Four core activities towards a relevant vulnerability assessment: Integrate, validate, visualize, and negotiate.

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Four core activities towards a relevant vulnerability assessment: Integrate, validate, visualize, and negotiate.

The future climate in the Nordic countries is expected to become "warmer, wetter, and wilder", and it is anticipated that this will cause more extreme weather events. Therefore, local authorities need to increase their ability to assess weather-related hazards such as floods, landslides, and storms, as well as people's sensitivity and capacity to cope with or adjust to such events. In this article, we present an integrated assessment of vulnerability to natural hazards, which incorporates both exposure and social vulnerability. An increased frequency and intensity of extreme weather events may make local societies more exposed, but how these societies will change in the future may increase or decrease their vulnerability to extreme weather events. In our assessment, we screen places and rank them by their relative scores on exposure and vulnerability indices. We also design a web-based visualization tool - ViewExposed - which shows maps that reveal a considerable geographic variation in integrated vulnerability. ViewExposed makes it easy to identify the places with the highest integrated vulnerability, and it facilitates the understanding of the factors that make these places exposed and/or vulnerable. As empirical validation, we correlate the exposure indices with insurance claims due to natural damage. However, we also emphasize a dialogue with relevant stakeholders to ensure a participatory validation. Our top-down exposure and vulnerability assessment benefits from a participatory bottom-up assessment, which is crucial for such an assessment to be used to support decisions on where necessary adaptive and preventive measures to climate-change-related hazards should be carried out.

Keywords: climate-change adaptation; exposure; integrated vulnerability assessment; geovisualization; participatory GIS

Introduction

Climate change is *likely* to *very likely* to lead to an increase in intensity and frequency of weather extremes (IPCC 2007). Several Norwegian municipalities may therefore become more exposed to weather extremes in the future. Although Norway is generally considered to be resilient to the negative impacts of climate change (O'Brien, Sygna and Haugen 2004), there is a considerable geographical variation in the level of exposure and vulnerability to extreme events in Norwegian municipalities. To be able to develop strategic plans for adaptation, we believe it is important to identify the most exposed and vulnerable municipalities, and to understand why these municipalities are exposed and/or vulnerable. Assessments of exposure and vulnerability are therefore needed, and the title of this article reflects what we consider to be four essential activities for good practice for such assessments. We draw on previous work for the vulnerability assessment, but combine it with assessments of exposure to create an integrated vulnerability index. Secondly, we validate the assessments using historical damage data. Thirdly, we develop visualization tools facilitating a participatory approach to integrated vulnerability assessments. A fourth activity is to continuously be in dialogue with stakeholders, who may have a different perception on exposure and vulnerability, to ensure that the assessment is perceived as relevant and correct.

These activities are part of a larger research topic on how the results from a screening of exposure and vulnerability can stimulate a debate on the reliability and relevance of such assessments. A reliable assessment of exposure and vulnerability could be used to support decision-making on where necessary adaptive and preventive measures to climate-change-related hazards should be carried out. However, this potential relies both on the scientific credibility of the assessments and on their societal relevance. In an attempt to increase the scientific credibility of our assessments, we validate the indices on exposure by using historical insurance claims to cover damages on buildings caused by floods, landslides, and storms during the period from 1980 to 2010. In order to increase the societal credibility of our exposure and vulnerability assessment, we follow Hinkel (2011) and Næss et al. (2006) suggestion that top-down approaches should form the basis for participatory vulnerability assessments.

The article proceeds as follows. First, we provide a short definition of the concepts of exposure and vulnerability before we present the framework for the integrated vulnerability assessment for Norway at the municipality level. We continue to outline how we construct indices of exposure to weather-related extreme events. The novel part of this research is to use historical data on insurance claims due to floods, landslides, and storms to validate the exposure indices as well as to decide weights for their relative importance. We further present a prototype for a visualization tool from which our top-down assessment will be disseminated. We also discuss how such a visualization tool could facilitate a dialogue with relevant stakeholders and how stakeholder participation and bottom-up assessment can improve our top-down vulnerability assessments.

Exposure and vulnerability

The 2012 Intergovernmental Panel on Climate Change (IPCC) report on climate-change-related extreme events and disasters defines 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, 32).

For our assessment of exposure, we count the relative number of assets (or elements at risk) situated inside a hazard zone for a physical event. As elements at risk, we use address points, that is, where people either live, work, or study. As physical events, we include floods, landslides, and storms. We either use existing hazard zones or generate new hazard zones for the impact of such events.

The impact that physical events may have on humans depends not only on hazard exposure but also on the sensitivity and adaptive capacity of local communities, i.e., their ability to anticipate, cope with, resist, and recover from an impact (Wisner et al. 2004). In a recent report on managing the risk of extreme events and disasters to advance climate-change adaptation, IPCC adopts the following definition by Wisner et al.:

> Vulnerability is defined … 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, 32).

In this article, we follow the above IPCC definition on vulnerability, which deviates from the one used in the Fourth Assessment Report (IPCC 2007), and use the characteristics of municipalities and their inhabitants as the basis for the vulnerability indices. According to Cutter, Boruff, and Shirley (2003), Greiving, Fleischhauer, and Lückenkötter (2006), and several other authors, a comprehensive vulnerability assessment needs to combine information on an area's physical exposure with its demographic and socioeconomic conditions. Our study is a contribution to this growing body of literature on integrated approaches to vulnerability assessment. We include three different measures on exposure and combine them with two measures on vulnerability into what we call an integrated vulnerability index (IntVI).

The integrated-vulnerability-assessment framework

To measure how Norwegian municipalities are exposed to climate-induced natural hazards, we first combine three types of exposure indices, which we then combine with two types of vulnerability indices. As illustrated in Figure 1, the exposure indices are combined with the vulnerability indices and finally merged into an integrated vulnerability index (IntVI).

FIGURE 1 HERE

IntVI expresses Norwegian municipalities' exposure and vulnerability to climate-related extreme events. In recent years, such assessments have been prepared for areas in the USA (Tate, Cutter, and Berry 2010), as well as for Germany (Fekete, Damm, and Birkmann 2010) and Austria (Kienberger, Lang, and Zeil 2009). The methods for designing the vulnerability indices somewhat vary; but among the most established, widespread, and well-documented indices are those developed by Susan Cutter and colleagues (Borden et al. 2007; Cutter 1996; Cutter, Mitchell, and Scott 2000; Tate, Cutter, and Berry 2010). We therefore use their methodological framework for our integrated vulnerability assessment for Norway, which is constituted of four major steps:

1. Create exposure indices for flood (EIF), landslide (EIL), and storm (EIS).
2. Combine each type of hazard exposure indices into a common exposure index (EI).
3. Assess vulnerability and create indices for socioeconomic vulnerability (SeVI) and built-environment vulnerability (BEVI).
4. Integrate physical vulnerability and social vulnerability to create an integrated vulnerability index (IntVI).

We do not consider the vulnerability for particular sectors such as agriculture or winter-sport industries but assess vulnerability in a general sense. As demonstrated by Tate et al. (2010), using a general framework for vulnerability assessment makes it possible to include assessments for other types of hazards whenever hazard zones for these are available.

Measuring hazard exposure

We measure exposure to extreme events by identifying the elements at risk that are within a zone of impact relative to elements found in the entire unit area. As demonstrated in Figure 2, elements at risk may be buildings, roads or other infrastructure, and agricultural land or other land-use categories. On a map, these will typically be represented as points, lines, and polygons, respectively. The unit area could be a county, a municipality, a lower administrative unit, or any other area division.

FIGURE 2 HERE

Our assessments of exposure to floods and landslides are based on existing flood hazard maps and the inventory of historical landslide events, respectively. To assess exposure to storm, we use a wind atlas showing the average number of storm hours. We have performed a similar assessment for the ward level in the Trøndelag region in previous studies (Rød et al. 2012); in this study, we assess the entire country of Norway at the municipality level. The municipality level is chosen because we have data on the number of insurance claims due to natural damage aggregated to the municipality level for the period from 1980 to 2010. We use these data to validate our measures on hazard exposure.

Flood exposure

The starting point for the Exposure Index for Flood (EIF) is the flood-inundation maps produced by the Norwegian Water Resources and Energy Directorate (NVE). These have been created for relatively large rivers in Norway that have a high damage potential and are bordered by extensive floodplains with settlements. Steep, tributary catchments have so far not been mapped. However, such areas can by affected by local flooding following intense precipitation events. The flood-zone maps cover different return intervals, and up to six intervals are mapped for Norwegian municipalities (10, 20, 50, 100, 200, and 500 years). We have chosen to leave out the 500-year return interval floods because of their uncertain statistical basis.

Municipalities are required to include a separate risk and vulnerability assessment as part of land-use planning, including a municipality master plan, zoning plan, and building-development plan (Miljøverndepartementet 2009). For example, dwellings, second homes, offices and industrial buildings, agricultural buildings, and schools should not be located or constructed in a manner making them prone to property damage caused by a 200-year flood. We identify that there are about 7300 buildings in Norway which may be exposed to a 200-year flood, an estimate which is slightly lower than that of a recent white paper (Meld.St.33 2012-2013).

We calculate EIF by counting the number of address points located within the different inundation zones, multiply this number by the relevant probability (e.g., 1/200 for a 200-year flood), and divide the result by the total number of address points located within the municipality. Finally, we sum together all elements. A generic expression for the calculation of the EIF is given in Formula 1 below,

$$EIF = \sum_{i=1}^{5} \frac{AP_i - AP_{i-1}}{AP_{mun}} \times \frac{1}{n} \qquad (1)$$

where AP_i is the number of address points situated inside the flood-inundation zone with return interval n. Because an address point located within a 10-year inundation zone also is situated within the other inundation zones, we only count the added number of address points falling within the inundation zone for the next return interval. AP_{i-1} represents the number of address points within the flood zone of the previous return interval, and the expression $AP_i - AP_{i-1}$ thus represents the increase of address points from one return interval to the next. AP_{mun} is the number of address points per municipality. The values for i and n are provided by the table below (for instance, when $i = 2$, $n = 20$).

i	1	2	3	4	5
n	10	20	50	100	200

NVE has completed flood-inundation mapping for only 131 of the 430 municipalities in Norway.[i] Consequently, there are 299 municipalities that have a score zero on EIF (because of no flood-inundation mapping). We are aware of this shortcoming in our flood-exposure assessment; as long as the national flood-inundation mapping is incomplete, any exposure assessment based on such maps will also remain incomplete.

Landslide exposure

We use the generic term landslide to cover all gravitational mass movements observed in Norway (clay slides, quick clay slides, mudflows, other landslides, rock slides, snow avalanches, ice falls, and subaqueous slides). For the authorities and inhabitants of endangered areas, the type of threat is of minor importance, and mitigation measures have to consider several types of rapid mass movements simultaneously (Jaedicke et al. 2008). Therefore, to generate the Exposure Index for Landslides (EIL), we use the historical landslide inventory from NVE, which includes all kinds of rapid mass movements. Each landslide event is registered as an independent occurrence and is identified by type, date, and coordinates. The database includes landslides registered by the Norwegian Public Roads Administration (NPRA), the Norwegian National Rail Administration (NNRA), the Norwegian Geotechnical Institute (NGI), and the Norwegian Geological Survey (NGU). A total of 95% of the landslides registered by NPRA occurred after the year 1983, which implies a lack of temporal homogeneity. Registrations from NNRA show a similar temporal inhomogeneity. Besides, because we are not primarily interested in measuring how infrastructure is exposed to landslides, we exclude the landslides registered by NPRA and NNRA. Fortunately, the registrations coded by NGI and NGU cover a longer time span: 95% of the events included happened after the year 1650, and the median year for the subset is 1875. For the subset of landslides used in our assessment, we have therefore only included landslide events that happened in 1650 or later and are registered by NGU or NGI.

In order to generate a hazard zone for landslide-prone areas, we generate buffer zones around the locations for the historical landslide events. Thereafter, for each municipality, we count the number of address points (AP) within the hazard zone relative to the total number of address points within the municipality. The EIL is then calculated as shown in Formula 2 below,

$$EIL = \frac{AP_{zone}}{AP_{mun}} \tag{2}$$

where AP_{zone} is the number of address points within the landslide hazard zone, and AP_{mun} is the number of address points within the municipality. We calculated the EIL for several buffer zones ranging from 40 to 2000 meters and correlated it with data on compensation claims from the Norwegian Natural Perils Pool. The 80-meter buffer zone yielded the highest correlation; consequently, this buffer size was used to generate the landslide hazard zone.

Wind exposure

A temperature increase will bring more energy to the atmosphere, which may increase the pressure differences. As a result, winds may become stronger. Scenarios for changes in wind speed in Norway are, however, associated with more uncertainties than changes in temperature and precipitation (Førland, Amundsen, and Hovelsrud 2007). Extreme wind velocities causing damage are of short duration (often only from ten minutes to few hours) and are thus difficult to foresee. The temporal resolution used in regional climate models is still too coarse for the models to simulate strong winds (Aall and Norland 2005). Nevertheless, the Norwegian Directorate for Civil Protection and Emergency Planning (DSB) estimates that it is very likely that events similar to the New Year's Day Storm in 1992 and the storm Gudrun in 2005 will happen again within a 100-year period (DSB 2011). We claim, therefore, that it is essential to identify the most wind-exposed places. Because there are no hazard maps showing wind-exposed places corresponding with flood-inundation maps, we use a dataset on average hours of wind speeds above storm's magnitude (that is, more than

20.8 meter per second). This dataset is compiled by Kjeller Vindteknikk (Kravik 2012) and is a raster-based GIS readable dataset with a 1-km spatial resolution. Thus, for each square kilometer of Norway, they have modeled the amount of time during which the wind speed exceeded storm's magnitude and averaged it over the entire period (from 2000 until 2011). We realize that this is a very short time period, but it is – to our knowledge – the best available storm data that exist for Norway.

By using this dataset in combination with the point locations for address points, we assign the average wind-speed hours with storm's magnitude to all address points (AP). We calculate the Exposure Index for Storms (EIS), for each municipality, by taking the sum of storm hours at the address-point locations ($\overline{V}_{AP}$) divided by the sum of storm hours at all pixel locations located within the same municipality ($\overline{V}_{mun}$). (See Formula 3)

$$EIS = \frac{\overline{V}_{AP}}{\overline{V}_{mun}} \tag{3}$$

Validation

Generally, Norway is considered resilient to the negative effects of climate change and is thus able to adapt to new conditions (O'Brien, Sygna, and Haugen 2004). An important reason for this capacity is the Norwegian Natural Perils Pool, which aims to compensate damages and losses caused by natural perils. In Norway, all buildings that have a fire insurance are by law also automatically insured against natural damage caused by flood, landslide, storm, and storm surge. The arrangement is administered by the Norwegian Natural Perils Pool: all insurance companies that insure properties in Norway are members of this organization. The insurance premium is currently 0.07 per thousand of the fire-insurance amount and is the same for everyone, independently of location and insurance company.[ii]

To control how well the indices for exposure reflect reality, we correlate the indices with the corresponding compensation claims from the perils pool. Thus, for instance, we correlate our EIL with the number per address point of compensation claims to cover damages caused by landslides during the entire period (from 1980 to 2010, see Figure 3B). Because insurance payments cover damages on building properties and we have used address points when constructing the indices, we believe this to be an appropriate method for validation. As administrative division, we use in the correlations the municipalities as they were in 2010, that is, 430 units. Figure 3 shows the results of correlating the peril compensation claims with the corresponding exposures. As shown, the exposure indices for landslides and storms are quite strong, whereas the exposure index for floods is weak.

FIGURE 3 HERE

Comprehensive hazard exposure

The simple idea behind comprehensive hazard exposure is to combine different types of natural hazards in the evaluation instead of assessing these threats individually. If a municipality potentially exposed to several natural hazards wants to initiate risk prevention, one should combine assessments of possible impacts from all potential hazards. A combined assessment of exposure will minimize the possibility for the municipality to relocate a planned development from a flood-exposed area to a landslide-prone area.

For the integrated hazard exposure, we combine the physical exposure indices for floods, landslides, and storms into one common Exposure Index (EI). A major challenge when combining the indices for exposure is to determine how these should be weighted when merged into one single index. In earlier studies (Rød et al. 2012), we have used the so-called expert assessed weighting. This implies a search for the best possible knowledge base from which we could logically determine how exposure to flood and landslide should be weighted. Expert assessed weighting is a difficult exercise, and the result may often be that, because of the lack of decision base, the various factors are weighted equally. A better alternative is a data-driven determination of mutually weighting, but this requires the availability of adequate empirical data. Again, we use empirical data from the Norwegian Natural Perils Pool on insurance payments due to damage on buildings caused by storms, floods, or landslides to determine the weights of the individual exposure indices when constructing EI. From the perils pool data, 60% of all insurance payments are due to damages caused by storm events. The shares of the other perils are 26% for flood, 7% for landslide, and 5% for storm-surge damage. We have so far not assessed storm-surge hazards; therefore, we scale the other percentages so that the sum of the weights equals one. The three exposure indices for storms, floods, and landslides can thereby be combined to a common EI by using the weights as indicated below in Formula 4:

$$EI = 0.64 \times EIS + 0.28 \times EIF + 0.08 \times EIL \tag{4}$$

Because we combine different indices for exposure, we need to transform these to a common scale before they can be added together. A common scale is achieved by a minimum-maximum transformation (see Formula 5),

$$x' = \frac{x - min}{max - min} \times 100 \tag{5}$$

where x' is the transformed value, x is the original value, and *min* and *max* are the minimum and maximum values of the index that is to be transformed, respectively. Finally, we multiply the result by 100 in order to bring the transformed values between 0 and 100.

Social vulnerability

Norway is an egalitarian country where socioeconomic differences are not very pronounced. The income distribution is even, gender equality is high, unemployment rate is low, and there are universal social services (Lahelma et al. 2002). These egalitarian characteristics also have an equalizing effect on wealth (Aaberge and Langøren 2006). Therefore, many may claim that social vulnerability is not relevant for Norway and other similarly developed countries. However, in any society, there is a certain level of social segregation, and we argue that it is naive to believe that the differences that after all exist in Norway will not affect people's vulnerability to natural disasters. Besides, the social and health inequalities that exist in Norway have increased during the 1980s and 1990s (Dahl et al. 2006; Mackenbach et al. 2003). We do not know how Norway as a society will develop in the future, but mapping the current status of social vulnerability could provide a useful baseline to assess future social vulnerability.

A challenge with social vulnerability is that it is not an observable phenomenon (Patt et al. 2008) and is therefore not easily measurable. The use of indicators is necessary, because no single measure exists that covers the whole spectrum of how vulnerability may be manifested. Cutter, Boruff, and Shirley (2003) have established an approach to quantify social vulnerability by applying a large number of measurable variables that each indicates a facet of the communities' vulnerability to environmental hazards. By using a principal-component analysis, they identify underlying factors that make places socially vulnerable to environmental hazards. Variation on the vulnerability score can be read as a relative indicator of unequal socioeconomic and demographic characteristics that in turn lead to an unequal capacity to resist and respond to hazards. When presenting an overall score, this approach also allows for a more detailed identification of the key factors driving vulnerability at specific locations: whereas poverty might be the most prominent factor in one area, ageing population may be the main driving element in another area.

Holand, Lujala, and Rød (2011) have followed Cutter's approach and adapted the social vulnerability index for the Norwegian context by identifying factors that make Norwegian municipalities socially and economically vulnerable to natural and other hazards. They have generated two types of vulnerability indices: a socioeconomic vulnerability index (SeVI) and a built environment vulnerability index (BEVI). SeVI is an index expressing the socioeconomic and demographic characteristics of Norwegian municipalities and their inhabitants. BEVI is an index expressing characteristics with infrastructure and building structures as well as geographical variables such as traveling distance to the nearest hospital (see Holand, Lujala, and Rød 2011 for details). Whereas EIF, EIL, and EIS express how places are exposed to flood, landslide, and storm events, SeVI and BEVI express the municipalities' capacity in pressing situations and how quickly local societies are able to restore to normal after a crisis. It is important to know where the most social vulnerable places are because an extreme event will be more disastrous and have prolonged consequences in such places.

Integrated vulnerability assessment

As claimed by Førland, Amundsen, and Hovelsrud (2007), in order to carry out a full analysis of societies' vulnerability to natural damage, the assessment of exposure should be combined with demographic and socioeconomic conditions. These are the conditions which Holand, Lujala, and Rød (2011) have assessed and mapped with indices for social vulnerability. For our integrated vulnerability index (IntVI), we therefore add weighted minimum-maximum transformed indices for combined exposure (EI), socioeconomic vulnerability (SeVI), and built-environment vulnerability (BEVI). (See Formula 6.)

$$IntVI = v_1\, EI + v_2\, SeVI + v_3\, BEVI \qquad (6)$$

We determine the weights in Formula 6 by experimental design. As initial conditions, we set $v_1 = 1.0$ and $v_2 = v_3 = 0$, and we test the correlations between municipality scores on IntVI and the numbers of compensation claims to cover damages caused by floods, landslides, and storms per address point. Step by step, we reduce v_1 and correspondingly increase v_2 and/or v_3 and make new correlations. We then calculate IntVI by using Formula 6 with the weights that result in the highest correlation with the measure of natural damage (v_1 = 0.6, v_2 = 0.2, and v_3 = 0.2) and map the Integrated Vulnerability Index as shown in Figure 4.

FIGURE 4 HERE

As demonstrated with the map in Figure 4, there is a considerable geographic variation in how Norwegian municipalities score on the Integrated Vulnerability Index. Although the most vulnerable municipalities are in the three northernmost counties, and among them are the municipalities at the Lofoten Islands (such as Værøy, Moskenes and Flakstad), there are also two municipalities in the western part of Norway which score high on IntVI (Lærdal and Luster). Whereas the highly vulnerable municipalities at the Lofoten Island also have many insurance claims (these are the three dot in the upper right corner in Figure 3D), this is not the case for Lærdal and Luster. These municipalities score high on IntVI but have a low number of compensation claims (in Figure 3D, they are both situated in the lower right corner). This means that we do not perform well when trying to assess the vulnerability of these municipalities because they have a lower number of claims than expected. Similarly, the municipalities at the Lofoten Islands have a higher number of claims than expected. These five entries, thus, contribute to weaken the correlation.

Because the Integrated Vulnerability Index is a composite measure, any inaccuracies of the components used to construct it will contribute to an inaccurate result. The low correlation we obtain between the Exposure Index for Floods and the insurance compensation claims for damages caused by floods contributes to an imperfect integrated vulnerability assessment. We will therefore continue to work on improving the various measures of exposure; but it is equally important to engage local stakeholders in a dialogue to assess and validate the components and parameters in order to improve the integrated vulnerability assessment.

Participatory validation

The maps that we have created are based on scientific knowledge but should not be perceived as final products mirroring reality because they are provisional representations of one possible perspective on exposure and vulnerability to extreme physical events. However, such spatial representations bear a great potential for supporting constructive discussions about integrated vulnerability assessments. Indicator-based vulnerability assessments as presented in this article can serve as a starting point for dialogues about local vulnerability. Because different interests and opinions shape the experienced relevance of exposure and vulnerability assessments, we believe it is important to integrate local and scientific knowledge.

Therefore, the development of exposure and vulnerability indices and of maps portraying such information needs to be accompanied by local involvement to ensure its usability and policy relevance. Although the indices can be scientifically validated with the help of historical data on insurance claims, we do consider participatory validation based on local expert judgments to be equally important. Participatory validation is based on local knowledge and engagement of local authorities, planners, and civil society and has the potential to enhance local ownership, confidence, and validity of the maps produced.

Local participation can be achieved either through physical meetings in the traditional form of workshops or through remote, web-based consultations structured around the thematic exploration of vulnerability indicators. To enable the latter, some preconditions are necessary: the information related to all parameters of the vulnerability assessment needs to be transparent, credible, and accessible. Moreover, users should be able to comment and question this information by means of interactive modules. These preconditions can be met by an open-access web-based visualization tool such as the ViewExposed application[iii] (see Figure 5A) equipped with interactive functions that enable the users to submit remarks and inquiries on specific vulnerability indices.

FIGURE 5 HERE

Thanks to multiple linked views consisting of map and data displays, ViewExposed presents the exposure and vulnerability indices in a comprehensive, transparent, and easily accessible way (Opach and Rød 2013). It allows the user to enter the web interface in any given setting (on an individual desktop or in a conference meeting), to select specific parameters (Figure 5 B) and vulnerability indices, and to compare the value for each of these for single municipalities. In this way, users can create their own understanding of the vulnerability indices and move between municipalities for comparison. Furthermore, users with specific local knowledge might actively contribute to the vulnerability assessment. They can use the submit-remark panel (see Figure 6) to comment and rate the assessments. The overall user rating might be displayed as a map layer providing a summary of all submitted remarks (e.g., symbol map shown in the last screenshot in Figure 6). Our approach bears similarities to the increasingly popular participatory methodology called Participatory GIS or

PGIS (Kingston 2007; Kingston et al. 2000; Sieber 2006), which entails local involvement in creating and working with geographic information.

FIGURE 6 HERE

We develop the visualization tool ViewExposed not only to highlight the most vulnerable areas. Through multiple linked windows (map, parallel coordinate plot, and table view), ViewExposed also allows to visualize how various factors contribute to high scores on the Integrated Vulnerability Index. Interaction is recognized as paramount for visualization tools to facilitate knowledge discovery (MacEachren and Ganter 1990, 74). We therefore design the visualization tool as a highly interactive system with the potential to enable understanding about what factors make a particular place vulnerable. ViewExposed's interactive interface enables the user to explore the data in a number of different representations: as maps and line graphs and in an ordinary table format. Users can interactively select regions and parameters that are of interest and support the analysis and understanding of large and heterogeneous data. The visualization-based interface has the ability to provide an intuitive understanding for the relations between different parts of the information. The involvement of the user in the exploration and validation of data has also been shown to encourage engagement in, for example, planning dialogues (Salter et al. 2009; Sheppard 2012). Visualization-supported dialogues facilitate the iterative validation of input data for single parameters and resulting indices. The maps can be displayed on a large screen during a stakeholder dialogue or on individual desktops, enabling the participants' interaction to explore data and to identify knowledge gaps and inconsistencies. By gathering stakeholders in a participatory process, these dialogues encourage collaboration and social learning as well as the refinement of the exposure and vulnerability indices (Larson and Edsall 2010; Sheppard et al. 2011; White et al. 2010).

Conclusions

This article describes the steps that led us to prepare an integrated vulnerability assessment through the exemplification of Norwegian municipalities. We have selected the municipality as the geographic level, because this allows for the validation of the exposure indices by correlating them with historical data on natural damage. The correlations have proved quite strong, except for floods. The Exposure Index for Floods does not correlate well with the number of claims due to floods, and we believe this is mainly due to an incomplete mapping of inundation zones. When we base our flood exposure assessment on incomplete hazard maps, it should not come as a surprise that the assessment of exposure is incomplete as well.

Our assessment could best be described as a top-down approach, and other authors have suggested that such top-down approaches could form a basis for participatory vulnerability assessments. To the best of our knowledge, no such basis exists for Norway on a local level. We believe that the type of assessment presented here might be useful in local-level planning to identify the most vulnerable municipalities and, with the use of visualization tools, to facilitate the understanding of factors making these municipalities vulnerable. This could provide a decision support for where adaptation strategies should be carried out and information on what kind of adaptation is needed. Through visualization-supported dialogues, we have started a process that sets out to further combine a top-down approach with a bottom-up approach. Through such dialogues, the exposure and vulnerability maps can be developed into more useful tools that can provide a basis for a more precise and proactive intervention in, for example, the form of land-use planning, prioritization of protective investments, and emergency planning. The ViewExposed visualization tool is a step in that direction because it enables the user to explore the parameters behind the exposure and vulnerability indices. It also allows the user to investigate whether a high score is caused by floods, storms, or landslides and whether socioeconomic conditions aggravate or alleviate the integrated vulnerability of the place. Local involvement is important for several reasons. First, local knowledge is important as a corrective measure to our assessment. Second, local data are an important addition to the information available through public national databases. Third, a local involvement will increase the validity and the use of the maps because more people will develop a sense of ownership of the maps and therefore have more reasons to trust them.

Lastly, we should add some cautionary remarks. Assessments based on indices such as those presented here have specific constraints. They simplify a complex reality, which is in fact their main purpose. But whether this simplification reflects reality in the best possible way will always be a matter of concern. When creating indices, a number of choices have to be made, some more theoretical and some more technical. These choices influence the outcome, as presented on the maps shown in Figure 1 and available from the ViewExposed application, thus confirming the geographical truism that every map is the product of a particular, socially conditioned conception of space and therefore a mental map (Axelsen and Jones 1987). Although all choices are made on the basis of our best knowledge, they could and should be challenged. Despite this, we consider the study presented here to be a useful contribution to an important ongoing debate on how to make local societies better prepared for the possible negative consequences of climate change.

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[i] We use the municipality boundaries as they were in 2010. There were 430 municipalities in Norway as of 2010.
[ii] See http://naturskade.no for more information.
[iii] At the moment at this URL: http://setebos.svt.ntnu.no/tomasz/gallery/Vul16/index.html (Google Chrome is recommended as web browser).

Figure 1. Framework for the integrated vulnerability assessment and the weighting of indices.

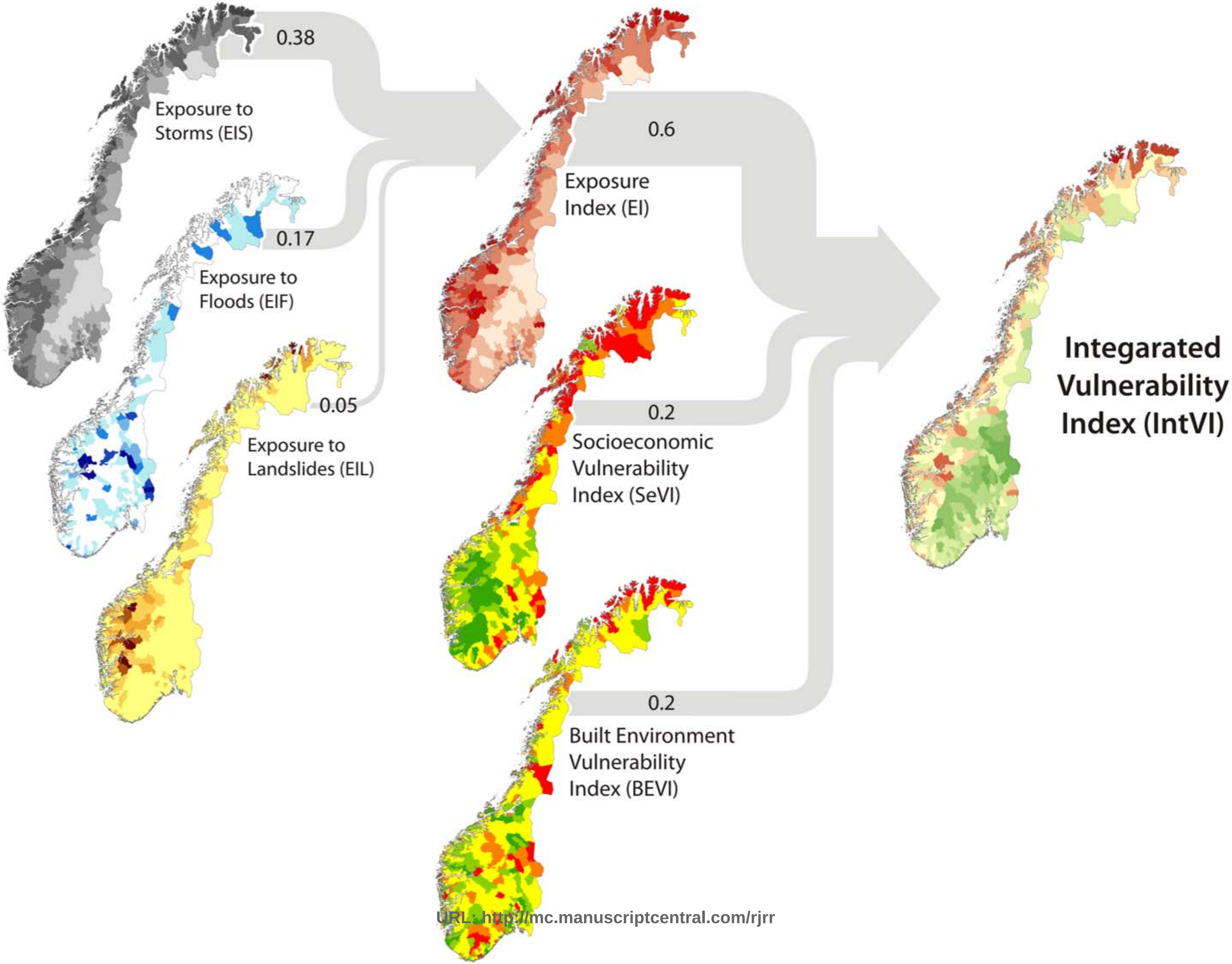
Figure 2. Elements at risk.

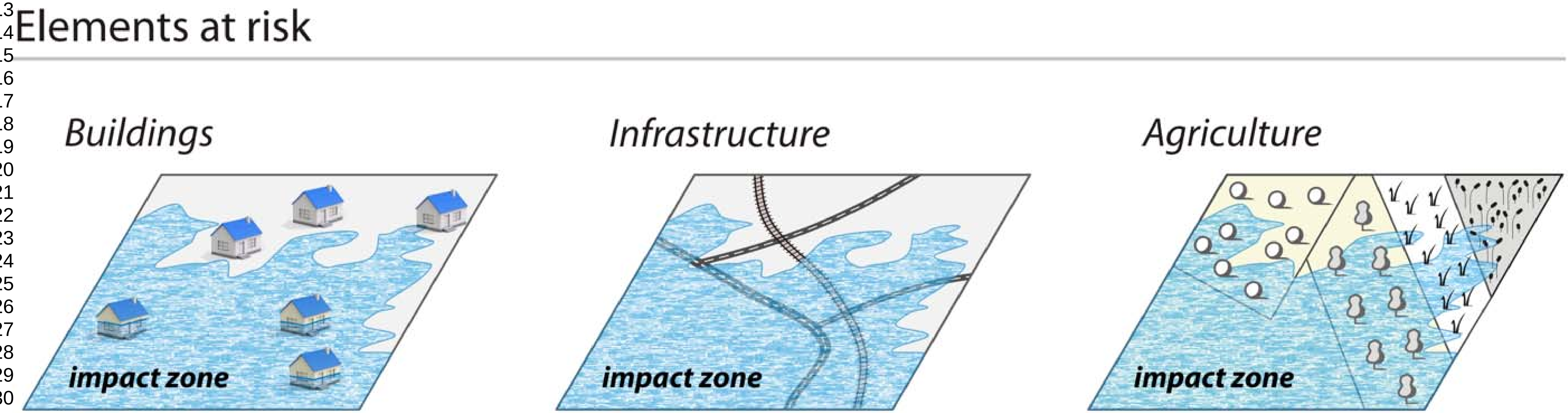
Figure 3. Relationships between exposure and vulnerability indices and compensation claims.

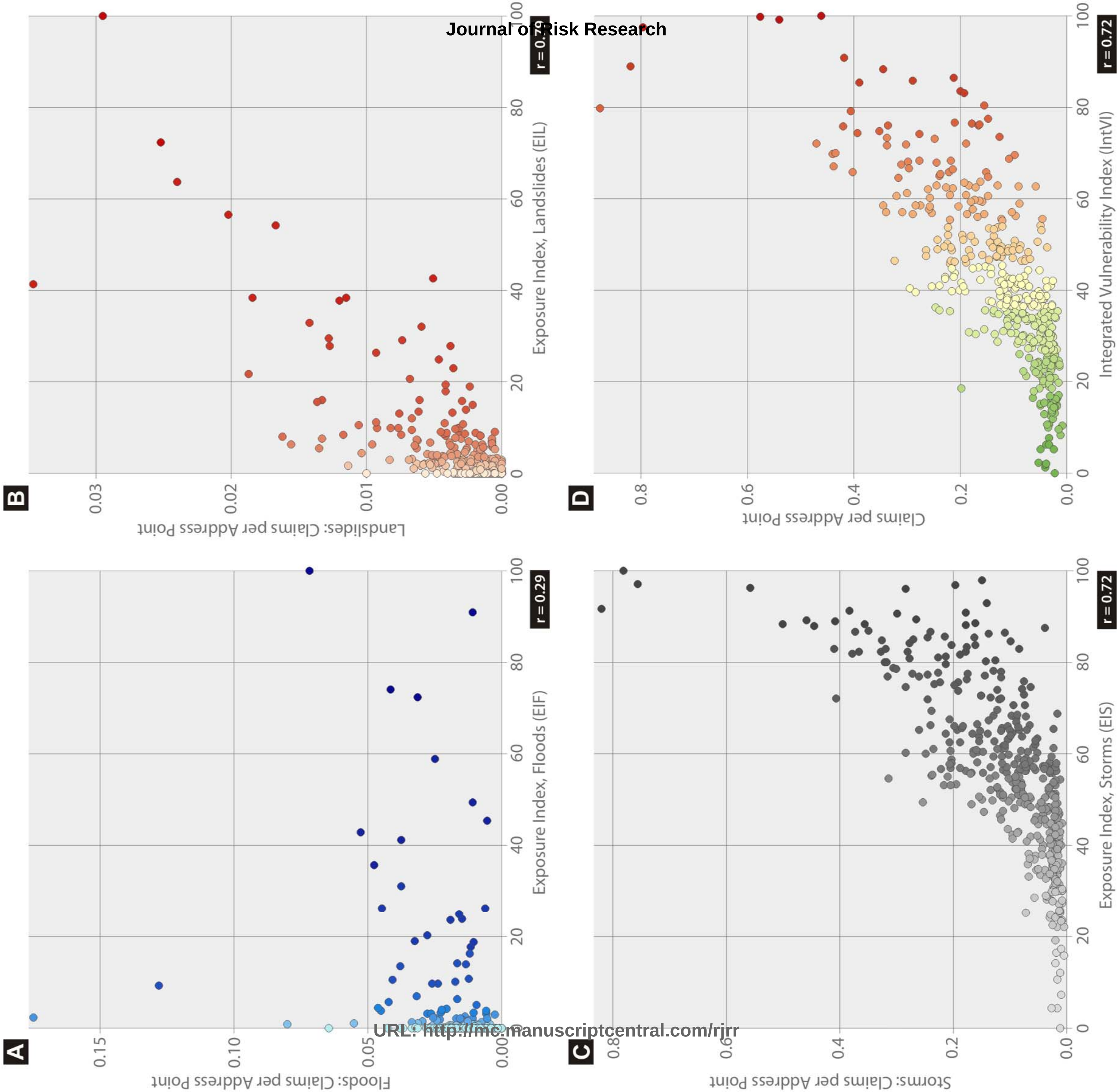
Figure 4. A map of the integrated vulnerability index (IntVI).

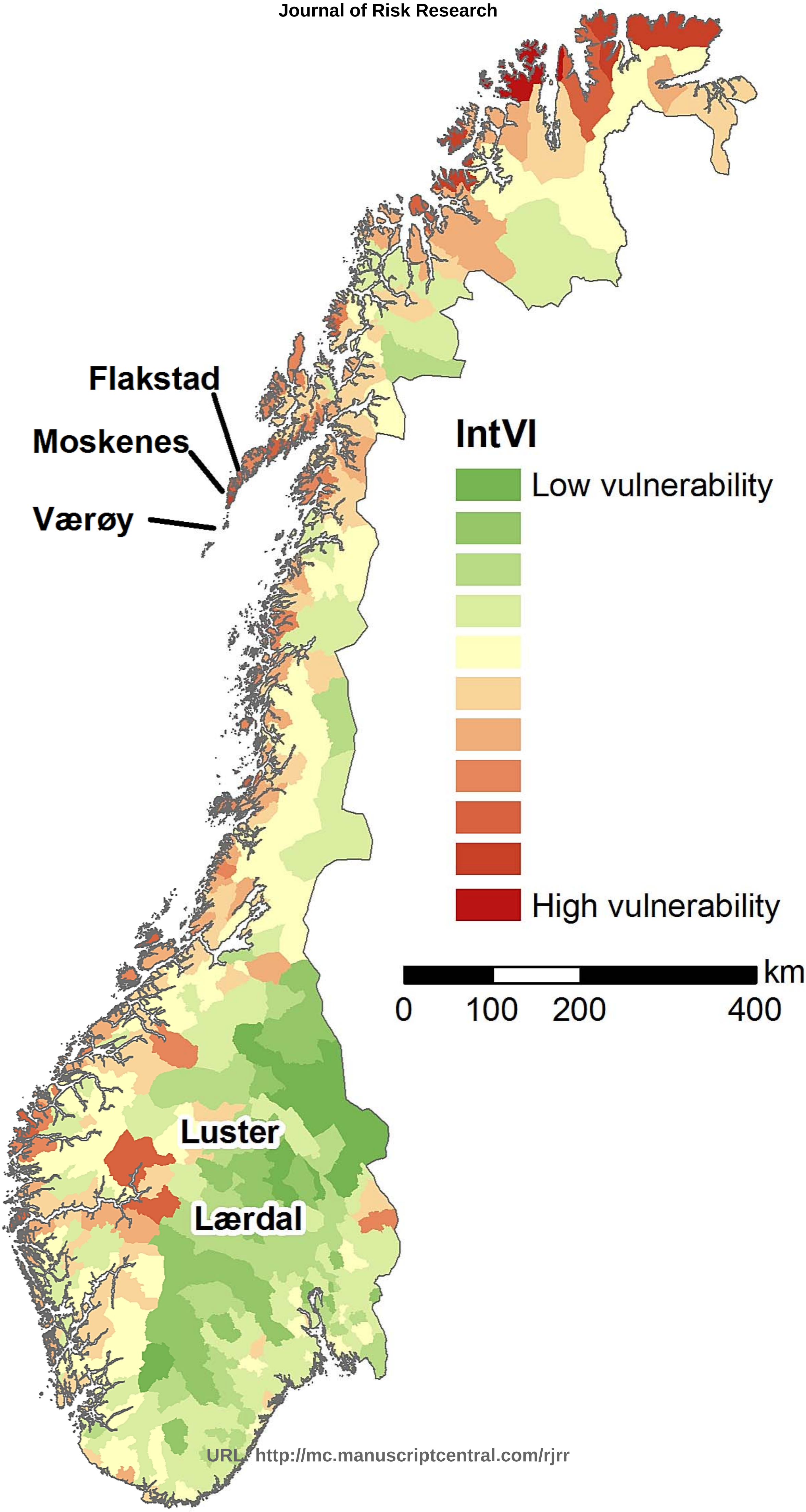
Figure 5. The web-based visualization tool ViewExposed.

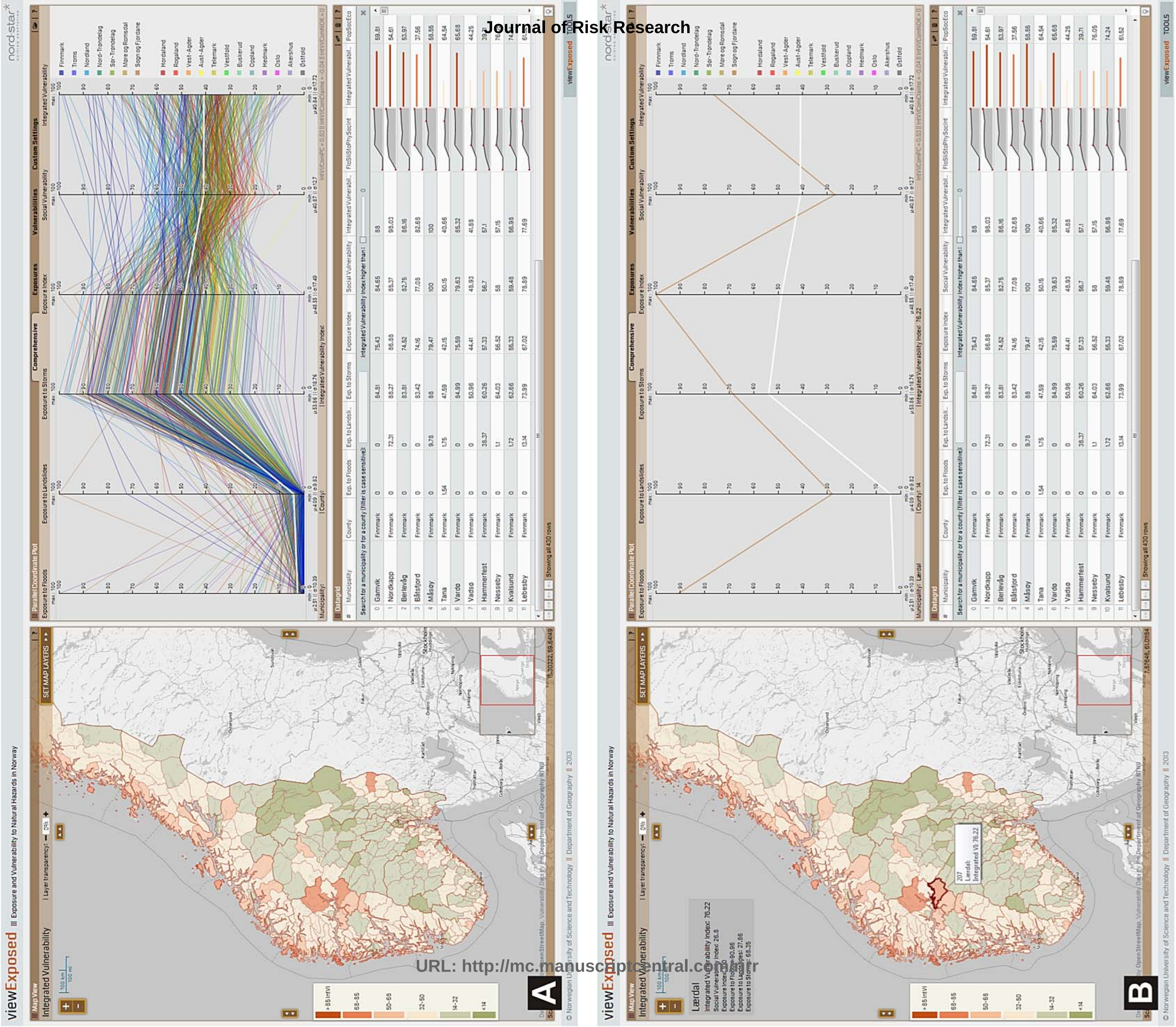
Figure 6. The interface for a participatory assessment on exposure and vulnerability.

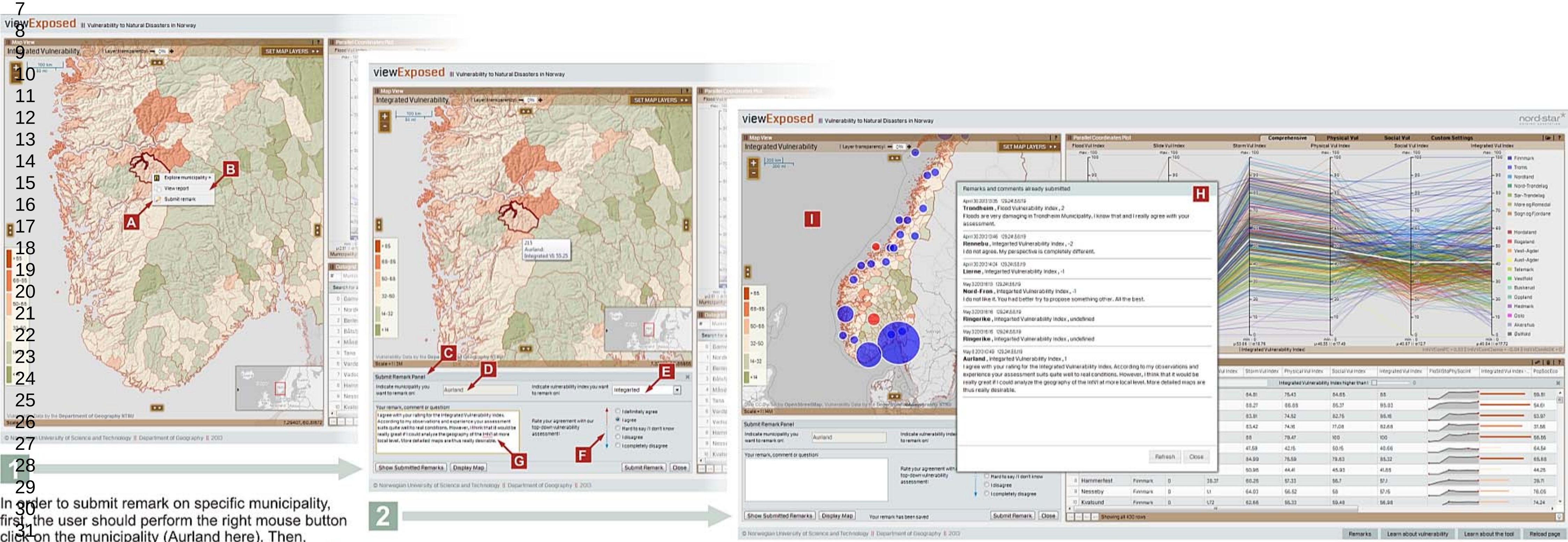

0.38
Exposure to
Storms (EIS)
0.17
Exposure to
Floods (EIF)
0.05
Exposure to
Landslides (EIL)
0.6
Exposure
Index (EI)
0.2
Socioeconomic
Vulnerability
Index (SeVI)
0.2
Built Environment
Vulnerability
Index (BEVI)
Integarated
Vulnerability
Index (IntVI)


Elements at risk
Buildings
impact zone
Infrastructure
impact zone
Agriculture
impact zone


A
Floods: Claims per Address Point
Exposure Index, Floods (EIF)
r = 0.29
B
Landslides: Claims per Address Point
Exposure Index, Landslides (EIL)
C
Storms: Claims per Address Point
Exposure Index, Storms (EIS)
r = 0.72
D
Claims per Address Point
Integrated Vulnerability Index (IntVI)
r = 0.72


Flakstad
Moskenes
Værøy
IntVI
Low vulnerability
High vulnerability
km
0
100
200
400
Luster
Lærdal





In order to submit remark on specific municipality, first, the user should perform the right mouse button click on the municipality (Aurland here). Then, he or she should select the 'Submit remark' item **A** from the context menu **B** to display / activate the Submit Remark Panel **C**.

Name of the selected municipality is transferred automatically to the text field **D** in the Submit Remark Panel **C**. Next, the user might indicate the index **E** he or she wants to remark on, rate the agreement with our top-down vulnerability assessment **F**, and finally, provide a remark, comment, or question **G**.

After submitting the remark, the user may display in a dedicated panel **H** all remarks already submitted and will also be able to display an extra layer in the map view **I** summarizing all given rates on specific vulnerability indices (this functionality is under development and will be implemented soon).