Social vulnerability indices and a sub-municipal index for Sweden

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Abstract
The goal of risk and vulnerability research is to reduce the harm done by disasters. A disaster is a combination of a natural hazard and a vulnerable society. Understanding vulnerability is vital to reduce disaster risk, or the potential of losses in property or life. Vulnerability is often divided into a technical, relating to buildings, infrastructure, and so forth, and a social which concerns the way different groups in society differ in their ability to mitigate, prepare, respond and rebuild in the wake of a disaster.

By exploring census data, an idea of where these vulnerable groups are located can be created and used to help them overcome barriers that prevent their preparedness. After an analysis of nineteen international studies focused on social vulnerability indices, a suggestion for a Swedish index is proposed. This Swedish index highlights thirteen indicators and seventeen variables that could be used to measure vulnerability in Sweden. National data sources for fifteen of the variables have been found and is presented. This index could be used to influence decision-making before a crisis by identifying those in need of additional assistance during the preparation and response phase of a disaster.

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To Sarah, my wife and life companion, thank you.

Sincerely,

Tobias Wagner

Table of Contents

List of figures

List of tables

1 Introduction

The field of risk and vulnerability management has, following its rebirth after the second world war as the civil defence movement, the goal of reducing the harm done by disasters to people, infrastructure, and the environment (Coppola, 2011, pp. 1-6). While the label of *risk and vulnerability management* varies depending on one's background, context, and country, and some other labels for the same context span from disaster or crisis management, to emergency response management, and on to various other terms, the goal remains the same.

To achieve this goal, it is necessary to understand disaster risk. This is the first priority in the *Sendai Framework for Disaster risk reduction* (UNISDR, 2015) which states that "policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be leveraged for the purpose of pre-disaster risk assessment, risk prevention and mitigation and for the development and implementation of appropriate preparedness and effective response to disasters" (UNISDR, 2015, p. 14).

Vulnerability is the first dimension mentioned above, and it is a key component in understanding risk. The term is used an additional ten times in the *Sendai Framework for Disaster Risk Reduction*. The Framework calls for research on the subject, data collection and promotion of access to the data collected, and perhaps above all, the application of the knowledge obtained to reduce disaster risk and strengthen the capacities of both nations and the general public (UNISDR, 2015, pp. 14-16).

The terms *risk* and *vulnerability* have several definitions which vary both between fields, and even at times within a single field itself. Understanding of risk can be condensed into the answers to the questions of (1) What can happen, (2) How likely is it, and, (3) What would be the consequences if an event were to occur (Kaplan & Garrick, 1981, p. 13). In contrast, vulnerability is a measure of the ability to deal with these consequences (Holand, Lujala, & Rød, 2011, p. 2; Vincent, 2004, pp. 5-6). The idea of vulnerability will be expanded upon further in chapter 3.

A few years after the publication of the Sendai Framework in late December 2017, a working group within the Swedish Department of Defence finalized a report concerning the closely related field of civil defence and how it should be organised in case of war or crisis in Sweden.

Totalling over 200 pages, it covers a broad variety of aspects on different levels, from an individual's responsibility all the way up to national interests and duties (Swedish Department of Defence, 2017). The first point in the list of national interests for the security of Sweden is "to accommodate the safety, security and health of its citizens" (Ibid., 2017, p. 15). It is proposed that the purpose of civil defence, among other things, is to "safeguard the civilian population" (Ibid., 2017, p. 83). As such, there is a great concern for the well-being of the people.

In the same report, it is stated that the "Individual's own responsibility is a key component of society's overall ability to resist and alleviate the consequences of serious disturbances in the functionality of the society. With good knowledge and preparation on the side of the individual, the public is able to focus its efforts on supporting those who are in need and are lacking the prerequisites to handle such a situation on their own" (Swedish Department of Defence, 2017, p. 77, also p. 164). Similar divisions of responsibility for preparation can be seen in other nations (Fekete, 2009). Not all have the capacity, knowledge, or resources to prepare sufficiently on their own, and the state maintains a responsibility to care for these individuals. As such, it is advisable to identify and assist these vulnerable groups which require extra assistance before an adverse event (Flanagan, Gregory, Hallisey, Heitgerd, & Lewis, 2011).

With this global and national call for research and action, the local level county administrative board of Skåne has recently been including social factors within its disaster risk management since "the handling of certain incidents can lead to additional or escalating incidents" (Eldeland, 2016, p. 55). When describing social factors, Eldeland (2016, pp. 55-57) uses terminology similar to that used in the Sendai Framework description of vulnerability. As such, all levels, from international via national and to local, accentuate the importance of individual preparedness and strengthening individuals' capacity to handle disasters.

The importance of a multilevel approach is emphasised by researchers. It is not enough to look only at a national or even a city level. Holand and Lujala (2013) cites a Norwegian study from 2005 in which "age-adjusted mortality rates for men can be up to three times higher in the poorest parts of Oslo (the capital) than in the richest (Sund and Krokstad, 2005, as referenced by Holand and Lujala, 2013).

One method to identify 'the vulnerable' and where those populations are located uses vulnerability mapping. While there is no direct way to measure an individual's or household's vulnerability, the use of a combination of proxy indicators enables ranking and comparison between areas. Such indicators are measurable representations of an aspect of reality (Øien, Utne, & Herrera, 2011), and indicators are regularly used in a vast variety of disciplines, both academic and professional.

While this is not the only method, another being a bottom-up approach through community mapping (Di Domenico, 2018), this thesis will address the usage and application of social vulnerability indicators both internationally and in Sweden.

Two earlier studies regarding this subject have been found for the context of Sweden, Lundgren and Jonsson (2012) and Carlsson-Kanyama et al. (2009). Both are introductory studies and rather small in scope. Carlsson-Kanyama et al. (2009) crates a vulnerability map against heat waves for a single municipality while Lundgren and Jonsson (2012) make a short literature study looking at vulnerability towards specific hazards of heat and flooding.

1.1 Purpose

This master's thesis strives to contribute to making society safer by adding to the knowledge about how indicators of social vulnerability can enhance risk and vulnerability assessments and related decision-making undertaken by Swedish authorities. It will aim to do so by building on preceding research and applying that research to a new country and thereby a new context.

1.2 Problem formulation

In order to achieve its purpose, this thesis will explore the following set of research questions:

- What indicators and variables are commonly used by researchers to measure social vulnerability?
- Which of these indicators and variables would be suitable to use on a sub-municipal scale in a Swedish context?
- Where can sub-municipal datasets related to these variables be obtained for the Swedish context?

1.3 Demarcations

The field of disaster risk management, even limited to vulnerability alone, is a vast one, transcending borders and boundaries. This study, however, is limited by the time and budget allocated to it. As such, demarcations were made.

Firstly, as described in section 2, a variety of international social vulnerability indices were studied. Related studies pertaining directly to vulnerability as a phenomenon were excluded. Additionally, while the indices examined were of diverse context and have been developed based on several geographical areas and scales, only English literature were considered, except from the one vulnerability map study briefly mentioned in the introduction.

The second demarcation regards the gathering of data. While confirmations of the existence of data sources were attempted, no attempt was made to collect the information these sources contained, nor was any such information analysed.

2 Method

To answer and explore the problem formulation above, a two-part method was employed. Initially, a literature study of social vulnerability indices was performed, followed by adapting the findings to the Swedish context. The adaptation of variables was performed following a procedure suggested by Holand and Lujala (2013, p. 322). Their procedure suggests the inclusion of the following three steps in indicator development:

1. Conceptual accommodation;
2. Technical accommodation;
3. Geographic accommodation.

As one of the research questions pertains to a general trend in social vulnerability indices, some accommodations varying from the method suggested by Holand and Lujala (2013) above have been made as outlined below. The main reason behind this is that Holand and Lujala adaptations are restricted to a single existing index (the index known as SoVI).

The method explained in this chapter follows the three steps above, preceded by the procedure for index search and indicator study which was performed to answer the first research question: What indicators are commonly used by researchers to measure social vulnerability?

2.1 Index search and indicator study

To answer the first research question, a literature review of studies examining social vulnerability indices was conducted. The search was wide in scope geographically and aimed to cover as many parts of the world as feasible. The initial search was mainly performed through a snowballing both forwards and backwards in time. It was initiated with the indicator study performed by Cutter, Burton, and Emrich (2010), whose work was very influential for this thesis.

While this snowballing method limits the search results to authors' citing or being cited by the first selected study, a multitude of studies were found which were diverse in time and geography. When a short complementary literature study was performed using LUBsearch, the search engine from Lund University Libraries, no additional studies were found when social vulnerability indicators and derivations of these terms were used.

From the found, nineteen studies were selected, and the indicators and variables of these further analysed. The studies were selected with a bias towards those that covered and/or

compared more than one index or were unique in geographical level or coverage. All indicators and, if included, their variables were put into a single document after which they were categorised and sorted (see Appendix – Indicator categorisation for the specific categorisation technique).

2.2 Conceptual accommodation

After the indicators and their variables had been extracted from the studies, a conceptual accommodation was performed, the intention of which was to "revise the conceptualizations of factors influencing social vulnerability for the particular context" (Holand & Lujala, 2013, p. 322). As such, the literature study above influenced the subsequent conceptual accommodation through the creation of a bank of knowledge of what indicators are used to measure vulnerability. Simultaneously, based on previously attained experience and knowledge, a conceptual accommodation to the Swedish context was performed. The motivation for each modified indicator is found in chapter **Error! Reference source not found.**. This conceptual accommodation answers the second research question: Which of these indicators, and variables can be applied to a Swedish context?

2.3 Technical accommodation

The main concern of technical accommodation is to "examine data availability" (Holand & Lujala, 2013, p. 322). While, theoretically, all required data could be collected, it is generally more practical to utilize data that already exists and is available, while taking care not to select data solely due to its availability as discussed in section 5.1. The technical accommodation was performed to answer the third research question: Where can datasets related to these variables be obtained for the Swedish context?

After the indicator search and the conceptual accommodation to the Swedish context, attempts were made to locate datasets that corresponded to the indicator requirements. The search began with the main provider of statistics: Statistics Sweden (SCB). Their databases were studied, and they were personally queried regarding availability and geographical scope. In addition, two more governmental bodies on national level were contacted regarding data not available with Statistics Sweden (chapter **Error! Reference source not found.** provides further details on this).

2.4 Geographic accommodation

The final step of the accommodation process suggested by Holand and Lujala (2013) is a geographic accommodation which deals with issues of scale and other factors that often

accompany the usage of GIS datasets and influence the result (Holand & Lujala, 2013, p. 322). As an example, this step covers how population density and area size is handled in relation to datasets with varying geographical boundaries. As mentioned in the demarcation above, no datasets are collected meaning no geographical accommodation was performed. However, since the existence of datasets were to be confirmed, a geographical scale based on data availability from Statistics Sweden (SCB) was considered. SCB Is the main source of statistical data for Sweden and has divided Sweden into 2523 districts, which averages to 8.7 districts per municipality. These districts correspond roughly to the earlier church parishes and have existed since 2016 (SCB, 2018). In addition, since 2018 SCB has created divisions along demographical statistical areas (Demografiska statistikområden, DeSO), which divide Sweden into 5985 areas, initially between 700 and 2700 inhabitants in each (SCB, 2018). Either of these two geographical division systems could be used for a sub-municipal analysis. Districts have slightly more data available free of charge, but cover a greater area, while DeSO data are primarily available on request only. Both DeSO and the districts data availability is presented in section 4.2.

2.5 Specific indicator criteria for a Swedish index

With the three types of general accommodation in mind when adjusting one index to a new setting, there are also indicator criteria that each individual indicator should fulfil. Each variable was measured according to the following four criteria: (1) simple to understand; (2) easy to measure; (3) relation to the area unquestionable; and (4) shows change over a specific timeframe (Cardona, 2006; Ehliar & Wagner, 2016, pp. 9-12; Øien, Utne, Tinmannsvik, & Massaiu, 2011). These criteria come from research in safety indicator development and have long been used in high-reliability organisation when developing indicators (Ehliar & Wagner, 2016).

In addition, as indicated in the problem formulation (section 1.2) the selection of variables was to be on a sub-municipal level and aimed to help decision making and prioritising before an adverse event. The indicators were also chosen with vulnerability outcomes defined as ‘who would require additional assistance during the response phase’ and ‘who has lost the most – measured by percentage of economic loss – as a guide for the recovery phase’.

3 Conceptualising and operationalising vulnerability – a framework

The term, concept and word *vulnerability* has many connotations which vary depending on context and field. Even within the field of disaster risk management the definitions vary. Regardless of connotation, vulnerability itself is complex and the understanding of it is far from complete.

Adger, Brooks, Bentham, Agnew, and Eriksen (2005) warn that this "complexity may render it tempting to give up conceptualising the understanding of vulnerability that underlies the analysis" (p. 22). This is a temptation that many fall for (Adger et al., 2005; Garbutt, Ellul, & Fujiyama, 2015, p. 4; Ruiter, Ward, Daniell, & Aerts, 2017, p. 1245). They continue to point out that "precisely because of the complexity, however, it is all the more important to outline a conceptual framework so that assumptions and weaknesses in understanding can be assessed" (Adger et al., 2005, p. 22).

This chapter is intended follow their advice and to outline the vulnerability concept that is used for this thesis. It does so by first attempting to pin vulnerability down in a larger context, followed by going deeper into how this concept is operationalised (section 3.2).

As mentioned briefly in the introduction, the top-down approach of using indicators is not the only method to measure vulnerability. The complementing bottom-up approach of 'community-based vulnerability assessment', where community members are involved in a more qualitative process to gauge their vulnerability, also exists (Di Domenico, 2018). While the concepts of vulnerability expressed below apply in both settings, section 3.2 and beyond pertain to indicators used in indices and as such, are less applicable in a bottom-up approach.

3.1 Pinpointing the vulnerability concept

To define the concept of *vulnerability*, the starting point chosen is *safety*. As previously mentioned, the wide purpose of this thesis is to make people safer, not only today but also in future contexts. While safety itself is a vast concept, it is commonly viewed as a lack of adverse consequences, as measured by number of fatalities, economic loss, and so forth (Hollnagel, 2014, especially chapter 2). It should be noted, and is done so by Hollnagel, that these indicators technically measure *the absence of safety*, rather than safety itself.

By moving beyond an immediate focus and adding a further temporal scale to safety, Becker (2014) connects sustainability to being the extension of safety into the future. He states that

"if [we focus] on the potential of future destructive courses of events . . . we typically assert that such activity or development is not sustainable. While the same situation, but with an immediate focus, would instead evoke notions of an unsafe condition" (Becker, 2014, p. 4).

Becker (2014, ch. 5) builds his concept of safety and sustainability on a knowledge of where we are today, as a society, where we want to be in the future, and a preferred way to get there. As time moves on, there are a variety of scenarios that could hinder this progress. These are the scenarios against which action today can safeguard (see Figure 1).

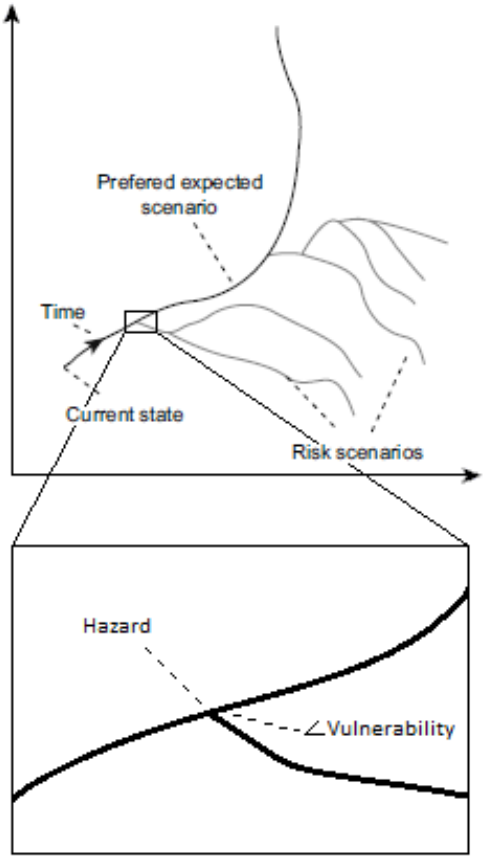

Figure 1 – Sustainability, adapted from Kaplan as found in Becker (2014)

In this setting, terms such as risk, hazard, resilience and vulnerability can be introduced by zooming in on a point where the actual scenario deviates from the preferred expected scenario.

The concept of risk was previously condensed into three questions of (1) What can happen, (2) How likely is it, and, (3) What would be the consequences if an event were to occur (Kaplan & Garrick, 1981, p. 13). In the figure above, risk becomes a potential deviation from a preferred trajectory and contains a combination of both hazard and vulnerability (Cardona, 2005, p. 1; Fekete, 2009, pp. 30-31); A hazard becomes a trigger activating a latent condition and constituting a "potentially damaging physical event, phenomenon or human activity" (UNISDR, 2015, p. 9, also Hollnagel, 2014, ch. 2).

Resilience concerns the capacity or ability to continue along the preferred path without hazards affecting the outcome (Cardona, 2006, p. 6; Van Zandt et al., 2012, p. 50), or the ability to continue in spite of risk scenarios. It has two generally divergent aspects – one technical and one social (Birkmann, 2007, p. 21; Cutter et al., 2010, pp. 1-2; Ruiter et al., 2017, p. 1232; Vincent, 2004, ch. 2.2). While both have a similar definition and end goal, the technical side tends to focus more on buildings and critical infrastructure while the social side has a greater emphasis on the community and the people living therein.

Vulnerability is the other side of a slightly different coin. Yang, He, Du, and Sun (2015), also differentiating the technical (*biophysical* is the term used by Yang et al.) and social, states that "vulnerability indicated the potential for loss" (p. 2). Holand and Lujala (2013, p. 1) use almost the same definition, adding consideration for the loss of property or life. The concept means that two identical hazards that occur will have different consequences due to the people, infrastructure and nature that exist where the hazard occurs (de Brito, Evers, Almoradie, & Delos, 2018; Tarling, 2017, ch. 1.1; Van Zandt et al., 2012, p. 30; Vincent, 2004, ch. 2.4). One part refers to the technical vulnerability, and the other to "social vulnerability, or the way social groups experience differential impacts from hazards" (Jeffers, 2013, pp. 2-3; Tarling, 2017, p. 12; Vincent, 2004, ch. 2.4).

It should be noted that these definitions are not entirely set in stone, and the concepts vary between authors. Vincent (2004) presents vulnerability in terms of anticipating, resisting, coping with and responding to a hazard – the same terms that Becker (2014) use to describe resilience (something Ruiter et al., 2017, p. 1233 also discovered when comparing several studies). Additionally, some researchers assign no difference between the technical and social, defining vulnerability as the "conditions determined by physical, social, economic and environmental factors and processes which increase the susceptibility of a community to the impact of hazards" (UN/ISDR as quoted in Birkmann, 2007, p. 21; also Jeffers, 2013, pp. 6-8).

3.2 Dimensions of vulnerability

Whilst moving towards an operational definition, Adger et al. (2005) state that "vulnerability is not a straightforward concept, and there is no consensus as to its precise meaning" (p. 28). There are general themes, one being the divide between social and technical vulnerability (Siagian, Purhadi, Suhartono, & Ritonga, 2014).

Adger et al. (2005, pp. 14-15) gives three additional characteristics of vulnerability that complicate the measurement and comparison of vulnerability of various people and places. Using these three characteristics, this section aims to go deeper into what vulnerability means in a more operational manner.

3.2.1 Vulnerability is geographically and socially differentiated

There are what could be considered generically vulnerable groups, such as the very old, the disabled, and newcomers to the community (Adger et al., 2005, pp. 29-30; King & MacGregor, 2000, p. 54). Vulnerability is an internal state that exists regardless of external hazards. As put

by Adger et al. (2005, pp. 29-30): “although social vulnerability is not a function of hazard, certain properties of a system will make it more vulnerable to certain types of hazard than to others”. As hazards are geographically bound – flooding tends to occur near water – so is vulnerability geographically differentiated (Adger et al., 2005, pp. 15-16; Cardona, 2005, p. i; Kienberger, Lang, & Zeil, 2009, p. 770) causing difficulties when the vulnerability of two or more groups are compared are compared.

This geographical differentiation can be resolved in at least two ways: (1) exclusion of indicators that specifically measure these phenomenon, such as nearness to rivers and so forth (as done by Cutter et al., 2010). Doing so removes important vulnerabilities for these areas in favour of comparison over larger areas. The other way is (2) by limiting the assessment of vulnerability to a specific hazard (as done by Cardona, 2005, pp. 27-32; Fekete, 2009).

In addition, the processes set up to manage vulnerability vary at different levels. As expressed by Cardona (2006), “Disaster risk is most detailed at a micro-social or territorial scale. As we aggregate and work at more macro scales, details are lost” (p. 1, see also Noriega & Ludwig, 2012, p. 13). Van Zandt et al. (2012) goes through various scales and examples of both positive and negative traits for each before deciding that for their analysis, a census block group provided the “smallest unit at which rich data are available” (p. 51). Others do not document this process (Tarling, 2017).

Neither do vulnerability nor adverse events follow the political or administrative boundaries used. As expressed by Kienberger et al. (2009), “The resulting entity [based on political or administrative boundaries] is a legally homogenous unit, characterized by legal fiat boundaries (Smith, 1995) that potentially obscure possible internal patterns reflecting spatial discontinuity [or] any other spatial phenomena. Policy-related decisions based on this information may be misleading and yield unwanted impacts” (p. 767). Additionally, the information required for stakeholders and decisionmakers varies from level to level (Cardona & Carreño, 2011, p. 28; Liu & Li, 2016, p. 1124).

The idea of social differentiation touches upon what has already been covered above with the divide between technical and social. It is perhaps summarized best by Flanagan et al. (2011): “the hazards and vulnerability literature reveals that categories of people living in a disaster-stricken area are not affected equally” (p. 2). Garbutt et al. (2015) also support this conclusion, writing: “Countries, counties and cities are not homogenous, but are instead made of unique

communities" (p. 2-3), illustrating how vulnerability is not only geographically differentiated but has a dynamic characteristic to it.

3.2.2 Vulnerability is a dynamic characteristic

As each community, city, county and country is unique in their vulnerability, similarly, their vulnerability will vary over time (Garbutt et al., 2015, p. 3); an individual can be resilient one day, and vulnerable the next. Cardona (2006) is clear in measuring the "prevalent" vulnerability in his index, and other researchers speak of the index being a snapshot in time (Ruiter et al., 2017).

However, as expressed by Ruiter et al. (2017), "most of the risk models . . . have largely refrained from considering (changing) vulnerability" (p. 1232), explaining that "the quantification of vulnerability in risk assessments is known to be extremely difficult, which is why most studies assume constant vulnerability over time" (p. 1232).

3.2.3 Vulnerability is the result of complex and poorly-understood interactions involving both physical processes and the human dimension

Jeffers (2013) alludes to the connection of risk to vulnerability, stating that "risk remains understood almost exclusively as a physical phenomenon, external to human society but impacting upon it in various ways" (p. 6). As Ruiter et al. (2017) states "quantification of vulnerability[is] extremely difficult" (p. 1232). Also seen in the Sendai Framework are calls for more research on this interaction between the physical and social (UNISDR, 2015). Several, if not all, of the authors state that their work is a "first attempt" to benchmark vulnerability (Cutter et al., 2010) or to adapt previous research to a new context (Holand & Lujala, 2013).

While the outcome of a scenario is determined by many factors, a study in Los Angeles County, USA, was able to explain almost 25% of the variance in outcome, measured in economic loses, by looking at vulnerability factors. (Noriega & Ludwig, 2012, p. 2). Similar results were found pertaining to casualty rates. They refer to vulnerability as "a multidimensional construct not easily captured with one single variable" (Noriega & Ludwig, 2012, p. 3). In addition, "very often, these factors are present in combinations (both poor and Black, for example), which can exacerbate vulnerability" (Van Zandt et al., 2012, p. 50).

Therefore, vulnerability is multi-dimensional, with social, geographical and temporal factors. With these many dimensions in mind, a method to quantify and assess vulnerability can use indicators and indices.

4 Indicators of vulnerability

An indicator is a measurable representation of an aspect of reality (Øien, Utne, & Herrera, 2011) with the purpose to: (1) monitor or collect information; (2) identify and investigate potential issues; and, (3) take action to mitigate these issues (Ehliar & Wagner, 2016; Øien, Utne, & Herrera, 2011). Additionally, there are several attributes or criteria required for indicators (Ehliar & Wagner, 2016).

One of the main attributes of indicators relates to their leading and lagging characteristics. While the distinction between these two types is not clear-cut, leading indicators are used to forewarn before a potentially adverse event attempt and, vitally, encourage actions to be taken, while lagging indicators represent past occurrences and preventive action for the specific event is not possible (Ehliar & Wagner, 2016). Reiman and Pietikäinen (2012) point out that "safety can never be guaranteed by relying only on lagging indicators" (p. 1998) and call for more indicators with leading characteristics. The same holds true for the study of safety termed disaster risk reduction.

In the specific field of vulnerability, an example of a potentially leading indicator could be monitoring change in age distribution if measured with the purpose to adjust evacuation plans should the elderly population be found to have increased. While an example of a clearly lagging indicator is the one used by Flanagan et al. (2011) for verification of their results. They use the difference in addresses receiving mail and compare it before and after the Katrina hurricane. This indicator cannot be used to prompt action, as it is only measurable after an adverse event.

The difference between an indicator and a variable varies from field to field. In this thesis, the variable is the actual measurement taken which results in a number, while indicator is more of an umbrella term on a higher level. As an example; "age" is an indicator while "the number of individuals under the age of 5" is considered a variable. It should also be stressed that indicators rarely measure a phenomenon directly, but should rather be considered proxies.

This chapter is divided into two main sections. The first presents the results of the literature study performed and answers the first research question: "What indicators are commonly used by researchers to measure social vulnerability?". After that follows, in section **Error! Reference source not found.**, a suggestion for a Swedish index. Included in this section is also where the data for each indicator and variable can be found.

4.1 International study

Nineteen studies were analysed with regard to the concepts surrounding and influencing vulnerability as discussed previously. The number of indices studied exceeds the number of studies, as several of the studies compared two or more indices. In total, 573 indicators were found and examined. The results of this analysis are found in this chapter. More information regarding the categorization procedure can be found in Appendix – Indicator categorisation.

4.1.1 Demography

Demography describes both the type of people living in an area and their composition. It is a category used by authors either directly (Ruiter et al., 2017; Tate, 2012; Vincent, 2004) or in combination with economic factors to create a socioeconomic category (Cardona, 2005; Fekete, 2009; Flanagan et al., 2011).

This study contains the following demographic indicators; age, crime rate, ethnicity, gender, household composition, inclusion and population distributed as found in Table 1.

4.1.1.1 Age

Some 10% of the variables studied directly relate to age, and all but one study has one or more age related variables (the exception being Noriega and Ludwig (2012)). The authors are mainly concerned with three vulnerability groups that the variables are intended to catch; children, the elderly and dependents.

Children are defined as the population under the age of 5 (Siagian et al., 2014; Tate, 2012; Van Zandt et al., 2012), 6 (Fekete, 2009), 12 (de Brito et al., 2018), 14 (Ruiter et al., 2017), 15 (Vincent, 2004), 16 (Garbutt et al., 2015; Ruiter et al., 2017), 17 (Fekete, 2009) or 18 (Liu & Li, 2016). Some authors use more general terms such as “the very young” (King & MacGregor, 2000), “very young people” or “young families” (Fekete, 2009), children (Garbutt et al., 2015; Holand & Lujala, 2013; Yang et al., 2015) or dependents (Adger, 1999; Adger et al., 2005; Cardona, 2005).

The definition of **Elderly** is more unanimous, with 65 and above being the most used (Fekete, 2009; Garbutt et al., 2015; Liu & Li, 2016; Sun, Xie, Semazzi, & Liu, 2014; Tate, 2012; Van Zandt et al., 2012; Vincent, 2004). However, 60+ (de Brito et al., 2018), 75+ (Fekete, 2009) and retirement age (Fekete, 2009; Garbutt et al., 2015) are also used. In addition, some sources simply leave elderly undefined (Cutter et al., 2010; Holand & Lujala, 2013; King & MacGregor,

2000; Yang et al., 2015). Tate (2012) uses the narrow category of “nursing home residents” (p. 19-21).

Several authors use the term **dependents** or **dependency** without defining the term further (Adger, 1999; Adger et al., 2005; Cardona, 2005). From the context or their categorisation, it becomes clear that it is mainly age that makes one considered dependant. An exception to leaving the term undefined is Liu and Li (2016) who define dependency ratio as age groups 0-18 and 65+ divided by the working age group of 19-64.

Additionally worth noting are the variables of median age (Tate, 2012), residents above the median age (Garbutt et al., 2015), and age distribution (Kienberger et al., 2009) which are also used to measure age-related vulnerability.

4.1.1.2 Crime rate

Two studies, both of which focus on indices within the subnational level, use crime rate as an indicator of vulnerability. While they are not the only two studies which examine this geographical level, they suggest that crime rate may be more indicative of a local vulnerability than a national vulnerability. One of the variables used implies this assumption, measuring “crime rate above national average” (Garbutt et al., 2015, p. 171). The other does not define the variable any further than “crime rate” (Ruiter et al., 2017, p. 1239). However, it is clear from context that it is a subnational measurement.

4.1.1.3 Ethnicity & Immigration

Ethnicity and immigration as indicators of vulnerability are used by several of the studies examined. Generally, the variables used can be roughly divided into two types; (1) percentages of ethnic minorities and (2) percentages of foreign immigrants, depending on where in the world the study is focused.

Some authors are very specific (Kienberger et al., 2009; Tate, 2012), while others only divide between western and non-western or white and non-white (Fekete, 2009; Holand & Lujala, 2013; Van Zandt et al., 2012) or separate all minority groups into a single group (Noriega & Ludwig, 2012; Yang et al., 2015). Two authors do not speak of ethnicity, but rather of foreigners regardless of their origin (Cutter et al., 2010; Ruiter et al., 2017).

This indicator is contextually specific, and some studies show that certain groups of immigrants are less vulnerable than the natives under specific circumstances. It also matters when the immigration occurred (Tate, 2012, p. 21).

Table 1 - Studies with indicators for Demographic factors

	Age	Crime rate	Ethnicity & Immigration	Gender	Household composition	Social capital & Inclusion	Population
Adger (1999)	■						
Adger et al. (2005)	■		■				
de Brito et al. (2018)	■						
Cardona (2005, 2006); Cardona and Carreño (2011)	■			■			■
King and MacGregor (2000)	■				■		■
Cutter et al. (2010)	■		■	■		■	
Fekete (2009)	■		■	■	■	■	■
Flanagan et al. (2011)	■		■		■		
Garbutt et al. (2015)	■	■	■	■	■		
Holand and Lujala (2013)	■		■	■	■	■	■
Kienberger et al. (2009)	■		■				
Liu and Li (2016)	■			■	■		■
Noriega and Ludwig (2012)			■				
Ruiter et al. (2017)	■	■	■	■	■		■
Siagian et al. (2014)	■			■	■		■
Tate (2012)	■		■	■			■
Van Zandt et al. (2012)	■		■		■		
Vincent (2004)	■						■
Yang et al. (2015)	■		■	■	■		■

4.1.1.4 Gender

Several studies measure the percentage of females (Bakewell & Garbutt, 2005; Fekete, 2009; Ruiter et al., 2017; Siagian et al., 2014; Tate, 2012; Yang et al., 2015), female-headed households (Fekete, 2009; Siagian et al., 2014; Tate, 2012), or female labour force participation (Cutter et al., 2010; Ruiter et al., 2017) as an indication of vulnerability. While being a female does not inherently make one more vulnerable, the culture and history of many countries have caused this discrepancy. Though gender equality definitions and rates differ across the globe, some studies use this factor as an indication of gender-based vulnerability (Holand & Lujala, 2013; Liu & Li, 2016).

Holand and Lujala (2013, p. 318), in their study of Norway express that "Nordic countries have high levels of gender equality, which reduces the significance of gender as a major contributor to vulnerability." They express local differences, however, and therefore they talk about a lack of gender equality rather than female-based variables.

4.1.1.5 Household composition

The composition of the households in the area affects vulnerability, the two extremes, one-person households (Fekete, 2009; Flanagan et al., 2011; Garbutt et al., 2015; Holand & Lujala, 2013; King & MacGregor, 2000; Ruiter et al., 2017; Van Zandt et al., 2012) and large families (Fekete, 2009; Liu & Li, 2016; Ruiter et al., 2017; Siagian et al., 2014; Yang et al., 2015) being more vulnerable. The reasoning behind varies between the authors and, more specifically, the national context in which their study is made. Fekete (2009, pp. 44, 52), studying Germany, sees large families as being more susceptible to dependency on outside medical and welfare assistance. One-person households, however, potentially lack the financial resources to prepare having only a single income. The studies using large families are predominantly from contexts where a large family is not the norm.

Quite a few of the authors mention single parents in conjunction with household composition, indicating that the presence of children or dependents causes the vulnerability (Bakewell & Garbutt, 2005; Fekete, 2009; King & MacGregor, 2000; Ruiter et al., 2017; Van Zandt et al., 2012). Others do not make this distinction (Garbutt et al., 2015; Liu & Li, 2016).

4.1.1.6 Social capital and inclusion

While inclusion is not mentioned by any of the authors, several indicators concerning a person's inclusion in the local society were put together. Lack of such social capital causes vulnerability. Social capital is not easy to measure. However, Holand and Lujala (2013) used

participation in municipal council elections as an indicator of the quality of social network, based on the work of Cutter et al. (2010), who used national, rather than municipal election data.

In addition to election turnout, Cutter et al. (2010) used the existence of civic and social organizations, as well as the number of religious adherents, as indicators of social capital.

Fekete (2009), basing himself on a study in New Orleans, speaks of the friendless, transients, and those people without local networks as more vulnerable. He measured an indicator used by Cutter et al. (2010) which was the "percent population born in a state that still resides in that state" (p. 7) in order to determine that group's social capital or inclusion.

4.1.1.7 Population

Rather than measuring the population density, researchers at times calculate vulnerability as related to a large or sustained change in population. As such, the change in population size in an area over time is an indicator used by many authors.

Several authors specify this change of population only as growth, and it is unclear if a negative growth is possible using their variables (Cardona, 2005; Fekete, 2009; King & MacGregor, 2000; Liu & Li, 2016; Siagian et al., 2014; Yang et al., 2015). In contrast, Holand and Lujala (2013) and Vincent (2004) specifically use both growth and decline in their variable. Others use additional measures such as positive birth rates (Holand & Lujala, 2013), long term residents (Fekete, 2009), newcomers to the community, and migrants (King & MacGregor, 2000) as indicators of existence or absence of vulnerability.

4.1.2 Economy

All of the authors examined in this analysis have identified at least one variable aimed at measuring the financial status of the individuals in the scope of their study. This indicator spans the various geographical scales and cultures which the studies cover. Some put quite a number of their indicators in this area (Cardona, 2005, 2006; Cardona & Carreño, 2011; Ruiter et al., 2017), and, in total almost 15% (14.87%) of the indicators examined measure an economic factor.

The indicators were aggregated over the following types: Assets, Benefits, Costs, Debt, Equality, GDP, Income, Insurance and Poverty. See Table 2 for their distribution among the authors. In general, the economic indicators are more defined in their variables than the indicators concerning demography. The break points are, however, mostly undefined.

4.1.2.1 Assets

Six authors use the assets available to the households or individuals as an indicator of their vulnerability. Generally, the presence of assets indicates a lower vulnerability, but there are also arguments that it indicates a potential for loss depending on the definition of vulnerability (Fekete, 2009, p. 25).

Mostly, it is home ownership that is measured (Cutter et al., 2010; Fekete, 2009; Ruiter et al., 2017). However, capital (Cardona, 2005; Vincent, 2004) is also used, or the more undefined "assets" (Kienberger et al., 2009) or "high status" (Holand & Lujala, 2013). Ruiter et al. (2017) is noteworthy in their definition, using the "ratio of expected financial loss to the total insured value" (p. 1239) as their variable.

4.1.2.2 Benefits

The benefits indicator concerns reliance on government support where an increased reliance on this support suggests an increased vulnerability (Adger et al., 2005, p. 20; Fekete, 2009, p. 43). Some authors also argue the opposite, where the presence of social security decreases vulnerability for the area because the presence of this safety net enables a baseline financial security in certain low-income countries (Adger et al., 2005, p. 20).

Variables are mainly the number of residents receiving social security (Fekete, 2009; Garbutt et al., 2015; Tate, 2012), or the ratio of these residents to the total (Holand & Lujala, 2013; Ruiter et al., 2017; Yang et al., 2015). Fekete (2009) also looks specifically at rent subsidies.

4.1.2.3 Costs

While the number of cost-measuring variables is limited to three, this indicator is brought up by three authors. Cardona (2005) measure the "annual increase in food prices" for countries in his study, where a large increase could result in an increased vulnerability for the people living in that country. However, both Ruiter et al. (2017) and Tate (2012) use sub-national measurements, look at the cost of renting as their variable using a similar reasoning as Cardona.

4.1.2.4 Debts

The debt status of households in an area serves a similar function as assets, but the inverse thereof. Some of the authors using debt could indicate a municipal or state debt rather than household debt, but this is left undefined by them.

Garbutt et al. (2015) use four variables ranging from bankruptcy rate, house repossession rate, landlord repossession rate, and insolvency rate. Other authors use debt repayments (Adger et al., 2005) or debt servicing (Cardona, 2005; Fekete, 2009) as a percentage of GDP, while Vincent (2004) uses only "private debt" as her variable.

Holders of debt are extra vulnerable should their income or assets be affected by a disaster. The potential outcome of this can also be seen in the variables used by Garbutt et al. (2015).

4.1.2.5 Inequality

The distribution of income as a measurement of inequality and resulting vulnerabilities are used by five authors. Three authors use inequality (Adger, 1999; Adger et al., 2005) or income distribution (Ruiter et al., 2017). Several others use the Gini index or Gini coefficient[1] as their way of measuring inequality (Adger et al., 2005; Cardona, 2005; Cutter et al., 2010; Ruiter et al., 2017).

Adger et al. (2005) state that "high levels of inequality are likely to result in the formation of highly vulnerable groups that are financially and socially marginalised, who lack the financial resources for adaptation and who may be forced to settle in exposed areas" (p. 39).

[1] The Gini coefficient is a measure of the dispersion of income or wealth among the residents of a nation. If everyone in a nation would have an equal income or wealth, the Gini coefficient would be 0, while a value of 1 would mean a single person possesses all the income or wealth.

Table 2 - Studies with indicators for Economy factors

	Assets	Benefits	Costs	Debts	Inequality	GDP	Income	Insurance	Poverty
Adger (1999)					■	■	■		■
Adger et al. (2005)				■	■	■		■	■
de Brito et al. (2018)							■		
Cardona (2005, 2006); Cardona and Carreño (2011)	■		■	■	■	■			■
King and MacGregor (2000)							■		
Cutter et al. (2010)	■				■			■	
Fekete (2009)	■	■		■		■	■	■	■
Flanagan et al. (2011)							■		■
Garbutt et al. (2015)		■		■			■		
Holand and Lujala (2013)	■	■					■		
Kienberger et al. (2009)	■						■		
Liu and Li (2016)							■		
Noriega and Ludwig (2012)							■		
Ruiter et al. (2017)	■	■	■		■	■	■		■
Siagian et al. (2014)									■
Tate (2012)		■	■			■	■		■
Van Zandt et al. (2012)									■
Vincent (2004)	■			■					■
Yang et al. (2015)		■				■	■		

4.1.2.6 GDP

Gross Domestic Product (GDP) is used by seven authors primarily on a regional or national scale. Mainly, GDP per capita is used (Adger et al., 2005; Cardona, 2005; Ruiter et al., 2017; Tate, 2012). Fekete (2009) specifies GDP per labour force and Yang et al. (2015) use the GDP ratio between sectors as a measurement. It is measured with a similar reasoning to inequality above, attempting to find the groups lacking the financial ability to prepare for disasters.

4.1.2.7 Income

Excluding poverty, which is measured using similar variables, income is the indicator used by most authors. The notion that the more you have the more you stand to lose (as introduced under assets above), is not prevalent when authors use income as a measurement for vulnerability.

Most authors measure median household income (Garbutt et al., 2015; Noriega & Ludwig, 2012) or income per capita (de Brito et al., 2018; Liu & Li, 2016; Ruiter et al., 2017; Yang et al., 2015). However, Adger (1999) and Kienberger et al. (2009) focus on the source of the income where a "risky" source causes a higher level of vulnerability. A risky source is one which is extra susceptible to a disaster, such as agriculture and fishing (c.f. 4.1.4.3 Sector and sector dependency).

In addition, the method of looking at the specific group of low income people (Holand & Lujala, 2013; King & MacGregor, 2000) or the number of households per income class (Ruiter et al., 2017) also exists. The common practice of looking at the lower end of the income scale is prevalent among most authors.

4.1.2.8 Insurance

Access to or ownership of insurance is looked at by three authors studying the USA (Cutter et al., 2010), Germany (Fekete, 2009) and a more universal study (Adger et al., 2005). Insurance is a way to handle risk, however, care should be taken so as not use insurance ownership to promote risky behaviour. This situation was seen by The National Flood Insurance Program (NFIP) in the USA, which is likely why Cutter et al. (2010) specifically looked at the population with health insurance coverage as an indicator of poverty, and through that, vulnerability rather than using the NFIP as a variable.

4.1.2.9 Poverty

Poverty is directly mentioned by ten authors. If the authors above using an income type indicator are included, all authors studied utilized one or more variables targeting poverty.

Poverty is brought forth as one of the most predictive indicators of vulnerability. Alexander (2008) put this bluntly by stating that “the poor and marginalised are much more at risk of death than are rich people or the middle classes”. This is also valid for other measurements of disaster outcome, for example, percentage financial loss. A loss of a very large percentage of net worth by a person deemed rich does not have nearly the same negative consequences of the loss of a moderate percentage by a person living below the poverty line.

With that noted, only one author defines poverty as a “population living on less than US$1 per day” (Cardona, 2005). A few mention “below the poverty line” (Tate, 2012; Vincent, 2004) or “in poverty” (Ruiter et al., 2017; Van Zandt et al., 2012). While others leave poverty undefined (Adger, 1999; Adger et al., 2005; Fekete, 2009; Flanagan et al., 2011; Liu & Li, 2016). This is likely due to the author using a national or global poverty standard, however, from the publications studied, this is not apparent.

4.1.3 Education

Education, as defined here, is closely coupled to one's ability to access and act upon the information required to decrease one's vulnerability. As such, the education category covers the following indicators: formal education, previous experience, information, language and literacy. Variables intended to cover these indicators exist in all but one of the studies examined, and most studies cover more than one of these aspects.

4.1.3.1 Formal Education

Having a formal education has been shown to decrease vulnerability. Twelve studies measured formal education in some way. While it is not a linear relationship and although each step contributes less than the one preceding it, and though education does not guarantee an ability to act upon information intended to decrease vulnerability, each level of education appears to decrease the total sum of vulnerability.

The measurement of education varies greatly with few authors measuring the same variable. Generally, education starts to be measured at high school or its equivalent (Fekete, 2009; Garbutt et al., 2015; Tate, 2012; Van Zandt et al., 2012). Measurement of college and university graduation or number of students is also common (Cutter et al., 2010; Fekete, 2009; Ruiter et al., 2017). Finally, some authors do not define clearly what is meant by "education" or "educated" (Fekete, 2009; Flanagan et al., 2011; Holand & Lujala, 2013; Kienberger et al., 2009; Siagian et al., 2014; Yang et al., 2015).

A few take a different path to measure access and priority of education through expenditure (Adger et al., 2005), the number of nearby physical schools (Fekete, 2009) or libraries (Yang et al., 2015), or directly using "access to education" as a variable (Ruiter et al., 2017).

4.1.3.2 Previous experience

Having experienced a disaster previously increases the preparedness and decreases vulnerability for the next such disaster (Coulston & Deeny, 2010). While this connection is well defined, only four of the authors use previous experience as an indicator for level of vulnerability. Of these, Cutter et al. (2010) and Liu and Li (2016) are most specific, looking at paid disaster declaration, recent hazard mitigation plans and insurance policies (Cutter et al., 2010), and hazard-related training (Liu & Li, 2016) respectively. de Brito et al. (2018) consider evacuation drills and training while Ruiter et al. (2017) look at awareness, attitudes, behaviours, and past experience.

Table 3 - Studies with indicators for Education factors

	Formal education	Previous experience	Information	Language	Literacy
Adger (1999)					
Adger et al. (2005)	■				■
de Brito et al. (2018)		■			
Cardona (2005, 2006); Cardona and Carreño (2011)			■		
King and MacGregor (2000)				■	
Cutter et al. (2010)	■	■		■	
Fekete (2009)	■			■	
Flanagan et al. (2011)	■			■	
Garbutt et al. (2015)	■			■	
Holand and Lujala (2013)	■				
Kienberger et al. (2009)	■		■		
Liu and Li (2016)		■	■		■
Noriega and Ludwig (2012)					
Ruiter et al. (2017)	■	■	■		■
Siagian et al. (2014)	■				■
Tate (2012)	■			■	
Van Zandt et al. (2012)	■		■	■	
Vincent (2004)			■		
Yang et al. (2015)	■				■

4.1.3.3 Access to information

Access to information is measured in two main ways, the presence of an early warning system (EWS) and the existence of communication or information equipment.

Kienberger et al. (2009) and Ruiter et al. (2017) look at EWS. The number of telephones (Liu & Li, 2016; Ruiter et al., 2017; Vincent, 2004), televisions (Cardona, 2005; Ruiter et al., 2017), or internet usage (Ruiter et al., 2017) is used to measure the existence of information-gathering equipment.

Both of these indicators (existence of EWS and communication/information) is argued with the same logic, access to information enables preparedness and informed decision-making.

4.1.3.4 Language

In a crisis, information tends to be expressed in the native tongue first, translations taking longer to secure. As such, several authors look at ability of understanding the majority language (Cutter et al., 2010; Flanagan et al., 2011; Garbutt et al., 2015; Tate, 2012; Van Zandt et al., 2012). These studies are from English speaking countries. While studying primarily English speaking countries, King and MacGregor (2000) look at "people lacking communication and language skills" (p. 54), whereas Fekete (2009) designates only language skills (p. 136) having Germany as his study area.

Outside the English-speaking countries, literacy appears to be the main language gauge.

4.1.3.5 Literacy

Like language above, literacy or illiteracy is measured as crisis information and other vulnerability-reducing initiatives tend to be in writing. Illiteracy also has links to formal education as mentioned above.

The five authors measuring literacy are generally looking at non-English-speaking countries and they measure the literacy rate/ratio in similar ways (Ruiter et al., 2017; Siagian et al., 2014; Yang et al., 2015), with the possible exception of Adger et al. (2005); Liu and Li (2016), who limit it to the population above the age of 15.

4.1.4 Employment and the private sector

Employment and especially the private sector is a vital aspect of our lives. Some sectors have been seen to be more vulnerable to hazards. Similarly, the employment status of individuals, especially marginalised individuals, is an indicator of how vulnerable society is as a whole.

Under this umbrella, the following indicators are found: Company, Contract, Sector, Unemployment, Unpaid and Work experience.

4.1.4.1 Company size

Two authors (Cutter et al., 2010; Kienberger et al., 2009) are concerned with the ratio of large to small businesses and the size of companies. A larger company tends to be more resilient in the face of hazards, while small companies tend to lack the buffers or geographical spread making them vulnerable more vulnerable to hazards.

4.1.4.2 Contract

Garbutt et al. (2015) is the only author looking at working conditions by using "49+ hours work week" (p. 169) as a variable. The motivation for using this specific variable is not clear apart from some five supporting references for all his employment and income variables.

4.1.4.3 Sector and sector dependency

As briefly stated in the introduction of this section, some employment sectors have been found to be more vulnerable than others. This is especially true for primary industries, such as agriculture and raw materials extraction. In addition, single-sector dependency causes a local society to be vulnerable should the sector suffer.

Three authors are concerned with the agriculture sector (Adger et al., 2005; Cutter et al., 2010; Ruiter et al., 2017), three in the extractive industries of forestry, fishing and mining (Cardona, 2005; Cutter et al., 2010; Ruiter et al., 2017; Tate, 2012), and one in secondary and other industries (Ruiter et al., 2017). Cutter et al. (2010) also look at the population employed in the creative class, Holand and Lujala (2013) use a division between professional or managerial, clerical or labourer and service sector, while Kienberger et al. (2009) look at the economic sectors specifically.

Two authors (Ruiter et al., 2017; Yang et al., 2015) measure sector dependency.

Table 4 - Studies with indicators for Employment factors

	Company size	Contract	Sector	Unemployment	Unpaid	Work experience
Adger (1999)						
Adger et al. (2005)			■			
de Brito et al. (2018)						
Cardona (2005, 2006); Cardona and Carreño (2011)				■		
King and MacGregor (2000)						
Cutter et al. (2010)	■		■	■		
Fekete (2009)				■		
Flanagan et al. (2011)				■		
Garbutt et al. (2015)		■		■	■	■
Holand and Lujala (2013)			■	■		
Kienberger et al. (2009)	■		■			
Liu and Li (2016)						
Noriega and Ludwig (2012)						
Ruiter et al. (2017)			■	■		
Siagian et al. (2014)						
Tate (2012)			■	■		
Van Zandt et al. (2012)				■		
Vincent (2004)						
Yang et al. (2015)			■	■		

4.1.4.4 Unemployment

As employment status is closely connected to income, unemployment is a contributing factor to vulnerability. In addition, employment is used to measure inclusion, assimilation, and gender equality.

All ten studies that measure employment use the specific variable of either percent employed or unemployed (see Table 4 above for sources). In addition, five look specifically at female employment rates (Cutter et al., 2010; Fekete, 2009; Garbutt et al., 2015; Ruiter et al., 2017; Yang et al., 2015). Fekete (2009) and Garbutt et al. (2015) also look at the disabled and foreign employment rates.

4.1.4.5 Unpaid & Work experience

Garbutt et al. (2015) attempt to capture the specific group of caregivers by two variables "providing unpaid care [20-49/50+] hours/week" (p. 171).

Similarly, he attempts to find the specific vulnerable group who have never worked (Garbutt et al., 2015).

4.1.5 Geography

The geography category gathers indicators which are less dependent on the people living in the area and rather more on the area itself. Land usage and apartment size do not depend on who lives in them, but rather the geographical area.

In this category, the following indicators are presented with their respective variables: Density, Environment, Land Usage, Location & services, Mobile homes, Residency, Resource usage, Standard and Tourism.

4.1.5.1 Density

Three different density variables are used, the first being population density as measured by some six authors (Adger et al., 2005; Cardona, 2005; Fekete, 2009; Holand & Lujala, 2013; Ruiter et al., 2017; Tate, 2012). While some benefits of scale exist, generally with an increase in population density, vulnerabilities are exacerbated.

Closely related, housing density (see also land usage) is measured by two authors (Kienberger et al., 2009; Tate, 2012). This is closely related to population density, and similar reasoning for both cases is brought up by these authors.

The third measurement is the number or percentage of vacant housing units measured by Cutter et al. (2010) and Van Zandt et al. (2012). The purpose is to determine how well the area might handle a sudden influx of population such as refugees or evacuees.

4.1.5.2 Environment

Three authors use variables measuring the environmental status of the area. These variables are unique and as such, are presented in order of author.

Adger et al. (2005) look at two water related variables: groundwater recharge per capita and water resources per capita (p. 80). This approach is aimed at finding out how vulnerable countries are to changes in groundwater which would influence their farming, industry, and other activities. In addition, Adger et al. (2005) measures the SO_2 (sulphur dioxide) emissions per area to find its environmental coping capacity.

Cardona (2005) uses the environmental sustainability index (ESI) as a variable along with “Soil degradation resulting from human activities” (p. 13). He uses both to compare countries with each other. Kienberger et al. (2009) summarises environmental status using an ecosystem integrity indicator consisting of two variables: “protected areas” and “retention areas” (p. 773).

These authors come from a more environmentally savvy background than the other authors. The relationship between the local environment and vulnerability is a different field, the indices of which were not examined in this study.

4.1.5.3 Land usage

In addition to the three authors using environmental indicators as presented above, three more authors are concerned with land usage. All of the authors measure the percentages of various coverage types; farmland (Adger et al., 2005; Cardona, 2005; Ruiter et al., 2017; Yang et al., 2015), urban areas (Adger et al., 2005; Ruiter et al., 2017), forests (Adger et al., 2005), silent land cover (Kienberger et al., 2009), and open space (Fekete, 2009).

There are also five authors who bring up variables with respect to urban versus rural areas (Adger et al., 2005; Fekete, 2009; Holand & Lujala, 2013; Ruiter et al., 2017; Tate, 2012; Vincent, 2004). The reasoning behind the variables is diverse, and there is no unified view on which group is more vulnerable. Rather, vulnerability depends on context and as such, becomes a potentially important variable to study further.

4.1.5.4 Location & services

Seven authors, most of those studying vulnerability at a sub-national scale, take note of the location of an area in relation to hazards and services as distance and nearness to these respectively influence the vulnerability of an area.

Adger et al. (2005), with a background in looking at flood risk (Adger, 1999), looks at coastlines, populations within 100km of a coastline, and flood prone populations.

Services addressed by the authors studied relate to evacuation and shelter (Cutter et al., 2010; de Brito et al., 2018; Fekete, 2009; Holand & Lujala, 2013), medical services (Garbutt et al., 2015; Holand & Lujala, 2013), the presence of central heating (Garbutt et al., 2015), and the "centrality of an economic activity in a network" (Ruiter et al., 2017).

4.1.5.5 Mobile homes

Cutter et al. (2010); Garbutt et al. (2015); Tate (2012) and Van Zandt et al. (2012) all look at the percentage of mobile homes in an area. These, being less sturdy than regular houses, are more susceptible to damage resulting in injuries to both their structure and the people living in them.

Table 5 - Studies with indicators for Geography factors

	Density	Environment	Land usage	Location& Services	Mobile homes	Residency	Resource usage	Standard	Tourists
Adger (1999)									
Adger et al. (2005)	■	■	■	■				■	
de Brito et al. (2018)				■				■	
Cardona (2005, 2006); Cardona and Carreño (2011)	■	■	■						
King and MacGregor (2000)									
Cutter et al. (2010)	■			■	■			■	■
Fekete (2009)	■		■	■		■		■	■
Flanagan et al. (2011)	■					■			
Garbutt et al. (2015)				■	■	■			
Holand and Lujala (2013)	■		■	■		■		■	
Kienberger et al. (2009)	■	■	■						
Liu and Li (2016)									
Noriega and Ludwig (2012)						■			
Ruiter et al. (2017)	■		■	■		■		■	
Siagian et al. (2014)								■	
Tate (2012)	■		■		■	■		■	
Van Zandt et al. (2012)	■				■	■		■	
Vincent (2004)			■						
Yang et al. (2015)			■			■	■	■	

4.1.5.6 Residency

Nine authors look at renters or tenure (Fekete, 2009; Holand & Lujala, 2013; Noriega & Ludwig, 2012; Ruiter et al., 2017; Tate, 2012; Van Zandt et al., 2012). Flanagan et al. (2011) and Yang et al. (2015) express this in terms of housing structure or building type. To do so, they refer to whether the building is commercial, rental, or of another kind.

Renters, compared to homeowners, tend to be less rooted to an area and invest less into their own preparedness. In addition, it can, in certain context, also indicate poverty (Noriega & Ludwig, 2012).

4.1.5.7 Resource usage

Yang et al. (2015) look at the density of resources available and energy usage per capita. In addition, similar to Adger et al. (2005) under environmental above, per capita water resource is a variable used. However, Yang et al. express this more in terms of production and industry vulnerability, whereas Adger et al. look more at how this influences the environment, and thereby the population.

4.1.5.8 Standard

The type of buildings in which people live affects their vulnerability. In order to capture this, a range of variables are used by the authors: house age or buildings built during specific years (Cutter et al., 2010; Fekete, 2009; Holand & Lujala, 2013; Van Zandt et al., 2012), building prices (Fekete, 2009; Holand & Lujala, 2013; Tate, 2012), or the size of a house/apartment (Fekete, 2009; Yang et al., 2015). A few authors look at the services available in the house such as water (Adger et al., 2005), sewage, and sanitation (Adger et al., 2005; de Brito et al., 2018; Ruiter et al., 2017), garbage accumulation (de Brito et al., 2018) and electricity (Siagian et al., 2014).

4.1.5.9 Tourism

Fekete (2009) has three variables aimed at the vulnerability of tourists. As non-locals, these are often left out of crisis information and planning, and as such, are more vulnerable.

4.1.6 Health

The health status of the population is paramount in determining how they will be able to cope with a disaster. Poor health affects outcomes, both directly, through an increased risk of death, and indirectly, through lack of mobility, dependence on medicine, and so forth.

This section looks at variables measuring health through the indicators of: health service capacity, disability, general health and health service quality.

4.1.6.1 Health service capacity

Access to health services is closely linked to the location of the area studied, and several authors look at this aspect (as shown in section 4.1.5.4 - Location & services). However, the capacity of these services is a variable used by many authors to see how well the health services will cope with a disaster. The most common variable is the number of hospital beds per X population (Cardona, 2005; Cutter et al., 2010; Garbutt et al., 2015; Yang et al., 2015). Two authors use the number of hospitals (Tate, 2012) or medical care centres (Fekete, 2009) as their variable.

4.1.6.2 Disability

Disability status is used by most authors. Disability complicates, and might even hinder, evacuation and the ability to act to reduce one's own vulnerability. Few authors, however, define disability or grade of disability.

Cutter et al. (2010) define disability as "sensory, physical, or mental disability" (p. 7), while all other authors leave it undefined (de Brito et al., 2018; Fekete, 2009; Flanagan et al., 2011; Garbutt et al., 2015; Ruiter et al., 2017; Tate, 2012; Yang et al., 2015). Holand and Lujala (2013) talk instead of "large special needs populations" (p. 317).

4.1.6.3 General health

Issues with one's health can cause similar vulnerability as disability, and similar to disability, health variables are not expressively defined. Garbutt et al. (2015) uses individuals reporting poor health while two other authors speak in terms of pre-existing health problems (Fekete, 2009; Ruiter et al., 2017). Liu and Li (2016) use the is simple designation "sick" (p. 1124).

Adger et al. (2005) uses indirect measurements of "calorie intake per capita" (p. 74) and "life expectancy" (pp. 69, 74) as their health variables.

4.1.6.4 Health service quality

Several authors have a variable measuring the quality of health services. This is done either by measuring the health care expenditure level of a locality (Adger et al., 2005; Vincent, 2004), or the number of medical staff per population (Cutter et al., 2010; Fekete, 2009; Tate, 2012; Yang et al., 2015). Noteworthy, is Garbutt et al. (2015) who look exclusively at mental health services as their health service quality variable.

Table 6 - Studies with indicators for Health factors

	Capacity	Disability	General health	Quality
Adger (1999)				
Adger et al. (2005)			■	■
de Brito et al. (2018)		■		■
Cardona (2005, 2006); Cardona and Carreño (2011)	■			
King and MacGregor (2000)		■		
Cutter et al. (2010)	■	■		■
Fekete (2009)	■	■	■	■
Flanagan et al. (2011)		■		
Garbutt et al. (2015)	■	■	■	■
Holand and Lujala (2013)		■		
Kienberger et al. (2009)				
Liu and Li (2016)			■	
Noriega and Ludwig (2012)				
Ruiter et al. (2017)		■	■	
Siagian et al. (2014)				
Tate (2012)	■	■		■
Van Zandt et al. (2012)				
Vincent (2004)				■
Yang et al. (2015)	■	■		■

4.1.7 State

Governmental structures and organisation exist to serve the citizens living within the borders of that government's jurisdiction. This responsibility extends to disasters, and government is generally in control of emergency services and other organizations with the purpose to assist people in need. The effectiveness of the government thus has an influence on the citizens' vulnerability.

Government, unless otherwise defined, corresponds to all levels of government including municipal, national, regional or federal (e.g. EU, USA), and international bodies (e.g. UN, WTO). The level of influence of these governmental organizations varies but could generally be seen as having a higher influence the closer the governmental entity is to the people.

4.1.7.1 Corruption

Adger et al. (2005) uses a "control of corruption" (p. 78) to measure corruption while Vincent (2004) uses data from Transparency International (p. 18). The motivation of both is that corruption influences all other state efforts. Both use indices aimed at comparison between nations.

4.1.7.2 Disaster Risk Reduction

Three authors are concerned with institutional experience and preparedness. These three are not unique in this, but they have variables directly measuring this factor explicitly. de Brito et al. (2018) and Cutter et al. (2010) measure the existence of institutions and programs, as well as the extent to which these services are available to the population. Ruiter et al. (2017) measure similarly, but additionally look at investments in precautionary measures (p. 1239) rather than the existence of them.

4.1.7.3 Governance

Many authors use governance for a similar purpose as corruption above, but rather measure the opposite. The stability (Adger, 1999; Adger et al., 2005; Ruiter et al., 2017) and quality of rule (Adger et al., 2005; Cardona, 2005) are measured, as well as the number of governments (Cutter et al., 2010) and types of institutions (Ruiter et al., 2017).

4.1.7.4 Public finance

The budgetary focus of governmental bodies indicates their priorities. Several authors look at infrastructure budget allocation (Cardona, 2005; Holand & Lujala, 2013; Kienberger et al., 2009), emergency services (Cutter et al., 2010), and social expenditure (Cardona, 2005).

Others are more concerned with the general state of finances (Holand & Lujala, 2013) or the municipal debt (Fekete, 2009).

4.1.7.5 Research and development

Adger et al. (2005) are the only ones concerned with research and development directly. Other authors focus on education (see 4.1.3.1 - Formal Education on page 24). Adger et al. (2005) comment that a sound investment in research and development provides the foundation on which to build adaptation strategies (p. 45).

4.1.7.6 Trade

Trade balance is an indicator of the dependency of the society as a whole measured by Cardona (2005) and Vincent (2004). Adger et al. (2005) measure the vulnerable sector of agriculture instead using “agricultural exports” as their variable.

Table 7 - Studies with indicators for State factors

	Corruption	Disaster Risk Reduction	Governance	Public finance	R&D	Trade
Adger (1999)			■			
Adger et al. (2005)	■		■		■	
de Brito et al. (2018)		■				
Cardona (2005, 2006); Cardona and Carreño (2011)			■	■		■
King and MacGregor (2000)						
Cutter et al. (2010)		■	■	■		
Fekete (2009)				■		
Flanagan et al. (2011)						
Garbutt et al. (2015)						
Holand and Lujala (2013)				■		
Kienberger et al. (2009)				■		
Liu and Li (2016)						
Noriega and Ludwig (2012)						
Ruiter et al. (2017)		■	■			
Siagian et al. (2014)						
Tate (2012)						
Van Zandt et al. (2012)						
Vincent (2004)	■			■		■
Yang et al. (2015)						

4.1.8 Transportation

Sub-national indices look at the mobility of people as an indicator. A lack of mobility means dependency on others for evacuation, which puts more pressure on the system. It also limits one's ability to secure employment and so forth.

Three indicators were identified: commuters, infrastructure, and vehicle access

4.1.8.1 Commuter

Three authors look at commuting, two directly (Fekete, 2009; Liu & Li, 2016) and one through the use of public transportation (Van Zandt et al., 2012). In the case of a disaster, commuters might have a more difficult time continuing to work and helping out in a disaster if employed in such a sector, making them more vulnerable.

This aspect is also brought up by Holand and Lujala (2013) when they look at communities with few access roads. Having a limited number of access roads increases the areas vulnerability in case such an access road would be unusable.

4.1.8.2 Infrastructure

While infrastructure is measured through public finance (4.1.7.4 on page 37), two authors (Cutter et al., 2010; Yang et al., 2015) look at the physical roads and their capacity. Of especial concern are the so-called lifelines or main evacuation roads.

4.1.8.3 Vehicle

Most, if not all, of the sub-national indices look at the access, or lack of access, to vehicles, the prime motivator being that a vehicle enables ease of evacuation. It is measured mostly in a unified way, the difference being the ratio of vehicles per population (Cutter et al., 2010; Fekete, 2009; Liu & Li, 2016; Ruiter et al., 2017) or vehicle per household (Flanagan et al., 2011; Garbutt et al., 2015; Tate, 2012; Van Zandt et al., 2012).

Table 8 - Studies with indicators for Transportation factors

	Commuter	Infrastructure	Vehicle
Adger (1999)			
Adger et al. (2005)			
de Brito et al. (2018)			
Cardona (2005, 2006); Cardona and Carreño (2011)			
King and MacGregor (2000)			
Cutter et al. (2010)		■	■
Fekete (2009)	■		■
Flanagan et al. (2011)			■
Garbutt et al. (2015)			■
Holand and Lujala (2013)			
Kienberger et al. (2009)			
Liu and Li (2016)	■		■
Noriega and Ludwig (2012)			
Ruiter et al. (2017)			■
Siagian et al. (2014)			
Tate (2012)			■
Van Zandt et al. (2012)	■		■
Vincent (2004)			
Yang et al. (2015)		■	

4.2 A Swedish index

Based on the findings of the literature and index study of the previous section, this section presents a suggestion for indicators that are feasible in Sweden as well as where the data for their variables could be found. This is followed by a discussion of the group of indicators as an index. Table 9 gives an overview of the indicators, variables, data sources and the geographical scale in which they are available.

The selection of indicators and their variables were subject to the general accommodation steps presented in sections 2.2-2.4 and the specific indicator criteria of being simple to understand, easy to measure, have an unquestionable relation to the area and show change over a specific timeframe (see section 2.5) These criteria caused the removal of some indicators and variables used internationally. As an example, the variable "distance to hospital" used by Garbutt et al. (2015), while being simple, easily measurable and with a clear connection to the area, was removed as the variable is somewhat static before an adverse event and would influence more like a weight than a variable.

The following indicators were selected: Age, Population change, Population density, Inclusion, Social Security, Household finance, Level of education, Time since last public advisory, Language, Companies and Sector, Unemployment, Disability and Vehicle access. These are discussed individually, with the reasoning behind the inclusion of that indicator and suggested variables found under each indicator section.

Several of these indicators with their specific variables are likely to correlate with each other. In this study, no attempt to avoid or verify the existence of such correlation has been made, which is further discussed in section 5.2.

4.2.1 Age

Age is one of the most commonly measured indicators with some 10% of all variables studied relating to age (see 4.1.1.1 above). As such, the relationship between age and vulnerability is well-documented. In addition, age as a variable is simple to understand, easy to measure and it changes yearly.

While only Vincent (2004) uses the age of 15 specifically, six authors use a age variables with breakpoints below the age of 15 and four above 15 years of age (see 4.1.1.1 above). 'Age 65 and above' is the most used variable for the elderly population. Both variables work well with

Swedish society: age 15 being when most students graduate from comprehensive school; and age 65 being the general retirement age.

Data are published yearly by SCB on the scale of 250x250m in urban areas and 1x1km outside urban areas and according to districts. The data are divided into five-year segments, and as such, the percentage of people 'younger than 15 years' and 'older than 65' are suggested as variables (SCB, 2017b).

Data are freely available from SCB, with earlier years available on request. A source of error is that classes with less than 3 people are removed from the cells (SCB, 2017b).

4.2.2 Population change

A quick change in population can indicate a strain on the system. With ten authors measuring this, the relation to vulnerability is well-documented. It is simple to understand, easy to measure and it changes over time. While a decline/strain for a single year might not be relevant, a longer trend, in addition to drastic changes, should be tracked even if gradual.

Population decline is not a common variable, being only used by Holand and Lujala (2013) and Vincent (2004). The rationale to use this variable in relation to rural areas is deemed valid, being of use in Norway (Holand & Lujala, 2013), a country close in context to Sweden.

Data are published openly on a yearly basis by SCB on the scale of 250x250m in urban areas and 1x1km outside urban areas and according to districts. A source of error is that classes with less than 3 people are removed from the cells (SCB, 2017c).

4.2.3 Population density

Population density is measured by six authors on both sub-national and national levels with the rationale that population density exacerbates vulnerabilities.

Like population change above, this variable is simple to understand, easy to measure using existing data, the relation to the area is clear and it reflects change over time influenced by the population growth variable. Accordingly, it strongly reflects the criteria for variables established in in section **Error! Reference source not found.**.

Data are published yearly by SCB on the scale of 250x250m in urban areas and 1x1km outside urban areas. Using this dataset, statistics for district or other geographical composition can be obtained. A source of error is that cells with less than 3 people have been removed (SCB,

2017c). In addition, data are readily available summarised per municipality, county and national level (SCB, 2017j).

4.2.4 Inclusion

Only two authors measure inclusion using election participation (Cutter et al., 2010; Holand & Lujala, 2013). Both are sub-national indices and Holand and Lujala (2013) work in a similar context as Sweden. Election participation is already used in Sweden as a way to focus political effort on specific areas, giving the variable a legitimacy among policy makers.

The variable itself is simple and already measured by credible sources. It updates every four years, and while the relation to the area is not well documented, there is some evidence that the variable indicates vulnerability.

Data are published by Valmyndigheten (The Swedish Election Authority) in relation to the elections held every four years. The scale goes from national, through regional and municipal, down to election districts. These do not correspond to the districts mentioned above, but instead are generally smaller in size and change slightly between elections. As such, care must be taken to compare geographically rather than by district (Valmyndigheten, 2014).

4.2.5 Social Security

Six authors are concerned with social security benefits. While the motivations and perceived influence of this variable differ with respect to vulnerability, for the Swedish context, the benefits are aimed to assist socio-economically vulnerable individuals and households, and thus the variable is an indicator of vulnerability.

The variable is simple to understand and the relation to vulnerability is documented and fits the context. It also shows a change over time, for the area as well as for individuals and households.

Data are published monthly and yearly on a municipal level by The National Board of Health and Welfare (Socialstyrelsen). Information can be divided into various subgroups, including foreign-born, number of children, and single person (Socialstyrelsen, 2018b). Sub-national data are available on request[2], with a handling time of 3-6 months and a cost ranging from 11 000 to 44 000 SEK (Socialstyrelsen, 2018a).

[2] Personal phone communication with Jesper Hörnblad, Socialstyrelsen

4.2.6 Household finance

Two variables are suggested for the household finance indicator: (1) median household income, and (2) ratio of households living below the poverty line. These variables cover well the financial aspects of vulnerability and their influence on vulnerability is well documented (see 4.1.2.7 and 4.1.2.9 above). In addition, the variables are simple to understand and easy to measure, while showing a change over time.

Data are available on a municipal level with SCB for median household income (SCB, 2017f) and on a lower level on request. Poverty is measured differently in Sweden than in other countries, and low economic standard is defined as 60% below the median value (SCB, 2017a). These data are available on a municipality level (SCB, 2017f) and on a lower geographical level on request.

4.2.7 Level of education

Education level is linked to vulnerability with twelve authors measuring it in some manner. For Sweden it is suggested that the ratio of people with 'less than 9 years of education' is used as a measurement. Potentially, the upper-secondary education (gymnasial utbildning) can be added to this.

The variable fulfils the criteria of simplicity, ease of measurement, relation to the area and showing change over time. It is openly published by SCB on a municipal level and divisible for age (16-74 years of age) and sex (SCB, 2017e). Data on lower geographical level are available on request.

4.2.8 Time since last public advisory

Four authors measure the experience of disasters as an indicator which reduces vulnerability. Each were concerned with the sub-national level. In Sweden, the public advisory is approximately used 20-50 times a year. Using this as a variable gives some indication of the inverse vulnerability. While a part of the system is tested quarterly, these tests are less likely to decrease vulnerability than having an actual alarm, which is limited geographically.

This variable is simple to understand, the relation to vulnerability is clear in the literature, and it changes over time. While the data exists, only data from 2017 forward are openly available via the Swedish Civil Contingency Agency (MSB). These data are published per event and municipality rather than the geographical area affected by the advisory. While more detailed data are possible to be found, they are not as easily accessible.

Data are found with MSB and updated approximately two weeks after an advisory depending on workload (MSB, 2018).

4.2.9 Language

An important variable of vulnerability is the language skills of the household. A lack of skill in the domestic language hinders one's ability to obtain information required to make an informed decision to lower one's vulnerability.

No data have been located regarding the number of non-Swedish speakers in an area. A less optimal proxy is foreign-born persons, for which data exist (SCB, 2017i). Data are also found as to when the person immigrated to Sweden. Neither proxy measures language skills in Swedish, and as such the language indicator is harder to measure and to understand. As such, by using the proxy the relation to area is not as clear, however, some authors use foreign born or minority groups as an indicator for vulnerability (see 4.1.1.3 Ethnicity & Immigration above).

4.2.10 Companies with less than five employees & Sector

A company is the prime source of income for many. While only two authors (see 4.1.4.1 above) look at the ratio of small to large companies, it is a relevant indicator for Sweden with 73% of all companies having no employees and 19.5% having four or less. These companies are sensitive to disruption and potentially lack the buffers of larger companies.

Similarly, sector dependence (as brought up in section 4.1.4.3) is a relevant variable for many regions of Sweden and especially the smaller municipalities. Both variables are simple to understand and easy to measure and SCB publishes annual data on this (SCB, 2017d). The relation to the area is not as well-documented as other areas, but the inductive reasoning is straightforward.

4.2.11 Unemployment

Grouped with social security recipients and household finance, the employment status indicator aims to measure household financial stability. Ten studies looked at the ratio of employed or unemployed to the general population, making it well-related to the area.

Unemployment variables are frequently used, making them familiar; they are easy to measure, their relation to area is well-documented and they show a change over time. SCB publishes annual data on a municipal level, divided by age and sex (SCB, 2017h). Data are available on order for lower geographical levels.

4.2.12 Disability

Disability variables are measured by ten authors; however, the definition of disability is unclear. Similarly, in Sweden there are many definitions of disability and data are not readily available from a national source. With the municipalities being the prime bodies responsible for disabilities, there appears to be an absence of any national database regarding disabilities tied to geographical areas[3].

The variable itself becomes less simple, as the definitions of the authors are diverse and it is not stated specifically what is a considered a disability. This also results in difficulties measuring the variable. However, the relation to the area is well documented by the authors above and a change over time is also apparent.

Data might exist on a municipal level; however this is unconfirmed and the data must then be validated to correspond over municipal borders.

4.2.13 Vehicle access

Eight authors use vehicle access as an indicator for vulnerability. In Sweden over 4.8 million passenger cars are registered (SCB, 2017k). They are, however, not evenly distributed among the population nor geographically. Ownership of a car enables evacuation, and low ownership in a region can put extra strain on the rescue system in the case of an evacuation.

As such, household vehicle ownership or passenger cars per 1000 population as a variable is related to vulnerability; it is simple to understand, easy to measure, and it changes over time. Data are published annually by SCB on a municipal level (SCB, 2017k) with lower geographical levels available on order.

4.2.14 The indicators as an index

The thirteen indicators presented individually above must also be considered together as an index, as their purpose is to cumulatively indicate a vulnerability status of the households in a geographically limited area, such that a municipality can make informed decisions and plan for response and recovery.

A strength of the index is that it covers all categories identified in the literature study, with the exception of state. The state category is more aimed at a county, national, or even

[3] Personal phone communication with Ulrika Eriksson, Socialstyrelsen.

international level. Most of the variables in this category, while influencing the municipality, do so over the whole municipal area, making sub-municipal comparison redundant.

The indicators are mainly lagging or reactive in their current form, especially unless pre-event actions and programmes are planned alongside the indicators. However, it is expected that the data can assist in focusing disaster risk reducing efforts and making them more effective.

Data for all variables, except disability, were located on a national level with reasonably easy access. Most of the data can also be found with SCB and a few other actors, which increases usability for municipalities through having few sources of contact. Disability data should be available internally at municipalities. This is, however, unconfirmed.

Table 9 - A potential index for Sweden

Category	Indicator	Variable	Data Source	Open[4]	Geographical scale
Demography	Age	Younger than 15 (%)	SCB (2017b)	Yes	250x250m urban, 1x1km rural, District (DeSO on request)
		Older than 65 (%)	SCB (2017b)	Yes	250x250m urban, 1x1km rural, District (DeSO on request)
	Population	Yearly population change (%)	SCB (2017c)	Yes	250x250m urban, 1x1km rural, District (DeSO on request)
	Inclusion	Municipal election participation (%)	Valmyndigheten (2014)	Yes	Election districts
Economy	Social Security	Social Security recipients (%)	Socialstyrelsen (2018b)	No	District and DeSO available on request
	Household finance	Median household income	SCB (2017f)	No	District and DeSO available on request
		Households with income below 60% of national median	SCB (2017g)	No	District and DeSO available on request
Education	Education	People with fewer than 9 years of education (%)	SCB (2017e)	No	District and DeSO available on request
	Previous experience	Time since last public advisory (0: 0, 1: 0.5, 2:1)	MSB (2018)	Yes	Municipality of the advisory given in dataset. Each advisory could be studied individually to find the exact geographical extent of the advisory
	Language	Non-Swedish speakers	Not found	-	-
		Foreign-born + immigration less than 5 years ago (%)	SCB (2017i)	No	District and DeSO available on request
Employment and the private sector	Private sector	Number of companies with fewer than five employees / Total population	SCB (2017d)	No	District and DeSO available on request
		Sector dependence	SCB (2017d)	No	District and DeSO available on request
	Unemployment	Unemployment ratio (%)	SCB (2017h)	No	District and DeSO available on request
Geography	Density	Population density	SCB (2017c)	Yes	250x250m urban, 1x1km rural, District (DeSO on request)
Health	Health	Disability	Not found	-	-
Transportation	Vehicle access	Household vehicle ownership per 1000 population	SCB (2017k)	No	District and DeSO available on request

[4] Open refers to availability of data on a geographical scale lower than municipality

5 Discussion

This discussion regarding the result and the disaster risk management subfield of vulnerability has been divided thematically and laterally, going from discussing the data availability and method used, on through data verification, and finishing with the definition of vulnerability.

5.1 Data availability and selection of indicators

As found in the study, much of the data required to create the suggested vulnerability index for Sweden are available from single sources; however, they are available only upon request on a geographical scale lower than a municipality. Care should be taken, however, to avoid the trap of defining vulnerability "through the availability of datasets rather than because the data truly represent vulnerability" (Fekete, 2009, p. 95). Transparency of decisions is vital, and, as was brought up in the beginning of chapter 3, the justification as to why certain variables and data were selected is not often explicitly expressed in studies.

This study searched for data availability after deciding upon which indicators and variables were desirable. However, the indices that served as a basis for this selection come from earlier studies that were, at times, lacking transparency and depth of definition. Section 4.1 shows that many authors leave the definition of variables outside of their articles, presenting only the indicator and the outcome.

Data availability, especially the operationalising of the data by professionals, has barriers of budget and time constraints. For Sweden, the datasets required were available on order with an associated cost[5] that must be justified by the result. While data could already be available and some of the datasets have uses in other fields, it is still a financial consideration, especially for smaller municipalities. The time it takes to calculate a yearly vulnerability index is not significant, given that the data exist. However, it is still time that must be justified.

With these barriers in mind, it could influence the future work of the national agency SCB. Especially considering that the Swedish crisis management system uses a bottom-up approach and could be much assisted in their efforts should barriers to data availability be reduced.

[5] A preliminary quota was given as 25 000 SEK for the municipality of Lund (average size municiaplity in southern Sweden) for seven of the variables suggested.

5.1.1 The usage of census data

One ethical concern that is brought up by e.g. Fekete (2009) is the use of standard statistics as the data source for vulnerability. These data sources are often lacking information concerning the people who are either outside of standard statistics or not registered. The data sources suggested above for population studies (Statistics Sweden and The Swedish Election Authority) take data from registered individuals, potentially leaving out those who are unregistered, such as the transient or homeless – people who are, arguably, the most vulnerable.

Additionally, care must be taken with the use of standard administrative borders where the geographical differentiation of vulnerability was considered, as touched upon in section 3.2.1. When using smaller geographical scales, vulnerability varies greatly depending on time of day, day of the week, and so forth, as people move about in their lives to and from home, work, or leisure. Ruiter et al. (2017) discuss this temporal scale, finding that earthquake models take this into account more than models for flood, indicating that cross-learning is needed. However, even on a larger geographical scale, indigenous nomad people tend to not fit the mould for standard administrative borders and statistics.

The use of census data and similar datasets also do not fully capture attitudes, actual preparation and the diverse values of the people living in an area (King & MacGregor, 2000). In order to capture this, a participatory bottom-up approach of 'community-based vulnerability assessments' should complement the data found through census records (see Di Domenico, 2018, for an example of a community-based vulnerability approach). There are also ethical concerns regarding the use of a top-down approach without any community involvement in decision-making, as these decisions could influence the inhabitants of said community in a manner not acceptable to them.

5.2 Verification and aggregation

The next step for the resulting variables for Sweden in Table 9 above is verification of the variables for the context of Sweden. As brought up in section 3.2.1 earlier, vulnerability is context specific and should therefore be verified for each context. Future studies should take these variables, collect the data for them and compare the results against either observed vulnerabilities after an adverse event, themselves over time, or with a measurable definition of vulnerability as will be discussed in section 5.3.

Such verification should also be designed with correlation and redundancy in mind. It is expected that several of the indicators suggested in this thesis correlate closely with each other as found by Noriega and Ludwig (2012). The study should also consider how much each indicator should influence the end sum as this might differ from indicator to indicator or even for the variety of events they cover.

In addition, the disaggregation of vulnerability from a high scale to a low scale could be studied further as different indicators vary in meaning and impact depending on the context of level. This is somewhat researched by Birkmann (2007) and further studies should build on his work.

Apart from aggregation of levels, there is an argument against the generic vulnerability presented here in this thesis and especially section 3.2. Adger et al. (2005) who were quoted earlier regarding generic vulnerabilities, also touch upon hazard-specific vulnerabilities (p. 38-39, see also Cardona, 2006). Verification should be made showing that the variables suggested above could be used as generic in the context of Sweden. The merits of hazard-specific variables are that they are more accurate. However, several indices will be required to cover the main potential hazards of an area which is an argument for a more generic index.

5.3 Vulnerability definition

An overall umbrella of improvement that covers most, if not all, of the issues brought up above is the lack of how to verify the measurment of vulnerability. As mentioned earlier, Noriega and Ludwig (2012) were able to explain 23.2% using their variables. They were able to do this by defining the outcome of a lack of vulnerability as economic losses. This type of verification after an adverse event is still rare.

A reason for lack of such analyses is that vulnerability is not thoroughly defined by authors, as pointed out by ten years ago by Adger et al. (2005) and very recently by Ruiter et al. (2017). While measuring vulnerability directly is likely an impossible task, measuring vulnerability as expressed by percentage financial loss, increased mortality rates, and so forth, after an adverse event is not. By defining the vulnerability through lenses such as these, statistical verification of indices, such as the one performed by Noriega and Ludwig (2012), is made possible and more definitive answers to what variables influence vulnerability are attainable. Flanagan et al. (2011) use the difference in mail delivery as their vulnerability measure.

This work tries to take to heart the importance of verification by choosing indicators using the lenses of “who would require additional assistance during the response phase and who has lost the most, as measured by percentage of economic loss” (p. **Error! Bookmark not defined.**). By clarifying this, comparison with real events is enabled and such a study is highly encouraged.

6 Summary and conclusions

The goal of risk and vulnerability research is to reduce the harm done by disasters. One way of doing this, as expressed in the Sendai framework for Disaster risk reduction, is through an understanding of disaster risk and its components, one of which is vulnerability. Vulnerability is often defined as "the potential of loss of property or life" and is often divided into two different types; technical or biophysical, and social. Technical vulnerability mainly concerns buildings, infrastructure, and, at times, the environment while social vulnerability is more interested in the "the way social groups experience differential impacts from hazards" (Jeffers, 2013, pp. 2-3).

One method of social vulnerability quantification is to use social vulnerability indices populated by proxy indicators, as vulnerability itself is not measurable. While several indices exist, there are many indicators that are common for multiple indices as shown in section 4.1.

The indicators used to measure social vulnerability in more than half the studies examined were age, ethnicity or immigration, gender, household composition, population growth, household income, poverty, level of education, employment status, population density, building quality and standard, and disability.

From these indicators, and a few others that are deemed important in the Swedish context, the index in this thesis was selected for Sweden as presented in Table 9 on page 49. The indicators were selected based on criteria of simplicity, ease of measurement, relation to a given area, and change over time.

It was found that twelve of the seventeen variables selected were found within Statistics Sweden, three were found within other governmental bodies and two were not found within the national bodies searched. One of these, pertaining to disability, is expected to exist within municipal government bodies in Sweden. Six of the datasets are freely available while the other nine must be requested from the national agencies for any level lower than municipal.

The index created here could, after statistical verification, be used to increase the level of information available during decision-making processes, and thus, reduce the harm done by disasters, increasing safety for the most vulnerable.

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Appendix – Indicator categorisation

While examining the studies pertaining to social vulnerability indices, their indicators were extracted and indexed into the following columns using Microsoft Excel: Category (indicating whether the author used a categorisation), Variable, Positive or negative impact, Author, Page, and Additional author (in case of literature reviews of several indices). Additionally, a new column was created. In this column, named Random, the "=rand()" function was used to generate a random number. The values in the Random column were copied into a new column, named Sort, after which the table was sorted, thus randomizing the order of variables to not introduce a bias towards any author's categorization. While, in theory, this "=rand()" function can create duplicates, frequency of this was deemed low and consequences of generating duplicates were non-existent due to the purpose above.

At this stage, the columns Sort, Variable, Author and Page were copied over to a new sheet. The variable of each row was then analysed and assigned a category, starting from the top. The first round resulted in nine categories; Demography (161), Economy (77), Education (53), Employment (54), Geography (68), Health (51), State (36), Transportation (19) and Other (54).

There was no attempt to equalise the categories in terms of number of members. Neither was any specific limit to the number of categories set, but numbers were kept reasonable. If an indicator didn't fit, had limited application to Sweden, or was considered less useful for a similar reason, it was put into an Other category.

As the Other category had quite a number of indicators, 9.42% of the total, these were checked once more, and each indicator re-evaluated. For some indicators (38), the original work was revisited to find the meaning of the indicator if unclear. After this secondary categorization, seven indicators were left uncategorised and removed due to being unclear (2) or not applicable (5). These can be found in Table 10 below. These consisted just above 1% of the total number of indicators studied.

Sorting the variables in each category into the various indicators

The 567 indicators remaining, having already been sorted into eight major categories, were further analysed within each of these categories aiming to collapse various indicators and variables into a single indicator. As an example, several authors use age as an indicator with slightly different wordings. These age indicators were grouped together into an age indicator

and placed under the demography categorization performed in the earlier step. This sorting was made in alphabetical order based on the categorisation and then indicator name.

Table 10 - Variables deemed not appropriate for further study

Variable	Comment	Author	Page
Animal protein consumption per capita	Food sensitivities	Adger et al. (2005)	69
Cereals production per capita	Food sensitivities and not applicable scale	Adger et al. (2005)	69
Fertiliser consumption	Ecosystem sensitivities and not applicable scale	Adger et al. (2005)	69
Flows of aid	Not applicable scale and not used by author	Vincent (2004)	18
Marginalisation	Undefined by author. Unclear what type of marginalisation as author does not define it further	Adger et al. (2005)	30
Welfare level	Undefined by author. Author's source does not define this further	Ruiter et al. (2017)	1239
Human development index	Not applicable scale	(Cardona, 2005)	13

At this stage, a number of aggregated indicators were duplicated and sorted into two or more indicators types. As an example, Garbutt et al. (2015, p. 169) use "elderly one-person households" as an indicator which features both age (elderly) and Household composition (one-person) within the indicator. Due to this, and also due to a few indicators being initially less appropriately sorted, a few indicators were recategorized.

Table 11 below shows the categories and the indicators found within that category.

At this stage, an analysis of each indicator was performed, the result of which is found in section 4.1 (page 14). During this stage, quality control was performed as to ascertain no indicator had by mistake been wrongly categorized. While the frequency of this is low (estimated 2), the consequence would be minimal unless the indicator were unique in its coverage. Even if this were the case, it would indicate that only a single author was concerned with this indicator and the validity of such an indicator should be questioned. In addition, it

was decided to move urban/rural from Demography to Geography as it pertains more to the location of the area than the people living therein.

Table 11 - Categories and indicators

Demography (174)	Age (60), Crime rate (2), Ethnicity (31), Gender (27), Household composition (25), Inclusion (9), Population (21)
Economy (88)	Assets (9), Benefits (12), Costs (3), Debt (8), Equality (8), GDP (11), Income (16), Insurance (3), Poverty (18)
Education (58)	Education (26), Experience (8), Information (8), Language (9), Literacy (7)
Employment (54)	Company (2), Contract (1), Sector (20), Unemployment (28), Unpaid & Work experience (3)
Geography (106)	Density (16), Environment (6), Land usage (12), Location (11), Mobile homes (5), Residency (12), Resource usage (3), Services (2), Standard (23), Tourists (4), Rural/Urban (12)
Health (51)	Capacity (8), Disability (21), General health (14), health service quality (8)
State (37)	Agriculture (3), Corruption (2), Disaster risk reduction (7), Governance (11), Public finance (10), R&D (2), Trade (2)
Transportation (16)	Commuter (3), Infrastructure (2), Vehicle (11)