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Social Vulnerability to Coastal Floods in Denmark:

investigating the spatial patterns among the Danish municipalities

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Abstract:

Climate change is expected to exacerbate the occurrence of coastal floods in Denmark. Concerned by the limited research of the social vulnerabilities in the flood risk assessments in Denmark, this research aims at quantifying the social vulnerability of the Danish population. Municipal-level socio-economic data are used to construct a social vulnerability index, based on the SoVI-Lite methodology, a simplified version of SoVI®. The social vulnerability to coastal flood is quantified for 97 Danish municipalities. The majority of the municipalities exhibit moderate levels of vulnerability. Twenty municipalities scored high levels of vulnerability and generate two clusters; one containing the four most populated and urban municipalities, and one with sparsely populated rural islands in the inner coast of the country. The municipalities with the lowest level of vulnerability to coastal floods tend to cluster around Copenhagen municipality. With the use of factor analysis three components of social vulnerability are identified as the most influential in the construction of vulnerability to floods. These factors explain 83% of the data variance. The findings suggest that vulnerability is connected with the particular socio-demographic challenges of each municipality. The findings can be incorporated in the existing flood risk assessments, while they can support the work of municipalities in the implementation of local flood management plans and raise awareness of the vulnerabilities to coastal flooding in the Danish society.

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List of Abbreviations

CCA - Climate Change Adaptation

DCA – Danish Coastal Authority

DRM - Disaster Risk Management

GIS - Geographic Information Systems

IPCC - the Intergovernmental Panel on Climate Change

LECZ - Low Elevation Coastal Zones

PAR - Pressure and release

SoVI – Social Vulnerability Index

SLR - Sea Level Rise

UN - United Nations

UNDP - United Nations Development Programme

UNDRR - United Nations Office for Disaster Risk Reduction

UNEP - United Nations Environmental Programme

UNISDR - United Nations Strategy for Disaster Risk Reduction

1 Introduction

Past flooding disasters have forced local and global authorities to launch and implement risk reduction strategies. Among the tools for accomplishing this goal, vulnerability assessments hold a prominent position. Vulnerability in general is the propensity to harm due to the exposure to different risks, hazards or stressors (Birkmann et al., 2013; Cutter & Emrich, 2006; Villagran De Leon, 2006). Vulnerability comprises an indispensable component in the risk reduction process across the world, because it has been proved that for successful disaster preparedness knowledge of the social drivers of vulnerability is crucial (Marchand, 2009). Therefore, different tools have been developed in order to quantify vulnerability in a specific context. As the climate continues to change and the occurrence of natural hazards becomes more frequent, identification of vulnerable population can be a tool for the governments and planners. As Birkmann (2005) points out risk reduction should also focus on identification and assessment of the vulnerabilities of people, instead of just focusing on the type of hazard. Concerned by the future risk of coastal flooding in Denmark due to the local impacts of climate change, this study will focus on identifying the population with the biggest propensity to harm in case of coastal flooding, the spatial distribution of social vulnerabilities and the potential spatial clusters of it.

1.1 Climate Facts

Climate change is a recognised discourse that has emerged over the past decades, with 97% of the published peer-reviewed climate research endorsing that the climate warming trends of the last decades are caused or accelerated by human activities (Cook et al., 2016). The evidence of the changing climate are undisputable; mean temperatures are rising, oceans are getting warmer, ice sea caps are shrinking exponentially, the sea levels are also rising, extreme weather events are becoming more frequent, are only some of the evidence globally (Nerem et al., 2018; Sun et al., 2006; U.S. Global Change Research Program, 2017; Wuebbles et al., 2017). Another agreement in the scientific community is that the climate will continue changing in the future, exacerbating the undesirable effects for human and ecological systems (EEA, 2017; Vinod, 2017).

The climate projections are alarming by verifying the aggravation of the climate change effects and the occurrence of more natural hazards (Cook et al., 2016; Doran & Zimmerman, 2009; Oreskes, 2004). Indeed, natural hazards related with hydro-meteorological events, such as floods and storms, have been increased exponentially in recent years, with tremendous human and economic losses (Vinod, 2017). UNEP (2015) estimates that the expected cost for adaptation for developing countries in billion US$ will increase dramatically from 150-300 billion in 230 up to 280-500 billion in 2050. The increase in climate adaptation cost globally is also supported by the findings of Lipinski and McGray (2010) who summarise existing estimations of the expected adaptation cost and point out an increase of tens of billions annually.

Coastal areas are considered especially vulnerable to the different impacts of climate change (McGranahan, Balk, & Anderson, 2007; Nicholls, Hoozemans, & Marchand, 1999; Sorensen et al., 2018) Disasters like Hurricane Katrina, point out that the coastal areas are prone to hazards (Marchand, 2009). Furthermore, the high concentration of human settlements in the coastal areas, due to the socio-economic assets of the coast, creates additional pressure in the increased exposure to natural hazards (Marchand, 2009). Hauer et al. (2016) conclude that with an average sea level rise (SLR) of 0.9 m up until 2100, just in the USA alone, 4.2 millions of people will be at risk of the destructive impacts of high sea levels. SLR is a common threat for coastal areas with low

elevation zones, like Denmark. Denmark is ranked in the top ten countries with the largest share of land in the low elevation coastal zone, with a share of 26% (Table 1.1). It is not surprising the fact the largest urban centers of the country are located near the coast and majority of the population lives in close proximity to the coast (Jebens & Sorensen, 2017). As a result, the expected impacts of climate change in Denmark increase the risk posed by the rising seas, and potentially could have substantial impacts in the socioeconomic activity of the country as a whole.

Table 1.1: Classification of countries with the largest amount of land in the Low Elevation Coastal Zone (LECZ). Areas along the coast that are located 10m below the sea level are classified as LECZ. Even though LECZ cover only 2% of the earth's surface, 10% of the global population resides in these zones (McGranahan et al., 2007)

Ranked by share of their land in the LECZ			
		Land area in LECZ	
Country**	Overall rank*	('000 km²)	%
Bahamas	158	12	93
Netherlands	132	31	75
Bangladesh	93	54	40
French Polynesia	171	1	32
The Gambia	163	3	26
Denmark	131	11	26
Qatar	162	3	23
Cuba	102	23	21
Vietnam	65	66	20
Guinea-Bissau	137	7	19

1.2 Construction of Disasters

Wisner et al. (2004) suggest that natural disasters are never truly natural. Thus, disasters encompass a natural and a social aspect. A disaster might be triggered by natural events, such as flooding or hurricanes, but the way it affects people and different areas is defined by the social, economic and power structures that shape the life of those people (Wisner et al., 2004). Therefore, is it important to recognize the importance of social, economic and demographic characteristics that can amplify or reduce the impacts of a natural hazard. The toll of these events is unequal for people around the world, and the most vulnerable people will suffer the most.

A disaster that pointed out the relation between social vulnerability and the distribution of the impacts of a natural hazard was hurricane Katrina, that stroke on August, 2005 in the Louisiana-Mississippi border (Myers et al., 2008). According to the findings of Myers et al. (2008), the biggest cost of the hurricane was distributed among the poorest population, dwellers of old buildings and members of ethnic minorities. Cutter and Emrich (2006) indicate that people with disabilities, elderly population, the population with lower than the average annual income and immigrants were identified as the most vulnerable in the case of hurricane Katrina.

1.3 Floods and the associated impacts

Globally millions of lives are affected, altered or destroyed by natural hazards every year (Vinod, 2017). Among the different types of hazards, a prominent position is held by floods. Kundzweicz (2012) defines flood as

"temporal presence of water in normally dry areas". Floods are occurring all over the world (Figure 1.1), manifested in different types, fluvial floods due to river overflow, flash floods due to intense precipitation, coastal surges due to storms that elevate sea water, or drainage overflow especially in urban areas (Rufat et al., 2015). The number of flood events from 1986 until 2005 is illustrated in Figure 1.1, which shows that flooding constitute a threat for people both in developed and developing countries, without many exceptions.

Regardless the type of the flood, the impacts can be crucial and even long-lasting in human lives, thus floods are considered destructive across the globe (Chorynski et al., 2012; Kundzewicz, 2012; Rodda et al., 2012). Floods are characterised by multi-causality, thus their impacts are determined not only by climatic factors. As Kundzweicz (2012) further states multiple socio-economic characteristics, like economic status and population density, affect the impacts of floods.

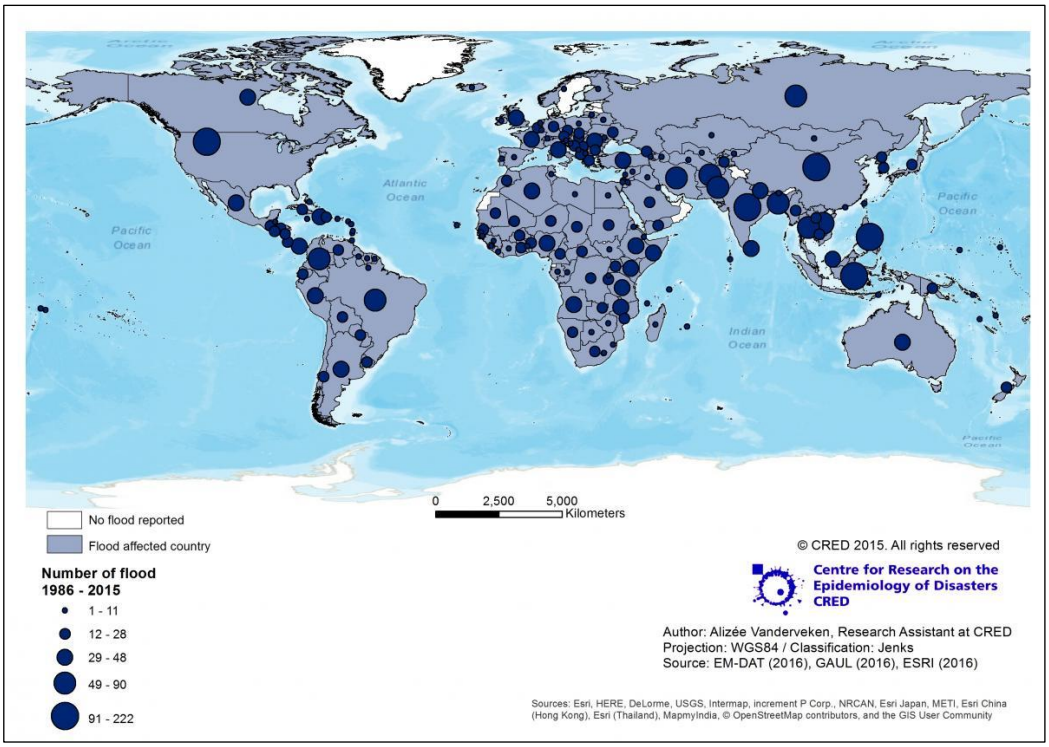

Figure 1.1: Flooding events across the word from 1986 – 2015 (CRED, 2015)

One could argue that the consequences of floods are bigger in less developed countries. Multiple flood disasters in the Philippines, Bangladesh and Pakistan illustrate the importance of the non-climatic factors that affect the flood consequences (Kundzewicz et al., 2014). In general, wealthy countries develop risk management plans and own warning systems, which can prevent or minimize human losses, while it is possible to reduce the material losses after a disaster (Peduzzi et al., 2013; Rodda et al., 2012; Vinod, 2017). However, that's not always the case; in the USA and Europe despite the constant efforts and investments in flood protection measures, the economic damages caused by floods hazards have not decreased, and floods still constitute a major threat (Mostert & Junier, 2010; Peduzzi et al., 2013). Globally, the material cost of flooding in the recent decades exceeds tens of billions of US$ every year (Kundzewicz, 2012; Kundzewicz et al., 2014; Peduzzi et al., 2013).

More precisely, the increase of flood hazards in Europe in the last decades has significantly raised the cost of economic damages up to 52 billion euros for flood related losses and 44 billion euros for storm related damages (European Environment Agency, 2011; Peduzzi et al., 2013).

1.4 Coastal Floods in Europe and Denmark

During the last 50 years, the economic losses associated with floods have been increased in the entire world (Chorynski et al., 2012; Grothmann & Reusswig, 2006; Kundzewicz et al., 2014). EU has experienced severe economic and even human losses; some examples of member states that have experienced flood disasters in the 20th century are Italy, Spain, Romania, Ukraine an Poland (Chorynski et al., 2012; Peduzzi et al., 2013).

In Denmark the biggest flood event was the large flood of November 1872 (Jebens & Sorensen, 2017). Jebens and Sorensen (2017) argue that this event was the worst coastal flood Denmark has ever experienced, with 250 human losses and 15,000 homeless people around the Southwest Baltic Sea. In addition, Denmark has been hit by multiple storm surges, especially in the last two decades (Jebens & Sorensen, 2017). Moreover, a major part of the Danish coastline has been hit by a storm surge at least one time between the years 1991 and 2009 (Figure 1.2). Moreover, the number of the reported damages per municipality for the same period is illustrated in Figure 1.2. According to the Danish Storm Council (2009), from 1991 until 2009, they provided almost 550 billion DDK for compensation for coastal flooding and storm surges material damages, and they conclude that the worst storm surge was the one of November 2006 with almost 4,000 reported material damages incidents (Figure 1.2).

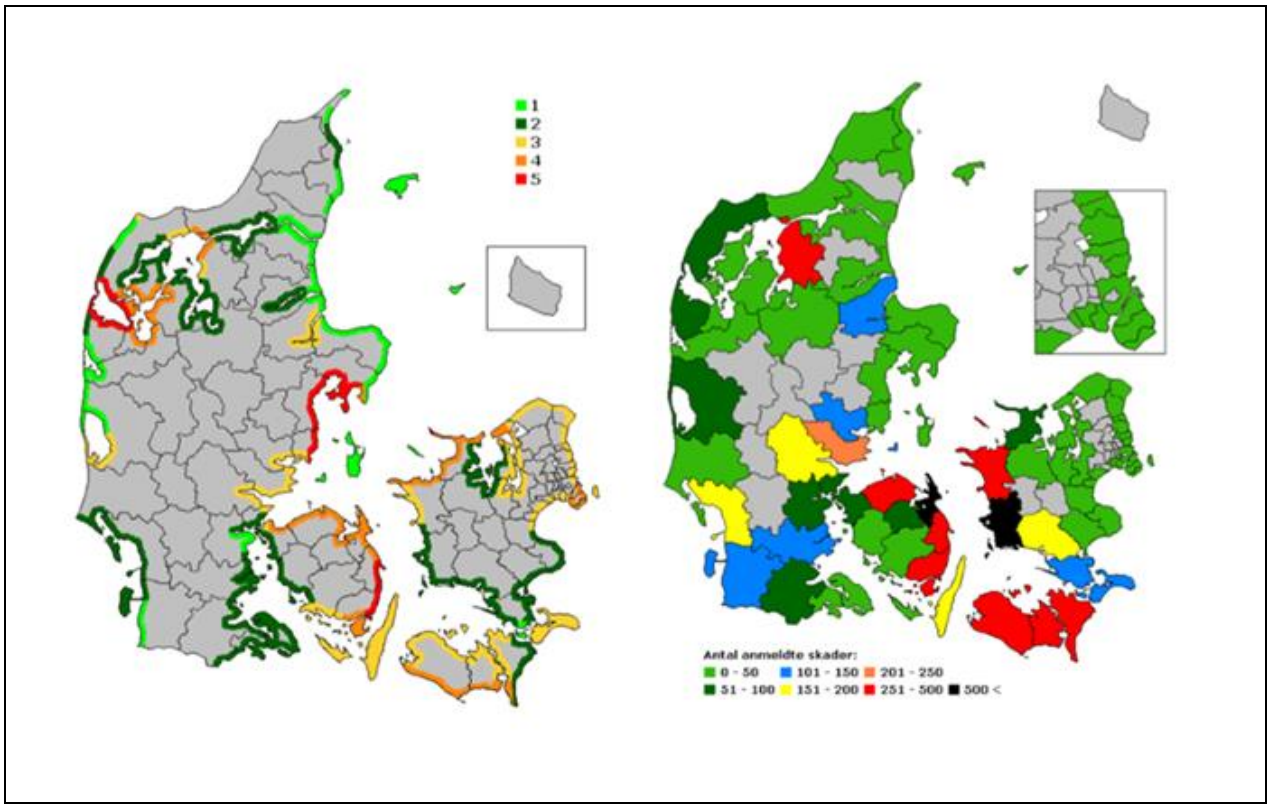

Figure 1.2: Number of coastal floods and number of reported damages from coastal floods per municipality, from 1991 – 2009 (Stormrådet, 2009)

The fluvial risk, because of the absence of big riverine systems, in Denmark is considered limited (Jebens et al., 2016). Jebens and Sorensen (2017) further claim that the risk of pluvial floods is relatively low as well. Meanwhile, notwithstanding this claim, in the last decade Denmark has experienced floods from extreme precipitation in many urban areas with significant economic damages. An example of how impactful the changing climate can be for the Danish society is the extreme rainfall in the summer of 2011, which result in sudden flood in Copenhagen with overall material losses of 6 billion DKK (Danish Government, 2012). This event was an alarming call for the Danish Government and the related stakeholders, highlighting that extreme weather and hydrological events are sudden and can disturb the everyday life of the Danish population.

The Danish Task Force on Climate Change Adaptation identified as the main challenges for Denmark the warmer summers, more extreme weather events, and changes in wind patterns, increased precipitation, and rise in the severity, the intensity and the frequency of storms and SLR (Ministry of the Environment and Food of Denmark & Enviromental Protection Agency, 2015). Additionally, Goodsite et al. (2013) also support that the major climate threat for Denmark is SLR. In the same paper, the authors present estimations from the Danish Meteorological Institute (DMI) upon an average sea level rise that could fluctuate from 0.3 m up to 1 m by the year 2100 (Goodsite et al., 2013). The impacts of the changing climate for Denmark can be significant, since a moderate SLR of 0.5 m could almost double the economic damages of one 100-year storm, with an estimated cost of 5 billion euros (Goodsite et al., 2013).

As Jebens and Sorensen (2017) additionally remark that the type of hazard that can significantly alter or disturb the socioeconomic activities of the country are coastal floods, and they also explain that the impacts of climate change are expected to be increased by the shifts in demography, the steep urbanization and the different development projects that are concentrated on the coastal areas. To conclude, the above mentioned facts signify that coastal flooding is a current and future threat Denmark.

1.5 Legislation and initiatives

The disastrous floods of the last two decades that shocked Europe made it clear that the flood reduction measures were insufficient. Therefore, efforts and measures for flood reduction were embarked by the European Union. As a response to the increased flood events and the related damages, the European Union launched the EU Flood Directive (2007/60/EC) in 2007, with a goal of minimizing flood risk and improving flood management through the union-member states (European Environment Agency, 2011; Jebens et al., 2016; Kundzewicz, 2012; Mostert & Junier, 2010). In accordance with the EU Flood Directive, the union's member states had to carry out a preliminary flood risk assessment in order to identify prone areas to flooding (Kundzewicz, 2012; Mostert & Junier, 2010). In addition, the in 2012 Danish government established that every municipality has to design implement municipal adaptation plans, especially for water related hazards (Sorensen & Jebens, 2015)

In the Danish context, the implementation of the EU Flood Directive comprises of the identification of the flood prone areas, followed by hazard, risk and vulnerability analysis, which the aim to include the results in the municipal adaptation plans (Sorensen & Jebens, 2015). The preliminary risk assessment was conducted by the Danish Coastal Authority (DCA) and the Nature Agency in 2011, proposing ten areas prone to coastal and fluvial floods (Jebens et al., 2016). These 10 areas are illustrated in Figure 1.3 with a red point. The initial assessment was followed by a second assessment phase in 2018, the findings of which suggested five additional areas (Kystdirektoratet, 2018b). The new areas at risk of flooding are depicted with a blue point in fFigure 1.3.

Overall, the flood risk assessment in Denmark appointed 14 areas prone to coastal and fluvial flooding, which require special attention in the planning process. For the identification of the areas at risk of flooding the union member states were compelled to follow a holistic framework, which included hazard, vulnerability and risk maps as the basis for appointing the flood risk areas (Jebens & Sorensen, 2017). For the vulnerability assessment, which is of great interest for this research, the criteria that were taken into consideration are categorized as tangible and intangible (Kystdirektoratet, 2018a, 2018b), and are summarised in Table 1.1.

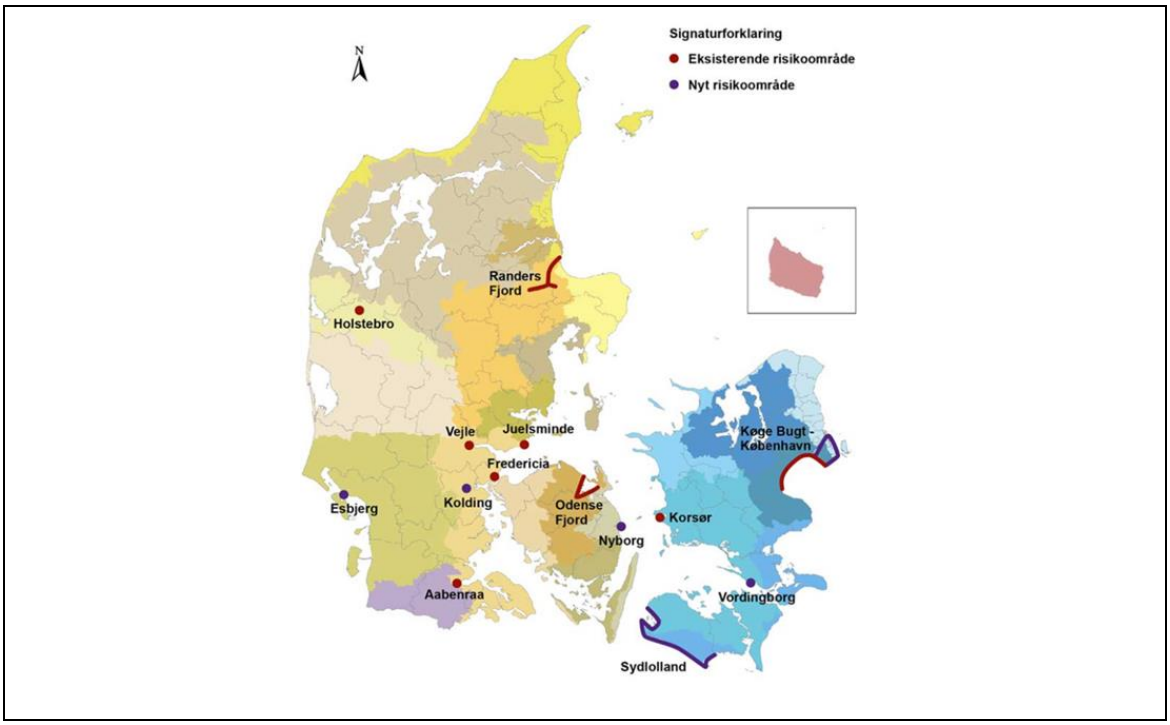

Figure 1.3: Areas at risk of flooding according to the DCA flood risk assessment. The areas with red are the ones identified through the preliminary risk assessment, while the blue ones represent the areas identified by the second assessment (Kystdirektoratet, 2018b)

Table 1.2: Vulnerability indicators, as they were uses in the vulnerability assessment as part of the flood risk assessment by the DCA (Kystdirektoratet, 2018a).

Population density	Sights of cultural heritage
Land use	Critical infrastructure
Infrastructure	Preparedness
Potential polluting enterprises	Local economic activity

1.6 Relevance of study

According to climate projections, with the expected intensification of climate hazards the social inequalities are expected to continue in the future (Agence Européenne de l'Environnement, 2013). Cutter and Emrich (2006) emphasise that the social vulnerability of the population in total is not distributed equally among individuals, groups or and the different areas of a country or a community. The rise in global population that is expected to

continue in the future, the ongoing urbanization and the high population density, especially in coastal areas, will intensify the social inequalities among individuals (Neumann et al., 2015). Even welfare countries, like Denmark, face social problems or challenges that will continue to occur. In combination with the expected effects of climate change as well as the occurrence of more natural hazards, it is expected to have diverse social and economic consequences within the same society, country or community.

Denmark will experience the adverse impacts in the years to come (Goodsite et al., 2013), and as it is shown in Figure 1.4 the vulnerable areas to coastal flooding are expected to increase by the year 2115 (Jebens & Sorensen, 2017). Due to the EU Flood Directive, the Danish Government appointed officially hazard, vulnerability and risk (Jebens et al., 2016; Jebens & Sorensen, 2017), which is important step towards an effective flood management policy and for flood risk reduction. Jebens and Sorensen (2015) also argue about the importance of quantitative social vulnerability assessments for successful flood risk management, in order to promote a people based mitigation approach.

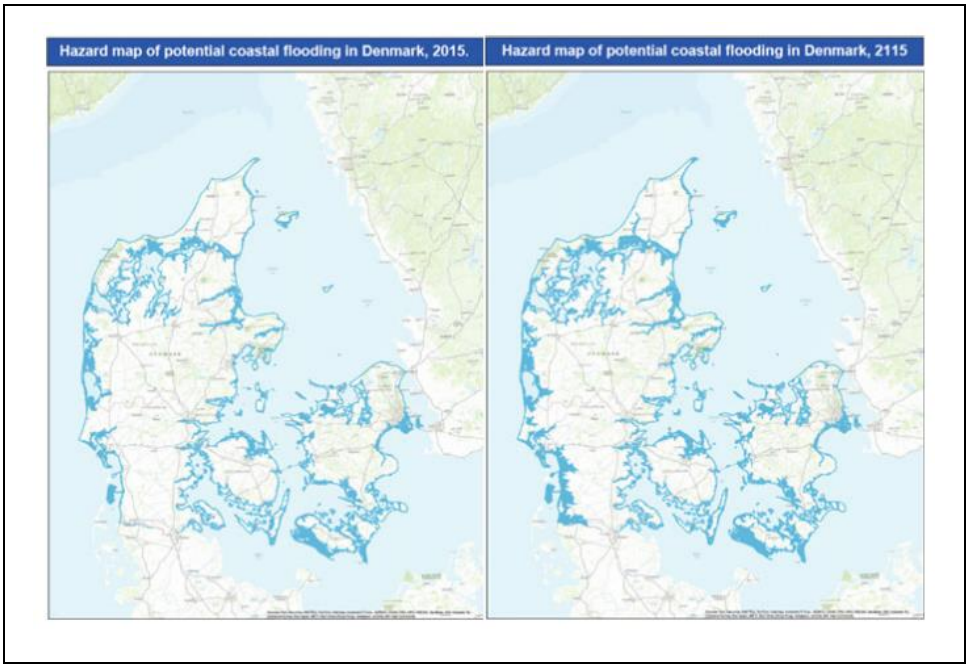

Figure 1.4: Hazard map of potential coastal flooding in Denmark in the years 2015 and 2115 (Jebens & Sorensen, 2017)

However, the indicators that were used for the vulnerability assessment correspond better to the exposure of the area (physical exposure of the area), and not to the social drivers of vulnerability that affect how a hazard and its impacts are distributed among the population. It seems that regardless the acknowledgement of the importance of the social vulnerabilities, the unequal exposure of population to hazards, like coastal flooding, as well as the distribution of vulnerability, are not fully explored neither in the disaster management field and nor in adaptation policies yet (Agence Européenne de l'Environnement, 2013). To add to this, an interview with the chief resilience of Vejle Municipality, a city that established the first resilience strategy in Europe, she denoted that 'Vulnerability is not a topic that we discuss'. This supports the argument that often the attention to vulnerability is neglected in developed countries, since a common perception is that society can cope with (Jebens & Sorensen, 2017). Thus, a way to measure vulnerability based on socio-economic and demographic characteristics of the Danish population could shed light into the topic and provide a holistic understanding of population

vulnerabilities and their drivers, by providing a deeper understanding of the society and its vulnerability (Jebens & Sorensen, 2017)

1.7 Research questions

The main objective of this research is to quantify social vulnerability of the Danish population to flooding, explore the spatial distribution of it and investigate if the identified areas from the Danish flood risk assessments pinpoint the areas not only with the biggest flood exposure but also the areas where the social impacts can be more devastating. The focus of this study will be placed on the local scale vulnerabilities of the Danish population, since floods risk initiatives are implemented in municipal level in Denmark. By constructing a quantitative social vulnerability metric, namely vulnerability index, this research aspires to explore in depth the socioeconomic characteristics that make Danish population more vulnerable to coastal floods and not focusing solely on the surroundings and the physical characteristics that make a place vulnerable to coastal floods. The findings of this research are expected to provide answers to the following research questions:

- ***Where do the most vulnerable people to coastal flooding live in Denmark?***
- ***What are the spatial patterns between and among the Danish municipalities?***

1.8 Thesis Outline

Given the current state of knowledge regarding coastal flooding in Denmark, this research aims to address vulnerability in a more holistic way, by taking into consideration social and economic indicators to identify the spatial clusters of society most likely to suffer if exposed to coastal floods (Chapter 1). Chapter 2 focuses on the research design, the selected theory of science and methods, and the limitations of the research that will affect the results. Furthermore, since vulnerability literature is vague, and the concepts are interdisciplinary vulnerability, risk, and their components will be discussed and defined in Chapter 3. Additionally, Chapter 3 elaborates on vulnerability theories and assessment models, and describes the theoretical framework of this research. Chapter 4 focuses on the indicators selection and the construction of the social vulnerability index. The results of the vulnerability assessment are presented within Chapter 5. Chapter 6 provides an interpretation of the findings of the research, discusses practical implications of the research, describes the limitations of the study and offers suggestions for further research. Finally, Chapter 7 summarises the findings of the research, the potential policy implication and the suggestions for future research.

2 Research Design

Research design encompasses the research strategy that is adopted by the researcher in order to find answers to the research question(s). Therefore, for assessing the social vulnerability to coastal floods in Denmark a mixed-methods research design is selected. A mixed-method research design is the combination of quantitative and qualitative methods and data, with major argument that this research strategy provides a more holistic research strategy (Creswell, 2009). The first section of the chapter discusses the theory of science that is adopted. Additionally, the employed methods are presented and the final section of the chapter focuses on the limitations and the delimitations, which affect the research process and the results of the study.

2.1 Theory of science

2.1.1 Constructivism

Constructivism or social constructivism is one of the research paradigms often used in social research. According to Creswell et al. (2013) in social constructivism people interpret the world based on personal experiences and meanings. These subjective meanings are the generated through social, historical and cultural interactions with others, resulting in multiple realities (Creswell, 2013). Hence the ontological stance in this worldview embraces the existence of numerous socially constructed realities. The epistemological belief from a constructivism worldview is that reality is also constructed through social interactions and knowledge can never be truly subjective (Creswell, 2013). In this research paradigm, the researcher's beliefs, meanings and experiences are significant in the process of knowledge creation. Reality and knowledge are "mind-dependent", since they acquire meaning through articulation and social norms that shape both the language and the way of thinking (Ritchie, et al., 2013). Chipangura et al. (2016) further agree that in constructivism reality and knowledge are generated socially and are fluid. Birkmann et al. (2013) argue that "the concept of vulnerability underscores the social construction of risk". They further propose that in order explore the way risk is constructed the different perceptions of vulnerability, hazard and risk should be investigated (Birkmann et al., 2013). Consequently, by adopting a constructivist stance, the researcher has to explore the multiple constructions of truth about a specific phenomenon.

A common critique when adopting a constructivist worldview refers to the subjectivity of the research and the associated results. By adopting an "empathetic neutrality" within this thesis, the researcher aims at building a common theoretical background for the readers in order to make the subjective personal preconceptions and values transparent (Ritchie et al., 2013). This is achieved though the literature review (Chapter 3), where the state of the art in vulnerability field is presented, as well as the relevant conceptual frameworks. In addition, within this chapter, the research design is discussed and the limitations-delimitations are unveiled. In this way, the researcher reveals their approach and aspires to be as objective as possible.

Within the paradigm of social constructivism, ontology and epistemology of disaster risk are defined as subjective (Chipangura et al., 2016). This worldview represents a shift in the disaster reduction and vulnerability field, a shift that "denaturalizes" disasters (Chipangura et al., 2016; Wisner et al., 2004). Wisner et al. (2004) suggest that risk is inseparable from aspects of social life. They further argue that natural hazards can act as an impetus, but the underlying socio-economic conditions create vulnerability and eventually a disaster (Wisner et al., 2004). Cutter et al. (2009) highlight the contribution of O'Keefe et al.'s (1976) paper in the shift from the

nature of the hazard to the social conditions that shape vulnerability. O'Keefe et al. (1976) explain that "Disaster marks the interface between an extreme physical phenomenon and a vulnerable human population... Without people there is no disaster.". This development points out the importance of the "non-natural" drivers of vulnerability and explains the idea of disaster risk and vulnerability as social constructed terms, since they are generated through interactions in social systems.

By adopting a social constructivist approach, it is accepted that vulnerability and risk are social constructs, which are context dependent and interpreted differently based on the selected discipline, context, scale or geographic area of focus. This paradigm interprets disasters as the outcome of social vulnerability of the population and from the 1980's holds a prominent position in the risk disaster field (Chipangura et al., 2016). Therefore, a social constructivist worldview is adopted in order to accomplish answering the research questions and investigating the spatial patterns of social vulnerability in Denmark. The selected conceptual framework, see Chapter 3 for details, supports the view of disasters generated through the interaction of natural and social factors; hence this is the most appropriate paradigm for the purposes of this research. Additional arguments, linking the choice of the paradigm with the conceptual framework exist in the following chapters.

2.2 Methods

This research adopts a mixed methods research design. This approach is selected since quantitative methods are common for making generalizations for a bigger geographic scale, such as a country, while the qualitative methods are the common choice for investigating people's opinion and perceptions of social phenomena (Walliman, 2011a, 2011b). However, mainly quantitative methods will be used for the quantifying social vulnerability to coastal flooding, since the vulnerability metric that is selected supports the selection of quantitative data. The qualitative methods will be used to explore perceptions of vulnerability for the problem formulation, the selection of data and the adaption of vulnerability indicators based on relative literature and documents. In general, a social constructivism worldview uses qualitative methods to explore individual's perception and understandings for a specific topic. However, the selected theory of science is related directly to the understanding of vulnerability and risk and the selection of the vulnerability framework and indirectly with the selected methods. It is well acknowledged that the use of mainly qualitative methods could help answer the research questions, but since this research will explore the vulnerability in national level, it was decided to stick with one type of methods as the main one.

2.2.1 Qualitative Methods

2.2.1.1 Literature Review

Fink (2005) defines literature reviews as "a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners.". Literature review is an important method for summarising the current knowledge and identifying gaps in the existing literature, as part of the initial research steps.

Therefore, literature review was conducted for the purposes of this thesis, and serves as the backbone of the theoretical background. Firstly, the literature review is a way to summarise the state of the art in vulnerability field, present the findings to the readers, while it makes possible to build a basic understanding around the complex issue of disaster risk and vulnerability. Therefore, is an integral step for building the theoretical

background of the research, presenting readers with the same information as the researcher, and clarifying the position of the researcher. Moreover, by reviewing the literature is possible to define the key concepts around the topic of vulnerability, and creates a common terminology for the investigated term among the researcher and the readers.

The literature review comprises chapter 3, which focuses on presenting the work of the pioneers of the field, justifying the selection of specific definitions and associated theories and framing research arguments, instead of conducting an extensive review of a long literature list. In order to conduct the literature review, a systematic search of keywords in the search engine of Aalborg University, Google Scholar and other databases was implemented. The literature that was selected was peer reviewed. Finally after detailed reading of the selected sources, the literature review chapter was synthesized, and is presented in the next chapter.

2.2.1.2 Semi-structured interview

According to Clifford et al. (2010) an interview can be defined as "verbal interchange where one person, the interviewer, attempts to elicit information from another person". A semi-structured interview has been conducted for this research to provide useful insights regarding the importance of vulnerability assessment and identification of vulnerability population on policy level in Denmark.

Semi-structured interviews provide bigger flexibility than structured interviews, while at the same time have a defined structured as a basis. This method allows the researcher to discuss topics of interest that derive from the interviewee during the interview process. As Bernard (2006; 2006) suggests semi-structured interviews are suggested to gain knowledge in a one-time meetings with the interviewee, due to the great degree of freedom and flexibility. The overall aim with the use of the interview is to gain a better understanding of the current interpretation of vulnerability as part of climate adaptation policies in municipal level in Denmark. For the semi-structured interview an expert in the field of climate adaptation was selected, while the findings of the interview were used as inputs in the formulation of the research problem.

2.2.1.3 Document Analysis

Document analysis is a qualitative method that is been used for interpreting the meaning of documents regarding a topic of interest (Bowen, 2009). Secondary document data are analysed with this method. The data include public records from the Danish Government, the DCA, the EU and the Storm Council. With the use of this method, documents related to vulnerability and flood risk reduction were reviewed as part of the process for the selection of the indicators to quantify social vulnerability to coastal floods in Denmark.

2.2.2 Quantitative Methods

2.2.3 GIS

Quantifying social vulnerability on a national level can be complex and is a process that requires large datasets. Thus, Geographic Information Systems (GIS) are used for utilizing and analysing mutli-scalar data. The GIS serve as a tool for the implementation of the social vulnerability model in Denmark, and permit the visualisation of the results of the model in a comprehensive way for practitioners and planners. Moreover, with the use of overlay analysis, layers that correspond to the social drivers of vulnerability can be explored in the scale of

choice, making it possible to monitor the spatial patterns, and identify the "hotspots" of the vulnerability that require attention in the planning process. Therefore, GIS are often used in vulnerability assessment cases.

For the purposes of this research all GIS processing was conducted within ArcMap 10.6. The data that were used are presented in Chapter 4, along with the detailed data analysis. The GIS were selected for the analysis part of the research in offer to present the vulnerability scores and allow comparison between municipalities. After the calculation of the vulnerability scores for each municipality, the following step was to import the data into the GIS in order to allow translate vulnerability scores into spatial information.

2.2.4 Principal Component Analysis (PCA)

Principal component analysis is a very useful method in order to manipulate large set of variables. PCA is a statistical method for reducing a large set of correlated variables into a smaller number of variables, by identifying the uncorrelated values that can represent the majority of the information of the original set of variables (Dunteman, 1989). The derived variables are named principal components (Dunning & Durden, 2011). The goal of this method is to create a smaller set of variables for facilitating the analysis process.

The method is used for identifying the most important variables, which can explain the drivers of social vulnerability. These variables correspond to the indicators used in the calculation of the vulnerability to coastal floods for each municipality in Denmark.

2.3 Limitations

Every type of research and its results are the outcome of multiple decisions made by the researchers. These decisions might include potential limits associated with the selected methods, called limitations. Another type of decisions that have a crucial impact on the implementation of the research are decisions around the research topic, these are called delimitations. Once those decisions are acknowledged and communicated to the readers, it is possible for the researcher to obtain a more neutral position. By clarifying the decisions that have been made before or during the research, it is possible for the reader to understand the choices that have shaped the research findings. Moreover, these decisions can be seen as suggestions for future research around the topic, since different research design and methods imply different findings. Overall, by identifying the limitations and the delimitations of the research, the scope of the research and how a problem is viewed and investigated it becomes clearer for the reader and it is important precondition for producing valued knowledge.

2.3.1 Limitations

- Qualitative data are more difficult to produce generalized conclusions, since the interpretation of them includes subjectivity;
- Quantitative data cannot easily shed light on individual's perceptions, experiences and opinions;
- Data availability and scale of the available data can disturb the social vulnerability assessment and the SoVI scores. Scale of data can vary from local, regional or national level for example;
- SoVI, like all the vulnerability metrics, is a relative measure of vulnerability.

2.3.2 Delimitations

- The selection of the interviewee for the semi-structured interview;

- Researcher subjectivity is significant in the selection of the theory of science, methodology and the vulnerability conceptual framework ;
- Adaptation of the indicators and of the hazard-of-place model to fit the Danish context;
- The use of mainly quantitative data;
- Language barrier in the analysis of the documents from Danish sources;
- Indicators selected to fit the context of coastal flooding in Denmark might be inappropriate to measure social vulnerability floods for another country;
- In this thesis only the social vulnerability aspect of the conceptual model is examined.

3 Theoretical framework – Key Concepts

The negative impacts of coastal flooding, like other types of natural hazards, vary according to the physical exposure of the area as well as the vulnerability of the people. Vulnerability is distributed unequally among individuals or groups of an area based on specific characteristics that they share, which affect their vulnerability level. Vulnerability is context dependent and therefore multiple definitions exist based on the discipline and the topic of research (Füssel, 2007). The way a researcher interprets vulnerability and risk affects significantly the way vulnerability is conceptualised and therefore quantified. Rygel et al. (2006) state that the first steps in vulnerability assessment is to select a conceptual framework and then define the associated terms. Thus, it is crucial to define the terms properly and create a clear understanding of what they stand for in this research, before proceeding in the conceptual framework selection. This chapter reviews the development of the concepts of risk, vulnerability, exposure and susceptibility. The following sections are advised to be seen in accordance with the Appendix I, II, III and IV for detailed presentations of risk, vulnerability, exposure and susceptibility definitions respectively.

3.1 Risk

Risk in its simplest form is defined as a measure of the threat posed by a hazard in a specific area (Cutter, 1996). The most traditional definition of risk was proposed by United Nations (UN) (1993), where it is defined as "Risk = Hazard x Vulnerability". A hazard refers to a natural, a technological or a human made event, and has the potential to disturb the social and economic situation of people in a certain area (Fitton, et al., 2018; Villagran de Leon, 2006; Wisner et al., 2004). The same interpretation of risk was selected again by the UN after eleven years, when they launched the global risk reduction initiative (2004). In this sense, risk has two components; hazard and vulnerability, which constitutes the interpretation commonly used in the risk and disaster reduction field, both in academia and on policy level. This definition implies that risk is defined by the magnitude or frequency of a hazard occurrence and the characteristics of the people that make them more vulnerable. This definition was prevalent in the disaster risk field until the mid-1980's and early 1990's (Cardona, 2003; Chipangura et al., 2016). Chipangura et al. (2016) state that from a realist worldview risk is perceived as an "objectively identifiable phenomenon", while Wisner et al. (2004) advocate that from this perspective risk is objective and independent of social and cultural conditions. To add to this, Füssel (2007) characterises this definition as "geocentric", because the focus is placed on the nature's role as the driving force of a disaster, neglecting the contribution of the human actors.

From a different perspective, Villagran de Leon (2006) interprets risk as the outcome of hazard occurrence, vulnerability of people and insufficient preparedness on behalf of the community. With this definition pre-existing conditions are considered to affect how the hazard is anticipated and the distribution of the hazard impacts in a community. Blaikie et al. (1994) and Dilley et al. (2005) suggest exposure as an additional component of risk, while Davidson et al. (1997) and Bollin et al. (2003) add adaptive capacity as a component in the risk definition. Despite the contradictory components that these authors suggest, the proposed definitions share a common feature. These definitions propose that human actions affect the generation of risk, adopting a more constructivist approach. Hence, risk is influenced by social conditions and interactions.

Despite the differences among the definitions and the adopted worldview, a point of convergence is the probabilistic nature of risk. Alexander (2000) argues that risk is "the likelihood, or more formally the probability, that a particular level of loss will be sustained by a given series of elements as a result of a given level of hazard". The UNISDR (2004) supports that risk is the probability of the unwanted impacts that are generated by the interaction of hazard and vulnerability. While, Downing et al. (2001) refer to risk as the "probability of hazard occurrence". However, the interpretation of the term "probability" in the above mentioned definitions can vary and therefore can create confusion, since probability refers both to the occurrence of the hazard and to the potential impacts of it.

Within this research, the term risk will refer to the interaction of hazard, exposure and vulnerability, according to the definition proposed by Winser et al. (2004). This definition highlights the contribution of the social, economic and cultural drivers of vulnerability as important factors in the construction of risk and aligns best with the theoretical worldview that is adopted for this research.

3.2 Vulnerability

In general, vulnerability is defined as the predisposition of an individual, or a group, to be harmed due to different risks, hazards or stressors (Cardona, 2003; Kaperson & Kasperson, 2001). Terms often associated with vulnerability are susceptibility, sensitivity, exposure, adaptive capacity and resilience, depending on the context of application each time. Despite the abundance of literature on vulnerability and its components, the only consensus that has achieved is about the fuzziness and the broadness of the definition (Adger et al., 2004; Birkmann et al., 2013; Costa & Kropp, 2013; Joakim, 2017; O'Brien et al., 2004). The confusion around vulnerability understanding and vulnerability assessment methods continues to grow not only between researchers of different disciplines, but also between practitioners and policymakers around the word (Adger et al., 2004; Costa & Kropp, 2013). The ambiguity of the term vulnerability can be attributed to the fact that many groups utilize the same concept giving a unique context-specific meaning, mainly because of the need to describe a unique situation of hazard and risk (Villagran de Leon, 2006). Therefore, many studies point out the need for a holistic approach for vulnerability (Birkmann et al., 2013; Cardona, 2003; Birkmann, 2006). For detailed reviews of vulnerability conceptual frameworks please advise the work of Birkmann (2006b), Füssel & Klein (2006), Villagran de Leon (2006) and Cutter et al. (2009). In Appendix III, 24 definitions of vulnerability are gathered, reviewing vulnerability research from 1981 until 2016.

Vulnerability concept originates from the disaster management research, which is considered to have started in the decade of 1940 (Cutter et al., 2009). White and Haas (1975) investigate the connection between people living in hazard areas and the vulnerability, which resulted in the generation of risk-hazard paradigm. This theoretical

approach is also observed in the work of Burton et al. (1978). By adopting a nature oriented approach, the hazards posed by nature as considered the main threat and the driver of vulnerability (Eakin & Luers, 2006), hence this approach is often described as nature centred (Cutter et al., 2009). Birkmann (2005; 2006b) argues that initially the understanding of vulnerability was limited, since it was perceived as a component of risk (Figure 3.1., first shpere) Scholars and policy makers in the Climate Change Adaptation (CCA) field of research are proponents of the risk-hazard paradigm (Breil et al., 2018; Cardona, 2003), where vulnerability is the outcome of exposure, sensitivity and adaptive capacity (Birkmann et al., 2013). This theoretical approach towards risk and vulnerability is illustrated also in the work of UN (1993) and the IPCC (2007; 2001a).

O'Keefe et al. (1976) argue to the natural focus of the risk-hazard paradigm by proposing that "disaster marks the interface between an extreme physical phenomenon and a vulnerable human population. It is of paramount importance to recognize both of these elements. Without people there is no disaster.". O'Keefe et al. (1976) first adopt the political economy school of thought. Overall, the political economy approach investigates the social, economic and cultural aspects of life in order to interpret vulnerability distribution and changes among different populations and the capacity of individuals to anticipate the impacts of a hazard (Cutter et al., 2009; Eakin & Luers, 2006). Additionally, the political economy approach connects vulnerability with shifts in the political landscape and the distribution of power (Birkmann et al., 2013). Hewitt's (1983) work criticise the overlay focus on the natural side of disasters, proposing that hazards are not natural. Chambers (1989), Watts and Bohle (1993), Blaikie et al. (1994) and Wisner et al. (2004) adopt also the political economy approach in their conceptualization of vulnerability and risk (Figure 3.1, third sphere). While, Wisner et al. (2004) propose that vulnerability comprises the probability of human lives to affected by a hazard, introducing in this way a definition that takes into consideration human actions, see the second sphere in Figure 3.1. Füssel (2007) further adds that the structure of society creates the preconditions for generating vulnerability, while accessibility to resources or information, political instability or conflicts affect people's lives and thus shape their vulnerability. Therefore, Cutter et al. (2009) characterise this approach as "human-centric", since human capacity and interactions are important components in this vulnerability approach.

The next theoretical development in the field of vulnerability research is dominated by a hybrid approach. Cutter (1996) propose the hazard of place model as a place-based approach, combining components from the two previous theoretical approaches. This integrated or holistic approach of dealing with vulnerability points out the dynamic nature of vulnerability and the importance of potential feedback loops in the vulnerability assessment (Cutter, 1996). According to the hazard of place model vulnerability is the result of the interaction between social and biophysical factors, while it suggests that vulnerability is dynamic (Cutter et al., 2009). An additional development in the vulnerability understanding is illustrated in the fifth sphere of Birkmann (Figure 3.1); where vulnerability comprises of additional components, hence the name multiple structures. Turner et al. (2003) define vulnerability as the outcome of the interaction of; exposure, adaptive capacity, susceptibility and coping capacity. The last sphere represents the final widening phase of vulnerability concept (Figure 3.1). As Birkmann (2005; 2006a) explains, researchers like Cardona (2003; 2012) and O'Brien et al. (2004) adopt a "multidimensional" vulnerability perception; a way of understanding that implies a focus besides the physical dimension.

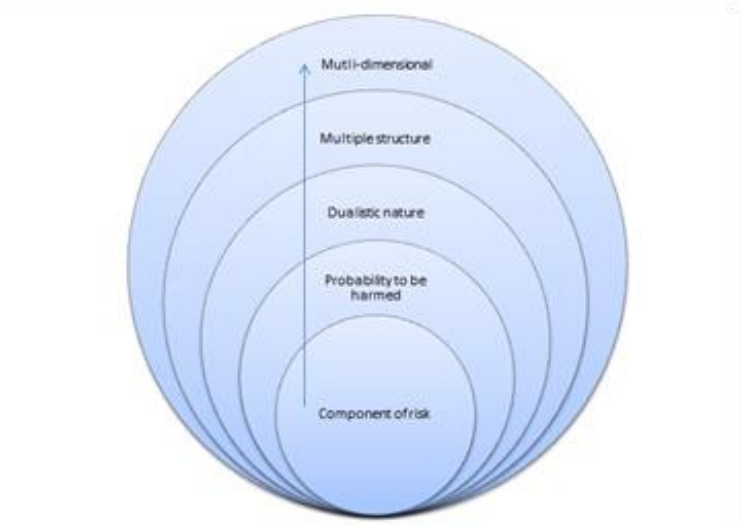

Figure 3.1 The widening of vulnerability concept, adapted from Birkmann (2005b; 2006). According to the figure, vulnerability has evolved from component of risk to a concept with multiple dimensions.

Despite, the development in the field of disaster management and vulnerability that brought attention to the social factors that affect vulnerability generation, researchers continue to differentiate biophysical and social vulnerability. Brooks (2003) remark that biophysical vulnerability comprises of the hazard event, exposure and sensitivity of a system. Brooks (2003) further point out that biophysical vulnerability implies the physical aspect of the hazard impacts, while Holand et al. (2011) claim that the term is closed related with the risk definition, as a function of hazard and vulnerability. On the contrary, social vulnerability is defined as "[T]he characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process)" (Wisner et al., 2004). Cutter and Finch (2008) define social vulnerability as "a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards". To add to this, Cutter et al. (2003) advocate that social vulnerability is influenced also by the social inequalities that are inherent in social systems. Therefore, one could argue that social vulnerability is a characteristic that can be found within social systems, since it is embedded in the social structure of the systems. In the context of this research, when using the term vulnerability it will refers to social vulnerability. As Myers et al. (2008) conclude that this notion of vulnerability is supporting the social construction of disasters though the social conditions that make individuals more or less vulnerable, while disasters are not considered natural phenomena and the human actors are not perceived as incapable to act, respond or adapt.

3.2.1 Vulnerability models

Besides the theoretical developments in vulnerability conceptualization, in order to accomplish assessing vulnerability a conceptual model is required. With acknowledgement of the existence of multiple vulnerability models, the two most cited models are presented. They are selected due to their longevity and their applicability by many scholars. The conceptual models of vulnerability aim at measuring vulnerability, while facilitating the indicator selection process (Birkmann, 2006a). Since, it is already stated that this research adopt a social constructivist view towards disasters and vulnerability, the presented models correspond to this perception of

vulnerability. The first section is dedicated to Blaikie's et al. (1994) "Pressure and Release" model, following by the hazard of place model, developed by Cutter (1996). Also, this section provides the arguments for the selection of the hazard of place model.

3.2.1.1 Pressure and release model

Pressure and release (PAR) model is a well acknowledged model among the plethora of the existing conceptual frameworks. This model was introduced by Blaikie et al. (1994), and developed further by Wisner et al. (2004). PAR model is built upon the premise that disasters are generated through the interaction between the exposure to a hazard and multiple socio-economic factors that shape human vulnerability (Singh, 2014; Wisner et al., 2004). Wisner et al. (2004) state that disasters are the outcome of the interaction between extreme natural events, named hazards, and vulnerability that is generated through social processes. Wisner et al. (2004) further highlight that "disasters are a result of the interaction of both; there cannot be a disaster if there are hazards but vulnerability is (theoretically) nil, or if there is a vulnerable population but no hazard event.". Therefore, this model focuses on the development of vulnerability, which is generated by hierarchical casual factors, which are the root causes, the dynamic pressures and the unsafe conditions (Figure 3.2).

Root causes of vulnerability constitute the large scale political, economic and social processes that influence the distribution of different types of resources among the members of a social system, and constitute the global social fabric (Singh, 2014; Wisner et al., 2004). Dynamic pressures are "processes and activities that 'translate' the effects of root causes both temporally and spatially into unsafe conditions", while unsafe conditions are defined as "the specific forms in which the vulnerability of a population is expressed in time and space in conjunction with a hazard" (Wisner et al., 2004). Blaikie et al. (1994) compliment the PAR model with the development of the Access Model. which is further developed in the work of Wisner et al. (2004). Access model "deals with the amount of 'access' that people have to the capabilities, assets and livelihood opportunities that will enable them (or not) to reduce their vulnerability and avoid disaster" (Wisner et al., 2004), providing a comprehensive way to link socio- environmental processes with a disaster event.

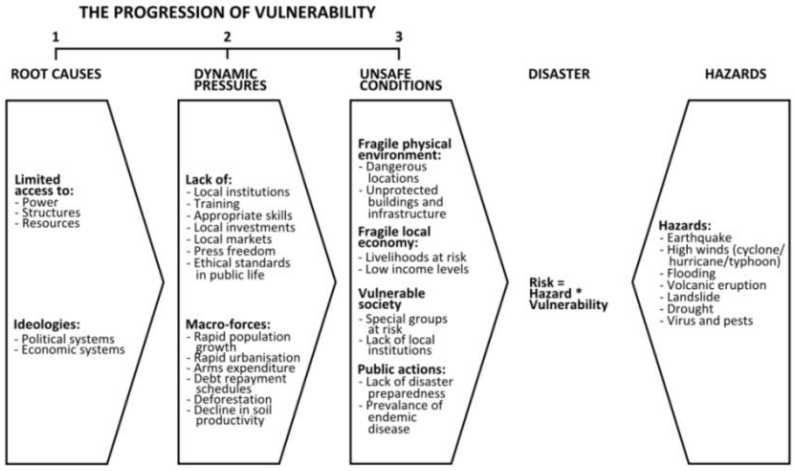

Figure 3.2: Pressure and Release Model (Wisner et al., 2004)

PAR model is mainly used to compare the vulnerability of different social groups, since it has the ability to identify the causes of vulnerability in a comprehensive way (Turner et al., 2003). Furthermore, PAR accomplishes highlighting the societal conditions that lead to the manifestation of unsafe conditions and generation of vulnerability, but fails at dealing with the biophysical side of vulnerability (Turner et al., 2003). Another limitation of the model is that vulnerability is perceived as static (Marchand, 2009). Consequently, this model is not suitable for quantifying vulnerability to coastal floods in Denmark, since it is contradictory to the adopted notion of vulnerability as dynamic.

3.2.2 Hazard of place model

Within this research, the interpretation of vulnerability and risk derives from the hazard-of-place model (Cutter, 1996). This conceptual framework was developed by Cutter (1996) and links social and biophysical vulnerability together in order to produce the overall or place vulnerability (Figure 3.3). The model was developed further by Cutter et al. (2000; 2003) providing a holistic approach towards disaster management. Cutter et al. (2000) argue that "the interplay of social, political, and economic factors - interacting separately, in combination with one another, and with the physical environment -creates a mosaic of risks and hazards that affect people and the places they inhabit.".

The model illustrates that risk, which is defined as "the likelihood of the event occurring and includes three sub elements: the potential sources of risk, the impact of risk itself, and an estimate of the frequency of occurrence.", interacts with possible mitigation actions and combined together they define the hazard potential (Figure 3.3). Furthermore, hazard potential of the system has a geographic component, for instance proximity to a hazard or other physical characteristics, and a social one, named the social fabric. Social fabric in this framework represents experiences, perceptions, and social characteristics that affect in a great proportion how hazard can distribute. Both components generate later the biophysical and the social vulnerability respectively. These scores combined constitute the total vulnerability or place vulnerability. Finally, place vulnerability is connected with feedback loops with risk and mitigation, which represent the dynamic nature of the system.

The hazard of place model is selected as the conceptual framework for the purposes of this research. This decision was made upon the fact that this model has a more "geographical" approach than other conceptual frameworks (Joakim, 2017). The model places geographic scale as a major component of the vulnerability assessment (Cutter et al., 2000). To add to this, Cutter (1996) further points out that vulnerability is quantified and interpreted in a specific geographic scale, thus this methodology takes into consideration both physical and social characteristics of a place and its people for assessing vulnerability. Furthermore, the hazard of place model is a dynamic and recognizes the feedback loops among the components of risk and hazard, while it acknowledges people as active actors of the system (Cutter et al., 2000; Cutter et al., 2003; Joakim, 2017). Therefore, the basic premise of the hazard of place model corresponds both to the understanding of vulnerability as a social construct and the inherent dynamic nature of the term. Finally, the model with a variety of vulnerability indicators support the use of mixed methods in quantification of social vulnerability. This research focuses on the social vulnerability side of the model (Figure 3.3); therefore, the place vulnerability for Danish municipalities cannot be estimated without further research.

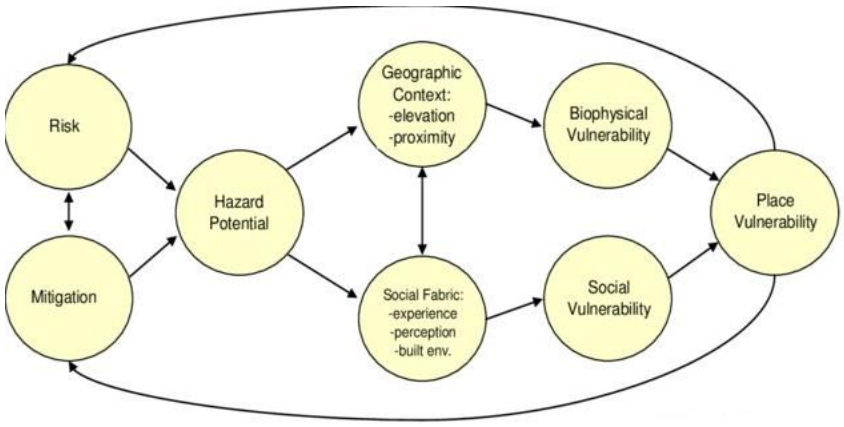

Figure 3.3: The hazard-of-place model (Cutter et al., 2000; Cutter, 1996; Cutter et al., 2003). This research aims at investigating the "social fabric" in Denmark in order to accomplish measuring social vulnerability.

3.2.2.1 Social Vulnerability Index (SoVI)

In order to be able to measure social vulnerability Cutter et al (2003) developed a quantitative comparative metric; the Social Vulnerability Index (SoVI). With the use of socio demographic data obtained from the census of United States, Cuter et al. (2003) manage to identify 11 indicators, which conceptualise the drivers of vulnerability in the specifc context. SoVI generates relative social vulnerability scores of an area with the use factor analysis of the demographic factors.

Dunning and Durden (2013) suggest that a significant advantage of this metric is that it allows to elaborate further on the drivers of vulnerability, instead focusing solely on the overall score. Moreover, the identification of the drivers, or the main indicators that affect social vulnerability, permits the comparisons not only of the total scores, but also the driving forces of vulnerability in a specific context. Kuhlicke et al. (2011) argue that SoVI is one of the vulnerability indices that can be transferable to different types of hazard and geographic contexts as well. Therefore, studies employing the SoVI as the selected vulnerability metric and implemented in Norway (Holand et al., 2011), Brazil (Hummell et al., 2016) , China (Chen et al., 2013) and Portugal (Guillard-Goncąlves et al., 2015), point out the transferability of the metric to other geographic and social contexts.

However, the statistical data process and the requirement of large data sets can be a daunting task both for researchers, but mainly for hazard and disaster reduction managers (Evans et al., 2014). Hence, Cutter et al. (2011) created a simplified metric based on the SoVI metric, the SoVI Lite (Cutter, et al., 2011). SoVI Lite utilize a smaller data set and the calculation of vulnerability is measured without statistical analysis (Cutter et al., 2011; Dunning & Durden, 2011; Evans et al., 2014). Overall, SoVI Lite comprises a version of the initial SoVI aimed a reducing the complexity of the statistical analysis procedure (Evans et al., 2014). This research will be conducted with the use of the SoVI Lite metric, which will be customized in terms of factors and indicators to be tailored to the Danish context. Detailed description of the customization of the metric, as well as the data collection and analysis, are discussed in the following chapter.

3.3 Exposure

The definitions that stand out in disaster risk literature define exposure as a way to measure a hazard (Birkmann et al., 2013; Blaikie et al., 1994). While, in the climate change community exposure is interpreted as the degree to which climate change can have adverse impacts on humans lives (IPCC, 2007; IPCC, 2001a). In another viewpoint, exposure is the "external side of vulnerability" (Bohle, 2001; Watts & Bohle, 1993). From this perspective, exposure denotes the negative impacts of a hazard that potential can alter the social conditions of a system. Furthermore, Turner et al. (2003) propose that exposure is the outcome of the interaction between inherent characteristics of the social system and the hazard occurrence. Costa and Kropp (2013) argue that there is an overlap in the use of term. In the disaster risk context exposure can denote both the external side of vulnerability and the internal side of risk. In this research, from now on, the term exposure will refer to "a component of vulnerability addresses not only the extent to which a system is subjected to perturbation, but also the degree and duration of that perturbation" (Adger, 2006).

Social vulnerability focuses on the social conditions that reduce the ability of individuals to anticipate the hazard event, instead of the importance of the negative consequences of a hazard (Costa & Kropp, 2013). Therefore, exposure, from this viewpoint, is an internal characteristic of the social system itself. For the purposes of this research, the authors adopt the definition proposed by Birkmann et al. (2013), where exposure is defined as "the extent to which a unit of assessment falls within the geographical range of a hazard event. Exposure extends to fixed physical attributes of social systems (infrastructure) but also human systems (livelihoods, economies, cultures) that are spatially bound to specific resources and practices that may also be exposed".

3.4 Susceptibility

In the disaster risk literature, susceptibility can be found as a component of risk in the definitions of White et al. (2005) and Scheuer et al. (2011). In this view, susceptibility represents the internal side of vulnerability, and refers to "the social, economic, political, psychological and environmental variables that intervene in producing different impacts amongst people with similar levels of exposure" (Costa & Kropp, 2013; P. White et al., 2005). Moreover, Cutter and Emrich (2006) view susceptibility as a component of vulnerability. On the other hand, the climate change community uses the term sensitivity for the same purposes (Costa & Kropp, 2013). Sensitivity, therefore, represents the internal side of vulnerability in accordance with the definitions of Turner et al. (2003) and IPCC (2007). Turner et al. (2003) suggest that sensitivity is affected significantly by the human-environmental interactions that take place in an exposed system. IPCC assigns sensitivity to the degree that a system is prone to climate change impacts.

Even though there is no universal definition among the different disciplines, authors seem to agree in the nature of susceptibility characteristics, since Birkmann et al. (2013), White et al. (2005) and Fekete (2010) agree that both social, economic and physical characteristics contribute in a system's susceptibility. Costa and Kropp (2013) remark additionally that susceptibility and sensitivity meaning coincide among the multiple definitions. In this research, the term susceptibility will correspond to the definition of Birkmann et al. (2013), who interpret the term as "the predisposition of elements at risk (social and ecological) to suffer harm".

3.5 Glossary

Chapter 3 has discussed the evolution of the literature in the field of risk and vulnerability. The main points of the chapter are that describe the working approach are summarised as follows:

• Within this research risk will refer to “Risk as consisting of two components. The first component is a measure of the natural hazard. The second, vulnerability itself, is equivalent to capacity and is, they argue, largely determined by socio-economic structure and property relations”, as proposed by Blaikie et al. (1994);

• Vulnerability corresponds to social vulnerability, and is defined as “a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards”, as proposed by Cutter and Finch (2008);

• The working approach within this research is based on the hazard of place model, because it is a place based approach that allow comparisons among places, while combines biophysical and social factors;

• Exposure corresponds to biophysical vulnerability, as it described by the hazard of place model. This research focuses on the social vulnerability to coastal floods; therefore exposure is not measured;

• Susceptibility stands for “the socio-economic and environmental characteristics of a system that shape the degree of impacts”, according to Fekete (2010).

4 Developing the Social Vulnerability Index

As it is stated in the previous chapter, this research project will conduct the assessment of the social vulnerability to coastal floods in Denmark by adopting the hazard-of-place conceptual model, which will be operationalised with the use of the SoVI Lite metric. Since SoVI is designed to use census data from the United States and is conformed to this specific socioeconomic context, the application of the metric requires an adaptation in terms of the indicators. Therefore, the indicators used in SoVI metric will be adapted based on the available data and local characteristics that affect how vulnerability is created in Denmark. The focus of this chapter is placed on the steps taken to develop an index of social vulnerability to coastal floods in Denmark. The first section presents the indicators utilised within the SoVI Lite and the rationale behind their selection, and discusses how the indicators are relevant to the Danish context. Following this, the data collection and the data sources are detailed.

4.1 Social Vulnerability Indicators

Cutter et al. (2008) define vulnerability indicators as "Quantitative measures intended to represent a characteristic or a parameter of a system of an interest". Cutter et al. (2009) further add to the definition the use of a single value for each indicator. Burton et al. (2018) argue that indicators cannot capture and quantify the overall vulnerability of a population, instead they should be seen as a way to understand at an extent the factors that construct vulnerability in this case. Hence, a meticulous task for the purposes of this research is to select indicators that will explain the social fabric of the Danish population.

The social vulnerability assessment of the coastal floods in Denmark is based on the SoVI Lite (Cutter et al., 2011). Subsequently, the SoVI Lite indicators will be used as a guideline for the indicators selection. The identified indicators by Cutter et al. (2011) are presented in Table 4.1. Along with the indicators, the rationale behind the selection their selection is presented, with the support of relevant literature. The rationale is mainly based on the detailed work of Cutter et al. (2003) with the addition of recent findings of supporting literature.

Table 4.1: Vulnerability indicators used by Cutter (2011) that have relevance to the Danish context. The brackets in the first column stipulate the relationship between vulnerability and the indicators. A positive relationship indicates that the indicator increase vulnerability, while a negative relationship decreases vulnerability.

Indicators	Rationale of selection	Supporting Literature
Population in poverty (positive)	Economic status of an individual, or a community, influences heavily the ability to respond and recover from a natural hazard. Wealthy people have the economic resources to anticipate the impacts of a hazard, due to savings, insurance of their material assets, while poor people are more prone to suffer and recover after a hazard. Moreover, poor people usually dwell in older houses, increasing the total cost of material damages.	(Blaikie et al., 1994; Burton, et al., 1993; Clark et al., 1998; Cutter et al., 2000; Cutter et al., 2003; Fothergill & Peek, 2004; Hewitt, 1997; Morrow & Peacock, 1997; Morrow, 1999; Platt, 1999; Rygel et al., 2006; Fitton, et al., 2018)
Population over 65 (positive)	Elderly population are prone to harm during or after a hazard, due to problems associated with health, restricted mobility, unwillingness for evacuation due to higher attachment to their property and have lower ability to respond and recover. Early	(Clark et al., 1998; Cutter et al., 2000; Cutter et al., 2003; Fitton, et al., 2018; Hewitt, 1997; Morrow,

	warnings might be insufficient for them, due to their non familiarity with technology.	1999; O'Brien & Mileti, 1992; Peacock, et al., 1997; Rygel et al., 2006)
Urban population (positive)	The high population or dwelling density might create difficulties in the evacuation process in case of emergency. Moreover, areas with lower dwelling density might be unprotected with defensive measures, like dikes in the case of coastal floods. To add this, rural dwellers often are employed in the primary sector; hence, they are often dependent on the local resources.	(Cova & Church, 1997; Cutter et al., 2000; Cutter et al., 2003; Fitton et al., 2018; Puente, 1999)
Dwellers in rental houses (positive)	Usually renters have lower income than house owners. They dwell in rental properties either due to lack of the resource to buy or because there are transients. Often renters are perceived to have higher vulnerability, due to lower economic power and lack of access to recovery resources, and limited social networks compared to house owners.	(Cutter et al., 2000; Cutter et al., 2003; Fitton et al., 2018; Heinz & Tufford, 2001; Morrow, 1999)
Female Population (positive)	Gender is an important factor in the distribution of vulnerability. Women have higher vulnerability than men, especially because of lower average income, employment in sector-specific positions and their family responsibilities. In a cause of evacuation during or after a disaster, women tend to prone to harm, since they are the one that have to supervise and help the vulnerable family members, like kids and elderly.	(Bianchi & Spain, 1996; Blaikie et al., 1994; Cutter, 1996; Enarson & Morrow, 1997; Enarson & Scanlon, 2002; Fothergill, 1996; Hewitt, 1997; Morrow, 1999; Peacock et al., 1997; Rygel et al., 2006; Fitton, et al., 2018)
Hispanic population (positive) Native American population (positive)	Racial and ethnic minorities often experience discrimination and marginalization. These people tend to have lower income and education level, higher unemployment rates, and live in areas with lower rent, resulting in clustering of minorities and weaker social networks. Moreover, many immigrants do not speak the language of the host country, increasing their vulnerability during or after a hazard.	(Bianchi & Spain, 1996; Clark et al., 1998; Cutter et al., 2003; Fothergill, 1996; Fothergill & Peek, 2004; Peacock et al., 1997; Rygel et al., 2006; Yelvington, 1997)
Population in nursing facilities (positive)	People in nursing facilities are vulnerable to hazards. Due to physical or mental disabilities, their response to disasters can be limited. In the evacuation process, these individuals need to be prioritized, due to potential problems in their mobility and they also need assistance for their recovery. Their recovery is also heavily dependent upon the social services; hence a hazard can interfere with their wellbeing and their recovery.	(Cutter et al., 2003; Morrow & Phillips, 1999; Rygel et al., 2006)

The indicators presented in Table 4.1 highlight that socially and economically marginalized populations are more vulnerable during or after a natural hazard (Cutter et al., 2003; Fitton et al., 2018). However, as it was discussed above, some of these indicators do not correspond in the Danish societal context. Hence, some indicators need to be adjusted in order to accomplish representing the marginalized Danish population. These indicators are the following:

- *Hispanic population*: In general, it is agreed that Denmark is characterised by a homogenous population with strong cultural identity (Moore, 2010; Wren, 2001). Wren (2001) claims that Danes are traditionally tolerant people with liberal ideas, however in the 1980's a shift in society changed the social equilibrium. In the recent years, many arguments have been raised around the integration of immigrants, racism and social marginalization. Wren (2001) argues about the rise of "cultural racism" in Danish society. Moore (2010) discusses about the xenophobia in Denmark and the new public discourses that have emerged and illustrate the shift in the mentality towards immigrants and refugees. Even though there are multiple ethnic groups in Denmark, the new discourses can be characterized as anti-Muslim (Wren, 2001). Muslims in Denmark are represented by different ethnic groups, which are generalized in the literature as Non-Western immigrants. Moreover, areas with high concentration of Muslims or Non-Western population, comprising over than 50% of the population, if combined with high criminality rates, unemployment, or low educational levels are identified as ghettos by the Danish Government (Boligministeriet, 2017). Therefore, it can be argued that Non-Western population is the most vulnerable racial minority in Denmark, which corresponds to the use of Hispanic population in SoVI Lite methodology.

- *Native American population*: The SoVI Lite metric includes Hispanic and Native American population as vulnerability indicators, underlying the diverse ethnic background of the American population. Discrimination, social isolation, lack of knowledge of the local language can increase the vulnerability of ethnic groups, as Table 4.1 shows. However, these indicators have to be adapted in order to reflect the societal context of the Danish population. Firstly, Greenlandic and Faroese people who live in Denmark represent the "Native American" indicator. One could argue that these two ethnic should be taken into consideration with regard the home-nation's relationship with Denmark. Both Faroese and Greenlandic people are considered Danish citizens; however, there are cultural and linguistic differences among them and the Danes.

The indicators that Cutter et al. (2011; 2003) identify illustrate the factors that influence vulnerability to a range of different natural hazards. Consequently, coastal flooding vulnerability studies tailor the indicators to the specific hazard type. Based on literature findings, an important factor in the case of coastal floods is car ownership. Singh et al. (2014) and Dwyer et al. (2004) point out that car ownership is among the factors that has an influence on human vulnerability. Hurricane Katrina showcases that access to a car is a key factor in generating social vulnerability (Rufat et al., 2015). Moreover, Fitton et al. (2018) advocate that that access to a car can decrease significantly the vulnerability of an individual, since it provides the ability to evacuate an area in case of emergency. Moreover, car availability reduces local dependency on services or resources (Fitton et al., 2018). Therefore, in a case of coastal flooding, car ownership is important and might be helpful in the recovery process after a hazard. For instance, if an individual need to be hospitalized in a distant facility, car can reduce distance and time. Another example refers to local goods and groceries, which after a disaster can be limited and more expensive. In this case, car ownership reduces the cost and also increases the choices for an individual. As a result, car availability is considered to decrease social vulnerability to coastal floods and is selected to be included in the vulnerability index.

Another indicator that has been omitted from the SoVI Lite metric (Cutter et al., 2011; Evans et al., 2014) is occupation. According to Cutter et al. (2003) employment based on resource extraction is vulnerable to natural

hazards. Especially in the case of coastal flooding, fisheries, agriculture and forestry might have greater difficulties recovering from a flood hazard, when compared to service oriented positions (Cutter et al., 2003). In Denmark, only 3% of the land is built up, while the rest is used for agricultural production and other locally based economic activities, including fisheries, forestry and farming (Bruun et al., 2012). Hence, one could argue that many people are employed in these industries, with occupation affecting significantly individual's capacity to recover from a coastal flood. People employed in these sectors are more prone to lose their jobs and experience economic difficulties after a flood, due to the dependence on the local resources. Hence, occupation in the primary economic sector is added in the vulnerability index, denoting an increase of social vulnerability.

Moreover, family structure seems to affect vulnerability distribution too. Single parent families often have lower income compared to families with two parents (Cutter et al., 2003), and have increased responsibilities regarding the assistance of other family members in case of emergency (Fitton et al., 2018). It is possible that single parent households already experience financial difficulties, which can be exacerbated during or after a hazard. Besides the struggles of evacuation, recovery process poses new difficulties since these decisions should take into consideration the wellbeing of the vulnerable family members (Fitton et al., 2018). More precisely, in a case of coastal flooding the economic cost for insurances or damage repairs might create an additional economic burden to the family. Therefore single parent families are selected for the index creation, indicating a positive relationship with vulnerability.

A final addition to the factors that affects vulnerability is social dependency. This indicator was identified by Cutter (2003) and used in the SoVI metric, but is omitted from SoVI Lite metric. However, social dependence is a crucial factor especially in the case of coastal floods. Social dependent people rely heavily on social services and governmental allowances (Cutter et al., 2003). This category includes unemployed, recipients of disability pensions and people on maternity or sickness related leaves. Therefore, people receiving public benefits might not only experience economic difficulties and struggles in the post-disaster period (Cutter et al., 2003), but they also require support during the hazard and the evacuation process. Consequently, indicators of social dependency are associated with increase of social vulnerability.

Currently, the only vulnerability assessment in regards to coastal flooding that has been undertaken in Denmark was part of the EU Flood Directive (2007/60/EC). The indicators that have been selected include population density, sights of cultural heritage, different types of infrastructure and land use (Kystdirektoratet, 2018b). These indicators are similar with the indicators of Mclaughlin and Cooper (2010). However, these variables are insufficient for measuring the social side of vulnerability, which is the aim of this research. Consequently, in order to produce a social vulnerability index for coastal floods socio-economic data for the Danish population will be used as indicators.

4.2 Social Vulnerability Data

For the purposes of the analysis and the vulnerability assessment data were obtained from Statistics Denmark (2019), expect the data for Greenlandic population in Denmark that were obtained from Statistics Greenland (2018). It is common for vulnerability assessment studies to utilize census data, e.g. Cutter et al. (2003), Myers et al. (2008), Armas et al. (2016), or geodemographics, which are demographic data for commercial purposes, e.g. Willis et al. (2010) and Fitton et al. (2018). However, both census data and geodemographic were rejected for the analysis. The available census data have as basis of analysis the regions in Denmark; therefore, due to the

larger geographic area they cover, they are rejected. On the other hand, the available geodemographic databases did not correspond to the range of factors that influence vulnerability. Another unit of available data is parish level. Despite the fact that Statistics Denmark provides some data in parish level, the data are unsatisfactory for the construction of the vulnerability index. Both geodemographies and parish data only cover the population, age and gender spectrum. Therefore, for the purposes of this vulnerability assessment the spatial scale is the municipality level, as the smallest available spatial unit that covers all the factors that affect vulnerability. Currently, Denmark is divided in 98 municipalities. However, some of the collected data include Christiansø island as a municipality, while it is usually considered to belong to Bornholm municipality. Hence, Christiansø is omitted from the analysis due to data inconsistences. The majority of the obtained data are for the year 2018, with some exceptions, which can be seen in Table 4.2.

Moreover, Statistics Denmark does not provide occupation dependency data or proportion of employees in specific industries in a smaller scale than regional. Therefore, due to data unavailability, instead of the type of occupation, educational attainment of adult people was considered for the SoVI Denmark. In general, low education level is associated with higher unemployment, unstable occupations, lower income and struggles during the recovery period (Cutter et al., 2003). More precisely, people with less educational and professional qualifications are more likely to lose their job after a hazard. (Mileti, 1999; Morrow, 1999). Due to data unavailability, the indicator of Faroese population in Denmark is not taken into consideration.

Following the SoVI Lite methodology (Cutter et al., 2011; Evans et al., 2014) fourteen indicators were selected to represent the social factors that influence vulnerability (Table 4.2). Eleven indicators are considered to have a positive directional influence with vulnerability, while for three indicators (urban residents, renters and car ownership) the influence that is observed is negative (Table 4.2). A positive relationship between the indicator and the vulnerability is assigned to the indicators that increase vulnerability to coastal floods, while the negative relationship indicates a reverse effect on vulnerability. The indicators' influence is based on the literature that has been presented in the previous section (Table 4.1).

Table 4.2: The indicators that relevant to the Danish context and are utilised in the creation of the vulnerability index for Denmark. In the field of the data source the code of each dataset is presented, along with the year of the data publication. All the data are provided by Denmark's Statistics (2019), with only exception the numbers of Greenlandic people, which were obtained from Greenland's Statistics (2018).

Indicator (vulnerability relationship)	Data Source
Poverty: Population earning less than 60% of median income (positive) Population earning less than 50 % of median income (positive)	IFOR12A, 2017
Elderly: Population over 65 (positive)	BY2, 2019
Urban: Population of urban residents (negative)	BY3, 2019
Renters: Number of households occupied by tenant (negative)	BOLIG101, 2018
Gender: Population of females (positive)	BYA, 2029
Race/ethnicity: Population of Non-Western Immigrants (positive) Population of people born in Greenland and residents of Denmark (positive)	FOLK1E, 2019Q1 GDPUH, 2018

Nursing population: Population of people in nursing homes and home nursing (positive) Recipients of disability pension (positive)	RESIO1, 2018 HJEMSYG, 2017
Car ownership: Proportion of households with at least one vehicle (negative)	BIL600, 2017
Occupation/ education: Proportion of adult population who attended only basic education (positive)	HFUDD10, 2018
Social dependency: Proportion of population receiving public benefits (positive)	AUKO1, 2018Q4
Family structure: Proportion of households that consist of single parents (positive)	FAM44N, 2019

However, as Fitton et al. (2018) remark when adjusting vulnerability indicators to a specific hazard they can contribute differently than usually perceived. Often renters are perceived to have higher vulnerability, due to lower economic power. However, in the case of coastal hazards, renters might not be affected in the same way with house owners. Renters do not have to pay to rebuild or reconstruct a dwelling, neither to pay for other economic damages, since they can relocate easily. Hence, dwellings occupied by renters indicate a vulnerability decrease, or a negative directional influence, in the case of coast floods. Likewise, urban residents are more prone to a hazard, due to potential complication in the evacuation process (Cutter et al., 2000; Cutter et al., 2003; Fitton et al., 2018). Fitton et al. (2018) highlight that coastal protection measures are concentrated around areas with high population and important infrastructure. Hence, increased urban population indicates a negative influence to vulnerability for this study.

4.3 Building the social vulnerability index

Once the data representing the social aspects of vulnerability are obtained, the data have to be standardized, with the use of an excel spreadsheet. Evans et al. (2014) explains that the population data should be converted into percentage values for implementing the SoVI Lite for Denmark and to allow further statistical analysis. This step is crucial because the data, shown in in Table 4.2, are in incompatible units.

The next step includes the conduction of correlation analysis. A prerequisite for the vulnerability assessment is the minimal statistical correlation among the selected vulnerability indicators (Table 4.2) (Fitton et al., 2018; Holand et al., 2011). By conducting the statistical correlation test it is confirmed that all aspects of social vulnerability are measured by a unique indicator (Fitton et al., 2018). The statistical correlation is conducted with the use of SPSS program. Based on the correlation value tier of $\pm$ 0.85, according to Willis et al. (2010) and Fitton et al. (2018), values with higher correlation were excluded from the analysis. Based on the generated correlation matrix, two indicator were highly correlated with r=0.970. The two indicators, proportion of people with income less than 60%, and 50%, of median income, were the highly intercorrelated. Hence, the first indicator was omitted, because the two indicators explain at some extent the same information about the population.

After converting all indicators values to percentages for each municipality, it is possible to normalize the selected indicators with z-score creation. According to Evans et al. (2014) z-scores constitute a statistical normalizing method which transforms variables to a similar numeric scale. The equation for calculating z-scores is defined by Evans et al. (2014) as:

$$Z - score\ q\ =\ (q\ -\ \mu)\ /\ \sigma$$

Where q is the indicator value, μ is the mean percentage of the q values; and σ is the standard deviation of the q values. Therefore, mean and standard deviation of the standardized values have to be calculated for the generation of the z-scores. The calculations are conducted in an excel spreadsheet.

$$\begin{aligned} SoVI\ Score\ =\ & (ZscorePoverty) + (ZscoreAge) - (ZscoreRenter) - (ZscoereCar) \\ & + (ZscoreImmigrants) + (ZscoreFemale) + (ZscoreDisability) + (ZscoreNursing) \\ & + (ZscoreBenefits) + (ZscoreEducation) + (ZscoreGreenlandic) + (ZscoreFamily) \\ & - (ZscoreUrban) \end{aligned}$$

Once the SoVI scores for each municipality are generated, the scores are imported in ArcGIS 10.6. With the use of choropleth mapping of the standard deviations of the scores, social vulnerability to coastal floods is illustrated spatially. Emrich and Cutter (2011) classified vulnerability scores as limited, moderate and elevated, while the same classification method was used by Evans et al. (2014). Borden et al. (2008) utilize a classification tier of 0.5 standard deviation as the breaking point among the classes mentioned above. In this research, vulnerability scores are classified following the tier of 0.5 in order to depict the vulnerability scores.

SoVI Lite method has been the basis of the vulnerability assessment. As it has been described before, this method does not impose a PCA for the indicators selection and the index composition. Hence, for the purposes of this research PCA is constructed after the index composition in order to identify the main drivers of social vulnerability in Denmark.

5 Results

One the social vulnerability index for coastal flooding in Denmark is constructed, it is possible to assess the vulnerability of each municipality. Therefore, this chapter presents the results of the conducted research and elaborates on the main factors of social vulnerability across the country.

5.1 Where do vulnerable people live?

It might not be surprising that the vast majority of the Danish municipalities expose moderate levels of vulnerability. The SoVI scores for the 98 Danish municipalities fluctuate from +3.33 (the highest value) to –1.43 (the lowest value). Overall, thirteen municipalities scored as very highly vulnerable with standard deviation of the total SoVI scores higher than +1.0, and seven municipalities as highly vulnerable. Forty one municipalities, representing the majority, have moderate vulnerability levels. Twenty seven Danish municipalities have low vulnerability, while nine of the municipalities scored very low on social vulnerability, with scores less than -1.0. The key findings can be seen in Table 5.1.

Table 5.1: The municipalities with the highest and the lowest vulnerability scores. The municipalities are classified from the largest score to the smallest in the first column, while the second column uses the reverse classification.

Most Vulnerable Municipalities	Least Vulnerable Municipalities
Ærø	Ballerup
Aarhus	Brønderslev
Odense	Herlev
Læsø	Varde
Copenhagen	Glostrup
Aalborg	Helsingør
Assens	Faxe
Samsø	Faaborg-Midtfyn
Fanø	Ringkøbing-Skjern
Lolland	Vesthimmerlands

One cluster of the most vulnerable people can be found in the urban areas of the country. Some of the highest vulnerable scores are attributed to Copenhagen, Aarhus, Odense and Aalborg, while similar vulnerability levels are noticed in Copenhagen's neighboring municipalities. The four biggest cities in Denmark are classified among the top ten most vulnerable municipalities across the country (Table 5.1). These urbanized areas share similar demographic traits, such as the highest population concentration in the country and the greater proportion of Non-Western citizens. Moreover, they constitute of highly social dependent and low income population, and the majority of the citizens are tenants. Thus, the most vulnerable population is not equally distributed among the urban centers of Denmark (Figure 5.1). On the contrary, among the most vulnerable municipalities are inhabited islands, like Æro, Samsø and Læsø (Figure 5.1), which are placed among the top five most vulnerable municipalities. It is observed from the data, that vulnerability in this case is shaped by the high proportion of elderly and their associated dependence due to health issues. The islands of Denmark have increased population in nursing facilities or home nursing and high proportion of recipients of disability pension. Moreover the islands have scored high in the primary education attainment, while the mean income of the residents is 60% lower than the average individual income. Moreover, these areas scored high on the concentration of Greenlandic

population, in a similar way with Aalborg and Odense. This is not surprising when considering the social challenges that rural Denmark is facing (Andersson & Laursen, 2011; Laursen, 2009). The rural parts of Denmark suffer from out-migration of young and skilled citizens, slow economic growth and high dependency on local resources and the primary sector (Andersson & Laursen, 2011).

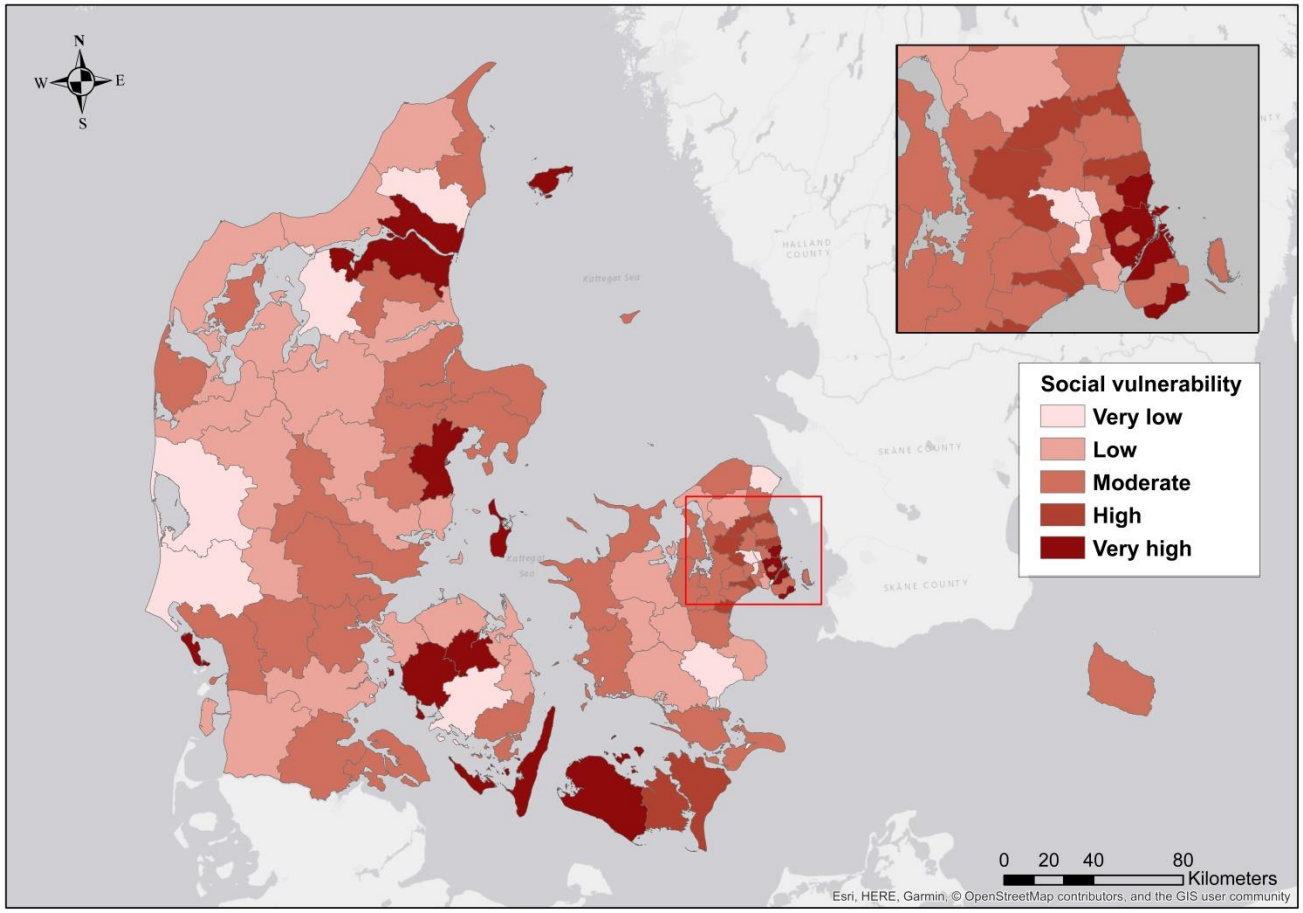

Figure 5.1: Social vulnerability of Danish municipalities. The municipalities around the metropolitan area of Copenhagen are enlarged to provide a detailed view due to the concentration of small municipalities The municipalities are ranked based on the standard deviation of the derived vulnerability scores, and are classified according to the legend of the map.

Municipalities that have scored less than -1.0 are labeled as very low vulnerability, and they are distributed unevenly across the country (Figure 5.1). Faaborg-Midfyn, Faxe, Varde and Brønderslev municipalities are among the areas where the least vulnerable live (Table 5.1). The majority of the low vulnerable municipalities include a mix of low urbanized municipalities, with low proportion of economic disadvantaged and social dependent citizens. The least social vulnerable people live in Ballerup municipality, while there is at least one municipality labeled as very low vulnerable in each region. In general, low vulnerability is the result of low social challenges. Low vulnerable municipalities are spread across the country, with a big cluster in the middle of Jutland (Figure 5.1). With similar population composition as the very low vulnerable municipalities, the majority of the population is mainly Danish, educated and owners of at least one vehicle.

The remaining municipalities are labeled as moderate vulnerable (Figure 5.1). This category includes forty one Danish municipalities. These areas present a relatively similarity in the social and economic situation of the population. They are rural and sub-urban areas, with limited ethnic background of the citizens, who are qualified for the labor market and with income higher than the average. Overall, the moderate scores of vulnerability are generated through the interaction of factors that increase and decrease the total vulnerability. Some notable clusters of moderate vulnerable municipalities can be observed in close proximity to the bigger urban centers of the country, e.g Aarhus, Odense and Copenhagen, and in the southern part of Jutland region.

5.2 Which are the main factors of social vulnerability?

For a holistic interpretation of the SoVI scores, PCA is conducted in order to highlight the most influential factors of the social vulnerability to coastal floods in Demark. While PCA is usually applied in order to identify the factors influencing vulnerability among a large set of variables and facilitate the index construction, for the purposes of this research PCA is conducted as a validation measure. The overall aim with the use of this method is to reassure that the selected indicators that are utilised to create the social vulnerability index for coastal floods in Denmark can be identified with the more traditional use of the PCA.

Once the PCA was conducted, three components are extracted with eigenvalues more than + 1.0 (Figure 5.2). The cumulative variance of these three components is around 83%, a percentage in accordance to the results of Cutter et al. (2011; 2003). In other words, these three cumulative components contain almost 83% of the information contained in the original set of variables. Therefore, it can be argued that the selected socio-economic data that have been used for the Danish vulnerability index are appropriate for conceptualizing the vulnerabilities of the population.

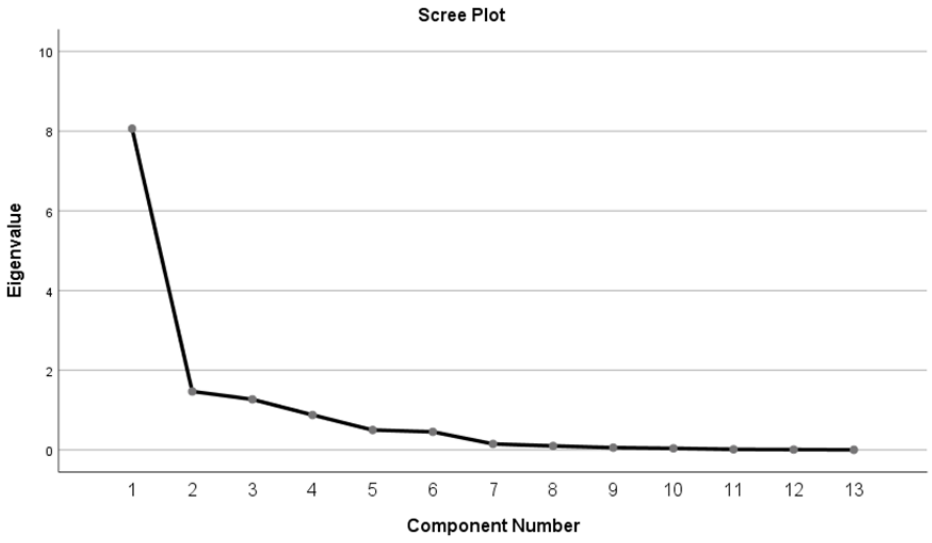

Figure 5.2: Scree plot diagram of the derived principal components. The three components have eigenvalues greater than +1.0 and are the components that contains the greatest amount of information of the original indicator values. The three components are named *Age, gender and socioeconomic status, Immigrants, Urbanism and special needs, and Accessibility and ethnicity.* The individual indicators of each component are explained further within the chapter.

The first component, named *Age, gender and socioeconomic status* (Figure 5.3) explains 62 % of the variance. This component distinguishes the municipalities based on the proportion of elderly, tenants, people with low income and dependent on social funding, female population, education level and family structure. It can be seen that the most vulnerable municipalities have scored high vulnerability as individual indicators of the first component (Figure 5.3). More precisely, the vulnerability of the urban municipalities seems to be related with high scores in tenants, income and the people receiving public benefit. On the contrary, the rural municipalities that have labeled as high and very high vulnerable can be attributed to increased scores in primary education, age, gender and single parents' families.

The second component explains 11 % of the total variance comprising of indicators about the proportion of non-western immigrants and their descendants, recipients of disability pension and urban population (Figure 5.4). According to Figure 5.4, the proportion of people receiving disability pension is moderate across the country, with a notable exception in Funen Island. Moreover, the immigration scores correspond to the total vulnerability patterns, besides the Western part of Zealand.

The final component accounts for 10 % of the total variance. This component comprises of the individual scores of car ownership across the county, as well as the proportion of Greenlandic population. Figure 5.5 shows that high concentration of Greenlandic population does not imply high vulnerability, while cart ownership scores seem to correspond with the total vulnerability scores, especially in the moderate vulnerable municipalities.

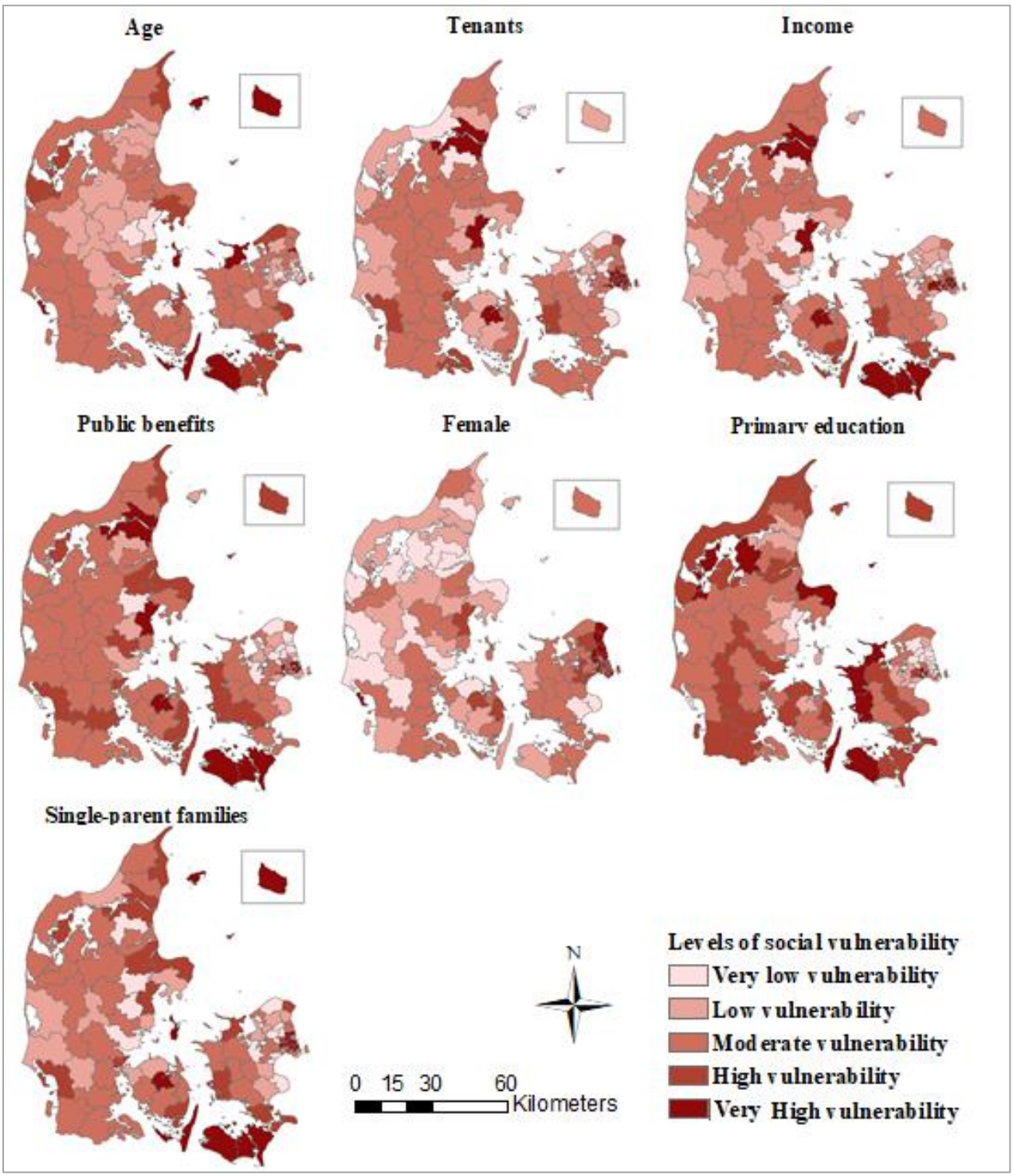

Figure 5.3: Vulnerability indicators that comprise component one. The individual indicators are presented based on their loadings classified from the largest to the smallest. The loadings of the indicators can be seen in Appendix

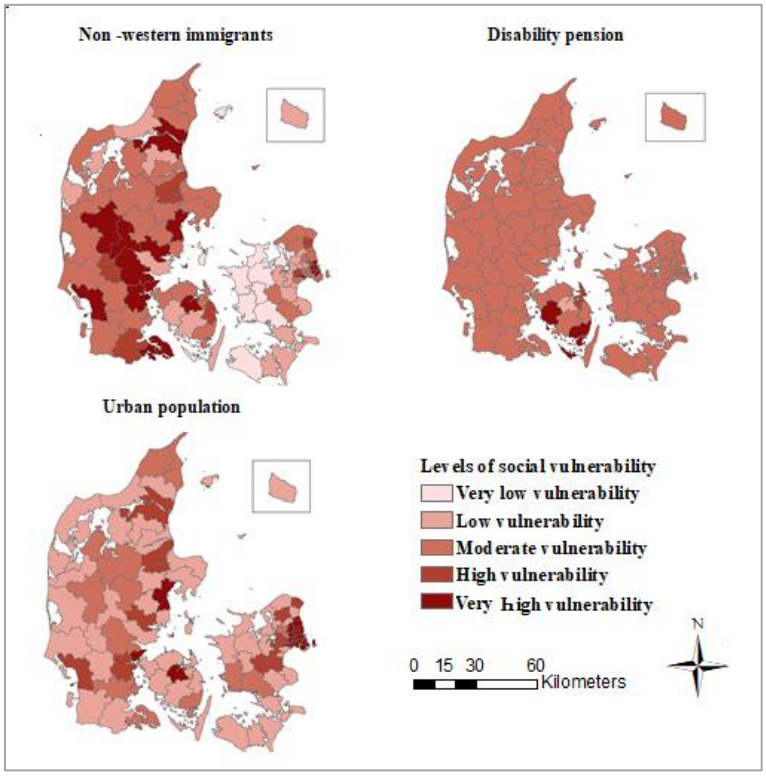

Figure 5.4: Component number two. The individual indicators are presented based on their loadings from the largest to the smallest. The loadings of the indicators can be seen in Appendix

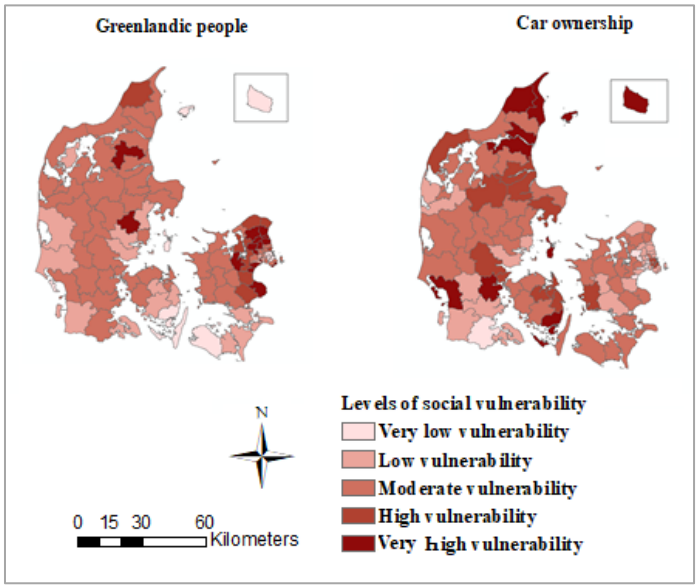

Figure 5.5: Component number three. The individual indicators are presented based on their loadings from the largest to the smallest. The loadings of the indicators can be seen in Appendix

6 Discussion

In section **1.7** the main objectives of this research were declared. These objectives are the following:

- Where do vulnerable people live in Denmark?
- What are the spatial patterns between and among the Danish municipalities?

This chapter aims at interpreting and reflecting upon the results reported in Chapter 5 and to discuss the implications of the study for coastal flood risk management in Denmark. Additionally, the limitations of the study are discussed, followed by suggestions for future research.

6.1 Key findings

The first aim is locating the most vulnerable population in Denmark. This has been achieved by creating the Social Vulnerability Index to coastal flooding for 97 Danish Municipalities, as it can be seen in chapter 5. According to the findings of this research, the most vulnerable people in Denmark are located in the four biggest cities and in the islands across the inner coast of the country (Table 5.1). The second aim of the research is captured by the second research question. With the use of the social vulnerability map for Denmark (Figure 6.1), it is possible to visualise the vulnerability scores of each municipality, allowing detecting patterns between the municipalities. Moreover, in section 5.2, the individual drivers of vulnerability are mapped in order to provide holistic view of the factors of that affect vulnerability in each municipality. Two cluster of very high social vulnerability are observed in Denmark. The first cluster comprises of the highly urbanized municipalities, which include large Non-Western immigrants' populations and single-parent families, low income populations and large numbers of people dependent on public benefits. The second cluster of highly vulnerability contains the islands of the inner coast of the county, comprising by elderly population, low skilled labor force and socially dependent population (public benefits, disability pension, single parents families, nursing). Another vulnerability pattern that is observed refers to the least vulnerable people, who reside in the suburbs of Copenhagen (Figure 6.1). A pattern of low vulnerability can be seen in Figure 6.1, where some of least vulnerable municipalities cluster. The municipalities include educated and wealthy populations, as well as families, factors that decrease social vulnerability.

The patterns of vulnerability suggest that social vulnerability of the Danish population, especially in the case of the high vulnerable islands, could be explained by the spatial polarization in the country. Andersson and Laursen (2011) explain that in the last decades the rural parts of the country struggle with out-migration of the young and skilled people and experience economic decline, due to centralization of economic opportunities in bigger cities. While, Hansen and Smidt-Jensen (2004) suggest that the lack of infrastructure and of skilled population can explain the decline in the rural parts of Denmark. The analysis of the individual vulnerability components propose that the high vulnerability of islands is influenced by the age and the educational level of the population. On the contrary, the highly urbanized municipalities of Denmark are experiencing economic and population growth (Andersson & Laursen, 2011), which explains the high concentration of skilled people. However, due to large population concentration, it is not surprising that the big cities include high numbers of marginalized populations (e.g. Non-Western immigrants, recipients of public benefits), which are stipulated to increase social vulnerability. Therefore, the results of the study propose that the spatial variance of social vulnerability to coastal floods in influenced at some extend by the urban development tendencies across Denmark.

Due to the different scale of analysis, the results of the generated vulnerability assessment to coastal floods cannot be compared with the vulnerability assessment of the DCA (Figure 6.1). However, it can be observed that both maps highlight the vulnerability of areas with increased population, such as Copenhagen, Aarhus etc. Nevertheless, the vulnerability assessment of the DCA differs with the generated assessment in the vulnerability of the islands along the inner coast of the country. As it is argued in Chapter 1, the existing vulnerability assessment is not an assessment of the vulnerabilities of the Danish population to coastal floods, since it includes indicators such as critical infrastructure, local economic activity and population density (Table 1.2). Therefore a reason behind the difference of the observed vulnerability patterns between the two maps (Figure 6.1) could be that the previous vulnerability assessment of the coastal floods underrepresents the vulnerability of rural areas because of the absence of critical infrastructure and the lower population.

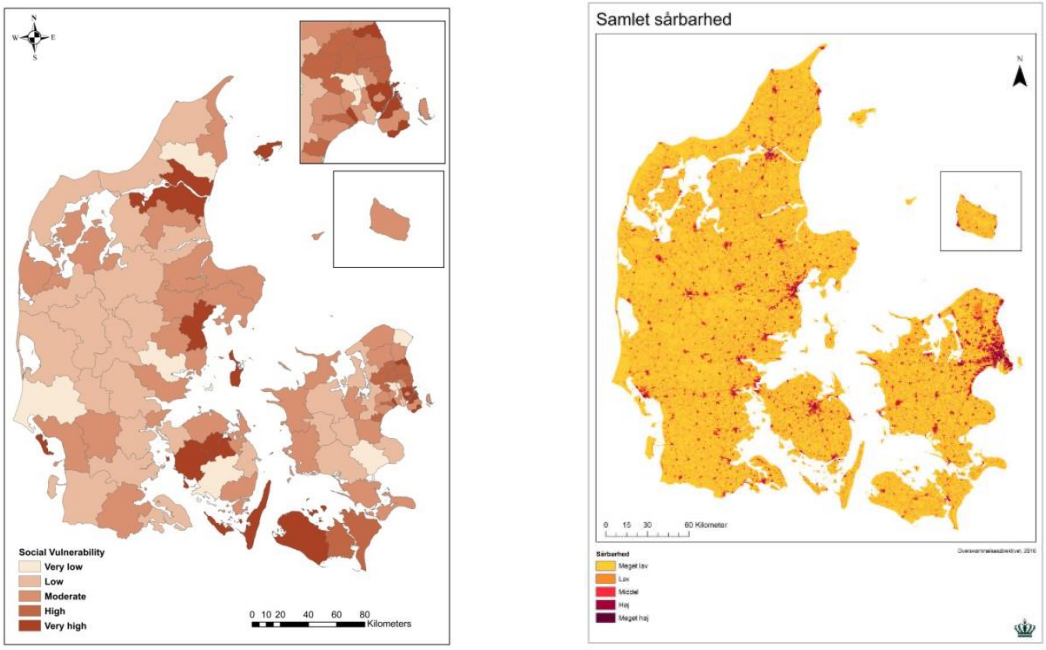

Figure 6.1: Map of social vulnerability to coastal floods generated for the purposes of this reasearch, and vulnerability map that was created by the DCA (2018a).

6.2 Implications for flood risk management in Denmark

It should be clear by now that flood risk assessment requires knowledge of the local conditions and the vulnerabilities of local population (Jebens & Sorensen, 2017). Sorensen and Jebens (2015) explain that the vulnerability assessment that was implemented by the DCA aimed at identifying social vulnerabilities. Thus, as it is discussed in section 6.1, this goal has not been achieved. Despite the identification of prone areas to flooding across the country, without the assessment of the social aspects of vulnerability, the results of the process can be misleading. The methodology that has been followed could either be incorporated into the existing flood risk assessment as a tool for identifying the social vulnerabilities of the society, which is missing. Alternatively, it may serve as the theoretical basis of a new way of defining hazard, risk and vulnerability that could lead in a holistic flood risk assessments and the establishment of nation flood programme.

The interview with Vejle's Resilience officer highlights the confusion around implementing social-oriented vulnerability or adaptation plans, as well as quantifying social vulnerability. She further discusses that:

"For instance, let's say that the entire city of Vejle gets totally flooded and people lose their homes. Are all of them insured? Will the insurance companies help them all? We don't have any knowledge about something like that, because in Denmark insurance is a private matter not a public one. Therefore, we have no idea how many people are insured. For deeper understanding of we have to take into consideration the whole community and most of all the vulnerable groups."

This quote supports the argument that awareness regarding the threat of coastal floods and their socio-economic impacts is limited in Denmark (Sorensen & Jebens, 2015). The flood management implementation is a municipal responsibility, while according to the Danish Coastal Act individuals are responsible for protecting themselves and their properties against flooding (Jebens & Sorensen, 2017). Thus, Danish society tends to undermine their vulnerability to coastal floods and this perception contributes to a superficial understanding of the threat posed by coastal floods. This study has generated maps of the individual drivers of vulnerability that can be used in the municipal adaption plans and the local flood risk management. Therefore, the results of this research can assist municipalities in the identification of their vulnerabilities based on their population composition and their needs. Consequently, local planning can re oriented towards the needs of the most vulnerable populations. At the same time, these results can increase the awareness of citizens, relevant stakeholders and emergency managements. Additionally, the greater awareness of the social vulnerabilities can promote engagement of the vulnerable groups in the flood risk management and the local planning process, which is an aim of many municipalities.

Jebens and Sorensen (2017) further discuss that the coping with floods would pose a challenge for Denmark due to problems of communication and coordination among stakeholders. Hence, this research can act as a barrier around the confusion of social vulnerabilities understanding among different stakeholders. Overall, this thesis contributes to the body of knowledge in the coastal flood risk management and vulnerability field. The findings of the research emphasise the applicability and transferability of the SoVI Lite methodology to different geographic contexts, while it comprises a step towards the construction of an index tailored to the Danish social context. This study exposes the social vulnerabilities of the Danish population, which is an important step for a mentality change towards vulnerability and more effective coastal flood risk management.

6.3 Limitations of the study

Social vulnerability assessments do not provide "end-point" results (Solangaarachchi, et al., 2012). By reflecting on the way this this research defines social vulnerability (Chapter 3), readers should keep in mind that social vulnerability is a component of the place vulnerability of each municipality. The hazard of place model dictates that social and biophysical vulnerability interact in order to create the place vulnerability. It is acknowledged by the authors that a complete vulnerability assessment is a long term project. Hence, this research contributes to the assessment only of the social aspects of vulnerability to coastal flooding.

Another challenge during this research was the potential bias during the indicators selection process. In order to address this limitation, extensive literature search was conducted and the selected indicators correspond to the general factors that are broadly identified as important in vulnerability assessments. Thus, challenges related to available data interfere with the vulnerability assessment. Moreover, the social vulnerability is conducted with

municipalities as the unit of the analysis, because they constitute the smallest administrative unit of analysis with plethora of available data. It is acknowledged that data at municipal level do not provide the greatest spatial resolution for the purposes of this research. Ideally, parish, postal code or address level data would offer a better resolution and present in further detail the spatial distribution of social vulnerability. However, data unavailability influences not only the indicators, but also the unit of the analysis. As a consequence, municipalities were selected since they comprise an acceptable unit of analysis for achieving the aims of this research.

A generalized limitation of the vulnerability indices is the conceptualization the dynamic processes that shape vulnerability (Schumann & Moura, 2015). Fekete (2012) elaborates on this challenge and explains that indicators can be used partially for interpreting a phenomenon. Rygel et al. (2006) argues that interpretation of experiences, ideas and cultural values cannot easily be represented by quantitative data. Therefore a small set of indicators has to be collected, comprising of the indicators that conceptualize the geographic context in the best way possible, in order to quantify vulnerability (Fekete, 2012). Adger et al. (2004) agree that developing of a vulnerability index is important for allowing comparison among places. Nevertheless, vulnerability indices are associated sometimes with over- or under-presentation of the individual factors, since the combined vulnerability score has the potential to favor or not individual factors, and hence lead to misinterpretation of the findings (Rygel et al., 2006). Since SoVI provides relative vulnerability scores (Cutter et al., 2003; Rygel et al., 2006), visualisation of the individual indicators is selected in order to provide a different perspective of the spatial distribution of vulnerability drivers. In this way, it is possible to draw the attention into the specific challenges that each area faces, instead of focusing solely on the generated vulnerability score. Another way to address this limitation is the validation of the results based on secondary disaster data. However, validation is omitted due data unavailability for coastal floods in Denmark, strengthening the argument that validation is a difficult research obstacle (Adger et al., 2004; Fekete, 2009; Fekete, 2012).

6.4 Future research recommendations

Within this research knowledge gaps are identified, which require to be addressed by future research in order to improve coastal flood management in Denmark. The suggestions include:

- Use of the original SoVI methodology, instead of SoVI Lite as the analytical framework of the social vulnerability assessment. By including more data, different patterns of vulnerability can be observed and the drivers of vulnerability can be explored in-depth;
- Use of data with greater spatial resolution. The analysis should be local, since the flood management plans are implemented by municipalities, but socio-economic data at parish, postal code or even address level will contribute to a better understanding of the spatial distribution of vulnerabilities;
- Investigation of past hazard events, both with quantitative and qualitative methods, which can create data set for validating the results of the social vulnerability index for Denmark. In this way, the complex social interactions, the historical and cultural drivers of vulnerability would be taken into consideration. The validation of the model's results can enhance the possibilities that the method poses for stakeholders across the country, while it can be applied to other types of hazards;
- Assessment of the future social vulnerabilities with projections of data and scenario building as a tool.

7 Conclusion

The conducted research focuses on the spatial distribution of the social vulnerability to coastal flooding among the Danish municipalities. More precisely the research aims at quantifying the social vulnerabilities in order to identify the most vulnerable populations and understand their social characteristics, by stating the two following research questions:

- ***Where do vulnerable people live in Denmark?***
- ***What are the spatial patterns between and among the Danish municipalities?***

By implementing the SoVI Lite methodology, which has been developed by Cutter et al. (2011), and the use of socio-economic data at municipal level, a social vulnerability index for coastal flooding is constructed for Denmark. The index comprises of 12 indicators and it has been used for assessing the vulnerability to coastal floods in of 97 Danish municipalities. Each municipality is assigned a vulnerability score as a whole unit. Therefore, the first aim of this research has been fully achieved with the creation of the social vulnerability index and the quantification of the vulnerability of each municipality (Table 7.1). The results of the vulnerability assessment indicate that the majority of the Danish municipalities, almost 42%, demonstrate moderate levels of social vulnerability. A considerable lower number of municipalities, 37%, are labeled as low vulnerable. Overall, 20 municipalities (21%) have been assigned high vulnerability to coastal flooding.

Table 7.1: Key findings

Most Vulnerable Municipalities	Least Vulnerable Municipalities
Ærø	Ballerup
Aarhus	Brønderslev
Odense	Herlev
Læsø	Varde
Copenhagen	Glostrup
Aalborg	Helsingør
Assens	Faxe
Samsø	Faaborg-Midtfyn
Fanø	Ringkøbing-Skjern
Lolland	Vesthimmerlands

Among the ten most vulnerable municipalities across the country, the four biggest urban centers of Denmark can be found. The top ten ranking also includes Læsø, Samsø, Fanø, Æro and Lolland, some of the big inhabited islands of the country (Figure 6.1). Once the vulnerability was quantified, it was possible to investigate the drivers of vulnerability in each municipality. The results of this study propose the existence of two contradictory spatial patterns among the vulnerable municipalities of Denmark. One notable cluster of high vulnerability includes the urban municipalities, while the second cluster of high vulnerability comprises of the rural islands of the inner coast. These two clusters can be attributed to contradictory factors, since the population composition is different among the areas.

In order to accomplish the second aim of this research PCA is conducted to highlight the most influential factor of the social vulnerability in Demark. The results of the PCA point out three components as the major drivers of social vulnerability in terms of coastal floods. The components are named *Age, gender and socioeconomic status, Immigrants, disability and urbanism, and Ethnicity and accessibility* respectively, and explain 83% of the data variance. The results indicate that the high vulnerability of the rural municipalities is connected with the demographic challenges that these parts of the county face. These municipalities are comprised mainly by elderly, low income or social dependent population, factors that affect positively the vulnerability and can explain the high levels of it. On the contrary, the most urbanized areas of the country, such as Copenhagen and Aarhus, are characterised by large numbers of immigrants and people dependent on financial support by the Danish state, which increase the vulnerability of urban municipalities. Therefore, the findings of the research suggest that social vulnerability to coastal floods vary among the Danish municipalities and these patterns follow at some extent the development of the country.

This resrearch contributes to the understanding of the social factors that can interfere with the ability of the Danish population to cope with hazard when encountered a coastal flooding. The findings of the research could either be incorporated into the existing flood risk assessment, serving as a tool for identifying the social vulnerabilities of the society, which is missing. Moreover, the identification of the most vulnerable municipalities can facilitate the planning process and the implementation of flood risk plans, considering the responsibility of municipalities to implement these plans. Municipalities can use the results of the study to understand their main social challenges and raise awareness among the civil society. As coastal floods are expected to become a great threat for coastal Denmark, social vulnerability assessment should be part of the coastal flood management process.

Further research is required for overcoming the challenges of creating an index tailored to the Danish context, while incorporating both qualitative and quantitative data. In this way, the complexities of the Danish population, the historical and cultural drivers of vulnerability will be taken into consideration. While, further research can propose ways to validate the results of the social vulnerability index for the coastal floods in Denamrk, in order to can enhance the possibilities that the index poses.

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