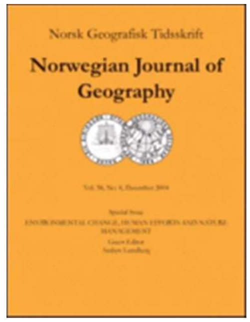

Quantifying vulnerability to flooding induced by climate change. The case of Verdal, Norway

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Quantifying vulnerability to flooding induced by climate change.

The case of Verdal, Norway

The article presents a methodology for the measurement of exposure and social vulnerability to hazards at local level. Using the small town of Verdal in central Norway as a case study, the authors examine its vulnerability to climate change induced flooding both at present and its potential vulnerability in the future. Data on river and surge flooding and sea level rise scenarios, which are overlapped spatially with present-day maps for land use, transport networks, and buildings, are used to assess exposure to flooding. In addition, the authors assess the study area's level of social vulnerability. The two measures are then combined to assess the integrated vulnerability for Verdal. The results of the analysis show that there are considerable differences across the study area regarding which units will experience the largest increases in vulnerability. The methodology used in the study is transferrable to other towns and municipalities, as well as to other types of hazards, both natural and man-made.

Keywords: *climate change, exposure, flooding, hazard of place, sea level rise, vulnerability*

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Introduction

Although climate change is a truly global phenomenon, its future impact ultimately will be local in the sense that the consequences will affect local people and communities. In order to be able to adapt and manage disaster risks, localized knowledge of such risks is needed. In this article we use a methodology that combines physical and social aspects of vulnerability to study hazards related to climate change at local geographical scale.

Coastal zones are inhabited by 75% of the population in Norway (SSB 2007), and are prone to climate-related phenomena such as storms, storm surges, and sea level rise. In this article, we study the vulnerability in Verdal, which is a small urban-like community located at the mouth of Verdal River, which flows into Trondheimsfjorden in Mid-Norway. Verdal, in common with many other settlements in the region, is located on a river delta, and over the last 40 years it has transformed from being a predominantly farming community to an industrial community centred around the construction of offshore oil installations.

In this article we first identify areas in Verdal exposed to floods, storm surges, and sea level rise. Exposure to present-day flooding is modelled using the simultaneous occurrence of a 10-year river flood and a 10-year storm surge. To assess future consequences of flooding caused by climate change, we use the scenario of 1 m sea level rise together with the simultaneous occurrence of present-day 100-year river flood and 100-year storm surge. Based on the area, buildings, and transport network flooded, we compile Exposure Index (EI) for the present day (EI Present) and the future (EI Future) for 15 basic statistical units, which are subdivisions of municipalities, in the centre of Verdal. In order to measure the 'propensity or predisposition to be adversely affected' (i.e. vulnerability) we generate a Socioeconomic Vulnerability Index (SoVI) (Cutter et al. 2003).

Further, in order to assess the potential impact of climate-related hazards at present and in the future, the EI and SoVI indices are combined to form what we call an Integrated

Vulnerability Index (IntVI), which summarizes the interplay between exposure and social vulnerability. Lastly we discuss the use of three socio-economic development patterns, derived from a set of scenarios and population projections, as a possible means for identifying future vulnerability patterns in Verdal.

The results show that it is possible, and important, to incorporate future climate change and socio-economic aspects both in assessments of a place's total vulnerability currently as well as in the rather distant future. As increased river flooding, storm surges, and raised water levels due to sea level rise affect areas differently depending on their distance from the coast, topography, land use, and built infrastructure, there will be local variations in the severity with which the different areas will be affected by these phenomena. This is aptly shown by the results of our analysis, where some units show little change in their total vulnerability over time while others shift from having a low vulnerability to high vulnerability.

Vulnerability to hazards

Research on climate change and natural disasters have traditionally been the realm of separate research communities that only in recent years have found together in a common interest in studying the relationship between climate change and natural disasters (Schipper & Pelling 2006; Thomalla et al. 2006). Vulnerability is a term commonly used in development and poverty studies, research on natural disasters as well as in studies of climate change, and it is a concept that has been extensively debated (se e.g. Cutter 1996; Agder 2006; Eakin & Luers 2006; Fussel 2007; Hogan & Marandola 2005; Hufschmidt 2011).

Representing the natural disaster tradition, Wisner et al. (2004) define vulnerability as «the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard (an extreme natural event or process)» (Wisner et al. 2004, 11). Within the climate research community vulnerability has commonly been defined as a function of exposure, sensitivity and adaptive capacity (McCarthy et al., 2001). Exposure is here seen as an element of vulnerability.

The 2012 Intergovernmental Panel on Climate Change (IPCC) report on climate change related extreme events and disasters adopt the definition by Wisner et al. cited above and define vulnerability as:

> *...the propensity or predisposition to be adversely affected. Such predisposition constitutes an internal characteristic of the affected element. In the field of disaster risk, this includes the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events* (IPCC 2012 p 32).

It this article we follow the IPCC definition and use characteristic of the people and households as the basis for the social vulnerability index. With regard to the term *exposure,* we again follow IPCC 2012 who provides a general definition of exposure as:

> *...the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage.'* (IPCC 2012 p 32).

In this article, we focus on buildings, roads, and residential, industrial, and agricultural land as key assets exposed to sea level rise, storm surge, and flood.

Cutter et al. (2003), Greiving et al. (2006) and Tate et al. (2010) argue that hazard exposure and social vulnerability should be analyzed jointly within a particular geographic place or social space, thereby providing insight into the total vulnerability of places. This is the approach we have chosen to use in this article. We measure exposure and socioeconomic vulnerability separately and then combine them together to measure the overall vulnerability of Verdal.

As Amundsen et al. (2010) point out, there has been little focus on proactive efforts concerning mitigation and adaptive actions to climate change in Norwegian municipalities. Currently, attention is on adaptation to historical natural events, but this lacks focus, information, and competence with regard to how climate change may alter local hazards. Further, Næss et al. (2006) and O'Brien et al. (2006) have emphasized that it is important to assess vulnerability and the effects of climate change at more regional and local levels in Norway.

Studies that incorporate the social vulnerability aspect and examine Norwegian municipalities and their vulnerability and adaptive capacities to climate change include O'Brien et al.'s (2003) assessment of the sensitivity of the local economy to changes in agriculture and tourism. Another approach is presented by Groven et al. (2006), who adopted Aall & Norland's (2005) suggestion of ranking Norwegian municipalities using variables that measure aspects of municipalities' sensitivity and adaptive capacity to climate change.

However, these studies do not systematically incorporate measurements of the exposure and social vulnerability as outlined by Cutter et al. (2000). To our knowledge, the only indicator-based assessment incorporating exposure and social vulnerability at a local scale in Norway to date was performed by Rød et al. (2010; 2012), who examined vulnerability at the sub-municipality level in the counties of Sør-Trøndelag and Nord-Trøndelag. Their study examines social vulnerability and exposure to present-day natural hazards such as river flooding, quick-clay slides, and landslides.

The present article contributes to this literature by incorporating the possible effects of climate change in the integrated evaluation of exposure and social vulnerability at sub-municipality level.

The study area

The case study area is the deltaic area of Verdal Municipality, located in the county of Nord-Trøndelag (Fig. 1). In 2011, the municipality had 14,334 inhabitants and a land area of 1489 km² (Verdal kommune 2011). The majority of the municipality's inhabitants live in and around the administrative centre. The case study area had 8329 inhabitants in 2009 and covered 2.4% of the total land area of Verdal Municipality. The study area is the most densely built-up area of the municipality. The area includes the central business district, the Ørin industrial area, and residential areas in and near the administrative centre. Many of the buildings and infrastructure in the study area are located close to the riverbanks or the seashore, with some 'trapped' between the two water elements. The study area also contains forested, agricultural, and nature conservation areas.

FIGURE 1 ABOUT HERE

Where Verdal River (Verdalselva) has cut through marine sediments deposited after the last Ice Age, the valley has raised terraces. These are fertile agricultural lands, some with housing estates. The shallow delta platform at sea level features vast tidal flats, consisting of a tideway and banks formed by waves. Verdal River is not regulated, but due to past problems relating to landslides, erosion, and flooding, it has been modified along most of its length by physical and technical interventions (Sæther & Larsen 2004).

Verdal has experienced severe river floods, the largest two in the 20th century occurring in 1932 and 1947. The third largest flood since 1900 occurred in January 2006, and caused erosion and landslides as well as severe damage to buildings and infrastructure, especially in areas further upstream. Storm surges pose a less acute challenge for Verdal than for areas on the open coast as wave activity and sea levels are less hazardous at the head of a fjord. The highest registered surge occurred in 1971, which rose 2.7 m over a.s.l.. The surge flooded a substantial part of the delta, but no severe consequences were recorded (Sæther & Larsen 2004).

In the 1970s, Verdal underwent rapid transformation from an agricultural municipality to an industrial one, and in 2010 industry still provided 20% of the total workplaces in the municipality (Verdal kommune 2010). Among the largest new establishments in the 1970s was Aker Verdal (now Kværner Verdal), a company that produces large steel constructions for Norwegian oil platforms. Due to new workplaces, the population of Verdal increased between 1970 and 1979 by 30% (from 9756 to 12,694) (SSB 2012). However, from the late 1970s onwards the community was put to the test as Aker Verdal started to suspend its workers. In subsequent decades this cornerstone company experienced severe upturns and downturns, which led to exceptionally large numbers of suspensions and terminations of contracts in 1999 as the oil sector's construction needs declined significantly (Irgens 2002).

In the 1980s and 1990s, low-cost buildings in central parts of Verdal attracted social clients also from outside the municipality. Statistical evidence shows that Verdal still experiences social problems, although to a less degree than before. The upturns and downturns of the cornerstone industry and the social challenges are reflected in Holand et al.'s study of municipality-level social vulnerability, in which Verdal received a relatively high score (Holand et al. 2011).

Methodology

We use Cutter et al.'s (2003) conceptual model on 'vulnerability of places' as a starting point from which to develop our methodology for studying sub-municipality level vulnerability to hazards. The model includes estimation of both exposure and social vulnerability, which are then combined to measure a place's total vulnerability. The model was initially intended for present-day assessments for counties in the USA and hence requires modification to fit the Norwegian context and incorporation of assessments related to the future.

The methodological steps for the preparing the indices are presented in Fig. 2. This method is useful also when assessing vulnerability to other types of hazards, making it viable for use as a 'total' assessment that includes all known hazards of a place. As we examine both present-day and future exposure, we generate vulnerability indices for both the present and the future.

FIGURE 2 ABOUT HERE

Assessment of Exposure (EI)

The assessment of exposure starts by identifying the hazards that are most relevant to the study area. The next step is to calculate the exposure to the hazards within the study units. As variables for our exposure measure, we use transport network length (in metres), densely populated, industrial, and agricultural area (in square metres), and number of buildings inundated by the storm surge, river flooding, and sea level rise. Sea level rise is only relevant for future EI.

As the measurement units and scale for these variables differ, the next step is to standardize the hazard exposure measures so that they are comparable. We use the following equation for standardization:

$$x' = \frac{x - min}{max - min} \times 100 \quad (1)$$

where x' is the standardized value and x is the value for which the standardized value is calculated. *Min* and *max* refer to minimum and maximum value registered for all study area's units for the specific consequence that is calculated.

As it is desirable to provide maps that are comparable across the present-day and future scenario, it is necessary to adjust the standardization process for EI so that we can calculate *comparable* scores for the present-day and future EIs. This mans that instead of calculating standardized values for present and future separately, we merge them. We do this by merging the estimates for the present-day and future and then use the minimum and maximum values from this merged set of estimates in Eq. 1.

In practice, for each measure, the standardization stretches the raw values to a scale between 0 and 100. In this way, the individual exposure measures can be added together, which is the next step in calculating the EI:

$$EI = w_1 \times Building + w_2 \times Transport + w_3 \times Area \quad (2)$$

where w is the relative weight[1] assigned for the individual exposure measure, and scores for the Building, Transport, and Area are the standardized values from Eq. 1. EI is calculated separately for present and future.

After constructing the EIs, the last step in the process is to map them in order to illustrate the spatial distribution of vulnerability in the study area.

Assessment of Social Vulnerability (SoVI)

The first step in assessing social vulnerability to physical hazard is to identify aspects that make people vulnerable to them. The aspects are then operationalized into measurable indicators for which data exist. In our study, we include nine variables that describe socio-economic status and population characteristics, using data obtained from Statistics Norway.

We use the Socioeconomic Vulnerability Index (SoVI), adapted from Cutter et al. (2003) and applied to Norway by Holand et al. (2011) and Holand & Lujala (2013), to quantify social vulnerability to flooding at sub-municipality level. The SoVI is based on a factor analysis that quantifies the characteristics so that each of the study units receives a score that measures its relative vulnerability vis-à-vis the other units included in the study.

The factor analysis reduces the information from several indicators that each describes a facet of a community's vulnerability to hazards to smaller number of factors. In our analysis, we use principal component analysis (PCA), and extract all factors with an eigenvalue larger than 1.0 and rotate the results using the Varimax rotation. We validate the number of factors using scree plots and parallel analysis (see, for example, Lance et al. (2006) or Velicer et al. (2000)).[2] We determine whether a factor has a tendency to decrease or increase the vulnerability, and in the instances where a factor decreases vulnerability, a negative sign is assigned to the factor score. Finally we add the factor scores together to construct the overall vulnerability score:

$$SoVI = \sum_i^n w_i \, Factor_i \qquad (3)$$

where n is the number of factors and w is the weight for the factor. The resulting SoVI score is then standardized by using Eq. 1.

Integrated vulnerability (IntVI)

Finally, we combine the exposure and social vulnerability indices into one composite index (Integrated Vulnerability Index, IntVI:

$$IntVI = w_1 \times EI + w_2 \times SoVI \quad (4)$$

where *w* is the weight assigned to the index. IntVI is calculated separately for both the present (using EI Present) and future (using EI Future). The resulting two IntVI indices are then mapped and analysed together with the SoVI and EI to gain an understanding of what constitutes total vulnerability.

Quantification of Vulnerability Indices for Verdal

This section provides information on the background data and how they were treated in order to construct the Exposure Indices (EI Present and EI Future), the Socioeconomic Vulnerability Index (SoVI) for Verdal, and the overall Integrated Vulnerability Index (IntVI). The results are then presented in the form of maps and discussed.

Exposure (EI Present and Future)

We measure exposure to flooding by the land area, length of transport network, and number of buildings inundated by storm surge, river flooding, and sea level rise. For present exposure, we use the 10-year river and storm surge floods that occur simultaneously, as this interval is relatively frequent. A storm surge is a natural occurrence where coastal water level rises due to a combination of low pressure and high winds creating high sea levels. It is worth noting that although the two may occur simultaneously, for example, in cases of severe storms, the probability of them occurring simultaneously is lower than once in 10 years.

To calculate the future exposure to flooding, we applied both sea level rise and the present 100-year interval flooding. As the existing flood zone mapping for the Verdal community produced by the Norwegian Water Resources and Energy Directorate (NVE) was based on the present sea level[3], a new modelling of water levels at specific flood return intervals, taking into account sea level rise, was obtained from the NVE. The mapping of the inundated areas was then based on terrain data obtained from airborne LIDAR.

Predictions concerning sea level rise by 2100 range substantially in the international literature, from a few centimetres to several metres (Pfeffer et al. 2008; Vermeer & Rahmstorf 2009). Due post-glacial rebound, the ground is expected to rise by c.50 cm in the region where Verdal is located and this will counterbalance sea level rise to a great extent. A high-end estimation for future sea level rise, obtained from the Norwegian Mapping Authority, sets the upper-boundary for Trondheim, located in the same region as Verdal, at 82 cm for the next 90 years (Simpson et al. 2012). For our exposure measure, we use a 1 m sea level rise.

Annual precipitation levels in the study region are projected to increase by up to 50% by the end of the 21st century, affecting river runoff greatly. It is also likely that Verdal will experience more periods of days with heavy precipitation as well as an increase in daily precipitation during such an event (Iversen et al. 2005; Roald & Asvall 2007; Hanssen-Bauer et al. 2009). Due to such an increase in precipitation and runoff, it is not unlikely that a present 100-year flood could appear as a 50-year event or even a 10-year event in the future (Lehner et al. 2006), as stream flow may increase, especially in autumn, winter, and spring (Beldring et al. 2006).

With regard to storm surges, there can be intensification at regional scales in the future, with considerable variations, leading to high degrees of uncertainty (Woth et al. 2005;

Hanssen-Bauer et al. 2009). Verdal may experience a slight intensification of existing surges, but notably the storm surge season may start earlier in the autumn and last longer in the spring (Hackett 2001), contributing to a higher number of storm surge events. To include the increased and more frequent flooding in the calculation of EI Future, we chose to incorporate the 100-year river and surge floods.

Inundated areas in the various flooding zones are illustrated in Fig. 3. In the case study area it is mainly agricultural land that is exposed to the 10-year river and storm surge floods (Appendix 1, panel B). With the future flood zones created using sea level rise scenarios of 0.5 m, 1 m, and 2 m and 100-year floods, more land is flooded close to the seashore as well as further up in the watercourse and northwards from Verdal River. Land south of the river, after it bends eastward, is less prone to flooding due to the higher elevation of the terrain. With sea level rise, industrial, residential, and business areas and transport routes close to the sea and riverbanks are affected. The major road, the E6, which crosses the delta, is not influenced by the 10-year river and storm surge flooding, but would become more affected under the future scenarios, especially with 1 m and 2 m sea level rise.

FIGURE 3 ABOUT HERE

We conduct the analysis at the basic statistical unit level. Basic statistical units are subdivisions of municipalities and are the lowest level for which Statistics Norway generates statistics.[4] Using ArcGIS, we create three variables that measure each basic unit's exposure to flooding: number of buildings inundated (*Building*), length of road and train tracks flooded (*Transport*), and agricultural, industrial or densely populated areas flooded (*Area*). The basic statistics for these units are listed in Table 1.

TABLE 1 ABOUT HERE

The third and fourth column in Table 2 shows the results for the variable *Building*. The column headed 'At present' indicates the numbers of buildings flooded for the present day if the 10-year river and storm flooding were to occur simultaneously. The column to the right, headed 'Increased flooding', presents the 1 m sea level rise with 100-year river and storm surge flooding. The totals show that the number of buildings flooded would increase from the present-day figure of 82 to over 673 under this scenario. It is expected that more than 20% of buildings in Ørin, Haug, and Stamphusmyra-Fætten could be affected. In Ørmelen 1, almost all buildings would be affected.

TABLE 2 ABOUT HERE

Table 2 also shows the results for the variable *Transport*. This variable measures the length (in metres) of public roads or railway tracks flooded. As the results show, the length inundated would increase from 0.7 km (present day) to over 30 km. In absolute and relative terms, Ørin, Ørmelen 1 and 2, Haug, Verdalsøra South, and Stamphusmyra-Fætten would be among the units most affected in the future.

The two columns on the right-hand side of Table 2 show the total densely populated, agricultural, and industrial areas flooded (see Appendix 1 for a breakdown of these three different land types for each unit). At present, Stamphusmyra-Fætten, Haug, Vinne, and Stiklestad experience the largest inundations. In the future, especially Ørin will experience considerable flooding (mainly an industrial area at present), but also densely populated areas in Ørmelen 1 and 2, Verdalsøra South, and Haug will be affected.

To incorporate the values from Table 2 into one index, we standardize the figures using Eq. 1 so that they can be added together, adjusting them so that they are comparable. As we regard the absolute extent of damage more interesting and relevant than the relative extent, in the standardization process we use the number of buildings, metres of transport network, and square metres of land inundated.

To standardize the variable *Building*, we set the minimum to 0 (as this is the lowest number of buildings inundated) and the maximum to 136, as this is the highest number of buildings in the flood zone under the 1 m sea level rise scenario (Ørmelen 1). The inundated transport network is standardized similarly. For the flooded area, we first add together the agricultural, industrial, and densely populated area flooded, before standardizing the variable. This means that in practice we assume that all types of area are equally important. We acknowledge that there are arguments for using other weightings, for example weighting densely populated and industrial areas more than agricultural land. This, however, is taken into account by including buildings and transport network separately in the calculation of EI.[5]

At this stage, all consequence variables are measured on the same relative scale (0–100) and can thus be added together using Eq. 2. Before doing that, we need to consider the weighting of the individual variables as this will have effect on the final EI score, although the impact is likely to be moderate (Jones & Andrey 2007). A common strategy in the literature has been to use equal weights (Rød et al. 2013). This approach can be warranted when there is no theoretical framework that would indicate other type of weighting or when the common understanding of the relative importance of the different components is lacking. In fact, inappropriate weights may skew the calculated index score even further from the "real" exposure. One possibility could be to use insurance payments to determine the weights. However, as long as we do not have insurance payments per "damaged" unit (that is, per square meter agricultural land or per meter of railway track inundated) these are difficult to operationalize in a local context.

In this article, the variable Area includes agricultural, densely populated, and industrial land inundated. When densely populated land is inundated, it is not only the "land" that is damaged, but also the buildings, roads and railway tracks on it. Therefore, we include them separately to give more weight to them. For this purpose, when using Eq. 2, we weight land by 50% (w_3) and buildings by 30% (w_1) and roads by 20% (w_2). We weight roads less than buildings as they do not always get damaged to same extent as buildings when inundated.

The resulting EI Present and EI Future are presented in Table 3 and mapped in Fig. 4. Table 3 shows that Stamphusmyra-Fætten and Haug are the most exposed units at present as well as in the future. Other basic units that would experience considerable increase in exposure include Ørin, Ørmelen 1 and 2, Stiklestad, and Verdalsøra South.

FIGURE 4 ABOUT HERE

TABLE 3 ABOUT HERE

Fig. 4 shows the basic units in the study area organized in five groups using the 'Natural Breaks' classification method. The classification method was applied to all 30 EI scores at the same time (15 for EI Present and 15 for EI Future). In other words, the two maps use the same break points for the intervals. Units with low relative exposure are indicated in green colours whereas those with increasing levels of vulnerability are indicated using a colour scale ranging from yellow to dark red, where the darker shades indicate higher levels of vulnerability.

As Fig. 4 shows, the basic units most exposed to present inundation are those bordering the river in the eastern part of the study area (Haug, Stiklestad, and Vinne), as well as Stamphusmyra-Fætten, which borders both the coast and river. EI Future indicates a considerable shift in vulnerability for several units. Basic units located around the delta and on the coast (Stamphusmyra-Fætten, Ørin, Ørmelen 1 and 2, and Verdalsøra North) in addition to Haug all shift from having a low level of exposure to having considerably higher exposure to flooding in the future.

As a sensitivity analysis, we calculated alternative EIs for present and future using equal weights in Eq. 2. The resulting EIs have a 99 percent correlation with the original ones. Although there are visual differences when the EIs are mapped – the break points change and some basic units fall on different sides of break points – the ranking of the basic units is barely changed. There are no rank changes with respect to EI present. With respect to EI future, there are two changes in the ranking: Ørmelen 1 and Verdalsøra South switch places (the original EI scores are 38 and 37, respectively, see Table 3) as do Ørmelen 2, Vinne, and Stiklestad (the original scores for the three are 24, 25, and 30, respectively). The map using the alternative EIs is not shown.

Social vulnerability

The indicators used in our SoVI model area are based on indicators that international literature has shown to affect social vulnerability (Cutter et al. 2003). Unfortunately, there are relatively few indicators available at basic unit level, but among those that exist we chose to use average income and wealth levels, labour participation rate, and the proportion of those in work that are employed in 'secure' public sector jobs. Other variables that we use to indicate higher vulnerability include the proportion of single-parent households, mortality rate, proportion of non-Western immigrants, high levels of population movement to the unit, and proportion of working population engaged in the primary sector. Table 4 lists the indicators included in our SoVI model, with definitions and the rational for their inclusion in more detail.

TABLE 4 ABOUT HERE

We deem it inappropriate to calculate a socio-economic vulnerability index only for the study area or for Verdal Municipality as a whole, as the number of basic units (15 for the study area and 37 for Verdal) is insufficient for factor analysis. Instead, we calculate the SoVI for all basic units in the counties of Nord-Trøndelag and Sør-Trøndelag and then extract the data for the study area using the approach used in Rød et al. (2012). In total, we use data for 1248 units. Appendix 2 lists the descriptive data for the whole sample used in constructing the SoVI and for the study area. To preserve anonymity, we do not include units with fewer than 50 inhabitants in the analysis. In the study area, one unit fell below this limit (Ørin had 12 inhabitants) and we therefore use the average SoVI score of the study area for Ørin in the analysis.

The factor analysis groups the indicators into three separate groups according to factor loading (Table 5). The first factor (Factor 1) highlights basic units in which revenues are high, the proportion of population in the workforce is high, people are employed in the public sector, and few work in the primary sector. Basic units that score highly on this factor are less vulnerable and therefore we assigned a negative sign to this factor. Factor 2 describes units in which people have little wealth (since capital assets load negatively on the factor), experience larger population movements into the basic unit (positive factor loading), and have a high proportion of non-Western immigrants. Factor 3 highlights units with a high number of single-parent households and mortality is high. These basic units are among those that are more vulnerable.

TABLE 5 ABOUT HERE

We use the factor scores from the factor analysis to add the three factors together to construct the final SoVI score for the basic units using Eq. 3. Weighting of these factor scores can have impact on the final index (Schmidtlein et al. 2008; Jones & Andrey 2007). As we are using factor analysis, we have basically two choices: We can either use equal weighting that assumes that each factor contribute to the final index equally or to weight the factor scores by the amount the factor in question explains variance in the data.[6] The latter approach is seen more appropriate when factor analysis is conducted at the local scale as it reduces the effect of possible outliers in the data (Wood et al. 2010) and takes into account the fact that the Factors 1 and 2 contribute more to socio-economic variability than Factor 3. We follow this approach and use weights when we add the factor scores together.

In practice, this means that the first factor is weighted by 0.26 as the factor explains 26% of the variance in the analysis. When we sum together the three factors to form the socio-economic vulnerability index we take into account that the first factor reduces vulnerability and adjust the sign for it. The overall vulnerability score for each unit can thus be calculated using the following equation (derived from Eq. 3):

$$SoVI = 0.26 \times (-Factor\ 1) + 0.25 \times (Factor\ 2) + 0.14 \times (Factor\ 3) \qquad (5)$$

After calculating the SoVI, we standardize it using the same procedure as used above for *Area*, *Building*, and *Transport* (Eq. 1). Table 3 shows the SoVI scores after the calculation using Eq. 5 is performed and the resulting scores have been standardized using Eq. 1. Clearly, Ørmelen 1 is the basic unit with highest vulnerability level, whereas Berg, Stiklestad, Haug, and Vinne are among the less vulnerable. This is illustrated in Fig. 5, which shows the result of using Natural Breaks classification on the SoVI score. Clearly, the most vulnerable units are located near the delta, namely Ørmelen 1–4 and Verdalsøra South and East.

FIGURE 5 ABOUT HERE

We also calculated the SoVI index using equal weighting in Eq. 3. The correlation between standardized scores resulting from the two approaches is 99 %. The only substantial change is for Mikvold-Frydenlund which has low score on Factor 3, thus becoming relatively less vulnerable when the third factor receives more weight: The standardized score drops from

23 to 10 while the average change for the other units is -3. This change alters Mikvold-Frydenlund's ranking from being the 10th most vulnerable basic unit to being the 13th most vulnerable unit. Also, basic units Verdalsøra East, Ørin, and Brannan, for which the original SoVI scores are 32, 31, and 30 respectively (Table 3), switch places when the alternative weighting is used.

Integrated vulnerability

The final step in our analysis is to combine the data on physical exposure and social vulnerability in an Integrated Vulnerability Index (IntVI). To obtain IntVI, we add the SoVI and EI scores together using Eq. 4. A common strategy in the literature is to use simple additive model although standard deviations (Piegorsch et al. 2007) and weights based on insurance payments (Rød et al. 2013) also has been used. In this article, we simply add the standardized scores together as we lack both theoretical and empirical understanding to weight exposure and social vulnerability, especially for the future. It is not given that weighting that might be appropriate for the present would be equally appropriate for the future.

We obtain the present-day Integrated Vulnerability Index, IntVI Present, for Ørmelen 1 by adding the EI Present score of 1 to the SoVI score of 100, resulting in IntVI score of 101 (Table 3). IntVI Future is obtained by summing EI Future (38) and SoVI (100), resulting in total score of 138.

Fig. 6 shows that total vulnerability at present is highest in the western part of the study area. One basic unit stands out, namely Ørmelen 1, which has a high total vulnerability score. This unit has a high population density, and in previous decades has housed low-income groups.[7] Even though EI Present assigns this unit a low EI score, its high score on the SoVI makes it among the most vulnerable at present.

FIGURE 6 ABOUT HERE

Taking sea level rise and more extensive river and storm surge floods into account, the IntVI Future shows that units in the lower delta are the most vulnerable in the study area, with the exception of Verdalsøra North which is situated at a higher elevation and has a low SoVI score (Fig. 6). Two units have the highest level of vulnerability: Ørmelen 1 and Stamphusmyra-Fætten. Otherwise, Verdalsøra South, Ørin, Ørmelen 2, and Haug are visibly vulnerable, with Haug having the largest change (as denoted by the change in colour from green to orange in Fig. 6). Basic units situated at higher elevations (Verdalsøra North and East, Mikvold-Frydenlund, Brannan, and Berg) are clearly less vulnerable. Only one unit appears less vulnerable in all maps and indices, namely Berg. This unit is situated at a higher elevation and is barely affected by flooding (Fig. 3). It also has the highest SoVI score in the study area.

Discussion

The Integrated Vulnerability Index (IntVI) presented summarizes the interplay between exposure and social vulnerability in the 15 basic units chosen for our study and thus provides an indicator of which areas may be most vulnerable to climate change related hazards. However, the index have limitations as a tool for predicting future vulnerability as it does not take into account future demographic, economic, and social changes that may make areas more or less vulnerable to the consequences of climate change.

One possible way to handle this is to use locally developed scenarios in climate change impact assessments. Such scenarios have been used for assessing the impact of future climate change in the UK (e.g. Holman et al. 2005a; 2005b) and in Norway (Groven et al.

2008). Holman et al. (2005a; 2005b) is based on three socio-economic scenarios coupled to local climate change scenarios in order to analyse the impacts of climate change on coasts and flood plains, agriculture, water resources, and biodiversity in two study areas in England. Groven et al. (2008) used expert-based scenarios based on assumptions linked to changes in demography, labour market, economy, settlement structure, and mentality as a basis for discussions with seven municipalities aiming at identifying socio-economic changes that might have implications for adaptation processes.

One advantage of using local-level scenarios for socio-economic changes instead of aggregated projections for socioeconomic development at the regional level is that they allow a place-bound and localized approach to assessing future vulnerability patterns. This can potentially provide a basis for local-level planning, especially if local stakeholders are involved in developing the scenarios. Although long time horizons combined with a high spatial resolution increases uncertainties, this approach allows for generating more detailed and localized scenarios for potential future development.

For our study areas there exist a set of scenarios developed in 2007 by *Trøndelagsrådet*, a committee responsible for coordinating policies and activities in the counties of Nord-Trøndelag and Sør-Trøndelag. Later, the two neighbouring municipalities, Levanger and Verdal, developed more localized interpretations of the scenarios. The scenarios are outlined in three storylines that we use to outline alternative paths of development regarding settlement patterns, the transport network, and agricultural and industrial development in Verdal (Innherred-Samkommune n.d.).

We link the three scenarios to three different population projections for Norwegian municipalities up until 2100. These projections have been prepared by Statistics Norway and are based on a set of assumptions regarding total fertility rates, life expectancies, immigration rates, and inland mobility patterns (Brunborg & Texmon 2009). The outcomes for Verdal vary substantially, with estimates ranging from a slight decline from the present population of c.14,000 to 12,725, to a doubling of the present population to 29,058.

Population change is in an indicator of both exposure and vulnerability. A growth in absolute numbers means that more people might be exposed to a hazard, while a decline indicates that fewer people would be exposed. Population growth due to immigration would also contribute to increased vulnerability, as immigrants are considered more vulnerable than other groups. Increased population density, which in most cases implies urbanization, will contribute to vulnerability. Lower population density can also contribute to vulnerability, as scattered population may be difficult to reach in emergency situations. Rapid growth may also imply a population with small children, which may contribute to increased vulnerability, whereas a population decline would indicate an aging population, which also would contribute to increased vulnerability.

Table 6 presents some rough indicators of basic units likely to be become more vulnerable in the future given different paths of social and economic development. The Table shows that the patterns of future vulnerability to climate change to a large extent will be dependent on future social and economic development. This means that the need for local-level climate change adaptation in the coming decades will probably depend as much future social and economic development as on climate change itself. If expansion of industry and settlement is located according to scenarios 2 and 3 in table 6 , more people and potentially more vulnerable people (i.e. young, elderly, immigrants) would be settled in areas identified as highly vulnerable to future storm surges and river flooding at present and even more in the future. If the settlement pattern develops as in scenario 1, fewer people would be exposed under present and future climate conditions in the study area. However, the more remote areas (basic units outside our study area) can become more vulnerable due to an aging and dispersed population.

TABLE 6 ABOUT HERE

To what extent Verdal will be susceptible to harm from future climate change induced floods, storm surges, and sea level rise will depend on what kind of general economic and social development the community experiences in the future. Different types of development produce different vulnerability patterns. In addition, the ability of the community and the municipality authorities to undertake climate change adaptation measures is a factor. To date, some location-specific measures have been put in place. For instance a recently added local building code requires that all new residential housing in low-lying areas must have a ground floor set at a minimum height of 4.75 a.s.l.. No basements or parking floors are allowed below this height.

Concluding remarks

In this article we have extended the 'hazard of place' model, originally developed by Cutter (1996) and Cutter et al. (1997; 2000), to include the future in order to uncover how climate change induced consequences can be taken into account in such a model. Our study measures exposure to river and surge flooding and sea level rise in the Norwegian small town of Verdal.

The applied method also included an assessment of social vulnerability for the study area. Assessments of exposure as well as social vulnerability were then integrated into one index, the *Integrated Vulnerability Index*. The results of the analysis show that there are considerable differences across the study area regarding which units will experience the largest increases in vulnerability.

Obviously, our approach has some weaknesses, which future research should address. The choice of exposure variables is based on readily available data and could be further refined to reflect “hotspots” such as care homes for elderly, schools, daycare centres for children, or locations for critical infrastructure. Similarly, the social vulnerability index reflects the available data and may thus exclude relevant aspects for measuring it. A related aspect is that of weighting when compiling the exposure, social vulnerability, and integrated vulnerability indices. Different weighting schemes do affect the index scores and could thus have impact on the relative ranking of the basic units.

A further issue is our inability to come with quantitative social vulnerability index for the future. This is due to lack of projected socioeconomic data in general, and in particular for sub-municipality units. How to compensate for this lack of data for social and economic development is, in our opinion, one of the most important issues for future research.

With regard to our exposure index, a logical next step would be to develop this to an index for physical vulnerability. Such an index would not only take into account whether the infrastructure, buildings, or land are in the risk of being flooded, but it would also convey how vulnerable these would be for damage should such an event occur.

In this article, we have applied the approach to sea level rise, storm surge, and river flooding and thus demonstrated that the approach allows for accounting for multiple hazards. A more comprehensive multihazard model would also account for other types of hazards. In the case of Verdal, a relevant hazard to include could be quick clay slides, and in other study areas the approach can accommodate relevant natural and manmade hazards.

By improving our understanding of climate change and consequent impacts on physical and socio-economic structures in societies, vulnerability assessments such as the one presented in this article contribute to planning at the local level and thus strengthen the adaptive capacities of local societies. As pointed out by Tate et al. (2010), preparedness is vital in order to reduce loss. To enable authorities to make proactive efforts, vulnerability mapping incorporating multi-hazards as well as socio-economic variables is crucial.

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[1] The actual weighting for Eq. 2-4 is discussed in the section «Quantification of Vulnerability Indices for Verdal».

[2] For a more detailed account of factor analysis see, for example, Goldberg & Velicer (2006).

[3] For more information and the existing flood-zone data for Verdal, please refer to Norwegian Water Resources and Energy Directorate (2009a, b).

[4] We use the shortened form 'basic unit' for basic statistical unit in this paper.

[5] The tables in this article include all necessary raw data for calculations of EI and SoVI. This enables other researchers to try other weighting schemes to see how they affect results.

[6] An alternative would be to weight the individual variables included in the index instead of conducting factor analysis. The weights could be based on expert evaluations or surveys, for example, but this type of subjective weighting is at the moment undertheorized and not fully developed. Factor analysis is considered an empirically objective method to such weight selection (Jones & Andrey 2007).

[7] Information on historical development in Verdal was obtained from Rudolf Holmvik, former chief officer at Verdal Municipality, 19 October 2010.

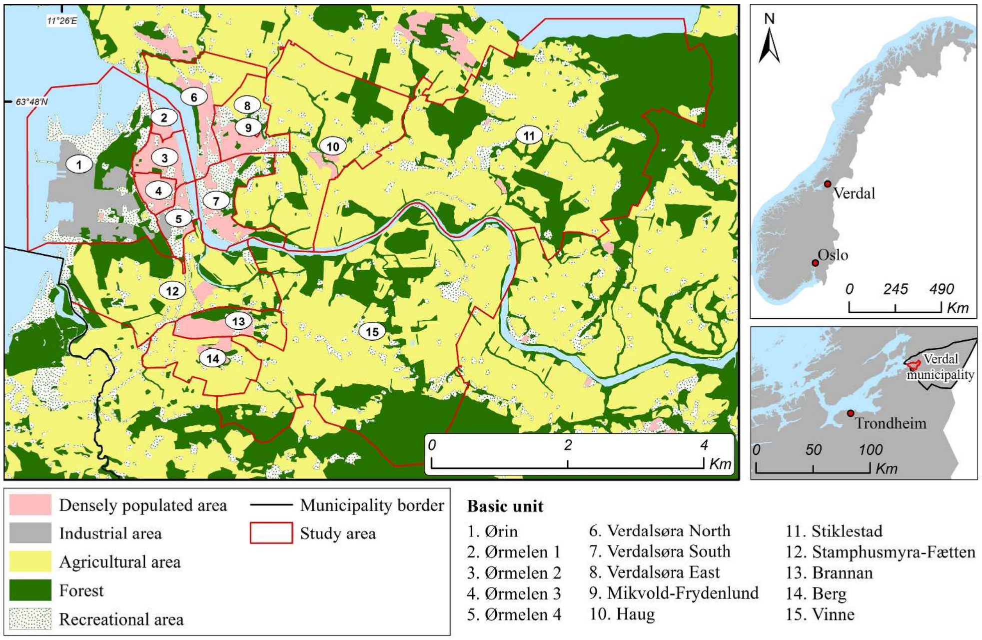

Fig. 1 Study area, basic units, and land use in the study area in Verdal Municipality
150x95mm (600 x 600 DPI)

1. Physical assessment (EI)

- Identify the hazards that are most relevant to the study area and acquire data on selected natural hazards
- Calculate exposure to hazards for the selected hazard variables within the study units
- Standardize the hazard exposure measures so that they are comparable
- Construct an exposure score based on the exposure data – one for EI Present and one for EI Future
- Map an exposure index to illustrate the spatial distribution of exposure in the study area

2. Social assessment (SoVI)

- Identify aspects that make people vulnerable to hazards
- Use factor analysis to generate a SoVI
- Standardize the SoVI scores
- Map a social vulnerability index

3. Integrated vulnerability (IntVI)

- Combine the physical and social vulnerability indexes into one composite index (Integrated Vulnerability Index, IntVI); this is done for both present (IntVI Present) and future (IntVI Future)
- Analyse the results by mapping the variation in IntVI across the study area
- Analyse the SoVI and EI to gain an understanding of what constitutes total vulnerability

Fig. 2 Step-by-step procedure for an overall vulnerability assessment

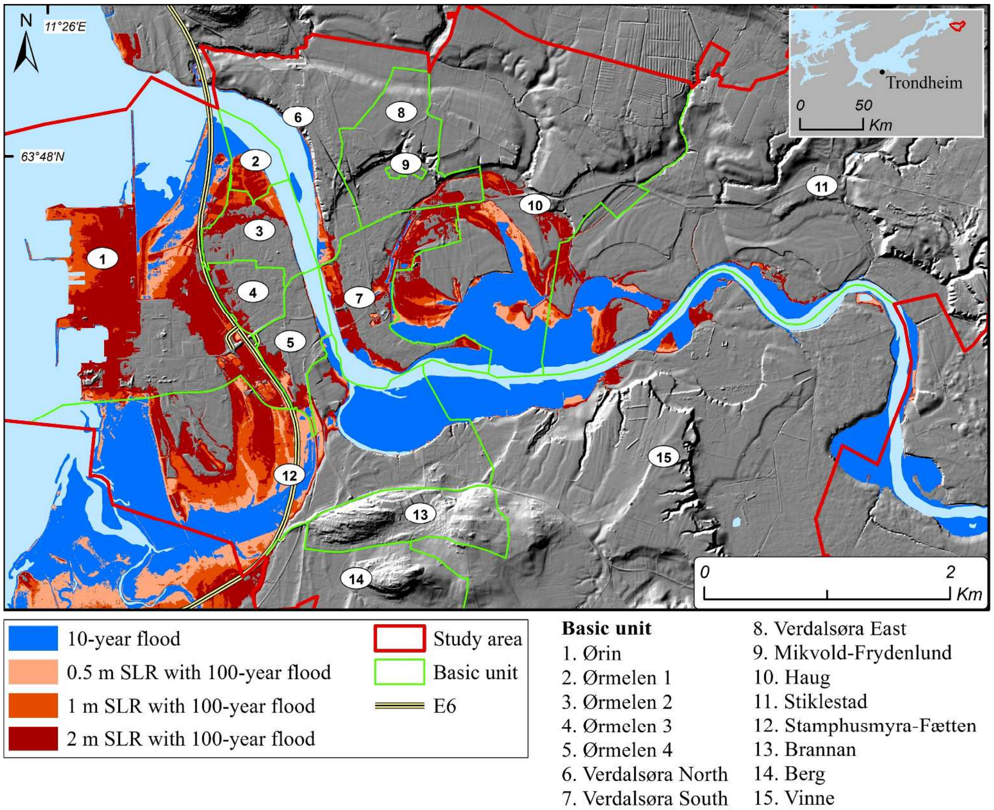

Fig. 3 Flood zones in the Verdal delta; the 10-year flood used in EI Present is shown in blue, and sea level rise (SLR) scenarios with 100-year storm surge and river floods used in EI Future are shown in different shades of red
165x136mm (600 x 600 DPI)

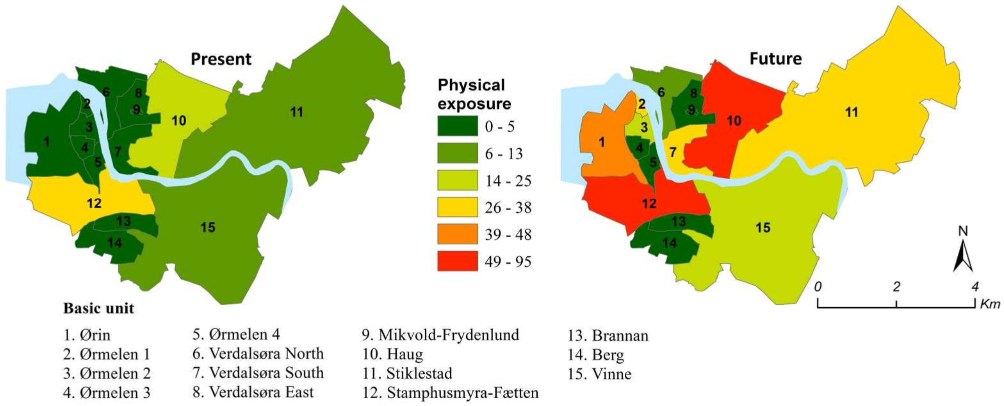

Fig. 4 Exposure Index for the study area for present and future (EI Present and Future).
108x46mm (600 x 600 DPI)

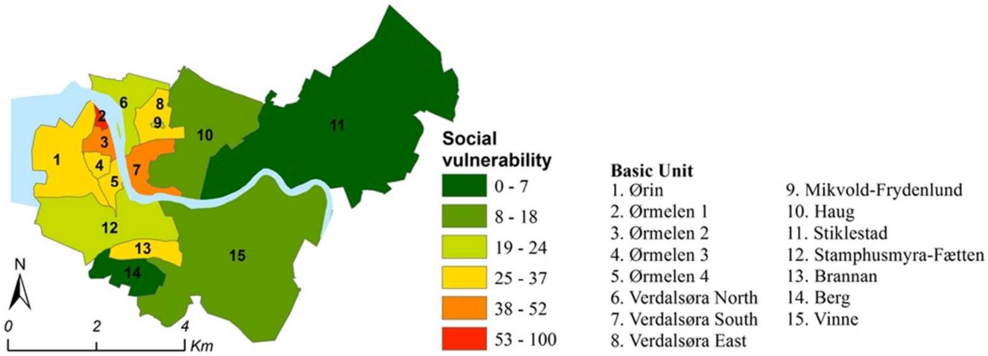

Fig. 5 The Social Vulnerability Index (SoVI) for the study area
83x30mm (300 x 300 DPI)

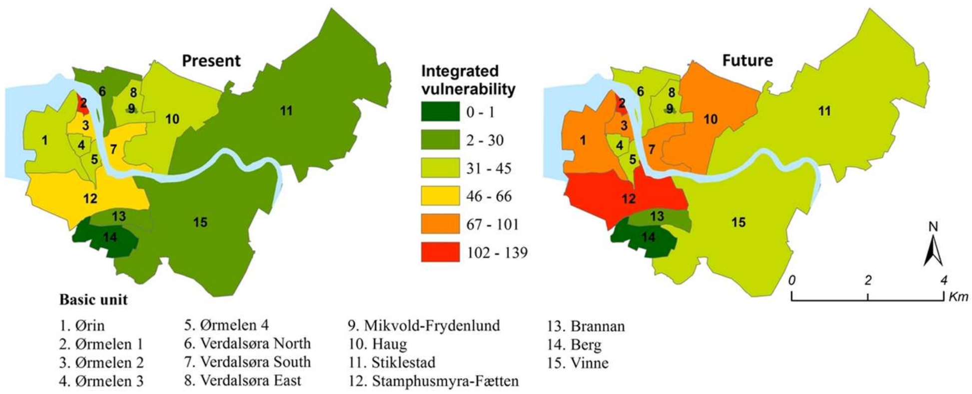

Fig. 6 Integrated vulnerability of the study area both at present and in the future
111x47mm (300 x 300 DPI)

Table 1. Basic statistics for the study area

		Population size	Total land area (m^2)	Number of buildings	Length of transport network (m)	Cultivated, densely populated or industrial area (m^2)
1	Ørin	12	2,272,746	285	30,849	1,032,057
2	Ørmelen 1	351	116,232	147	1729	80,457
3	Ørmelen 2	892	382,484	601	7473	303,170
4	Ørmelen 3	659	271,423	417	6258	208,324
5	Ørmelen 4	236	352,030	190	7634	125,844
6	Verdalsøra North	934	1,112,359	585	11,789	854,317
7	Verdalsøra South	1328	854,098	648	20,296	296,407
8	Verdalsøra East	867	809,379	546	10,953	485,905
9	Mikvold-Frydenlund	181	33,561	50	405	23,926
10	Haug	466	3,849,967	438	18,371	2,893,027
11	Stiklestad	527	11,157,975	584	38,408	6,083,713
12	Stamphusmyra-Fætten	297	3,029,566	382	18,984	1,608,977
13	Brannan	879	678,185	540	9737	432,187
14	Berg	453	1,066,239	281	8193	938,674
15	Vinne	247	9,498,294	305	30,579	5,746,288
	Totals	**8329**	**35,484,539**	**5999**	**221,660**	**21,113,273**

Table 2. Consequences of flooding for buildings, transport network, and cultivated, densely populated, and industrial land caused by a 10-year surge and river flooding (for the present) and by a 100-year surge and river flooding and 1 m sea level rise (for the future)

		Building		**Transport network (m)**		**Cultivated, densely populated or industrial land (m^2)**	
		At present	Increased flooding	At present	Increased flooding	At present	Increased flooding
1	Ørin	6 (2%)	78 (27%)	663 (2%)	6390 (21%)	3905 (0%)	273,915 (27%)
2	Ørmelen 1	0 (0%)	136 (93%)	440 (25%)	1729 (100%)	688 (1%)	75,752 (94%)
3	Ørmelen 2	10 (2%)	75 (12%)	43 (1%)	1686 (23%)	1931 (1%)	46,031 (15%)
4	Ørmelen 3	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	4 (0%)
5	Ørmelen 4	7 (4%)	12 (6%)	168 (2%)	761 (10%)	63 (0%)	10,690 (8%)
6	Verdalsøra North	6 (1%)	31 (5%)	42 (0%)	596 (5%)	1253 (0%)	16,404 (2%)
7	Verdalsøra South	15 (2%)	109 (17%)	466 (2%)	4153 (20%)	2758 (1%)	51,218 (17%)
8	Verdalsøra East	1 (0%)	3 (1%)	0 (0%)	115 (1%)	97 (0%)	3011 (1%)
9	Mikvold-Frydenlund	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
10	Haug	4 (1%)	102 (23%)	787 (4%)	3466 (19%)	306,046 (11%)	730,465 (25%)
11	Stiklestad	0 (0%)	3 (1%)	792 (2%)	2224 (6%)	155,917 (3%)	425,046 (7%)
12	Stamphusmyra-Fætten	29 (8%)	115 (30%)	2686 (14%)	8064 (42%)	351,255 (22%)	903,125 (56%)
13	Brannan	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
14	Berg	0 (0%)	3 (1%)	0 (0%)	57 (1%)	1 (0%)	721 (0%)
15	Vinne	4 (1%)	4 (1%)	712 (2%)	1433 (5%)	194,524 (3%)	363,777 (6%)
	Totals	**82** (1%)	**673** (11%)	**6799** (3%)	**30,675** (14%)	**1,018,440** (5%)	**2,900,159** (14%)

Table 3. The SoVI, EI, and IntVI scores for present day and future

		EI Present	EI Future	SoVI	IntVI Present	IntVI Future
1	Ørin	3	48	31	35	80
2	Ørmelen 1	1	38	100	101	138
3	Ørmelen 2	3	24	43	46	67
4	Ørmelen 3	0	0	37	37	37
5	Ørmelen 4	2	5	35	37	41
6	Verdalsøra North	1	9	23	24	32
7	Verdalsøra South	5	37	52	56	89
8	Verdalsøra East	0	1	32	32	33
9	Mikvold-Frydenlund	0	0	23	23	23
10	Haug	20	72	18	38	90
11	Stiklestad	11	30	7	18	37
12	Stamphusmyra-Fætten	33	95	24	56	119
13	Brannan	0	0	30	30	30
14	Berg	0	1	0	0	1
15	Vinne	13	25	15	28	39

Table 4. Variables, variable definitions, and variables' effect on social vulnerability (data source and definitions: Statistics Norway); the analysis used data for 1248 basic units; to ensure anonymity, only basic units with more than 50 inhabitants were included in the analysis

Variable	Definition	Effect on vulnerability	
Capital assets (NOK)	Median pre-tax assets for persons 17 years and older, 2008	–	Income and wealth are among the most common indicators used to measure social vulnerability. When seeking shelter, and in the reconstruction phase, access to financial resources is important, especially if public provisions emergency services, reconstruction, and compensation are inadequate or delayed. Therefore, people with high income and assets would be less vulnerable (Morrow 1999; Cutter et al. 2003).
Income (NOK)	Median pre-tax income for persons 17 years and older, 2008		
Labour participation (%)	Proportion of population active in the labour force (21–67 years), 2009	–	People that work tend to have higher incomes, larger social networks, and better health. Those with 'safe' public jobs have relatively better job security in times of crisis (Cutter et al. 2003)
Secure job (%)	Proportion of labour force (21–67 years) employed in public and social security administration and by municipality and county, 2009		
Migration (%)	Migration to the basic unit (in Norway) during the period 1999–2008, % of total population in 2009	+	In general terms, non-Western immigrants have less connection with local communities, smaller and narrower social networks, and may need extra assistance in a crisis situation, due to language barriers. To a certain extent, this also applies to migrants from other basic units in Norway. In addition, the rapidly increasing population puts pressure on local services such as day care and health (Morrow 1999; Cutter et al. 2003).
Immigration (%)	Non-Western first- and second-generation immigrants, % of total population, 2009		
Primary sector (%)	Proportion of labour force (21–67 years) employed in primary sector, 2009	+	Primary industries are vulnerable to climate-related disasters, due to the negative impact on agriculture, forestry, and mining (Cutter et al. 2003).
Single-parent households (%)	Proportion of single-parent households, 2009	+	Child care is a critical activity during a crisis and the resources available to a household are affected by the number of parents. Therefore, social vulnerability increased for basic units with many single-parent headed households (Fothergill 1996; Cutter et al. 2003; Heinz Center for Science Economics and the Environment 2000).
Mortality rate (log)*	Mortality per 1000, accumulated over the period 1999–2008	+	High mortality reflects the age structure, but is also associated with poorer health and lower income (Elstad et al. 2006).

Note: * 10 basic units had unexplainably high mortality rates. These were replaced by average rate for the neighbouring basic units. In addition, we took logarithmic transformation of the values to decrease the impact of high values on the results

Table 5. Factor loadings; the table shows the results of Principal Components Factoring (PCF) analysis with Varimax rotation and Horst normalization; the analysis is based on 1248 Norwegian basic units and 9 variables; sign adjustment: negative (−) or positive (+)

	Factor 1	**Factor 2**	**Factor 3**	**Sign**
Primary sector	−			
Income	+			−
‘Secure’ job	+			
Labour participation	+			
Capital assets		−		
Migration		+		+
Immigration		+		
Single-parent households			+	+
Mortality			+	
Total variation explained by the factor	0.26	0.25	0.14	

Table 6. Socioeconomic scenarios for Verdal for 2100 with an estimate of possible impacts on study areas basic units

Scenario	Population growth	Industry and agriculture	Settlement	Infrastructure	Implications for vulnerability	Areas likely to become more/ less vulnerable	Basic units in study area
1 Forever Green	Decline (c.12,000)	• Tourism • Ecological agriculture	Scattered (passive houses)	• 'Green' • Developed public transportation system	• Scattered and aging populations may be difficult to reach in cases of emergency	÷ All areas in general + possibly increased vulnerability in more remote areas	All reduced vulnerability
2 Forever Young	Increase (c. 20,000)	• Young entrepreneurs • Local production	High density in centrally located areas	• Based on public transportation	• More people in high-density settlements along the rivers • Increased immigration	+ in established settlements	Ørmelen 2–4, Verdalsøra North, South and East
3 Forever Growth	Rapid Growth (c.30,000)	• Industrial growth • Industrial farming	Density increases in established areas, on waterfronts, and along transport routes	• Express trains • Four-lane highways	• More people living in exposed areas and more people living along waterfronts • Potential for higher economic losses in industry and agriculture	+ In general ++ Areas along rivers and waterfronts	All increased vulnerability, especially in Ørin, Ørmelen 1−4, Verdalsøra North and South, Haug, and Stamphusmyra-Fætten

Appendix 1. Densely populated, cultivated, and industrial land inundated at present by a 10-year surge and river flooding and projected to be inundated in the future by 100-year surge and river flooding and 1 m sea level rise; note that only basic units that have areal with the specific land use type are included

A. Total densely populated area inundated by flooding (m^2)

		Total densely populated area	At present		Increased flooding	
1	Ørin	422	0	(0%)	64	(15%)
2	Ørmelen 1	80,457	688	(1%)	75,752	(94%)
3	Ørmelen 2	303,170	1931	(1%)	46,031	(15%)
4	Ørmelen 3	208,324	0	(0%)	4	(0%)
5	Ørmelen 4	77,046	0	(0%)	0	(0%)
6	Verdalsøra North	301,064	1253	(0%)	16,404	(5%)
7	Verdalsøra South	247,596	2294	(1%)	33,152	(13%)
8	Verdalsøra East	226,109	90	(0%)	1214	(1%)
9	Mikvold-Frydenlund	23,926	0	(0%)	0	(0%)
10	Haug	75,202	20	(0%)	26,227	(35%)
11	Stiklestad	17,543	0	(0%)	129	(1%)
12	Stamphusmyra-Fætten	65,407	0	(0%)	0	(0%)
13	Brannan	288,573	0	(0%)	0	(0%)
14	Berg	110,322	0	(0%)	0	(0%)
	Total	2,025,161	6276	(0%)	198 976	(10%)

B. Total cultivated area inundated by flooding (m^2)

		Total cultivated area	At present		Increased flooding	
1	Ørin	7303	87	(1%)	2294	(31%)
5	Ørmelen 4	440	0	(0%)	2	(0%)
6	Verdalsøra North	553,253	0	(0%)	0	(0%)
7	Verdalsøra South	48,811	464	(1%)	18,066	(37%)
8	Verdalsøra East	259,796	7	(0%)	1,797	(1%)
10	Haug	2,817,825	306,026	(11%)	704,238	(25%)
11	Stiklestad	6,066,170	155,917	(3%)	424,917	(7%)
12	Stamphusmyra-Fætten	1,543,570	351,255	(23%)	903,125	(59%)
13	Brannan	143,614	0	(0%)	0	(0%)
14	Berg	828,352	1	(0%)	721	(0%)
15	Vinne	5,746,288	194,524	(3%)	363,777	(6%)
	Total	18,015,422	1,008,282	(6%)	2,418,937	(13%)

C. Total industrial land inundated by flooding (m^2)

		Total industrial land	At present		Increased flooding	
1	Ørin	1,024,333	3819	(0%)	271,558	(27%)
5	Ørmelen 4	48,357	63	(0%)	10,688	(22%)
	Total	1,072,690	3882	(0%)	282,246	(26%)

Appendix 2. Descriptive statistics related to the variables included in the SoVI model

	Whole sample					Study area				
Variable	**#**	**Mean**	**Std. Dev**	**Min**	**Max**	**#**	**Mean**	**Std. Dev**	**Min**	**Max**
Capital assets (NOK)	1248	41,114	69,562	-496,885	403,596	14	28,346	28,085	-10,435	90,386
Migration (%)	1248	107.8	78.9	8.4	601.8	14	128.8	48.3	65.7	249.9
Immigration (%)	1248	2.6	4.3	0.0	54.9	14	3.8	5.5	0.0	21.4
Primary sector (%)	1248	4.3	5.6	0.0	38.7	14	1.9	2.0	0.0	7.0
Income (NOK)	1248	286,878	43,954	15,198	429,987	14	275,006	34,162	219,090	341,310
'Secure' job (%)	1248	9.8	6.6	0.0	38.0	14	8.6	3.2	2.1	13.8
Labour participation (%)	1248	78.7	9.3	12.5	103.7	14	76.3	8.2	58.3	90.5
Single-parent households (%)	1248	5.0	3.1	0.0	16.7	14	6.9	2.7	1.9	13.3
Mortality rate	1248	27.3	32.1	0.0	235.0	14	26.4	15.5	0.0	59.0