding this research. Additionally, in section 8.3, suggestions for future research will be given.

This research applied quantitative and qualitative methods and explored a variety of subjects linked to the main subject. As a consequence of the complexity of the main subject, the research scope is wide and entails different aspects. However, it is fundamental to note how the aspects are related. The aspects studied within the research are as follows: (1) *State-of-the-art models:* an assessment of models frequently used in literature to assess the impact of floods with their subsequent advantages and limitations, (2) *Flood Vulnerability:* defining and assessing the vulnerability of the case study Maastricht, (3) *Flood Risk Governance:* evaluating the barriers, stimuli, and enablers of stakeholders concerning flood risks in real estate through literature and exploratory interviews and examining opportunities.

8.1. Conclusion research sub-questions

Within this section, the four research sub-questions are answered. The individual answers to the research sub-questions have cumulatively allowed for answering the primary research question.

1) What are the state-of-the-art models that describe the relationship between flood risk and real estate value?

Two main streams of methods exist to assess the influence of flood risk on real estate values. These methods are stated and perceived preference methods. The stated method leverages the view of residents (e.g., through interviews). In contrast, the perceived preference utilizes the revealed preference (e.g., what do we see in reality?) primarily through transactional data. Numerous approaches to examine the perceived preference are available. The assessed methods and their subsequent explanation, advantages, and limitations have been summarized in Table 8.1.

Method	Explanation	Advantage	Limitation
Hedonic Price Models	- Break down characteristics and estimate monetary value of each characteristic	- Extrapolate effect of every attribute on value - Widely used in literature	- Non-inclusion tax and interest rates - Definition many variables - Detailed data required - Chance of misspecification
Difference-in-Difference	- Compare certain groups that are exposed to different treatments (e.g. control group and intervention group)	- Extrapolate single attribute	- Assumes spatial independence - Assumes groups to be equal without treatment
Repeat-sales Method	- Comparing different sales on same property	- Less specific characteristics data required	- Only yields price ranges - Property needs to be sold twice since event
Willingness-to-pay	- Assess the additional amount an individual would pay for something	- Quantify impact of preventive measures	- Requires price variations - No possibility to assess new products
Regression Discontinuity	- Analyze candidate/object for a treatment on the basis of arbitrary threshold value	- Requires less assumptions - No detailed data required	- Possible endogenous problems - Difficult to distinguish characteristics - Weak statistical power - Can only assess mean effects on object around threshold
Spatial Regression Model	- Spatial weighted matrix to assess the presence of systematic spatial distribution	- Improves consistency - Does not assume independent observations	- Forces a continuous pattern onto the spatial arrangement of an area - Requires complete, detailed data set

Table 8.1: State-of-the-art models review

2) What is the most appropriate model to evaluate flood risk impact for the case study Maastricht?

Although all methods possess aspects that could be beneficial to assess flood risks, it was concluded that the Hedonic Price Model and the Spatial Regression Model would be most suitable for assessing future flood vulnerability in the case study due to their capability to assess and extrapolate the effects of environmental disasters in hypothetical scenarios when detailed data is available.

In addition, the difference-in-difference method is deemed most suitable for assessing past risks in the case study due to its capability to infer a single attribute over time. This technique can compare groups that have experienced a different treatment (e.g., flooded or not flooded). Furthermore, employing multiple methods can contribute to yielding robust results. However, an important implication within this answer is that the most suitable method depends on the data available to the researcher, the level of granularity of this data, and the specific parameter that the researcher aims to assess. It could therefore be argued that the "most" appropriate model thus does not exist, whereas it can be concluded that every model has its advantages for specific studies.

3) How can future flood risks and vulnerability levels be defined and considered in residential real estate in the case study?

For the first part of the research sub-question (*"How can future flood risks and vulnerability levels be defined"*) utilizing literature, a framework was constructed to define "flood vulnerability." The categories influencing vulnerability were socio-economic (i.e., social, economic, and demographic), disaster-bearing capabilities, and flood exposure. A visual representation of the framework is presented in Figure 8.1.

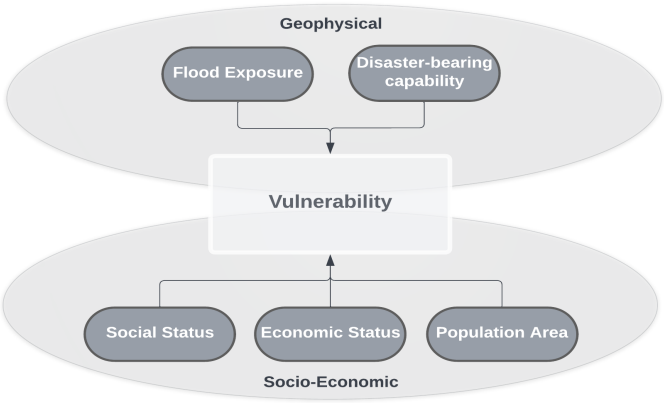
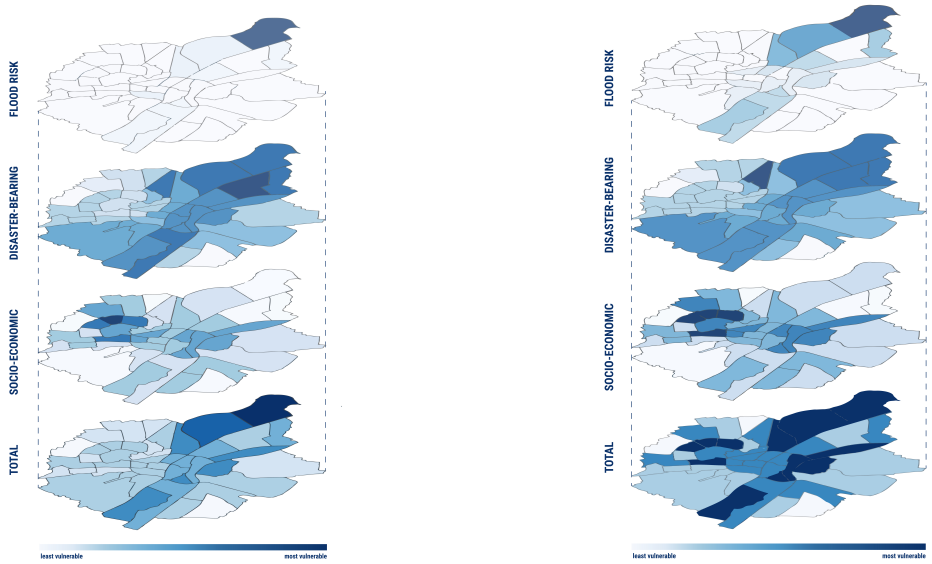


Figure 8.1: Vulnerability Factors (Author's Image)

The sixteen indicators within the categories were defined as population density, age, dependent people, financial aid, income, unemployment, education, gender, foreign population, rental housing, soil capacity, building year, property type, flood risk, inundation depth, extreme flood risk, and extreme inundation depth.

When exclusively examining the flood exposure of the case study (i.e., flood chance and inundation depth), the vulnerable neighborhoods were densely clustered near the river. Adding socio-economic and disaster-bearing capabilities indicators significantly impacted the neighborhoods' final flood vulnerability scores. Subsequently, a shift was perceived from vulnerable areas adjacent to the river to a more dispersed vulnerability pattern by adding socio-economic and disaster-bearing capabilities indicators. Within the statistical weighing, neighborhoods adjacent to the river were primarily considered vulnerable. The vulnerability levels were more scattered within the equal weighting, as seen in Figure 8.2.

Thus, the third sub-question can be answered by concluding that vulnerability levels can be defined by analyzing a subset of indicators of socio-economic, disaster-bearing capability, and flood exposure vulnerabilities. Within the case study Maastricht, the vulnerable areas were concluded to be located adjacent to the Meuse, in Maastricht-west and Maastricht-Oost.



Total Vulnerability Scores with statistical weighing

Flood Vulnerability Scores with equal weighing

Figure 8.2: Vulnerability Scores Axonometry (Author's Image)

4) How can relevant stakeholders contribute to keeping residential property values stable?

A framework by Graaskamp (1992) was altered and adapted to enable answering the fourth sub-question. The barriers, stimuli, and enablers of seven chosen stakeholders (i.e., insurers, financial institutions, investors, developers, residents, government, and municipality) were assessed through literature and semi-structured exploratory interviews. The complete overview of the coding assessment conducted to arrive at the barriers, stimuli, and enablers is given in Appendix E.

Subsequently, the barriers were coupled with the enablers, after which opportunities and the main implications for managing flood risks for the assessed stakeholders were explored. These opportunities can be summarized as follows:

- **Enhance Awareness:** due to a lack of awareness, the risks of flooding in an area are frequently (partly) neglected or assumed to be taken care of by other stakeholders. Developers and residents have been established to primarily experience this barrier. Moreover, the general risk awareness in the Netherlands is seemingly low. The government, municipalities, insurers, and financial institutions could be vital in enhancing awareness and causing subsequent adaptive action through regulation (e.g., through a waterlabel) or economic incentives (e.g., subsidies),
- **Collaborate and Uniformize:** transparency between stakeholders and effective communication can enable cooperation and reduce the experienced barrier of complexity due to regulations and laborious processes in the Netherlands. Stakeholders that experience regulation as a limitation were identified as investors and developers. Additionally, straightforward communication can be facilitated through a shared comprehension of risk levels. Lacking uniformity seemed to pose a barrier for financial institutions. To reduce this barrier, collaboration of all assessed stakeholders in which the government might be central could prove beneficial,
- **Knowledge as a common good:** knowledge of flood risks seems to be a commercial commodity currently, whereas flood risks are undeniably a collective issue. The varied range of expertise and knowledge between stakeholders could complement each other, reducing the uncertainties and interdependencies within flood risks. For example, developers, residents, and municipalities appeared to depend on the government for flood safety or regulation. All stakeholders were found to experience a form of limited capabilities as a barrier, in which limited knowledge resources might be alleviated through knowledge sharing. Subsequently, by economic incentives, stakeholders such as investors, the government, or municipalities were identified as having the capacity to alleviate the barrier of limited financial resources,

- **Divide and Conquer:** ambiguity in task divisions and organized irresponsibility seemingly lead to flooding risks receiving a low priority. Stakeholders who were found to experience the lack of priority as a barrier were investors, developers, the government, and municipalities. Clarifying task division, multi-actor engagement, and incentives to integrate flood risks could potentially alleviate the barrier of lack of priority. The most critical stakeholder in enabling the aforementioned incentives was concluded to be the government by regulation (e.g., through the Building Decree). Additionally, financial institutions and insurers could contribute to prioritizing flood risks for stakeholders by expressing the importance of flood risks via position papers.

Thus, the answer to the research sub-question can be summarized as, although the interrelations are complex, the assessed stakeholders can play a role to managing residential property values in two ways. On the one hand, they can contribute by recognizing their potential to make a positive impact and taking responsibility. On the other hand, the subset of stakeholders can contribute by incentivizing other stakeholders to act similarly through collaboration, economic (dis)incentives, diminishing risks, enhancing awareness, regulation, and discouraging. Fundamental to the role of stakeholders in maintaining the stability of residential real estate values are the importance of cooperation, transparency, and the central role of the Dutch government in creating incentives to alleviate the experienced barriers.

8.2. Conclusions main research question

This thesis had the aim of answering the following main research question:

How can the impact of flood vulnerability on residential real estate values be assessed, and how can stakeholders contribute to maintaining the stability of residential property values?

To answer this question, quantitative and qualitative methods have been applied. First, the state-of-the-art models were assessed through an academic literature review. Second, a vulnerability framework was constructed through a literature review and applied to the case study through quantitative data analysis. Third, through qualitative research, the role and potential contribution of stakeholders were evaluated.

This research has highlighted that the potential devaluation of real estate due to floods could have a prominent role within the practice of many of the assessed stakeholders as well as the Dutch economy. Still, methods to assess the risks and subsequent devaluation seem to be in their infancy. Moreover, accessible models that integrate flood risks with an assessment of potential value decline seem yet to be developed.

The central question of this research can be answered by concluding that the impact of flood vulnerability can be assessed through several economic theories, in which the definition of vulnerability and the chosen indicators are vital. Furthermore, the definition and usage of parameters within these models and the level of detail within the dataset influence the subsequent outcomes of the models and should thus be carefully considered.

Moreover, it was concluded that solely considering flood exposure (i.e., chances/water-depth of flooding) when defining vulnerability may be too narrow to construct an integral assessment of flood vulnerability. This research concluded that incorporating socio-economic and disaster-bearing indicators significantly impacts the total flood vulnerability. The definition of flood vulnerability should therefore be carefully defined and evaluated to avoid skewed or incomplete outcomes within the assessments of the relationship between residential real estate values and flood vulnerability.

Additionally, stakeholders might contribute to protecting the value of the residential real estate by actively adapting to flood risks and incentivizing each other towards similar behavior. Incentivizing each other can ostensibly be achieved through enhancing awareness, economic (dis)incentives, diminishing risks, regulation, discouraging, and collaboration.

When considering the role of stakeholders in maintaining the stability of residential property values, this research advocates that devaluation risks might be reduced through cooperation, long-term commitment of involved stakeholders, and taking ownership of the risks. Moreover, this research hints towards a vital role for both the government and insurers within the practice in the Netherlands. Finally, integrative solutions and divided responsibilities could ease pressure on the Dutch real estate system.

8.3. Recommendations

Looking back at the process, boundaries had to be set, excluding certain aspects of the complex topic. Within the following section, recommendations for future research will be presented.

8.3.1. Linear regression on transactional data

Future research could leverage transactional data on residential real estate to assess if connections exist between the defined flood vulnerability levels within the case study and the subsequent values of local residential real estate. As an addition to this research, the vulnerability index constructed in this thesis could be applied to property level. Thereafter, one of the state-of-the-art models could be used to assess if correlations exist between the total vulnerability and the value of a property. Primarily the hedonic pricing or spatial regression models would be suitable to apply in combination with the constructed vulnerability framework. Subsequently, the relation could be assessed through a linear regression with the determining parameter of "flood vulnerability" to see the impact of flood vulnerability levels on local residential real estate values.

8.3.2. Validating interviews stakeholders

Future research could validate the assessed barriers, stimuli, and enablers by conducting validating interviews with diverse types of the assessed stakeholders and either confirm or disprove the proposition derived from the analysis in this research. Additionally, including residents within the interviews through, for example, a local housing corporation or selection of residents that live in areas with different vulnerabilities could confirm or disprove the residents' perspective as concluded within this research. Moreover, additional data may be retrieved by increasing the perspectives considered in this research, after which the stakeholder analysis can be enhanced. An interesting addition to this research could be to organize a workshop with all stakeholders to assess the interaction and trigger awareness.

8.3.3. Implications on the Dutch practice

Within this research, the aim has been to identify opportunities to alleviate barriers that stakeholders experience when incorporating flood risks in practice. Future studies could assess the regulatory framework of the Netherlands and provide policy suggestions on how to implement the outcomes of this research. Moreover, research into multi-actor engagement and best practice experiences from other countries could prove beneficial within this assessment.

8.3.4. Multiple case studies

Future research could focus on applying the framework to several case studies to validate the vulnerability index constructed for this research. Moreover, considering case studies with different socio-economic and geographic gradients might enforce the framework's implications. Subsequently, the results of the divergent set of multiple case studies could be compared, after which deficiencies within the framework could be assessed, resulting in an enhanced framework that could potentially be leveraged in practice. Applying the constructed framework to case studies that are more socially and physically vulnerable could highlight its importance and potential deficiencies in current strategies.

8.3.5. Vulnerability assessment in practice

The link between the vulnerability framework in theory and flood-alleviating measures in practice could be assessed in additional research. This could be done by considering the actions and strategies of stakeholders such as municipalities or the government throughout qualitative research. The approach and strategies to alleviate flood risks could be studied within this assessment. The importance and subsequent implications of socio-economic factors within these strategies could be assessed throughout, for example, land use planning.

8.3.6. Application of economic models and data use stakeholders

Future research could explore in depth the different stakeholders' data sources. The different outcomes could be assessed by understanding the different data sources to move toward uniformity in flood scenarios between stakeholders. Moreover, by evaluating in what stadium their models are to assess the impact of floods on real estate and comparing the subset of these models, future research could contribute to an integral model accessible to all stakeholders.

9 Reflection

Within this final chapter, the researcher and writer of this report will share the researcher's perspective of this research topic as developed throughout the research, elaborate on the personal process, and finally reflect on the used research design and methods.

9.1. Researcher Perspective

Within this research, it appeared to me that perception is fundamental in our understanding of flood risks. When assessing the effect on values, the issue of devaluation due to floods might initially be negligible if people do not believe flood events will happen. One might wonder why society would be hesitant to fully comprehend the effects of floods. Potentially, this can be attributed to a phenomenon such as a flood event being force majeure. On an individual level, residents may be rendered powerless against flooding. Worrying about something we have a limited ability to influence might feel ineffectual.

However, within the conducted research, it became clear to me as a researcher that this might clash with an observed phenomenon relating to flood risks. Namely, flood preparedness might require the input and cooperation of every stakeholder on all levels, including residents. This can be explained as the government being limited in its influence, as decisions on housing levels have to be made by residents themselves. Another observation throughout the research was that in academic literature, the human side of flood issues is easily neglected in economic models. I would argue this is not because it is thought to be unimportant. The reason, in my perspective, might be that it entails ambiguity and adds complexity to an already difficult issue. Moreover, human behavior can be unpredictable in some cases, thus, potentially more challenging to quantify.

After conducting the research, I would argue that the core of the complex issue of floods' effects on real estate values is tripartite. First, a mismatch seems to exist between flood risks being the sole responsibility of public authorities within the Netherlands and the need for active cooperation of stakeholders on all levels. Second, flood risks being the sole responsibility of the government seems to have led to a passive attitude of other stakeholders. This behavior is seemingly reinforced through the limited level of flood risk perception in the Netherlands, combined with the hesitation of stakeholders to embrace the urgency of the issue and subsequently own the risks. The joint effect of these observed occurrences results in organized irresponsibility - everyone contributes to the issue of rising risks, and everyone wishes to diminish the risk, but no one desires the responsibility.

The available evidence in this research suggests that in the current system in the Netherlands, stakeholders are only incentivized to a limited extent to adapt actively. Moving forward, I consider the sequence in which the government acts to be vital in moving toward alleviating organized irresponsibility and improving flood awareness. Thus, when taking the example of introducing a waterlabel, I believe this should be done in close collaboration with stakeholders such as insurers and financial institutions. Namely, by first ensuring people are able to insure their properties, the devaluing of real estate through the implementation of water labels may be prevented. In addition, the stakeholder' timelines and subsequent responsibilities can further evolve into complex challenges as the initiators do not experience the downsides of building in risky areas. In outlook to the future, I feel this research demonstrated that constructing or altering regulations so it effectively challenges and incentivizes all involved stakeholders to adapt actively requires additional research.

Third, the economic models currently being leveraged to understand the potential adverse effects of flood events on real estate values focus on flood scenarios. These flood risk scenarios are already ambiguous and, therefore, challenging. However, I believe a mismatch might exist between the applied definition of flood risk in theory in academic literature and the implications of total flood vulner-

ability in practice. Essentially, it could be considered that a neighborhood's resilience influences its attractiveness and thus can influence the real estate values of the properties within this. Based on my understanding of the evidence, it seems there are possibilities to integrate flood vulnerability in the used economic models. I believe the scientific momentum might be moving towards integrating the assessed subset of aspects when considering the effect of floods on real estate values. Moreover, an accessible tool to understand the flood risks and their subsequent effect on real estate seems missing for stakeholders; my expectations are that the market will progress in developing readily accessible methods as the demand will most likely continue to increase.

9.2. Personal Process

In retrospect, I believe that my perspective lacked a full comprehension of the complexity of the effects of floods on our built environment, specifically the real estate values, at the start of this research. Throughout the process, I learned that the relationship between flooding and real estate values could be ambiguous. Flooding does not exclusively entail damage and, therefore, potential devaluation, but many more factors also come into account when attempting to understand the effects of flood events. Throughout this research, I was able to develop a more integrative understanding of the complexity of the effects of climate change on real estate- and that the topics discussed within this research are only the tip of the iceberg.

Additionally, I was capable of experiencing the value of evaluating topics through different methods, scales, and perspectives. Both assessing the flood vulnerability (i.e., the scale of humans, houses, and neighborhoods) and the structure of this research (i.e., the scale of parameters, economic model, and stakeholders) taught me the importance and potential value of an integrative approach within research. In the future, I am keen to apply this integrative view on issues critically- are we considering all the important aspects of this issue, and how can we combine different perspectives? Moreover, I encountered the interesting challenge of employing both quantitative and qualitative measures and combining them and discovered the complexity of integrating different methods.

9.3. Research Design & Methods

During the process of this research, agility was required as the research differed from the design and applied methodologies that were initially constructed. The data required to execute the original research proposal was unavailable to me, making the quantitative analysis to assess the relation between flood vulnerability and real estate transactions in the case study that was initially planned unfeasible. To some extent, this was a disappointment at the outset. In retrospect, obtaining the data was more difficult than expected. However, this showed me the importance of thoroughly investigating the availability of resources needed for research before advancing.

Moreover, it turned out it was also an opportunity. By re-framing the research design, applying mixed methods was required, which allowed me to gain a bit more understanding of the complexity of the topic. Using mixed methods allowed me to reflect on the importance of stakeholder behavior and simultaneously on the complexity of quantifying the effects of flooding on real estate values.

As mentioned by Ivankova and Wingo (2018), an advantage of applying mixed methods can be "a comprehensive assessment of a problem from different perspectives.". Likewise, throughout the research, I experienced using mixed methods as an effective advantage in acknowledging and understanding the variety of perspectives on the risk of devaluation of real estate due to flooding.

In retrospect, applying mixed methods may have proved more educational than the original research proposal. However, a disadvantage I experienced within this research is that the combination of methods limited the extent to which both methods were applied as the time and attention had to be divided. Therefore, there was limited space to dive into the details of both analyses (e.g., what regulations on flood risks are in place in the Netherlands and what additions could there be?).

References

Abebe, Y. A., Ghorbani, A., Nikolic, I., Manojlovic, N., Gruhn, A., & Vojinovic, Z. (2020). The role of household adaptation measures in reducing vulnerability to flooding: A coupled agent-based and flood modelling approach. *Hydrology and Earth System Sciences*, *24*(11), 5329–5354.

Adnan, M. S. G., Abdullah, A. Y. M., Dewan, A., & Hall, J. W. (2020). The effects of changing land use and flood hazard on poverty in coastal bangladesh. *Land Use Policy*, *99*, 104868.

Aerts, J. C., & Botzen, W. W. (2011). Climate change impacts on pricing long-term flood insurance: A comprehensive study for the netherlands [Symposium on Social Theory and the Environment in the New World (dis)Order]. *Global Environmental Change*, *21*(3), 1045–1060. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2011.04.005

Al-Bassam, A. M., Zaidi, F. K., & Hussein, M. T. (2014). Natural hazards in saudi arabia. *Extreme natural events, disaster risks and societal implications*, 243–251.

Anguelovski, I., Connolly, J. J., Pearsall, H., Shokry, G., Checker, M., Maantay, J., Gould, K., Lewis, T., Maroko, A., & Roberts, J. T. (2019). Why green "climate gentrification" threatens poor and vulnerable populations. *Proceedings of the National Academy of Sciences*, *116*(52), 26139–26143.

Ann Conyers, Z., Grant, R., & Roy, S. S. (2019). Sea level rise in miami beach: Vulnerability and real estate exposure. *The Professional Geographer*, *71*(2), 278–291.

Anne-Marie Bor, J. D., & Hertog, I. M. (2021). Nederland klimaatbestendiger maken: Welke rol spelen financiële instellingen? en welke kansen liggen er in samenwerking met overheden?

Anonymus, A. (1995). Druk op de dijken 1995: De toestand van de rivierdijken tijdens het hoogwater van januari-februari 1995. *TAW publicatie*.

Anselin, L. (2002). Under the hood issues in the specification and interpretation of spatial regression models. *Agricultural economics*, *27*(3), 247–267.

APG. (2018). *"responsible investment report"*. https://apg.nl/media/0yyly5wu/responsible-investment-report-apg-2018_2-1.pdf

Arjen Schreuder. (2022). *(onderzoek naar invoering verplicht waterlabel voor woningen)*. Retrieved March 12, 2022, from (https://www.nrc.nl/nieuws/2022/12/20/onderzoek-naar-invoering-verplicht-waterlabel-voor-woningen-a4152072)

Aroca-Jiménez, E., Bodoque, J. M., & García, J. A. (2020). How to construct and validate an integrated socio-economic vulnerability index: Implementation at regional scale in urban areas prone to flash flooding. *Science of the Total Environment*, *746*, 140905.

Asselman, (van Heeringen, K., de Jong, J., & Geertsema), T. (2022). *Juli 2021 overstroming en wateroverlast in zuid-limburg* (tech. rep.). Deltares. https://www.valkenburg.nl/data/downloadables/8/0/2/juli_2021_overstroming_en_wateroverlast_in_zuid-limburg.pdf

Atreya, A., & Czajkowski, J. (2019). Graduated flood risks and property prices in galveston county. *Real Estate Economics*, *47*(3), 807–844.

Atreya, A., & Ferreira, S. (2015). Seeing is believing? evidence from property prices in inundated areas. *Risk Analysis*, *35*(5), 828–848.

Atreya, A., Ferreira, S., & Kriesel, W. (2013). Forgetting the flood? an analysis of the flood risk discount over time. *Land Economics*, *89*(4), 577–596. Retrieved November 1, 2022, from http://www.jstor.org/stable/24243692

Attoh, E. M., de Bruin, K., Goosen, H., van Veldhoven, F., & Ludwig, F. (2022). Making physical climate risk assessments relevant to the financial sector – lessons learned from real estate cases in the netherlands. *Climate Risk Management*, *37*, 100447. https://doi.org/https://doi.org/10.1016/j.crm.2022.100447

Bagstad, K. J., Stapleton, K., & D'Agostino, J. R. (2007). Taxes, subsidies, and insurance as drivers of united states coastal development [Ecological Economics of Coastal Disasters]. *Ecological Economics*, *63*(2), 285–298. https://doi.org/https://doi.org/10.1016/j.ecolecon.2006.09.019

Bakkensen, L. A., & Barrage, L. (2022). Going underwater? flood risk belief heterogeneity and coastal home price dynamics. *The Review of Financial Studies*, *35*(8), 3666–3709.

Baldauf, M., Garlappi, L., & Yannelis, C. (2020). Does Climate Change Affect Real Estate Prices? Only If You Believe In It. *The Review of Financial Studies*, *33*(3), 1256–1295. https://doi.org/10.1093/rfs/hhz073

Baptista, S. R. (2014). Design and use of composite indices in assessments of climate change vulnerability and resilience. *The Earth Institute, Columbia University: New York, NY, USA*.

Battistin, E., & Rettore, E. (2008). Ineligibles and eligible non-participants as a double comparison group in regression-discontinuity designs [The regression discontinuity design: Theory and applications]. *Journal of Econometrics*, *142*(2), 715–730. https://doi.org/https://doi.org/10.1016/j.jeconom.2007.05.006

Beck, J., & Lin, M. (2020). The impact of sea level rise on real estate prices in coastal georgia. *Review of Regional Studies*, *50*(1), 43–52.

Becketti, S. R. (2021). The impact of climate change on housing and housing finance. *Available at SSRN 3929571*.

Beierle, T. C. (2002). The quality of stakeholder-based decisions. *Risk Analysis: An International Journal*, *22*(4), 739–749.

Beltrán, A., Maddison, D., & Elliott, R. (2019). The impact of flooding on property prices: A repeat-sales approach. *Journal of Environmental Economics and Management*, *95*, 62–86. https://doi.org/https://doi.org/10.1016/j.jeem.2019.02.006

Beltrán, A., Maddison, D., & Elliott, R. J. (2018). Is flood risk capitalised into property values? *Ecological Economics*, *146*, 668–685.

Bennett, A. (2004). Case study methods: Design, use, and comparative advantages. *Models, numbers, and cases: Methods for studying international relations*, *2*(1), 19–55.

Bernstein, A., Gustafson, M. T., & Lewis, R. (2019). Disaster on the horizon: The price effect of sea level rise. *Journal of Financial Economics*, *134*(2), 253–272. https://doi.org/https://doi.org/10.1016/j.jfineco.2019.03.013

Bin, O., Crawford, T. W., Kruse, J. B., & Landry, C. (2008). (viewscapes and flood hazard: Coastal housing market response to amenities and risk). *Land Economics*, *84*(3), 434–448. https://EconPapers.repec.org/RePEc:uwp:landec:v:84:y:2008:i:3:p:434-448

Bitter, C., Mulligan, G. F., & Dall'erba, S. (2007). Incorporating spatial variation in housing attribute prices: A comparison of geographically weighted regression and the spatial expansion method. *Journal of geographical systems*, *9*, 7–27.

Boruff, B. J., Emrich, C., & Cutter, S. L. (2005). Erosion hazard vulnerability of us coastal counties. *Journal of Coastal research*, *21*(5), 932–942.

Bosker, M., Garretsen, H., Marlet, G., & van Woerkens, C. (2019). Nether lands: Evidence on the price and perception of rare natural disasters. *Journal of the European Economic Association*, *17*(2), 413–453.

Botzen, W. J., Aerts, J., & van den Bergh, J. C. (2009). Dependence of flood risk perceptions on socioeconomic and objective risk factors. *Water resources research*, *45*(10).

Brilly, M., & Polic, M. (2005). Public perception of flood risks, flood forecasting and mitigation. *Natural Hazards and Earth System Sciences*, *5*(3), 345–355. https://doi.org/10.5194/nhess-5-345-2005

Bruin, K. d., Romain, H., Evain, J., Clapp, C., Dahl, M. S., & Bolt, J. (2019). Physical climate risk: Investor needs and information gaps. *CICERO Report*.

Bubeck, P., Dillenardt, L., Alfieri, L., Feyen, L., Thieken, A. H., & Kellermann, P. (2019). Global warming to increase flood risk on european railways. *Climatic Change*, *155*, 19–36.

Buckman, S. T., & Sobhaninia, S. (2022). The impact of sea-level flooding on the real estate development community in charleston sc: Results of a uli member survey. *Journal of Sustainable Real Estate*, *14*(1), 4–20.

Bulmer, E., & del Prado-Higuera, C. (2021). Revitalizing the global alliances for sustainable development: Analyzing the viability of sustainable development goal 17—a multi-actor governance approach. *Sustainability*, *13*(8), 4247.

Bunten, D. M., & Kahn, M. E. (2017). Optimal real estate capital durability and localized climate change disaster risk. *Journal of Housing Economics*, *36*, 1–7.

Caloia, F., & Jansen, D.-J. (2021). Flood risk and financial stability: Evidence from a stress test for the netherlands.

Card, D., & Krueger, A. B. (1993). *Minimum wages and employment: A case study of the fast food industry in new jersey and pennsylvania* (Working Paper No. 4509). National Bureau of Economic Research. https://doi.org/10.3386/w4509

CBS. (2022). *Lage inkomens grens*. (https://www.cbs.nl/nl-nl/onze-diensten/methoden/begrippen/laag-inkomen)

Centraal Bureau Statistiek. (2021). *Opvattingen over klimaatverandering. Centraal Bureau Voor De Statistiek*. Retrieved September 20, 2022, from (https://www.cbs.nl/nl-nl/longread/rapportages/2021/klimaatverandering-en-energietransitie-opvattingen-en-gedrag-van-nederlanders-in-2020/2-opvattingen-over-klimaatverandering)

Centraal Bureau Statistiek. (2022). *Wijk- en buurtstatistieken. Centraal Bureau Voor De Statistiek*. Retrieved September 20, 2022, from (https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/wijk-en-buurtstatistieken)

Chau, K. W., & Chin, T. L. (2002). A critical review of literature on the hedonic price model. *International Journal for Housing Science and Its Applications*, *27*, 145–165. https://ssrn-com.tudelft.idm.oclc.org/abstract=2073594

Clapp, J. M., & Giaccotto, C. (1998). Price indices based on the hedonic repeat-sales method: Application to the housing market. *The Journal of Real Estate Finance and Economics*, *16*, 5–26.

Clayton, J., Devaney, S., Sayce, S., & Van de Wetering, J. (2021). Climate risk and real estate prices: What do we know? *The Journal of Portfolio Management*, *47*(10), 75–90.

Committee on Guidelines Principles for Social Impact Assessment (SIA). (1995). Guidelines and principles for social impact assessment. *Environmental Impact Assessment Review*, *15*(1), 11–43.

Coninx, I., & Bachus, K. (2007). Integrating social vulnerability to floods in a climate change context. *Retrieved April*, *10*, 1–26.

Corfe, S. (2019). Co-living: A solution to the housing crisis. *The Social Market Foundation*.

Cronin, C. (2014). Using case study research as a rigorous form of inquiry. *Nurse researcher*, *21*(5).

Cupal, M. (2015). Flood risk as a price-setting factor in the market value of real property. *Procedia Economics and Finance*, *23*, 658–664.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. In *Hazards vulnerability and environmental justice* (pp. 143–160). Routledge.

Damm, M. (2010). *Mapping social-ecological vulnerability to flooding* (Doctoral dissertation). Universitäts- und Landesbibliothek Bonn.

Daniel, V. E., Florax, R. J., & Rietveld, P. (2009a). Flooding risk and housing values: An economic assessment of environmental hazard. *Ecological Economics*, *69*(2), 355–365.

Daniel, V. E., Florax, R. J., & Rietveld, P. (2009b). Floods and residential property values: A hedonic price analysis for the netherlands. *Built Environment (1978-)*, *35*(4), 563–576. Retrieved October 5, 2022, from http://www.jstor.org/stable/23290004

De Blaeij, A. T., & van Vuuren, D. J. (2003). Risk perception of traffic participants. *Accident Analysis & Prevention*, *35*(2), 167–175.

De Koning, K., & Filatova, T. (2020). Repetitive floods intensify outmigration and climate gentrification in coastal cities. *Environmental research letters*, *15*(3), 034008.

De Nederlandsche Bank. (2017). Waterproof? an exploration of climate-related risks for the dutch financial sector. In *Report*.

Defra, E., & Flood, E. (2003). The appraisal of human-related intangible impacts of flooding. *R&D Project*.

Dinh, Q., Balica, S., Popescu, I., & Jonoski, A. (2012). Climate change impact on flood hazard, vulnerability and risk of the long xuyen quadrangle in the mekong delta. *International journal of river basin management*, *10*(1), 103–120.

Driessen, P. P., Hegger, D. L., Bakker, M. H., van Rijswick, H. F., & Kundzewicz, Z. W. (2016). Toward more resilient flood risk governance. *Ecology and Society*, *21*(4).

ENW. (2021). *Hoogwater 2021, feiten en duiding* (tech. rep.). ENW. file:///C:/Users/vandervl0778/Downloads/211102_enw_hoogwater_2021-dv-def.pdf

European Parliament, C. o. t. E. U. (2020). *Regulation (eu) 2020/852 of the european parliament and of the council* [https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf].

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Social vulnerability indicators in disasters: Findings from a systematic review. *International journal of disaster risk reduction*, *22*, 219–227.

Fazal, M., Panzano, B., & Luk, K. (2020). Evaluating the impact of blended learning: A mixed-methods study with difference-in-difference analysis. *TechTrends*, *64*, 70–78.

Fekete, A. (2010). *Assessment of social vulnerability for river-floods in germany* (Doctoral dissertation). Universitäts-und Landesbibliothek Bonn.

Filatova, T. (2014). Market-based instruments for flood risk management: A review of theory, practice and perspectives for climate adaptation policy. *Environmental science & policy*, *37*, 227–242.

Florax, R. J., Travisi, C. M., & Nijkamp, P. (2005). A meta-analysis of the willingness to pay for reductions in pesticide risk exposure. *European Review of Agricultural Economics*, *32*(4), 441–467.

Forman, J., & Damschroder, L. (2007). Qualitative content analysis. In *Empirical methods for bioethics: A primer* (pp. 39–62). Emerald Group Publishing Limited.

Forrest, S. A., Trell, E.-M., & Woltjer, J. (2021). Emerging citizen contributions, roles and interactions with public authorities in dutch pluvial flood risk management. *International journal of water resources development*, *37*(1), 1–23.

French, N., & Gabrielli, L. (2018). Pricing to market: Property valuation revisited: The hierarchy of valuation approaches, methods and models. *Journal of Property Investment & Finance*.

Fuerst, F., & Warren-Myers, G. (2021). Pricing climate risk: Are flooding and sea level rise risk capitalised in australian residential property? *Climate Risk Management*, *34*, 100361.

Galantino, M. G. (2022). Organised irresponsibility in the post-truth era: Beck's legacy in today's world at risk. *Italian Sociological Review*, *12*.

Gemeente Maastricht. (2022). *Maastricht klimaatatlas*. Retrieved September 20, 2022, from (https : //maastricht.klimaatatlas.net/)

Gerritsen, H. (2005). What happened in 1953? the big flood in the netherlands in retrospect. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *363*(1831), 1271–1291.

Gharbia, S. S., Naughton, O., Farrelly, V., Lyons, R., & Pilla, F. (2016). Attitudes to systemic risk: The impact of flood risk on the housing market in dublin. *2016 18th Mediterranean Electrotechnical Conference (MELECON)*, 1–5.

Gibson, M., & Mullins, J. T. (2020). Climate risk and beliefs in new york floodplains. *Journal of the Association of Environmental and Resource Economists*, *7*(6), 1069–1111.

Giordano, R., Pluchinotta, I., Pagano, A., Scrieciu, A., & Nanu, F. (2020). Enhancing nature-based solutions acceptance through stakeholders' engagement in co-benefits identification and trade-offs analysis. *Science of The Total Environment*, *713*, 136552. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.136552

Graaskamp, J. A. (1992). Fundamentals of real estate development. *Journal of Property Valuation and Investment*, *10*(3), 619–639.

Grases, A., Gracia, V., García-León, M., Lin-Ye, J., & Sierra, J. P. (2020). Coastal flooding and erosion under a changing climate: Implications at a low-lying coast (ebro delta). *Water*, *12*(2), 346.

Greene, G., Paranjothy, S., & Palmer, S. R. (2015). Resilience and vulnerability to the psychological harm from flooding: The role of social cohesion. *American Journal of Public Health*, *105*(9), 1792–1795.

Haasnoot, M., Kwadijk, J., Van Alphen, J., Le Bars, D., Van Den Hurk, B., Diermanse, F., Van Der Spek, A., Essink, G. O., Delsman, J., & Mens, M. (2020). Adaptation to uncertain sea-level rise; how uncertainty in antarctic mass-loss impacts the coastal adaptation strategy of the netherlands. *Environmental Research Letters*, *15*(3), 034007.

Hagenlocher, M., Hölbling, D., Kienberger, S., Vanhuysse, S., & Zeil, P. (2016). Spatial assessment of social vulnerability in the context of landmines and explosive remnants of war in battambang province, cambodia. *International Journal of Disaster Risk Reduction*, *15*, 148–161.

Haining, R. (2001). Spatial autocorrelation. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social & behavioral sciences* (pp. 14763–14768). Pergamon. https://doi.org/https://doi.org/10.1016/B0-08-043076-7/02511-0

Hall, A. (2013). The north sea flood of 1953. *Arcadia*, *5*, 148.

Hallstrom, D. G., & Smith, V. K. (2005). Market responses to hurricanes. *Journal of Environmental Economics and Management*, *50*(3), 541–561. https://doi.org/https://doi.org/10.1016/j.jeem.2005.05.002

Hargrave, M. (2021). *Hedonic pricing*. Retrieved September 20, 2022, from https://www.investopedia.com/terms/h/hedonicpricing.asp

Havekes, H., Koemans, F., Lazaroms, R., Poos, D., & Uijterlinde, R. (2004). Water governance: The dutch water board model. *The Hague: Dutch Association of Water Boards, no year*.

Heffernan, T. W., Daly, M., Heffernan, E. E., & Reynolds, N. (2021). The carrot and the stick: Policy pathways to an environmentally sustainable rental housing sector. *Energy Policy*, *148*, 111939.

Henstra, D., & Thistlethwaite, J. (2017). *Climate change, floods, and municipal risk sharing in canada*. Institute on Municipal Finance; Governance.

Hertin, J., Berkhout, F., Gann, D., & Barlow, J. (2003). Climate change and the uk house building sector: Perceptions, impacts and adaptive capacity. *Building Research & Information*, *31*(3-4), 278–290.

Hidano, N., Hoshino, T., & Sugiura, A. (2015). The effect of seismic hazard risk information on property prices: Evidence from a spatial regression discontinuity design. *Regional Science and Urban Economics*, *53*, 113–122.

Hino, M., & Burke, M. (2021). The effect of information about climate risk on property values. *Proceedings of the National Academy of Sciences*, *118*(17), e2003374118.

Hirsch, J., Braun, T., & Bienert, S. (2015). Assessment of climatic risks for real estate. *Property Management*, *33*(5), 494–518.

Hochstenbach, C., & Aalbers, M. B. (2023). The uncoupling of house prices and mortgage debt: Towards wealth-driven housing market dynamics. *International Journal of Housing Policy*, 1–29.

Hoeksema, R. J. (2007). Three stages in the history of land reclamation in the netherlands. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *56*(S1), S113–S126.

Holand, I. S., Lujala, P., & Rød, J. K. (2011). Social vulnerability assessment for norway: A quantitative approach. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, *65*(1), 1–17.

Hoogwater, T. F. F. F., et al. (2021). Hoogwater 2021 feiten en duiding. *ENW report*.

Inoue, R., & Hatori, K. (2021). How does residential property market react to flood risk in flood-prone regions? a case study in nagoya city. *Frontiers in Water*, 55.

Isa, M., Fauzi, A., & Susilowati, I. (2019). Flood risk reduction in the northern coast of central java province, indonesia: An application of stakeholder's analysis. *Jàmbá: Journal of Disaster Risk Studies*, *11*(1), 1–9.

Ivankova, N., & Wingo, N. (2018). Applying mixed methods in action research: Methodological potentials and advantages. *American Behavioral Scientist*, *62*(7), 978–997.

Jackson, C., & Orr, A. (2021). The embeddedness of sustainability in real estate investment decision-making. *Journal of European Real Estate Research*, *14*(3), 362–380.

Jacob, R., Zhu, P., Somers, M.-A., & Bloom, H. (2012). A practical guide to regression discontinuity. *MDRC*.

Jeugdjournaal. (2021). *'al bijna 13.000 schademeldingen na overstromingen in limburg'*. Retrieved March 9, 2023, from https://jeugdjournaal.nl/artikel/2392629-al-bijna-13-000-schademeldingen-na-overstromingen-in-limburg.html

Johannsdottir, L. (2014). The geneva association framework for climate change actions of insurers: A case study of nordic insurers. *Journal of cleaner production*, *75*, 20–30.

Jongejan, R., & Maaskant, B. (2015). Quantifying flood risks in the netherlands. *Risk Analysis*, *35*(2), 252–264.

Jorissen, R., Kraaij, E., & Tromp, E. (2016). Dutch flood protection policy and measures based on risk assessment. *E3S Web of Conferences*, *7*, 20016.

Karmakar, S., Simonovic, S. P., Peck, A., Black, J., et al. (2010). An information system for risk-vulnerability assessment to flood. *Journal of Geographic Information System*, *2*(03), 129.

Kaufmann, M. (2018). Limits to change – institutional dynamics of dutch flood risk governance. *Journal of Flood Risk Management*, *11*(3), 250–260. https://doi.org/https://doi.org/10.1111/jfr3.12307

Kim, B., & Kim, T. (2016). A study on estimation of land value using spatial statistics: Focusing on real transaction land prices in korea. *Sustainability*, *8*(3), 203.

Kirby, R. H., Reams, M. A., Lam, N. S., Zou, L., Dekker, G. G., & Fundter, D. (2019). Assessing social vulnerability to flood hazards in the dutch province of zeeland. *International Journal of Disaster Risk Science*, *10*(2), 233–243.

Koop, S., Monteiro Gomes, F., Schoot, L., Dieperink, C., Driessen, P., & Van Leeuwen, K. (2018). Assessing the capacity to govern flood risk in cities and the role of contextual factors. *Sustainability*, *10*(8), 2869.

Krokstad, S. (2004). Socioeconomic inequalities in health and disability.: Social epidemiology in the nord-trøndelag health study (hunt), norway.

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. *The Review of Financial Studies*, *33*(3), 1067–1111.

Kyngäs, H., Mikkonen, K., & Kääriäinen, M. (2019). *The application of content analysis in nursing science research*. Springer.

Lee, D. S., & Lemieux, T. (2010). Regression discontinuity designs in economics. *Journal of economic literature*, *48*(2), 281–355.

Li, K., & Li, G. S. (2011). Vulnerability assessment of storm surges in the coastal area of guangdong province. *Natural Hazards and Earth System Sciences*, *11*(7), 2003–2010.

Liang, Y., Gillett, N. P., & Monahan, A. H. (2020). Climate model projections of 21st century global warming constrained using the observed warming trend. *Geophysical Research Letters*, *47*(12), e2019GL086757.

Lindenberg, M., & Crosby, B. (1981). *Managing development: The political dimension*.

List, J. A., & Gallet, C. A. (2001). What experimental protocol influence disparities between actual and hypothetical stated values? *Environmental and resource economics*, *20*(3), 241–254.

LIWO, W. N. (2022). *Basisinformatie-overstromingen.nl*. (https://basisinformatie-overstromingen.nl/#/maps)

Lo, A. Y., & Chan, F. (2017). Preparing for flooding in england and wales: The role of risk perception and the social context in driving individual action. *Natural Hazards*, *88*(1), 367–387.

Loucks, D. P., Stedinger, J. R., Davis, D. W., & Stakhiv, E. Z. (2008). Private and public responses to flood risks. *International Journal of Water Resources Development*, *24*(4), 541–553.

Maddison, D., Elliott, R. J., et al. (2018). Is flood risk capitalised into property values? *Ecological economics*.

Malpezzi & Stephen. (2003). Hedonic pricing models: A selective and applied review. *Housing economics and public policy*, *1*, 67–89.

Mandel, A., Tiggeloven, T., Lincke, D., Koks, E., Ward, P., & Hinkel, J. (2021). Risks on global financial stability induced by climate change: The case of flood risks. *Climatic Change*, *166*(1-2), 4.

Mary Le. (2021). Climate risk and commercial real estate development patterns. *MOODY'S ANALYTICS*.

MAX Vandaag. (2021). *Overstroming-limburg*. Retrieved March 13, 2023, from https://www.maxvandaag.nl/blogs/jan-slagter-max-komt-in-actie-voor-limburg/attachment/overstroming-limburg-anp-900-500/

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., White, K. S., et al. (2001). *Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of working group ii to the third assessment report of the intergovernmental panel on climate change* (Vol. 2). Cambridge University Press.

McKenzie, R., & Levendis, J. (2010). Flood Hazards and Urban Housing Markets: The Effects of Katrina on New Orleans. *J Real Estate Finan Econ 40*, 62–76. https://doi.org/DOI10.1007/s11146-008-9141-3

Mehryar, S., & Surminski, S. (2021). National laws for enhancing flood resilience in the context of climate change: Potential and shortcomings. *Climate Policy*, *21*(2), 133–151.

Miller, R. G., & Pinter, N. (2022). Flood risk and residential real-estate prices: Evidence from three us counties. *Journal of Flood Risk Management*, *15*(2), e12774.

Mills, E. (2009). From risk to opportunity: Insurer responses to climate change 2008. *CERES Report. www. ceres. org*.

Mills, J. (2020). The global bystander effect: Moral responsibility in our age of ecological crisis. *Journal of Futures Studies*, *25*(2), 61–76.

Ministry of Infrastructure and Water Management. (2022). Water en Bodem sturend. https://open.overheid.nl/documenten/ronl-c35e65eba0903d738ae26dab222462337b0d8de7/pdf

Mol, J. M., Botzen, W. W., Blasch, J. E., & de Moel, H. (2020). Insights into flood risk misperceptions of homeowners in the dutch river delta. *Risk analysis*, *40*(7), 1450–1468.

Monnin, P. (2018). Integrating climate risks into credit risk assessment-current methodologies and the case of central banks corporate bond purchases. *Council on Economic Policies, Discussion Note*, *4*.

Morrow, B. H. (1999). Identifying and mapping community vulnerability. *Disasters*, *23*(1), 1–18.

Mulder, J., Hommes, S., & Horstman, E. (2011). Implementation of coastal erosion management in the netherlands [https://doi.org/10.1016/j.ocecoaman.2011.06.009]. *Ocean & Coastal Management*, *Volume 54, Issue 12*(12), 888–897.

Murfin, J., & Spiegel, M. (2020). Is the risk of sea level rise capitalized in residential real estate? *The Review of Financial Studies*, *33*(3), 1217–1255.

Nazeer, M., & Bork, H.-R. (2019). Flood vulnerability assessment through different methodological approaches in the context of north-west khyber pakhtunkhwa, pakistan. *Sustainability*, *11*(23), 6695.

O'Donnell, E. C., & Thorne, C. R. (2020). Drivers of future urban flood risk. *Philosophical Transactions of the Royal Society A*, *378*(2168), 20190216.

OECD. (2018). Climate-resilient infrastructure. (14). https://doi.org/https://doi.org/https://doi.org/10.1787/4fdf9eaf-en

O'Neill, E., Brereton, F., Shahumyan, H., & Clinch, J. P. (2016). The impact of perceived flood exposure on flood-risk perception: The role of distance. *Risk Analysis*, *36*(11), 2158–2186.

Ouazad, A., & Kahn, M. E. (2019). *Mortgage finance in the face of rising climate risk*. National Bureau of Economic Research.

Pant, R., Thacker, S., Hall, J. W., Alderson, D., & Barr, S. (2018). Critical infrastructure impact assessment due to flood exposure. *Journal of Flood Risk Management*, *11*(1), 22–33.

Perazzini, S. (2020). Public-private partnership in the management of natural disasters: A review. *arXiv preprint arXiv:2006.05845*.

PGGM. (2021). *"annual report of pggm n.v."* https://www.pggm.nl/media/nuep1jz1/annual-report-of-pggm-n-v-2021.pdf

Piccininni, F. (2014). The evolving "nature" of environmental risk: A responsible approach for residential and commercial real estate. *Environmental Claims Journal*, *26*(4), 308–318.

Podwórna, M. (2022). The aging of a building versus its life cycle with regards to real estate appraisal. *Real Estate Management and Valuation*, *30*(2), 84–95.

Pour, S. H., Abd Wahab, A. K., Shahid, S., Asaduzzaman, M., & Dewan, A. (2020). Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: Current trends, issues and challenges. *Sustainable Cities and Society*, *62*, 102373.

Programme, N. D. (2021). *"advies deltacommissaris: Houd bij woningbouw rekening met het klimaat van de toekomst"*. Retrieved December 6, 2021, from https://www.deltaprogramma.nl/nieuws/nieuws/2021/12/06/advies-deltacommissaris-houd-bij-woningbouw-rekening-met-het-klimaat-van-de-toekomst

Pryce, G., Chen, Y., & Galster, G. (2011). The impact of floods on house prices: An imperfect information approach with myopia and amnesia. *Housing Studies*, *26*(02), 259–279.

Punt, E., Monstadt, J., Frank, S., & Witte, P. (2022). Beyond the dikes: An institutional perspective on governing flood resilience at the port of rotterdam. *Maritime Economics & Logistics*, 1–19.

Redactie Waterform. (2021). *'geen land ter wereld zou onder 9 meter nap bouwen'*. Retrieved March 9, 2023, from https://www.waterforum.net/geen-land-ter-wereld-zou-onder-9-meter-nap-bouwen/

Reisinger, A., Wratt, D., Allan, S., & Larsen, H. (2011). The role of local government in adapting to climate change: Lessons from new zealand. In *Climate change adaptation in developed nations* (pp. 303–319). Springer.

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of political economy*, *82*(1), 34–55.

Runhaar, H., Mees, H., Wardekker, A., van der Sluijs, J., & Driessen, P. P. (2012). Adaptation to climate change-related risks in dutch urban areas: Stimuli and barriers. *Regional environmental change*, *12*(4), 777–790.

Ruppert, T., & Deady, E. L. (2017). Climate change impacts on law and policy in florida. *Florida's climate: Changes, variations, & impacts*.

SAKAMOTO, J., MICHIBATA, T., OGASAWARA, M., & ISHIKAWA, H. (2022). Empirical analysis of the impact of the great east japan earthquake and effect of estimated tsunami inundation on real estate transactions. *Journal of the Eastern Asia Society for Transportation Studies*, *14*, 36–49.

Sakhel, A. (2017). Corporate climate risk management: Are european companies prepared? *Journal of Cleaner Production*, *165*, 103–118.

Schwerdt, G., & Woessmann, L. (2020). Chapter 1 - empirical methods in the economics of education. In (. Bradley & C. Green) (Eds.), *The economics of education (second edition)* (Second Edition, pp. 3–20). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-815391-8.00001-X

Shokry, G., Connolly, J. J., & Anguelovski, I. (2020). Understanding climate gentrification and shifting landscapes of protection and vulnerability in green resilient philadelphia. *Urban Climate*, *31*, 100539.

Sirmans, G., MacDonald, & L., M. (2006). The Value of Housing Characteristics: A Meta Analysis. *Journal of Real Estate Literature*, 215–240. Retrieved October 4, 2022, from https://doi.org/10.1007/s11146-006-9983-5

Sirmans, G., Macpherson, D. A., & Zietz, E. N. (2005). The composition of hedonic pricing models. *Journal of Real Estate Literature*, *13*(1), 3–43. Retrieved October 4, 2022, from http://www.jstor.org/stable/44103506

Snel, K. A., Priest, S. J., Hartmann, T., Witte, P. A., & Geertman, S. C. (2021). 'do the resilient things.'residents' perspectives on responsibilities for flood risk adaptation in england. *Journal of Flood Risk Management*, *14*(3), e12727.

Snel, K. A., Witte, P. A., Hartmann, T., & Geertman, S. C. (2020). The shifting position of homeowners in flood resilience: From recipients to key-stakeholders. *Wiley Interdisciplinary Reviews: Water*, *7*(4), e1451.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.07.039

Spielman, S. E., Tuccillo, J., Folch, D. C., Schweikert, A., Davies, R., Wood, N., & Tate, E. (2020). Evaluating social vulnerability indicators: Criteria and their application to the social vulnerability index. *Natural Hazards*, *100*(1), 417–436.

Spijkerboer, R. C. (2021). Institutional harmonization for energy transition.

Stathatou, P.-M., Kampragou, E., Grigoropoulou, H., Assimacopoulos, D., Karavitis, C., Porto, M., Gironás, J., Vanegas, M., & Reyna, S. (2016). Vulnerability of water systems: A comprehensive framework for its assessment and identification of adaptation strategies. *Desalination and Water Treatment*, *57*(5), 2243–2255.

Statistiek, C. B. (2022). *Laagopgeleiddefinitie*. (https://www.cbs.nl/nl-nl/nieuws/2019/33/verschil-levensverwachting-hoog-en-laagopgeleid-groeit/opleidingsniveau)

Stichting Climate Adaption Services. (2022). *Klimaateffectatlas*. Retrieved September 10, 2022, from (https://www.klimaateffectatlas.nl/nl/)

Stoddard, I., Anderson, K., Capstick, S., Carton, W., Depledge, J., Facer, K., Gough, C., Hache, F., Hoolohan, C., Hultman, M., et al. (2021). Three decades of climate mitigation: Why haven't we bent the global emissions curve? *Annual Review of Environment and Resources*, *46*, 653–689.

Suykens, C., Tarlock, D., Priest, S. J., Doorn-Hoekveld, W., & Van Rijswick, H. (2019). Sticks and carrots for reducing property-level risks from floods: An eu–us comparative perspective. *Water International*, *44*(5), 622–639.

Tang, Y., Cook, T. D., & Kisbu-Sakarya, Y. (2015). Reducing bias and increasing precision by adding either a pretest measure of the study outcome or a nonequivalent comparison group to the basic regression discontinuity design: An example from education. *Society for Research on Educational Effectiveness*.

Tapsell, S., Tunstall, S., Penning-Rowsell, E., & Handmer, J. (1999). The health effects of the 1998 easter flooding in banbury and kidlington. *Report to the Environment Agency, Thames Region. Flood Hazard Research Centre, Middlesex University, Enfield*.

Taylor, Z. J., & Aalbers, M. B. (2022). Climate gentrification: Risk, rent, and restructuring in greater miami. *Annals of the American Association of Geographers*, *112*(6), 1685–1701.

TCFD. (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. *TCFD*. https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf

Tennberg, M., Vuojala-Magga, T., Vola, J., Sinevaara-Niskanen, H., & Turunen, M. (2018). Negotiating risk and responsibility: Political economy of flood protection management in northern finland. *Global warming and human-nature dimension in northern Eurasia*, 207–221.

Terpstra, T., & Gutteling, J. M. (2008). Households' perceived responsibilities in flood risk management in the netherlands. *International Journal of Water Resources Development*, *24*(4), 555–565.

Tewari, H. R., Bhowmick, P. K., et al. (2014). Livelihood vulnerability index analysis: An approach to study vulnerability in the context of bihar.

Thaler, T., & Levin-Keitel, M. (2016). Multi-level stakeholder engagement in flood risk management—a question of roles and power: Lessons from england. *Environmental Science & Policy*, *55*, 292–301.

The Institute of Environment Research. (1986). *Socio-economic evaluation of the integrated flood relief plan of the west bank*. Chulalongkorn University.

The Joint Research Centre-European Commission. (2008). *Handbook on constructing composite indicators: Methodology and user guide*. OECD publishing.

Thistlethwaite, J., & Henstra, D. (2017). Municipal flood risk sharing in canada: A policy instrument analysis. *Canadian Water Resources Journal/Revue Canadienne Des Ressources Hydriques*, *42*(4), 349–363.

Thistlethwaite, J., Henstra, D., Brown, C., & Scott, D. (2020). Barriers to insurance as a flood risk management tool: Evidence from a survey of property owners. *International Journal of Disaster Risk Science*, *11*, 263–273.

Thompson, J. J., Wilby, R. L., Hillier, J. K., Connell, R., & Saville, G. R. (2022). Climate gentrification: Valuing perceived climate risks in property prices. *Annals of the American Association of Geographers*, 1–20.

Townshend, I., Awosoga, O., Kulig, J., & Fan, H. (2015). Social cohesion and resilience across communities that have experienced a disaster. *Natural Hazards*, *76*, 913–938.

Uittenbroek, C. J., Janssen-Jansen, L. B., Spit, T. J., & Runhaar, H. A. (2014). Organizational values and the implications for mainstreaming climate adaptation in dutch municipalities: Using q methodology. *Journal of water and climate change*, *5*(3), 443–456.

Urban Land Institute. (2019). *"climate risk and real estate investment decision-making"*. https://www.heitman.com/news/climate-risk-and-real-estate-investment-decision-making/

Usman Kaoje, I., Abdul Rahman, M. Z., Idris, N. H., Razak, K. A., Wan Mohd Rani, W. N. M., Tam, T. H., & Mohd Salleh, M. R. (2021). Physical flood vulnerability assessment using geospatial indicator-based approach and participatory analytical hierarchy process: A case study in kota bharu, malaysia. *Water*, *13*(13), 1786.

Vaandrager, D. (2020). A systems approach to exploring institutional absorptive capacity and adaptability. *Emergence Complexity and Organization*.

Van Baars, S., & Van Kempen, I. (2009). The causes and mechanisms of historical dike failures in the netherlands. *E-WAter journal, 2009*.

van den Hurk et al., B. (2014). KNMI'14: Climate Change scenarios for the 21st Century – A Netherlands perspective (Scientific Report WR2014-01) [www.climatescenarios.nl].

Van Der Klaauw, W. (2010). Regression-discontinuity analysis. In S. N. Durlauf & L. E. Blume (Eds.), *Microeconometrics* (pp. 214–220). Palgrave Macmillan UK. https://doi.org/10.1057/9780230280816_26

Veiligheid & Justitie. (2013). *Wet veiligheidsregios, artikel 1*. Retrieved January 1, 2013, from (https://wetten.overheid.nl/jci1.3:c:BWBR0027466&paragraaf=1&artikel=1&z=2018-09-19&g=2018-09-19)

Verbond van Verzekeraars. (2020). *Hoe ga je om met het verzekeren van het restrisico tegen overstroming?* Retrieved January 1, 2013, from (https://www.verzekeraars.nl/media/8163/vvv-popa_overstroming_2020.pdf)

Verbond van Verzekeraars. (2022). *Zijn overstromingsrisico's verzekerbaar*. (https://www.verzekeraars.nl/publicaties/actueel/zijn-overstromingsrisico-s-verzekerbaar)

Verheul, W. J., & Hobma, F. (2022). Institutionele ruimte voor wonen: De woning crisis en achterliggende systeemkwesties op de agenda. *Bestuurskunde*, *31*(1), 3–18.

Vesteda. (2021). *"annual report 2021"*. https://vestedareport.com/annual-report-2021/corporate-sustainability-and-social-responsibility

Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox—implications for governance and communication of natural hazards. *Risk analysis*, *33*(6), 1049–1065.

Walsh, P., Griffiths, C., Guignet, D., & Klemick, H. (2019). Adaptation, sea level rise, and property prices in the chesapeake bay watershed. *Land economics*, *95*(1), 19–34.

Warbroek, B., Holmatov, B., Vinke-de Kruijf, J., Arentsen, M., Shakeri, M., de Boer, C., Flacke, J., & Dorée, A. (2023). From sectoral to integrative action situations: An institutional perspective on the energy transition implementation in the netherlands. *Sustainability Science*, *18*(1), 97–114.

Warren-Myers, G., Aschwanden, G., Fuerst, F., & Krause, A. (2018). Estimating the potential risks of sea level rise for public and private property ownership, occupation and management. *Risks*, *6*(2), 37.

Wei, F., & Zhao, L. (2022). The effect of flood risk on residential land prices. *Land*, *11*(10), 1612.

Werritty, A., Houston, D., Ball, T., Tavendale, A., & Black, A. (2007). Exploring the social impacts of flood risk and flooding in scotland.

Wihlborg, M., Sörensen, J., & Olsson, J. A. (2019). Assessment of barriers and drivers for implementation of blue-green solutions in swedish municipalities. *Journal of environmental management*, *233*, 706–718.

Wind, H., Nierop, T., De Blois, C., & de Kok, J.-L. (1999). Analysis of flood damages from the 1993 and 1995 meuse floods. *Water resources research*, *35*(11), 3459–3465.

Zanetti, V. B., de Sousa Junior, W. C., & De Freitas, D. M. (2016). A climate change vulnerability index and case study in a brazilian coastal city. *Sustainability*, *8*(8), 811.

Zdaniuk, B. (2014). Ordinary least-squares (ols) model. In A. C. Michalos (Ed.), *Encyclopedia of quality of life and well-being research* (pp. 4515–4517). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_2008

Zhang, Y., Hwang, S. N., & Lindell, M. K. (2010). Hazard proximity or risk perception? evaluating effects of natural and technological hazards on housing values. *Environment and Behavior*, *42*(5), 597–624. https://doi.org/10.1177/0013916509334564

A

Interview Protocol

Interviewer: Linde van der Ven
Interviewee: [Name]
Organisation: [Organisation Name]

Introduction
First, I would like to thank you for taking the time to complete this interview. As mentioned, this interview will be part of my master thesis research for my master's in construction management and engineering at the Technical University of Delft in collaboration with my internship company Arcadis.

This thesis aims to assess the past and future effects of climate change and, in particular, floods on real estate. For this study, Maastricht is taken as a case study. This research aims to assess the methods that can be employed to analyze the effects of past floods and future flood risks on residential real estate and understand the role stakeholders can have in maintaining the stability of residential property values. This could contribute to our knowledge of the effects of climate change on real estate and what the effects will be for homeowners whose property is located in areas prone to floods. This will allow for a better understanding of real estate and construction industry choices.

Previously, I have conducted a literature study to assess the state-of-the-art models and outcomes in theory. However, I am inquisitive to see how flood risk is taken into account in practice, what implications you reckon it will have, and what challenges you currently face regarding flood risk within your role. Therefore, the questions throughout the interview will focus on these subjects.

Practicalities
The information provided will be purely for academic purposes and will be handled with care. The information will be confidential, and results will not be traceable to individual participants. If you rather not answer a question or withdraw from the interview, you may do this at any time. The interview will be approximately 30-45 minutes.

For research purposes and to validate the data, I would like to ask if you would be okay with me recording this interview. Naturally, the recordings will be destroyed after the data analysis. Moreover, the interview transcripts will be sent to the participant for review and correction before the results are analyzed.

[RECORD]
The recording has started, and as confirmation, the question will be repeated: do you agree to this interview being recorded?

Part 1 - General
To better understand your function and responsibilities, I would first like to hear about you and your function.

- Could you tell me about your company and related function?

Part 2 - Flood risk and devaluation
To understand how flood risk and devaluation of real estate play a role within your function, I would like to ask some questions from this perspective.

- Could you share your perspective on including flood risk in current building projects?
- What methods are available for you to assess vulnerability now?
- Who do you think is responsible for flood insurance?

- Who do you think should be responsible for flood insurance?

Part 3 – Barriers

- Do you currently perceive barriers within your job when considering flood risk within projects?
- Do you perceive conflicts of interest with other relevant stakeholders regarding flood risks?
- Do you expect conflicts of interest to occur in the future with other stakeholders regarding flood risks?
- Which stakeholder do you believe should contribute the most to diminishing flood risks?

Part 4 – Drivers

- Do you see opportunities in collaboration with other relevant stakeholders regarding flood risks?
- Why is flood risks important within your function?
- What do you think your company's role is in reducing the impact of floods and their subsequent potential devaluation of real estate?

Part 5 – Methods

- What methodology does your company leverage to assess the vulnerability to flooding risk within a project?
- Do you think flood risks are sufficiently considered within projects?
- What timelines does your company consider regarding flood risks?

Part 6 – Conclusion

- Are there any experiences or other things not discussed during the interview that you would like to share?

Closing Thank you again for taking the time to cooperate with this interview and for your valuable input.

B

Interview Invitation Letter

Dear [name],

With this letter, I would like to invite you to participate in my graduation research, titled “The effects of floods on residential property values”. This research is carried out to fulfill my master’s degree in Construction, Management, and Engineering at the Faculty of Civil Engineering of Delft University of Technology, and as a graduate intern at Arcadis.

This thesis aims to assess the past en future effects of climate change and in particular floods on real estate. For this study, Maastricht is taken as case study.The aim of this research is to assess how floods and flood risk vulnerabilities are currently taken into account in residential real estate prices and understand the role that stakeholders can have in maintaining the stability of residential real estate values. This could contribute to our knowledge on the effects of climate change on real estate and what the effects will be for home-owners whose property is located in areas prone to floods. This will allow for a better understanding of choices in the real estate and construction industry, and for different actors to understand what they could do to contribute to reducing the effects.

I would like to identify barriers, drivers, and considerations in practice, to compare this with considerations and models within the literature, and understand the current barriers that investors, insurers, and other important stakeholders currently face. The duration of the interview will be approximately 45-60 minutes. For the interview, I would like to ask permission to record to interview in order to transcribe and analyze the information in a later phase. If preferred. the data of the interview will be coded anonymously and your name (nor your company) will not be stated anywhere.

Your participation in this study is entirely voluntary and you can withdraw at any time. When questions occur you would rather want to omit during the interview this is naturally possible.

If you participate, I would like you to sign the consent form attached, to ensure the data and answers are confidential. In case you have any questions about this research, feel free to contact me (email: R.P.J.vanderven@student.tudelft.nl, telephone number: +31654346988).

Sincerely,

Linde van der Ven

C

Interview Consent Form

Interview consent form
Interviewer: Linde van der Ven
Interviewee:
Organisation:

Please tick the appropriate boxes

Participation in study	**Yes**	**No**
1. I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves audio-record of the interview for data analysis purposes, after which the recording will be deleted.	☐	☐
Use of data for research		
4. I understand that personal information collected about me that can identify me, such as name and/or email-address, will not be shared beyond the study team.	☐	☐
5. I understand that the (identifiable) personal data I provide will be destroyed.	☐	☐
6. I understand that after the research study the de-identified information I provide will be used for the graduation thesis report and presentation at the Technical University of Delft, unless indicated that information is confidential.	☐	☐
7. I agree that my responses, views or other input can be quoted anonymously in research outputs. Names or personal details will not be used unless agreed otherwise.	☐	☐
Data storage		
8. I acknowledge the publication of the graduation thesis to be archived in the TU Delft educational repository so it can be used for future research and learning.	☐	☐

Signatures

_____	_____	_____
Name of participant	Signature	Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Linde van der Ven		_____
Researcher name:	Signature	Date

D

Vulnerability Assessment

	Social									Disaster			Flood Risk		
	EDUCATIO	DENSITY	AGE	DEPENDEN	RENTAL	ETHNICITY	GENDER	EMPLOYEE	INCOME	BUILDING	DRY FLOOI	SOIL CAPA	FLOOD RIS	EXTREME I	WATERDEPTH
Variance	0,068007	0,087514	0,030084	0,083901	0,090739	0,045764	0,0248751	0,026343	0,066199	0,045039	0,059161	0,164475	0,095549	0,037251	0,036513
Squarted Varince	0,260781	0,295828	0,173448	0,289656	0,301229	0,213926	0,157718	0,162305	0,257293	0,247777	0,24323	0,405556	0,309109	0,193004	0,191083
K	3,834631	3,380338	5,765426	3,452369	3,319736	4,67451	6,340412	6,161232	3,886625	4,03588	4,111329	2,465752	3,2351	5,181235	5,233339

	EDUCATIO	DENSITY	AGE	DEPENDEN	KOOPWOI	ETHNICITY	GENDER	EMPLOYEE	INCOME	BUILDING	DRY FLOOI	SOIL CAPA	FLOOD RIS	EXTREME I	WATERDEPTH
WEIGHT	0,058924	0,051943	0,088593	0,05305	0,051012	0,071829	0,097428	0,094675	0,059723	0,062016	0,063175	0,037889	0,049711	0,079616	0,080417

		Social									Disaster			Flood Risk				
Neigbourhoods	**POSTAL CODE**	**EDUCATIO**	**DENSITY**	**AGE**	**DEPENDEN**	**RENTAL**	**ETHNICITY**	**GENDER**	**EMPLOYEE**	**INCOME**	**BUILDING**	**DRY FLOOI**	**SOIL CAPA**	**EXTREME I**	**EXTREME I**	**WATERDEPTH**	**Scores Iyenger and Sud**	**Scores Equal Weighing**
Jekerkwartier	6211	0,039729	0,319895	0,499392	0,325603	0,8	0,574101	0,8187492	0,809524	0,421348	0,923512	0,130719	0,169068	0,228576	0,032665	0,098254	0,437895591	0,346545311
Kommelkwartier	6211	0,017379	1	0,539036	0,51196	0,853333	0,541166	0,9025974	0,809524	0,5	0,879425	0	0	0	0	0	0,459262192	0,307898918
Statenkwartier	6211	0,346814	0,976168	0,311958	0,392012	0,986667	0,628097	0,8456968	0,84127	0,640449	0,753034	0,027027	0,220079	0,283988	0	0	0,486175825	0,363759798
Boschstraatkwartier	6211	0,046382	0,575853	0,344045	0,179494	0,88	0,530915	0,8316285	0,650794	0,494382	0,974476	0,084388	0,579783	0,473054	0,062917	0,061117	0,449007624	0,416322222
Sint Maartenspoort	6221	0,398266	0,463727	0,375428	0,471021	0,986667	0,512583	0,9143856	0,714286	0,853933	0,997998	0,080378	0,923721	0,020768	0,036179	0,055886	0,511039122	0,445743954
Wyck	6221	0,082218	0,989816	0,536779	0,226929	0,786667	0,501922	0,8842103	0,698413	0,241573	0,878062	0,036697	0,999998	0,246794	0,026404	0,044862	0,471369754	0,43136963
Villapark	6212	0,216642	0,415958	0,729655	0,322039	0,186667	0,244195	0,8721848	0,603175	0,196629	0,956388	0,249567	0,319793	0,310212	0,036528	0,080191	0,408956468	0,357228776
Jekerdal	6212	0,207181	0,412598	0,671049	0,376781	0,213333	0,167824	0,8317232	0,507937	0,151685	0,992239	0,557823	0	0,170351	0	0,089723	0,386654878	0,332241513
Biesland	6213	0,138107	0,318425	0,629867	0,280379	0,413333	0,239759	0,8781749	0,698413	0,117978	0,958272	0	0	0,006898	0,003662	0,013922	0,353569021	0,246766556
Campagne	6213	0,125022	0,337953	1	0,856486	0,533333	0,092113	0,8981058	0,603175	0,162921	0,963978	0	0	0	0	0	0,406891061	0,277816375
Wolder	6213	0,385496	0,275276	0,77796	0,440205	0,24	0,152133	0,8441331	0,571429	0,146067	0,976036	0	0	0	0	0	0,358053733	0,250400193
Sint Pieter	6212	0,311116	0,00168	0,65792	0	0,146667	0,207947	0,788961	0,428571	0,468477	0,945286	0,634146	0,048383	0,11951	0,01187	0,025546	0,354004208	0,309835788
Brusselsepoort	6217	0,388374	0,766089	0,409326	0,354903	0,666667	0,82729	0,9217331	1	0,432584	0,813958	0	0	0	0	0	0,471990741	0,30403119
Mariaberg	6214	0,656843	0,929449	0,528071	0,548715	0,973333	0,505006	0,8720813	0,857143	0,848315	0,865622	0	0	0	0	0	0,519261038	0,345030396
Belfort	6216	0,473949	0,550131	0,672872	0,461267	0,133333	0,227701	0,8762809	0,587302	0,050562	0,986922	0	0	0	0	0	0,368942775	0,259043107
Pottenberg	6216	1	0,524724	0,631603	0,874296	1	0,457748	0,8257792	0,793651	0,97191	0,951374	0	0	0	0	0	0,545045794	0,367919787
Malpertuis	6217	0,966517	0,566509	0,626321	0,96149	0,986667	0,548794	0,7951636	0,793651	1	0,946927	0	0	0	0	0	0,553679576	0,3735516
Caberg	6217	0,918667	0,567874	0,622689	0,89959	1	0,54096	0,8229852	0,809524	0,988764	0,753034	0	0	0	0	0	0,538960571	0,349264909
Oud-Caberg	6218	0,567238	0,11916	0,835453	0,966018	0,453333	0,139283	0,9141929	0,571429	0,280899	0,868101	0	0	0	0	0	0,41178544	0,275974445
Malberg	6218	0,803571	0,415958	0,745469	1	0,8	0,337748	0,8486731	0,730159	0,606742	0,382347	0	0	0	0	0	0,464877931	0,275383712
Dousberg-Hazendans	6215	0,485074	0,154436	0,47005	0,368777	0	0,13597	0,7525271	0,365079	0	0	0	0	0	0	0	0,21545839	0,101181981
Daalhof	6215	0,649824	0,630656	0,683229	0,692556	0,533333	0,192404	0,8158371	0,650794	0,47191	0,991726	0	0	0	0	0	0,44012956	0,307248972
Boschpoort	6219	0,784045	0,171969	0,611071	0,677195	0,666667	0,245484	0,768606	0,650794	0,544944	0,585924	0,209446	0,818713	0,52492	0,744324	0,432885	0,566631154	0,558126401
Bosscherveld	6219	0,462841	0,008294	0,897163	0	0,293333	0,695364	0,788961	0,52381	0,468477	1	0	0,280536	0	0	0	0,399178772	0,295550045
Frontenkwartier	6217	0,34127	0,084829	0,553804	0,197688	0,813333	0,413294	1	0,793651	0,55618	0,903704	0	0,015295	0,03103	0	0	0,419191191	0,281634685
Belvédère	6219	0,462841	0,001365	0,358865	0	0,604	0,512583	0,525974	0,793651	0,468477	1	1	0,267343	0	0	0	0,416448601	0,389992007
Lanakerveld	6218	0,405665	0,008294	0,512665	0	0	0,30369	0,788961	0,52381	0,468477	1	0	0	0	0	0	0,308019534	0,222650416
Wyckerpoort	6224	0,489661	0,443255	0,561179	0,607775	0,88	0,456154	0,8260263	0,730159	0,550562	0,888185	0,196581	0,969914	0,353498	0	0	0,515800393	0,472937098
Heugemerveld	6221	0,693643	0,881155	0,505262	0,578054	0,813333	0,471012	0,8506728	0,714286	0,494382	0,736231	0,138425	1	1	0	0	0,55942557	0,54169511
Wittevrouwenveld	6224	0,896581	0,499108	0,483471	0,629123	0,84	0,480427	0,8474026	0,730159	0,870787	0,794529	0,083778	0,973269	0,571268	0	0	0,555855555	0,501688434
Nazareth	6222	0,770124	0,263622	0,533298	0,793102	0,973333	0,355832	0,776748	0,793651	0,848315	0,936581	0,182548	0,787347	0,698942	0	0	0,559274792	0,51571397
Limmel	6222	0,575203	0,173543	0,441952	0,440122	0,786667	0,285682	0,8278261	0,68254	0,561798	0,904468	0,226553	0,903413	0,704372	0,007515	0,098254	0,493032339	0,492927974
Scharn	6226	0,364565	0,185617	0,57616	0,375217	0,466667	0,291512	0,8693852	0,634921	0,292135	0,820695	0,341284	0,154956	0,04995	0	0	0,389888228	0,302105076
Amby	6225	0,561293	0,150761	0,659418	0,606544	0,293333	0,167283	0,8378842	0,571429	0,123596	0,635323	0,357616	0,145761	0,153985	0	0	0,376765411	0,290725792
Beatrixhaven	6222	0,462841	0	0	0	0,604	1	0,3506494	0	0,468477	0,822986	0,631579	0,984289	0,09868	0	0,006164	0,325688342	0,38952063
Borgharen	6223	0,405665	0,061102	0,706387	0,653173	0,32	0,091345	0,7662897	0,634921	0,219101	0,963252	0,4	0,948269	0,85197	0,407577	0,592437	0,538428125	0,605499917
Itteren	6223	0,462841	0,03601	0,672872	0,779473	0,093333	0	0,7174972	0,539683	0,247191	0,916806	0,5240642	0,9330835	0,959932	1	1	0,603698132	0,724094691
Meerssenhoven	6222	0,462841	0,00084	0,71773	0	0,604	0,14702	0	0,793651	0,468477	1	0,782609	0,421803	0,695744	0,018668	0,454804	0,435476231	0,493164522
Randwyck	6229	0,104345	0,07727	0,494219	0,383233	0,573333	0,362004	0,8248526	0,634921	0,286517	0,855879	0,267626	0,98962	0,767452	0,061287	0,053108	0,441894835	0,471318872
Heugem	6229	0,632828	0,306037	0,565064	0,682196	0,613333	0,229827	0,8630624	0,587302	0,38764	0,762946	0,2081	0,991428	0,685396	0,279416	0,267997	0,525966818	0,535301507
Heer	6227	0,568541	0,366089	0,590492	0,55763	0,56	0,248211	0,8312646	0,603175	0,382022	0,950837	0,386536	0	0	0	0	0,42510321	0,322946109
De Heeg	6228	0,566079	0,451024	0,517509	0,617245	0,506667	0,299613	0,772754	0,603175	0,47191	0,99587	0	0,145596	0	0	0	0,410595632	0,304828629
Vroendaal	6228	0,204048	0,058688	0,726076	0,832961	0,226667	0,155521	0,8684687	0,444444	0,078652	0,123975	0	0	0	0	0	0,285395358	0,146942664
Binnenstad	6211	0	0,695538	0,238954	0,102319	0,866667	0,759537	0,836719	0,825397	0,3707865	0,968584	0,258065	0,398236	0,03823	0,026533	0,027656	0,440998413	0,364734287

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