Analysis of social vulnerability to climate change in the Helsinki Metropolitan Area

Final report

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29th December 2015

HSY

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Tiivistelmä:

Ilmastonmuutoksen haitalliset vaikutukset ovat joillekin ihmisryhmille koettelevampia kuin toisille. Sosiaalinen haavoittuvuus pyrkii kuvaamaan näitä ihmisryhmäkohtaisia vaikutuseroja. Ihmisen haavoittuvuutta määrittävät heidän fyysiset ominaisuutensa kuten ikä ja terveydentila. Lisäksi haavoittuvuuteen vaikuttaa ihmisten kyky selviytyä tulvista tai helleaalloista - varautua niihin ennalta, selviytyä tilanteen aikana ja mahdollisuuksista korjata vahingot. Myös asuinympäristön ominaisuudet kuten asuinrakennukset ja viheralueet, vaikuttavat asukkaiden haavoittuvuuteen.

Pääkaupunkiseudun ilmastolähtöisen haavoittuvuuden kartoituksessa selvitettiin ihmisten sosiaalista haavoittuvuutta tulville ja helteille. Työn tuloksena syntyi joukko haavoittuvuutta kuvaavia yksittäisiä ja yhdistelmäindikaattoreita sekä kuvaus siitä, miten haavoittuvuus jakautuu alueellisesti pääkaupunkiseudulla. Lisäksi työssä tuotettiin yhdistelmäindikaattori hulevesihaitan (disadvantage) alueellisesta jakaantumisesta pääkaupunkiseudulla. Käytetty menetelmä on kuvattu tarkemmin englanninkielisessä raportissa (Kazmierczak 2015).

Työn tuloksia voidaan käyttää kaupunkisuunnittelussa ja myös muiden sektoreiden kuten sosiaali- ja terveysalan ja pelastustoimen, suunnittelussa lähdeaineistona sekä päätöksenteon tausta-aineistona. Indikaattoreita voi myös hyödyntää sopeutumistoimien priorisoinnissa ja kohdentamisessa. Kartoitus nostaa esiin pääkaupunkiseudun haavoittuvia ryhmiä ja voi lisätä tietoisuutta ilmastonmuutokseen sopeutumisesta ja haavoittuvuudesta.

Työn toteutti Dr. Aleksandra Kazmierczak Cardiffin yliopistosta tiiviissä yhteistyössä HSY:n ja Manchesterin yliopiston asiantuntijoiden kanssa. Työssä sovellettiin Iso-Britanniassa kehitettyä sosiaalisen haavoittuvuuden kartoitusmenetelmää (Lindley ym., 2011). Kartoituksessa käytettiin HSY:n aineistojen lisäksi useilta eri tahoilta saatuja aineistoja. Aineistot kartoitusta varten muokkasi ja valmisteli projektitutkija Jussi Välimäki HSY:stä. Indikaattorien valintaan ja kehittämiseen osallistuivat ilmastoasiantuntija Susanna Kankaanpää, paikkatietoasiantuntija Mikko Nikkanen sekä harjoittelija Noora Piila HSY:stä.

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Abstract page

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Abstract:

Climate impacts and extreme weather events can affect some people more than others. How badly a person or group will be affected will depend on their social vulnerability – that is, how well they are able to cope with and respond to events like floods and heatwaves. The main drivers of social vulnerability relate to personal features such as age and health, characteristics of the living environment, and the social and institutional context that affect the ability of people to adapt.

In this project, an analysis of the indicators reflecting different aspects of social vulnerability to climate change in the Helsinki Metropolitan Area was carried out. The indicators were combined into a set of indices that describe different dimensions of social vulnerability and social vulnerability to flooding and heat. The work provides an understanding of the spatial distribution of social vulnerability to climate change in the Helsinki Metropolitan Area.

This work builds on cooperation between the Helsinki Region Environmental Services Authority (HSY), University of Manchester and Aleksandra Kazmierczak. In the work, the framework and method for mapping the distribution of social vulnerability and climate disadvantage in the UK developed in the University of Manchester (Lindley et al., 2011) was used and adopted to the Helsinki Metropolitan Area. The method is described in more detail in the longer report by Aleksandra Kazmierczak (2015).

The results of the mapping exercise can be used as background information in urban planning and other sectors such as social and health care, preparedness planning, rescue services and housing. The indicators can be used when making decisions about allocation of resources and actions and in prioritizing adaptation policies. Mapping makes vulnerable groups more visible and can increase awareness about climate change adaptation issues and vulnerability.

The work was carried out by Dr. Aleksandra Kazmierczak from the Cardiff University in close co-operation with the HSY and University of Manchester experts. In the mapping exercise, data from different sources including the Statistics of Finland, the Finnish Environment Institute and the Housing finance and development centre of Finland ARA, were used. The data for the mapping was edited and prepared by project researcher Jussi Välimäki from HSY. Climate expert Susanna Kankaanpää, GIS expert Mikko Nikkanen and intern Noora Piila from HSY took part in the identification and development of suitable indicators.

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Contents

1 Introduction

The aim of this project was to carry out an analysis of the indicators reflecting different aspects of social vulnerability to climate change available for the Helsinki Metropolitan Area and to combine them into a set of indices. It is envisaged that this report will provide an understanding of the spatial distribution of social vulnerability to climate change in the Helsinki Metropolitan Area and guide further vulnerability assessments.

This project builds on the previous cooperation between Helsinki Region Environmental Services Authority (HSY), University of Manchester and Aleksandra Kazmierczak (March – May 2015). That initial project offered advice on how the framework for mapping the distribution of social vulnerability and climate disadvantage in the UK developed for the report Climate change, justice and vulnerability (Lindley et al., 2011) could be implemented in the Helsinki Metropolitan Area. That involved recognising the different vulnerability aspects relevant to Helsinki Metropolitan Area and identifying potential suitable indicators and data sources.

Section 2 of this report explains the conceptual framework underpinning the development of social vulnerability indices to climate change. Section 3 outlines the main steps in the project. Section 4 lists the datasets used in the analysis of social vulnerability to climate change. In section 5, the initial list of indicators is presented whilst section 6 presents how this initial list was reduced based on the analysis of correlations between the indicators. Section 7 presents the methods of processing of the original indicators to allow combining them into indices of social vulnerability, which is a subject of section 8. Section 9 describes how the index of vulnerability to flooding was combined with the hazard of flooding to estimate flood disadvantage in the Helsinki Metropolitan Area. Section 10 presents the datasets emerging from the project, section 11 discusses strengths and limitations of the data and methods used in the vulnerability and disadvantage assessment. Section 12 concludes with recommendations for future assessments of vulnerability to climate change in the Helsinki Metropolitan Area.

2 The conceptual framework supporting the assessment

The conceptual basis for combining the indicators into an index of vulnerability is the framework developed by Lindley et al (2011) and adjusted to the risk of flooding by Kazmierczak et al. (2015), where social vulnerability is understood as the degree to which people's health and well-being would be negatively affected if they came into contact with flooding or high temperatures (Figure 1). Social vulnerability is a combination of:

- Sensitivity (personal characteristics such as age or health that increase the likelihood that a flood / heat wave event will have negative health and well-being impacts on people),
- Adaptive capacity (the ability of people to prepare for, respond to and recover after flooding / heat wave, related mainly to their social and material situation), and,
- Enhanced exposure (the aspects of the physical environment, such as housing and presence of permeable surfaces, which accentuate or offset the severity of flood events).

According to the risk triangle framework, if any one component or „side" of the triangle is zero, then there is no risk (Crichton, 1999). Therefore, in locations where social vulnerability is high but the likelihood of flooding is close to zero, the negative impacts of flood events on health and well-being will not be realised. Flood disadvantage, therefore, only occurs where social vulnerability coincides with hazard-exposure, i.e. where vulnerable communities live in areas that may be exposed to flooding. Therefore, the level of flood disadvantage reflects the combined magnitude of social vulnerability to flooding and the magnitude of hazard-exposure.

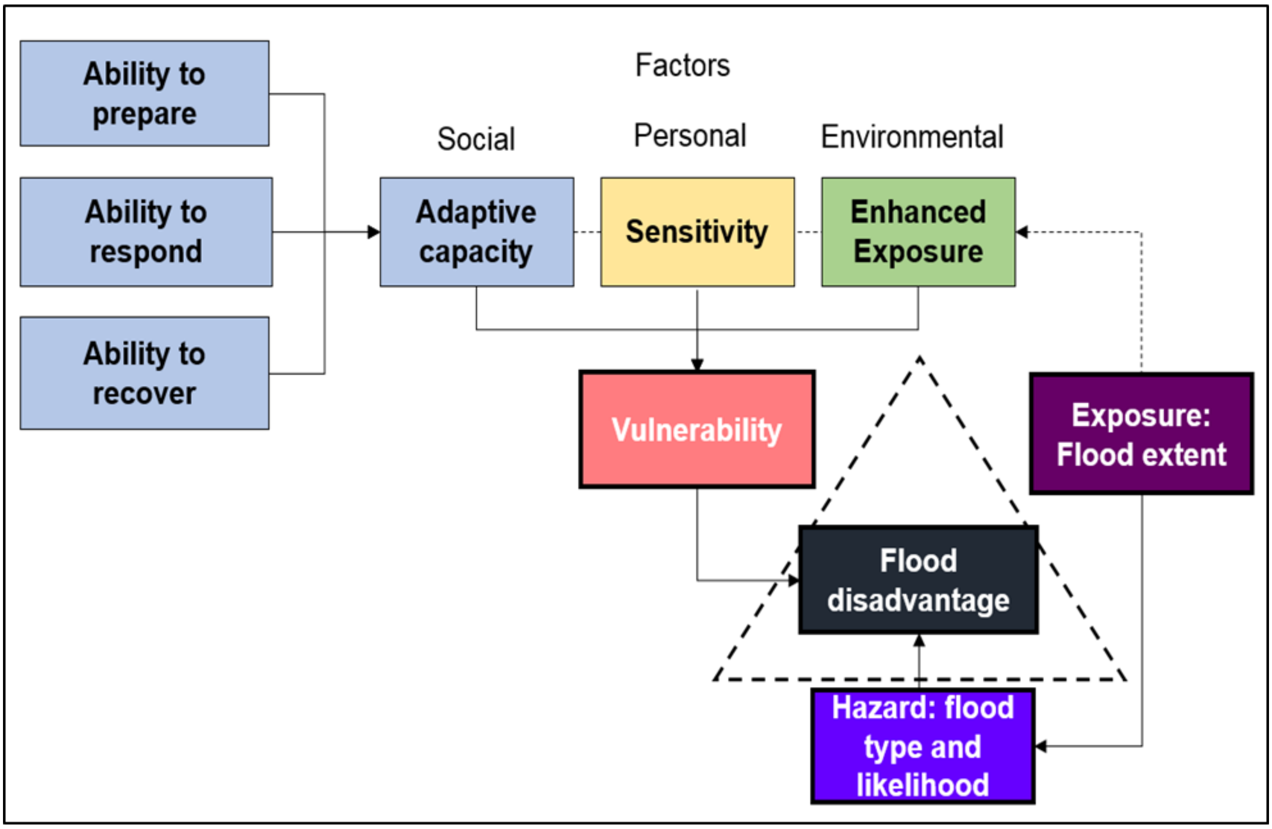

Figure 1. The framework of social vulnerability to flooding and flood disadvantage (Kazmierczak et al., 2015; after Lindley et al., 2011).

This project is carried out for two main hazards associated with climate change: flooding and high temperatures (heat waves). The framework for flood disadvantage assessment presented in Figure 1 can also be used for assessing social vulnerability to heat waves. In the case of high temperatures, however, the 'ability to recover' is not relevant, as people recover from high temperatures very quickly, and the heat wave events tend not to leave lasting effects on housing or neighbourhoods. Therefore, in the case of heatwaves, adaptive capacity is a combination of the ability to prepare for and ability to respond to high temperatures.

In addition, due to the paucity of data, it was not possible to assess spatial variations in temperatures across the Helsinki Metropolitan Area; therefore, whilst the social vulnerability to high temperatures is analysed, the scope of the project does not extend to the assessment of heat disadvantage.

3 Overview of the steps involved in the project

The project was carried out in close collaboration with HSY and all steps were consulted with the HSY team involved. The steps were discussed via email and two video-conferences were organised (9th December and 17th December) to discuss progress and emerging issues.

The steps followed in the project involved as follows:

A. Identification of the broad themes contributing to social vulnerability to climate change in the Helsinki Metropolitan Area. This was done in advance of the project, through earlier collaboration between

HSY, University of Manchester and Aleksandra Kazmierczak (March – May 2015) and internal discussions at HSY.

B. Identification of datasets holding the relevant data by HSY (section 4).

C. Extraction of the relevant data to be processed as indicators of climate change from the datasets (section 5), resulting in the initial list of indicators (Table 1) proposed to HSY.

D. Processing of indicators involving the following:

- Calculating the indicators, mainly as percentages, using the relevant radix values, or carrying out other calculations (see section 5; Table 1)

- Reduction of the number of indicators based on analysis of bi-variate correlations and in discussion with HSY (see section 6; Table 2)

- Processing of the indicators using log-transformation; range standardisation and reversing of values (where relevant – see section 7).

E. Combination of the indicators into indices of social vulnerability to flooding and heatwaves (section 8; Table 4), after aligning them to the dimensions of the conceptual framework (Table 3).

F. Combination of the social vulnerability to flooding with flood exposure indices for different types of flooding and return periods (section 9).

G. Mapping the indices (sections 8 and 9).

There was some iteration between the different steps as the suitability of indicators and processing methods was discussed with HSY.

4 Identification of datasets holding the relevant data

The following spatial datasets were received from HSY:

a. Accessibility_Grid.shp

b. Grid_Database.shp

c. CarOwners_YKR.shp

d. Commute_point_YKR.shp

e. PopulationGrid_YKR.shp

f. Social_housing_Grid.shp

g. LowVegetationGrid_eng.shp

h. Trees_Grid_eng.shp

i. L_T_unemp_Grid.shp (Long Term Unemployment)

j. Flooded buildings (1:20; 1:50; 1:100; 1:250 annual probability of flooding)

k. Flood hazard (sea, lake and river flooding: 1:20; 1:50; 1:100; 1:250 annual probability of flooding)

l. Pluvial flooding probability

The spatial context for the assessment is the extent of the Grid Database in the Helsinki Metropolitan Area. The Grid Database contains Statistics Finland's co-ordinate based statistical data calculated by map grid (250x250m), which gives an opportunity to observe phenomena in different areas independently of administrative boundaries. The product contains data by selected key variables describing the population's structure, education, main type of activity and income, households' stage in life and income, as well as buildings and workplaces. The Grid Database is updated annually with the latest statistical data[1]. The Grid Database within the Helsinki Metropolitan Area consists of 6813 cells (Figure 2).

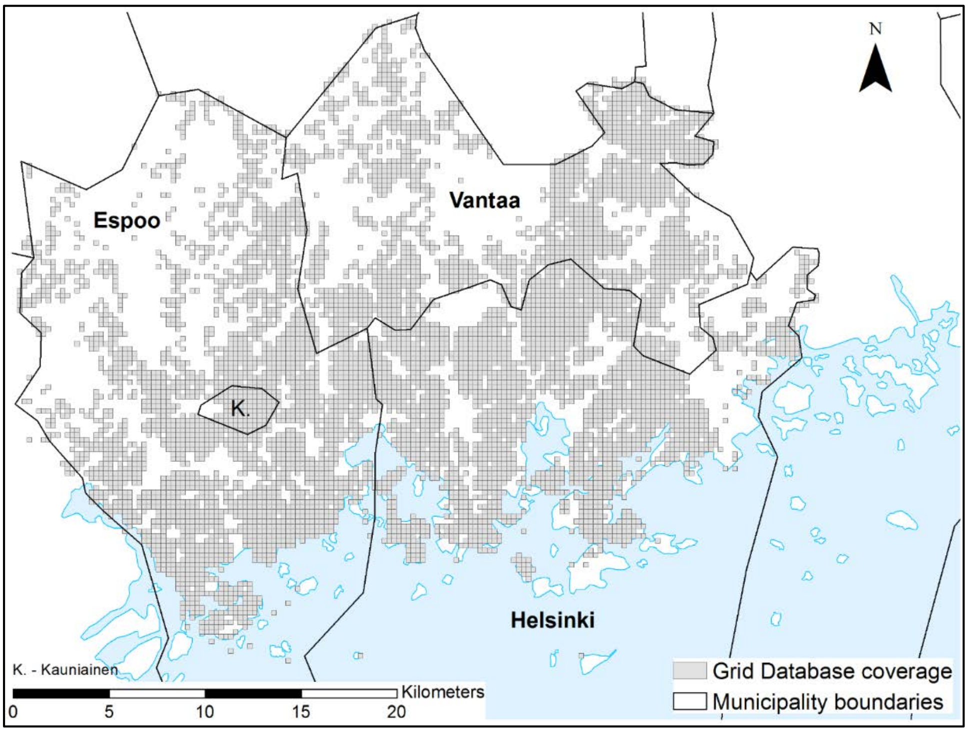

Figure 2: Extent of the Grid Database in the Helsinki Metropolitan Area.

5 Development of the initial indicator list

Table 1 presents the initial set of 33 indicators resulting from the extraction of relevant data from the datasets listed in section 4 and discussed with HSY on the 9th December. Table 1 also provides a brief justification of the indicator proposed. The number of indicators was then reduced based on the analysis of correlations between them (section 2).

[1] http://tilastokeskus.fi/tup/ruututietokanta/index_en.html

No.	Indicator	Source	Date	Calculation method	Justification
1.	Percentage of people with basic studies in the population	Grid Database	2012	100 * ko_perus / ko_ika18y	Low education levels, and illiteracy in particular, may prevent people from understanding information provided by authorities on the risk of flooding or heat waves, emergency procedures or preventative/recovery actions.
2.	Average size of households	Grid Database	2013	te_takk	Larger households (containing more people) may be more difficult to evacuate in the case of emergency and to provide alternative accommodation for in the recovery phase.
3.	Occupancy rate (m^2 / person)	Grid Database	2013	te_as_valj	Low occupancy rates (i.e. low dwelling area per person) may suggest overcrowding, which may pose problems in flood response and recovery phases (see above); also, smaller dwellings are more likely to be occupied by people on low incomes.
4.	Percentage of households with young children	Grid Database	2013	100 * te_plap / te_taly	Young children and babies are one of the age groups prone to health problems related to flooding and high temperatures. People caring for young children may need additional support during flooding and in the aftermath of flooding. Also, parents of very young children (in particular lone parents) may be socially isolated in comparison to other groups and thus more heavily reliant on the support provided by State during extreme weather events.
5.	Percentage of households with school-age children	Grid Database	2013	100 * te_klap / te_taly	Parents of school-age children are a group that tends to have the most extensive social networks through their engagement in school activities with other parents and as a result of their children's social networks. Therefore, higher percentage of school-age children may suggest higher potential for self-help in a neighbourhood and thus lower social vulnerability.
6.	Percentage of pensioner households	Grid Database	2013	100 * te_elak / te_taly	Older people are more prone to health problems associated with flooding and heat waves. They may need additional support during floods and periods of high temperatures. They also may have lower incomes than working-age people.
7.	Percentage of rented households	Grid Database	2013	100 * te_vouk_as / te_taly	People living in rented accommodation, in comparison to owner-occupiers, have less control over the physical characteristics of the dwelling and are less likely to implement measures that could reduce the risk of overheating or flood water ingress. In the UK, tenants are less likely to have contents insurance than owner-occupiers. In the aftermath of flooding, tenants are dependent on their landlords to refurbish the dwellings damaged by flood waters. In addition, tenants tend to live in a given area for a shorter period of time, thus may be less familiar with the local risk of flooding and have less extensive social networks in the neighbourhood than owner-occupiers.
8.	Average (mean) income of households	Grid Database	2012	tr_ktu	The lower the income, the lower people's capacity to prepare their houses for flooding and heatwaves through investment in physical structures (e.g. property-level flood protection measures or additional shading). Those on low incomes are less likely to insure their belongings from flooding. Less affluent people may also struggle to replace their belongings in the aftermath of flooding.
9.	Median income of households 2012	Grid Database	2012	tr_mtu	See 8.
10.	Percentage of lowest income households	Grid Database	2012	100 * tr_pi_tul / tr_kuty	See 8.
11.	Percentage of unemployed in labour force	Grid Database	2012	100 * pt_tyott / pt_tyove	Unemployment is associated with lower income – see 8.

No.	Indicator	Source	Date	Calculation method	Justification
12.	Percentage of students in the population	Grid Database	2012	100 * pt_opisk / pt_vakiy	Usually, high percentage of students comes from outside the city they study in, thus students compared to other residents may be less familiar with the local risk of flooding and have less extensive social networks in the neighbourhood, which could limit the locally available support for them in the event of flooding.
13.	Percentage of pensioners in the population	Grid Database	2012	100 * pt_elakel / pt_vakiy	Older people are more prone to health problems associated with flooding and heat waves. They may need additional support during floods and periods of high temperatures. They also may have lower incomes than working-age people.
14.	Percentage of economically inactive people in the population	Grid Database	2012	100 * pt_tyovu / pt_tyovy	Economic inactivity may be associated with lower income – see 8.
15.	Percentage of long-term unemployed in the labour force	Long Term Unemployed	2012	100 * LTU_number / pt_tyovy	Long-term unemployment tends to be associated with lower income – see 8.
16.	Location within 1km from a railway station	Accessibility	2012 (?)	None	Areas that are easily accessible by public transport (railways) may be accessed more quickly in the event of flooding than those that are located in places with less well-developed public transport. Being able to come home (e.g. from work) quickly in the event of flooding may allow people to take care of their families and belongings and reduce losses.
17.	Accessibility zone	Accessibility	2012 (?)	None	Areas that are easily accessible by walking, cycling and public transport may be accessed more quickly in the event of flooding than those that are located in places with less well-developed public transport. Being able to come home (e.g. from work) quickly in the event of flooding may allow people to take care of their families and belongings and reduce losses. The lower the accessibility, the higher the vulnerability.
18.	Percentage of surface water area in the grid	Higher vegetation	2012	100 * water_ha / 6.25	Presence of surface water provides cooling during periods of hot weather. The higher the percentage of water area in the grid cell, the lower the vulnerability.
19.	Percentage of built-up areas in land area	Higher vegetation	2012	100 * build_ha / land_ha	The higher the proportion of built-up area in the grid, the higher the likelihood of the location to become overheated or to be affected by flood waters which cannot infiltrate into the ground due to high proportion of surface sealing.
20.	Percentage of total green space in land area	Higher vegetation	2014	100 * [tr_area_ha + lv_area_ha] / land_ha	Presence of vegetation and permeable surfaces may facilitate infiltration of flood water and mitigate the flood effects. The higher the percentage of the total vegetation area in the land area of the grid cell, the lower the vulnerability.
21.	Percentage of lower vegetation in land area	Lower vegetation	2014	100 * lv_area_ha] / land_ha	Presence of low-level vegetation (<2m) provides some cooling in the event of heat waves. The higher the percentage of low vegetation area in the land area of the grid cell, the lower the vulnerability.
22.	Percentage of area covered by trees in land area	Higher vegetation	2014	100 * tr_area_ha / land_ha	Presence of trees, compared to lower vegetation, provides more effective cooling during periods of hot weather through shading. The higher the percentage of trees area in the grid cell, the lower the vulnerability.
23.	Median household income	YKR car owner data	2014 (?)	med_tulo	See 8

No.	Indicator	Source	Date	Calculation method	Justification
24.	Percentage of households with no car	YKR car owner	2014 (?)	1 – [100 * (one_car + two_car_pl) / ak_yht]	Not having a car may make it more difficult to move family and belongings from flood-risk area to safety in the event of flooding. Also, not having a car may be related to low income.
25.	Percentage of single person households	YKR car owner	2014 (?)	100* ak_1 / ak_yht	People living on their own may lack support in the event of flooding or heatwaves, in particular if they have health problems.
26.	Percentage of households containing 7 or more people households	YKR car owner	2014 (?)	100* ak_7 / ak_yht	Larger households (with more people) may be more difficult to evacuate in the case of emergency and to provide housing for in the recovery phase.
27.	Percentage of children aged 0-6 years in the population	YKR population	2014 (?)	100 * v_0_6 / v_yht	Young children and babies are one of the age groups prone to health problems related to flooding and high temperatures.
28.	Percentage of school age children in the population	YKR population	2014 (?)	100* v_7_14 / v_yht	Parents of school-age children are a group that tends to have the most extensive social networks through their engagement in school activities with other parents and as a result of their children social networks. Therefore, higher percentage of school-age children may suggest higher levels of self-help in a community or neighbourhood and thus lower social vulnerability.
29.	Percentage of people over 75 years old in the population	YKR population	2014 (?)	100 * v_75 / v_yht	Older people are more prone to health problems associated with flooding and heat waves.
30.	Percentage of women over 75 years old in the population	YKR population	2014 (?)	100 * v_75n / v_yht	Older women in France have been found to have higher death rates as a result of heat than older men (Pirard et al., 2005), therefore they have been identified as a potentially highly vulnerable group.
31.	Average commute length	YKR commute	2014 (?)	Sum of [(matka * yht)] / [number of commuting trips in the grid cell]	Places that are characterised by high average commute length may not be reached by their inhabitants easily in the event of flooding. Therefore, these areas may suffer grater material losses, or the people who are 'left behind' (economically inactive, older, children) may require additional support because they cannot rely on the presence of their family members.
32.	Number of households rented from ARA	Social housing	?	H_res_apt	People living in rented accommodation, in comparison to owner-occupiers, have less control over the physical characteristics of the dwelling that would reduce the risk of overheating or flood water ingress. In the UK tenants are less likely to have contents insurance than owner-occupiers. In the aftermath of flooding, tenants are dependent on their landlords to refurbish the dwellings damaged by flood waters. In addition, people renting from ARA (The Housing Finance and Development Centre of Finland) are likely to have lower incomes.
33.	Access in the case of emergency	YKR commute and Accessibility	2014/ 2012?	Mean commute distance * accessibility class	Places that are characterised by high average commute length, and additionally have low accessibility by walking, cycling or public transport, may not be reached by their inhabitants easily in the event of flooding due to the time-consuming journey and limited travel modes. Therefore, these areas may suffer grater material losses, or the people who are 'left behind' (economically inactive, older, children) may require additional support because they cannot rely on the presence of their family members.

Table 1. Initial set of indicators of social vulnerability to climate change (in no particular order)

6 Reduction of the number of indicators based on the analysis of correlations

Spearman's rank correlation was used to investigate the associations between the indicators identified in the available datasets. This type of correlation analysis does not require a linear relationship between the two variables and thus provides a good method of quickly and efficiently analysing the relationships between indicators. The presence of strong correlations (exceeding +/- 0.8) was used as a basis for reducing the number of indicators. The decision, which of the highly-correlated indicators to remove from the dataset was also supported by the currency (date) of the dataset and the number of missing values[2].

6.1 Analysing correlations among indicators related to income

a) Average income of households (grid database 2012; tr_ktu) and median income of households 2012 were very strongly correlated (grid database; tr_mtu): $r=0.957$; $p< 0.001$

   The median income was retained as an indicator as median values tend to be affected by extreme values (outliers) in the data to a lesser extent than mean values. Therefore, median income is more representative as a central tendency measure for grid cells with large variations in incomes between individual households. In addition, at the scale of the Helsinki Metropolitan Area, the charts below (Figures 3 and 4) show how the average (mean) income tends to have more extreme values, skewing the distribution of data more than the median income; whilst the median income does not exceed 200,000 euros, the highest mean income exceeds 1 million euros.

[2] In several of the datasets provided, the values for grid cells with low number of households or population were hidden (values of -1). Also, some of the datasets had radix values of 0 for some grid cells, thus precluding calculation of percentages for these cells (as this would require division by 0). The cells for which it was not possible to record or calculate the indicators were recorded as missing the given indicator (values of -2), and were excluded from further transformations and calculation of indices.

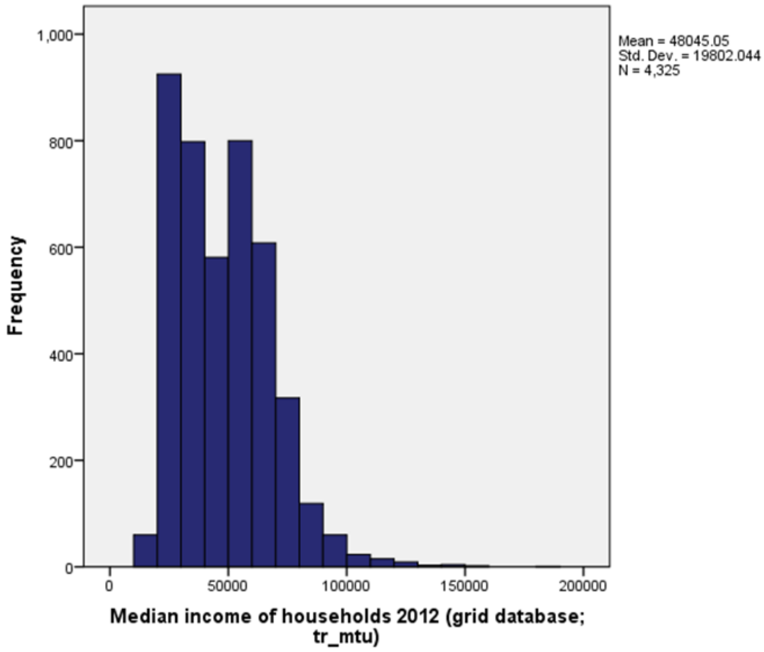

Figure 3. Median household income 2012. The outlying values have been circled as they are represented by single records and they are barely visible compared to the bars with high frequencies.

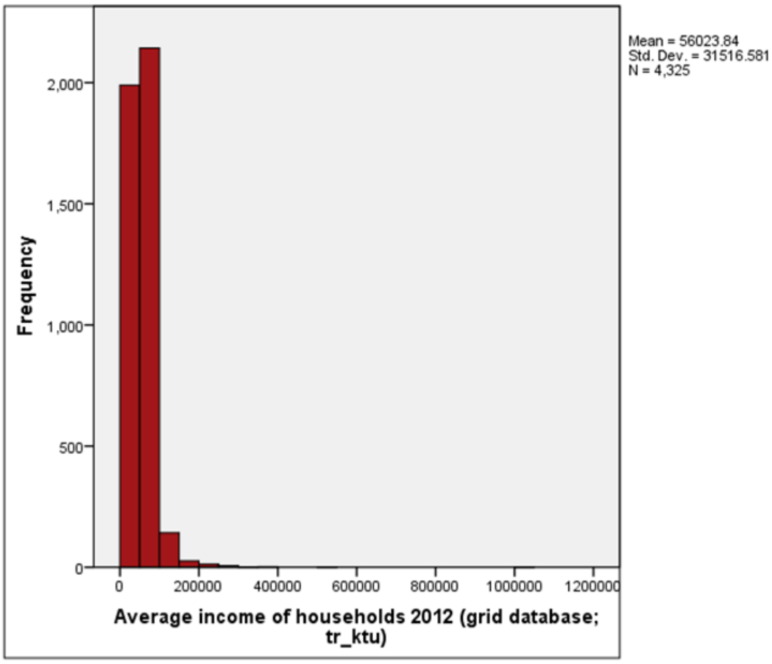

Figure 4. Mean household income 2012. The outlying values have been circled as they are represented by single records and they are barely visible compared to the bars with high frequencies.

b) Median household income (Grid Database; retained in the previous step) was positively and very strongly correlated with median income (YKR data): r=0.973; p< 0.001. The YKR median income was retained as a more up-to-date indicator (despite a marginally higher number of missing values: 2450 compared to 2488).

c) There was a strong negative correlation between the percentage of lowest income households (grid database) and median income (YKR data); (r=-0.813; p<0.001); the % of lowest income households indicators was rejected as the YKR median income indicator is more up to date.

d) There was a strong negative correlation between the percentage of households with no car and median income (YKR data): r=-0.816; p< 0.001. However, the information about percentage of households with no car also reflects social vulnerability to flooding associated with ease of access, evacuation and removal of belongings. It is not being used as a proxy for income; thus, both indicators have been retained.

6.2 Analysing correlations among indicators related to age

a) Percentage children of school age (YKR data) and percentage of households with children of school age (Grid Database) had very strong positive correlation: r= 0.910; p<0.001.

   Percentage of children of school age (YKR data) was retained as an indicator because it has 87 missing values (compared to 2450 missing values for percentage of households with children of school age in the grid database). Also, the YKR data is more recent.

b) Percentage of pensioners in the population and percentage of pensioner households had strong positive correlations: r=0.860; p<0.001

   Percentage of pensioners in the total population (YKR data) was retained because it has 1901 missing values compared to 2450 missing values for percentage of households with pensioners in the Grid Database. Also, the YKR data is more recent.

c) Percentage of pensioners in the population (retained in point b) had a strong, positive correlation with percentage of people over 75 years old in the population (r=0.820; p<0.001). The percentage of people over 75 in the population had only 87 missing values compared to 101 in the case of percentage of pensioners, thus the percentage of people over 75 in the population was retained.

d) There was understandably a strong positive correlation between the percentage of older people and percentage of women over 75 (r=0.892; p<0.001). The initial consideration of older females as a separate (sub)indicator of vulnerability to high temperatures was based on the literature reporting higher incidence of deaths in heat waves among older women compared to older men (e.g. Pirard et al., 2005). However, this evidence is largely limited to France and evidence from USA indicates that older men are more likely to die as a result of extreme temperatures than women (e.g. Berko et al., 2014). Therefore, the impact of gender on mortality and morbidity during high temperature spells is inconclusive and, consequently, only the indicator on the percentage of people over 75 has been retained in the list of indicators.

6.3 Analysis of correlations among other indicators

a. Average size of households had a very strong, negative correlation with percentage of single person households (YKR data) (r = -0.928; p< 0.001). Percentage of single-person households are a good indicator of potentially less dense social networks and less support available in the case of extreme weather; the links between the average size of households and their vulnerability to high temperatures and flooding are less straightforward (both single person and very large households may be more vulnerable – see Table 1). Therefore, average size of households has been removed from the list of indicators.

b. In addition, the average size of households has strong positive correlations with median income (YKR data; r=0.791; p<0.001) and percentage children of school age in the population (YKR data; r=0.752; p<0.001). Therefore, the information about household size is to a large extent captured by these two indicators.

c. Surprisingly, there was only a medium-strength correlation between the percentage of built-up areas and percentage of green space in the land area of the grid (r=-0.724; p<0.001). This may be due to these two indicators being developed based on different datasets and may indicate a spatial overlap between the built-up and green space categories of land cover. The percentage of total green space has been retained as an indicator, as it is easier to understand what it contains (low and high vegetation). Also, from the perspective of developing future climate adaptation actions, it may be easier to discuss the increase of green space rather than reduction of the build environment area.

d. There was no statistically significant correlation between the accessibility class and the average length of commute distance. Therefore, it is either possible to use both these indicators separately to inform about different aspects of accessibility, or to use their combination into the indicator of ‘access in case of emergency’. In discussion with HSY, accessibility class and ‘access in case of emergency’ were retained, and the average commute length was removed from the list of indicators.

The above analysis of bi-variate correlations allowed to remove 10 redundant indicators from the initial list and the revised indicator list includes 23 indicators (Table 2). 19 indicators of this list are relevant to social vulnerability to flooding and 15 relate to social vulnerability to high temperatures.

In addition, following the discussions with HSY, an indicator reflecting housing type was added to the dataset. Data was provided on number of dwellings in blocks of flats, which are potentially more difficult to ventilate and thus more prone to overheating than houses.

Code	Indicator	Aspect of vulnerability	Number of grid cells with valid values	Processing method
i_1	Location within 1km from a railway station	Access	6813	Reversing (1 – value)
i_2	Accessibility zone	Access	6629	Range standardisation
i_3	Percentage of households with no car	Access	5948	Range standardisation
i_4	Access in case of emergency	Access	6287	Log (ln) transformation; Range standardisation
i_5	Percentage of people with basic studies	Information	4884	Range standardisation
i_6	Percentage of children 0-6 years old	Age	6726	Range standardisation
i_7	Percentage of people over 75 years old	Age	6726	Range standardisation
i_8	Percentage of unemployed in the labour force	Income	4573	Range standardisation
i_9	Percentage of economically inactive people in the population	Income	6756	Range standardisation
i_10	Percentage of long-term unemployed in the labour force	Income	6496	Range standardisation
i_11	Median household income	Income	4363	Log (ln) transformation; Range standardisation; Reversing (1 – value)
i_12	Occupancy rate	Overcrowding	4363	Range standardisation; Reversing (1 – value)
i_13	Percentage of households containing 7 or more people	Overcrowding	5948	Range standardisation
i_14	Percentage of dwellings in flats	Housing	6617	Range standardisation
i_15	Percentage of water area in the grid cell	Physical environment	6813	Range standardisation; Reversing (1 – value)
i_16	Percentage of total green space area in the land area	Physical environment	6804	Range standardisation; Reversing (1 – value)
i_17	Percentage of low vegetation area in the land area	Physical environment	6804	Range standardisation; Reversing (1 – value)
i_18	Percentage of area covered by trees in land area	Physical environment	6804	Range standardisation; Reversing (1 – value)
i_19	Percentage of students in the population	Social networks	4912	Range standardisation
i_20	Percentage of single person households	Social networks	5948	Range standardisation
i_21	Percentage of school age children in the population	Social networks	6726	Range standardisation; Reversing (1 – value)
i_22	Percentage of rented households	Tenure	4363	Range standardisation
i_23	Percentage of dwellings rented from ARA	Tenure	6813	Range standardisation

Table 2. List of indicators selected based on the analysis of correlations and consultation with HSY.

Following the analysis of the descriptive statistics of these indicators, some minor corrections were made:

1) Percentage of long-term unemployed people was calculated against the radix (number of people in labour force) corrected by the average growth of the labour force in the Helsinki Metropolitan Area between 2012 (year when data on labour force was collected for the Grid database, see Table 1) and 2015 (the year of the long-term unemployment data). This growth was estimated by HSY as circa 3.43% (therefore, the new radix value was 103.43% of the number provided in the Grid database). The values in several grid cells, where the number of long-term unemployed people still exceeded the total labour force were corrected so that the percentage of long-term unemployed was 100%;

2) The cells where the percentage of total green space or percentage of low vegetation exceeded 100% of land area were changed to 100.00%;

$$\frac{x_i - X_{min}}{X_{max} - X_{min}}$$

3) The number of residential apartments rented from ARA was recalculated as a percentage of all residential apartments in the grid cell using an updated radix value provided by HSY.

7 Processing the indicators

The original set of indicators use different units (e.g. people; households; euros; m2/person). In order to be able to combine them into indices, they had to be processed to make them comparable with each other and allow their combination into indices. The processing methods used include logarithmic transformation, standardisation and reversing the values.

7.1 Logarithmic transformation

The vast majority of the indicators in Table 2 were calculated as percentages, therefore have a similar range of values. However, two of the indicators (Median household income – i_11 and Access in case of emergency – i_4) have large ranges of values, are substantially skewed and are characterised by the presence of outliers. These indicators needed to be log-transformed before further processing because outliers may affect the results of standardisation.

Natural logarithm transformation was used; coefficients on the natural-log scale are directly interpretable as approximate proportional differences: with a coefficient of 0.06, a difference of 1 in x corresponds to an approximate 6% difference in y (Gelman and Hill, 2007). Values of 0 were excluded from the logarithmic transformation.

7.2 Standardisation of indicators

In order to meaningfully combine the indicators into indices it is advisable to present them on uniform scales. Range standardisation used here results in the range of values between 0 and 1, which allows easy and transparent combination of the indicators into indices.

Range standardisation compares each value of a variable, xi, to the minimum, Xmin. This is then divided by the distance between the minimum, Xmin , and the maximum, Xmax , of the variable.

The formula is:

$$\frac{x_i - X_{min}}{X_{max} - X_{min}}$$

Range standardisation has been used by the English Office for National Statistics in developing classifications of output areas (smallest census units in the UK) since 1991, as it is well-suited to social data (ONS, 2015). However, this method does not work well if the data contain outliers, hence two of the indicators were log-transformed in the previous step.

Another commonly used method of standardisation is Z-scores. It was used in the assessment of vulnerability to climate change in the UK, on which this project is based (see Lindley et al. 2011 and Kazmierczak et al., 2015). This standardisation method compares each value of a variable, xi, to the variable mean x.

This is then divided by the standard deviation. Z-score standardisation works well when the data are normally distributed; however, this is not the case for the majority of the indicators in this assessment. Z-score standardisation also results in various ranges of values, including negative values, which may be problematic when the indicators are combined together (some indicators may cancel each other out). Therefore, the decision was made to replace this method with range standardisation here

7.3 Reversing the values

In the case of the majority of the indicators, high values are associated with high vulnerability. However, in the case of several indicators (i_1, i_11, i_12, i_15, i_16, i_17, i_18, i_21 – see Table 2), the higher values of the indicator suggest lower vulnerability. These indicators were reversed following the formula:

Final indicator = 1 - standardised value of the indicator

The spreadsheet developed in the course of this project (see section 10) provides values of original indicators, as well as their log-transformed, standardised and reversed values to allow tracing and replicating the processing of the indicators.

8 Developing the indices of social vulnerability to climate change

The indicators identified and processed in the previous steps were added together in different combinations to reflect various dimensions of vulnerability.

8.1 Positioning the indicators in the social vulnerability assessment framework

The alignment of the indicators against the vulnerability assessment framework is presented in Table 3. Different dimensions of vulnerability are represented by varying number of indicators. For example, enhanced exposure to flooding is represented by one only indicator (percentage of green space in the grid cell), whilst 14 indicators are relevant to the ability to respond to flooding.

Sensitivity (i.e. the personal characteristics that make individuals more prone to harm during extreme weather events) is calculated in the same manner for flooding and heat waves. In the case of social vulnerability to heat, the aspect of ‘ability to recover’ has not been considered (see also section 2). As opposed to flooding, in the case of heat the recovery of people after a spell of high temperatures is very quick and their physical environment is not affected or affected minimally compared to the aftereffects of floods.

Code[3]	Indicator	Aspect of vulnerability	Weight in vulnerability to flooding	Weight in vulnerability to heat	Sensitivity	Dimensions of social vulnerability to flooding				Dimensions of social vulnerability to heat		
						Ability to prepare	Ability to respond	Ability to recover	Enhanced exposure	Ability to prepare	Ability to respond	Enhanced exposure
i_1	Location within 1km from a railway station	Access	0.25	0			Y					
i_2	Accessibility zone	Access	0.25	0			Y					
i_3	Percentage of households with no car	Access	0.25	0			Y					
i_4	Access in case of emergency	Access	0.25	0			Y					
i_5	Percentage of people with basic studies	Information	1	1		y	y	Y		y	Y	
i_6	Percentage of children 0-6 years old	Age	0.5	0.5	Y							
i_7	Percentage of people over 75 years old	Age	0.5	0.5	Y							
i_8	Percentage of unemployed in labour force	Income	0.25	0.25		y	y	Y		y	Y	
i_9	Percentage of economically inactive people in the population	Income	0.25	0.25		y	y	Y		y	Y	
i_10	Percentage of long-term unemployed in the labour force	Income	0.25	0.25		y	y	Y		y	Y	
i_11	Median household income	Income	0.25	0.25		y	y	Y		y	Y	
i_12	Occupancy rate	Overcrowding	0.5	0			y	Y				
i_13	Percentage of households containing 7 or more people	Overcrowding	0.5	0			y	y				
i_14	Percentage of dwellings in flats	Housing	0	1								Y
i_15	Percentage of water area in the grid cell	Physical environment	0	0.33								Y
i_16	Percentage of total green space area in the land area	Physical environment	1	0					y			
i_17	Percentage of low vegetation area in the land area	Physical environment	0	0.33								Y
i_18	Percentage of area covered by trees in land area	Physical environment	0	0.33								Y
i_19	Percentage of students in the population	Social networks	0.33	0		y	y	Y				
i_20	Percentage of single person households	Social networks	0.33	0.5		y	y	Y		y	Y	
i_21	Percentage of school age children in the population	Social networks	0.33	0.5		y	y	Y		y	Y	
i_22	Percentage of rented households	Tenure	0.5	0.5		y		Y		y		
i_23	Percentage of dwellings rented from ARA	Tenure	0.5	0.5		Y		y		y		
Number of indicators used in calculation of indices		23	19	15	2	10	14	12	1	9	7	4

Table 3. Alignment of the indicators used in the assessment with the components of the framework

[3] Used in the accompanying shapefile

8.2 Calculating the indices of social vulnerability to climate change

Calculating the indices of social vulnerability to climate change in this project is based on the following assumptions:

a) All aspects of vulnerability (access, information, age, income, overcrowding, housing, physical environment, social networks and tenure, see Table 3) have equal importance;

b) All indicators within a given aspect of vulnerability used in the assessment of social vulnerability to flooding or heat waves have equal importance.

This means that in calculating the indices of social vulnerability to climate change, the indicators are multiplied by [1 / number of indicators in the aspect of vulnerability] in order to avoid over-representing the aspects with a higher number of indicators (see Table 3). For example, in the case of the sensitivity aspect, both percentage of children under 6 years old and percentage of people over 75 years old are multiplied by 0.5 as there are two indicators in this domain; the weight of the income indicators is 0.25, due to the presence of four indicators in this aspect.

Table 4 presents the formulas used in the calculation of indices. In the previous approach used in the UK (Lindley et al., 2011; Kazmierczak et al., 2015), the combined index of vulnerability was a sum of sensitivity, enhanced exposure and ability to prepare, respond and recover. However, this resulted in double- or even triple-counting of some of the indicators that contribute to more than one dimension of vulnerability (and therefore effective double or triple weighting of the income, information and social network aspects). To avoid this, in this project all relevant indicators have been included only once in the assessment of total vulnerability to flooding and heat waves.

Additionally, the values for indices representing individual aspects of vulnerability (or ‘thematic domains’, e.g. income or access) were calculated to enable presenting the spatial distribution of various issues influencing vulnerability in the Helsinki Metropolitan Area.

The indices were calculated for the highest possible number of cells in the grid. The indicators were characterised by different numbers of missing values (see Table 2); consequently, the indices were calculated for the cells for which all indicators contributing to a given index had valid values. As a result, the indices are available for cell count varying between 4217 (61.9% of the grid cells) in the case of total social vulnerability to flooding and 6804 (99.9% of the grid cells) for enhanced exposure to flooding (Table 4).

All indices after calculation were standardised using range standardisation in order to represent them on a uniform scale 0-1. However, it should be noted that whilst for all indices the values range between 0 and 1, they reflect the range of values for a given index only. Therefore, the values cannot be compared among the indices (in particular for indices developed for different collection of grid cells).

In the case of ability to prepare, respond and recover, the final index values were reversed (1 – standardised value), so that a low score reflects a low ability to prepare, respond or recover, and high score – high ability to prepare, respond and recover. This was done in order to avoid describing and interpreting the maps from the angle of low and high ‘inability’ to prepare, respond and recover.

Code[4]	Index	Formula (see Table 4 to compare codes and weightings)	Number of grid cells with valid index	% of grid cells with valid index
SENS	Sensitivity to flooding and high temperatures	0.5*i_6 + 0.5*i_7	6726	98.7
F_EXP	Enhanced exposure to flooding	i_16	6804	99.9
F_A_PRE	Ability to prepare for flooding	i5 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + 0.33*i_19 + 0.33*i_20 + 0.33*i_21 + 0.5* i_22 + 0.5*i_23	4257	62.5
F_A_RESP	Ability to respond to flooding	0.25 * i_1 + 0.25 * i_2 + 0.25 * i_3 + 0.25 * i_4 + i_5 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + (0.5*i_12 + 0.5 * i_13 + 0.33*i_19 + 0.33*i_20 + 0.33*i_21	4218	61.9
F_A_REC	Ability to recover after flooding	i_5 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + 0.33*i_19 + 0.33*i_20 + 0.33*i_21 + 0.5* i_22 + 0.5*i_23 + 0.5*i_12 + 0.5 * i_13	4257	62.5
F_VULN	Total social vulnerability to flooding	0.25 * i_1 + 0.25 * i_2 + 0.25 * i_3 + 0.25 * i_4 + i_5 + 0.5*i_6 + 0.5*i_7 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + 0.5*i_12 + 0.5 * i_13 + 0.33*i_19 + 0.33*i_20 + 0.33*i_21 + i_16 + 0.5* i_22 + 0.5*i_23	4217	61.9
H_EXP	Enhanced exposure to high temperatures	i_14 + 0.33 * i_15 + 0.33 * i_17 + 0.33 * i_18	6615	97.1
H_A_PRE	Ability to prepare for high temperatures	i_5 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + 0.5*i_20 + 0.5*i_21 + 0.5* i_22 + 0.5*i_23	4311	63.3
H_A_RESP	Ability to respond to high temperatures	i_5 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + 0.5*i_20 + 0.5*i_21	4311	63.3
H_VULN	Total social vulnerability to high temperatures	i5 + 0.5*i_6 + 0.5*i_7 + 0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11 + i_14 + 0.33 * i_15 + 0.33 * i_17 + 0.33 * i_18 + 0.5*i_20 + 0.5*i_21 + 0.5* i_22 + 0.5*i_23	4307	63.2
ACCESS1	Domain score - Access	0.25 * i_1 + 0.25 * i_2 + 0.25 * i_3 + 0.25 * i_4	5773	84.7
AGE	Domain score – Age	0.5 * i_6 + 0.5 * i_7	6726	98.7
INCOME	Domain score – Income	0.25*i_8 + 0.25*i_9 + 0.25*i_10 + 0.25*i_11	4311	63.3
INFO	Domain score – Information	i_5	4884	71.7
TENURE	Domain score – Tenure	0.5* i_22 + 0.5*i_23	4363	64.0
GREEN	Domain score – Greenspace	0.33 * i_15 + 0.33 * i_17 + 0.33 * i_18	6804	99.9
SOC_NETS	Domain score – Social networks	0.33*i_19 + 0.33*i_20 + 0.33*i_21	4642	68.1
OVERCROWD	Domain score - Overcrowding	0.5*i_12 + 0.5 * i_13	4363	64.0

Table 4. Formulas used to calculate the indices of social vulnerability to climate change

[4] As used in the accompanying shapefile

8.3 Spatial representation of the indices of social vulnerability to climate change

The indices calculated following the formulas in Table 4 can be presented spatially. The maps in this section apply equal interval classification in five classes, slicing the 0-1 range into 0.2-wide intervals (Table 5). The maps in Figures 5-10 show varying spatial distribution of different dimensions of vulnerability to flooding; Figures 11-14 show the mapped dimensions of vulnerability to heat, whilst Figure 15 shows an overview of the thematic domains, or aspects of vulnerability. These maps emphasise the multi-dimensional character of social vulnerability to climate change. On all maps, darker shades indicate higher vulnerability.

Value of index	Label
0.00 – 0.20	Very low
0.21 – 0.40	Low
0.41 – 0.60	Medium
0.61 – 0.80	High
0.81 – 1.00	Very high

Table 5. Values of indices of social vulnerability to flooding and labels used

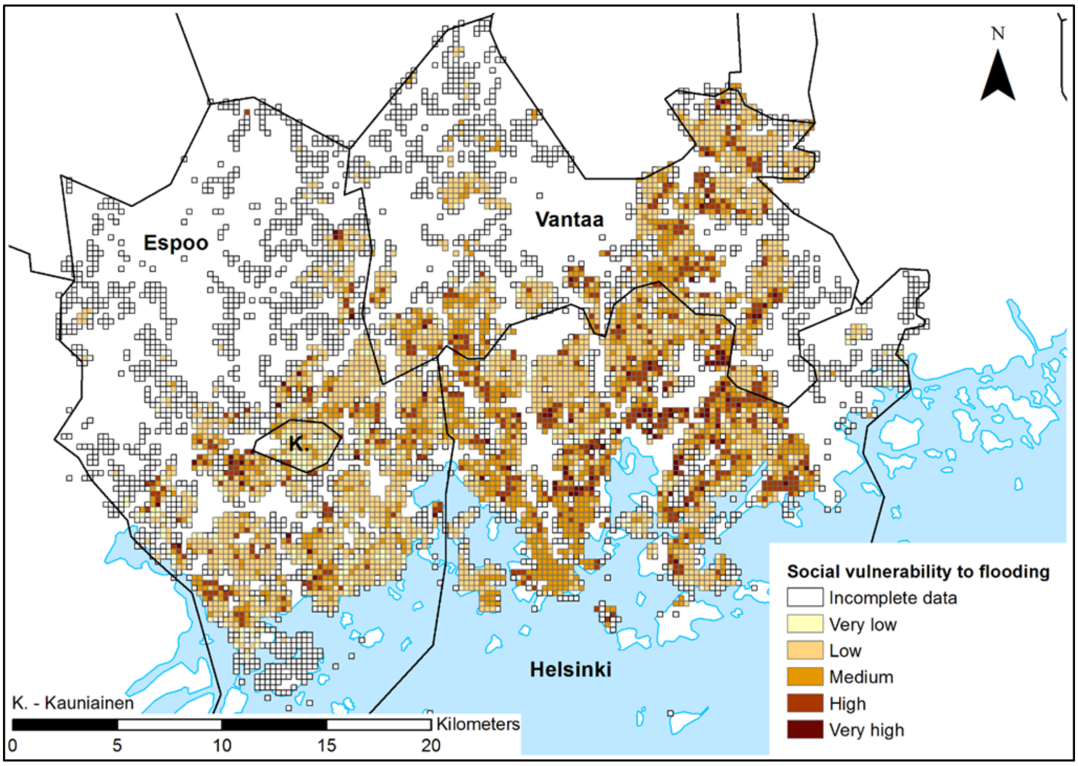

Figure 5. Social vulnerability to flooding in the Helsinki Metropolitan Area.

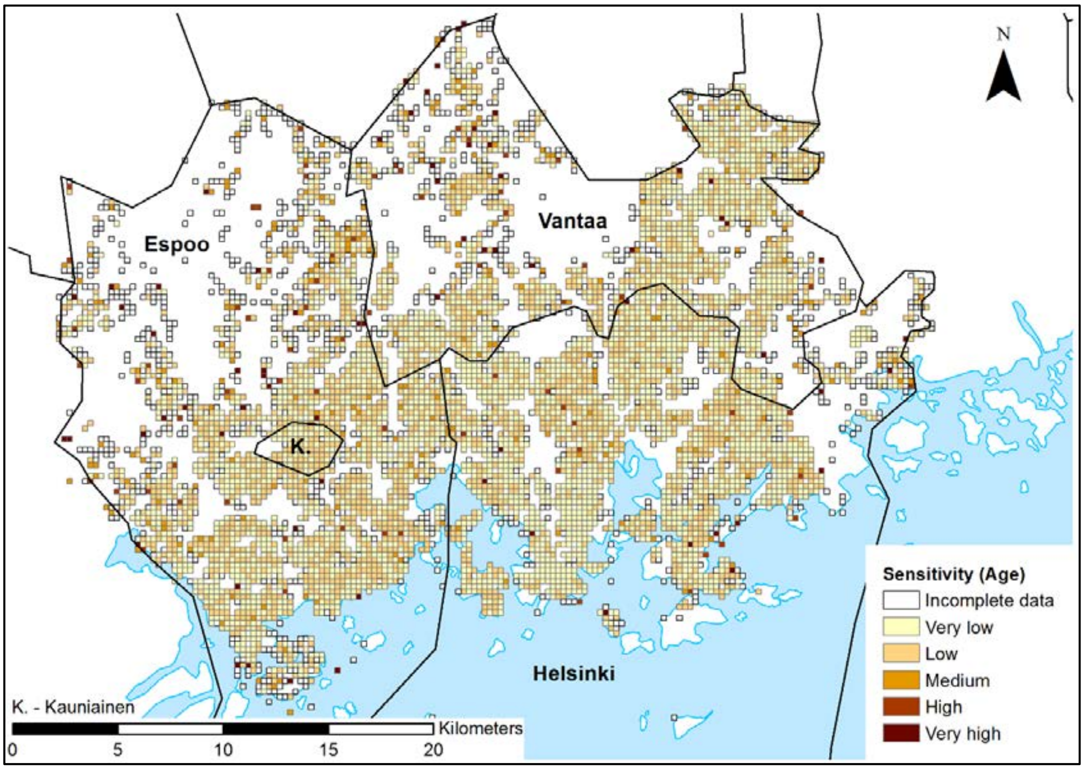

Figure 6. Sensitivity to flooding and heat waves in the Helsinki Metropolitan Area.

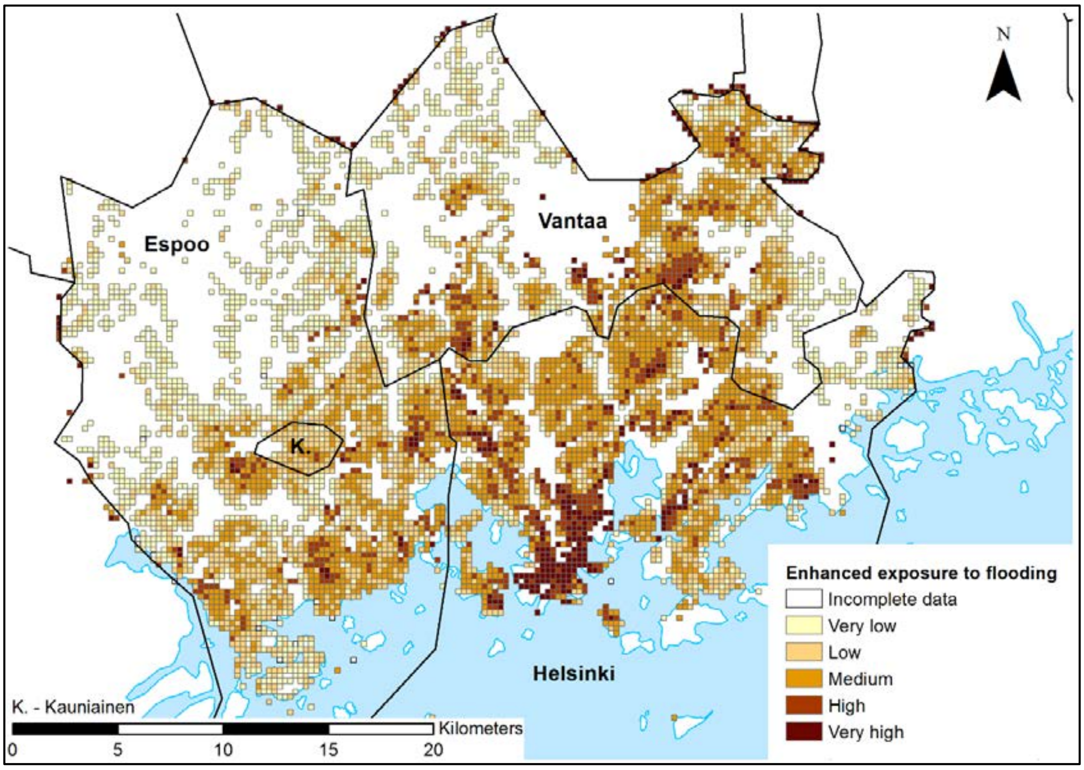

Figure 7. Enhanced exposure to flooding in the Helsinki Metropolitan Area.

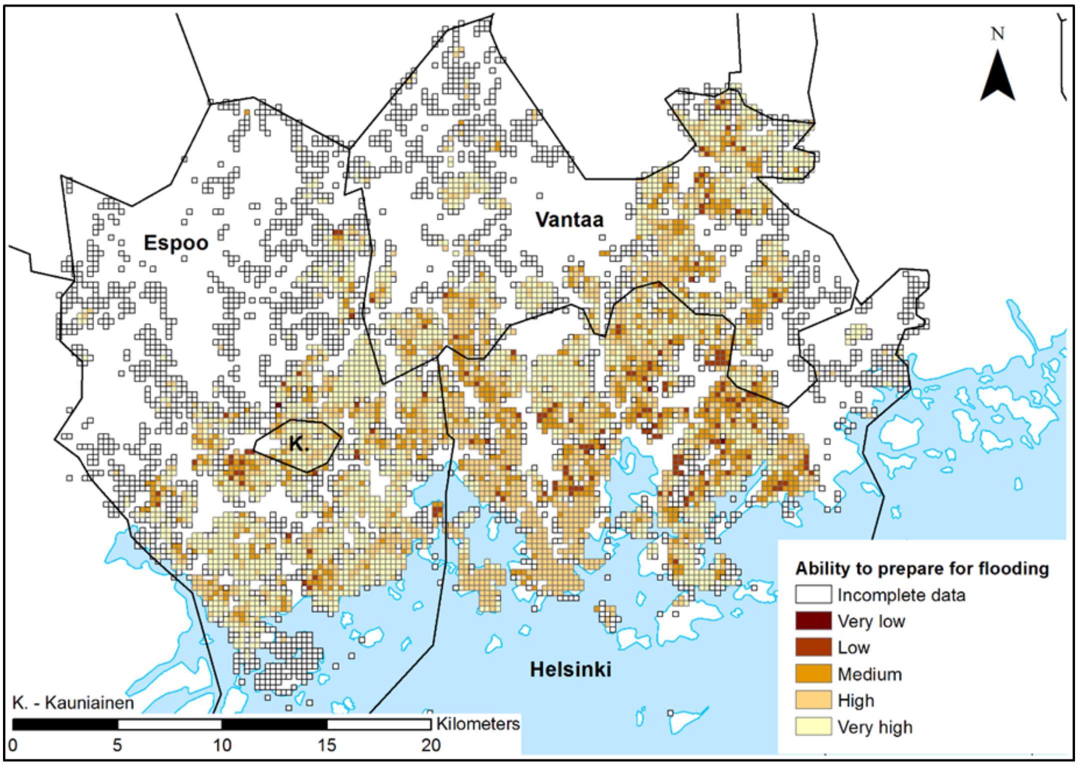

Figure 8. Ability to prepare for flooding in the Helsinki Metropolitan Area

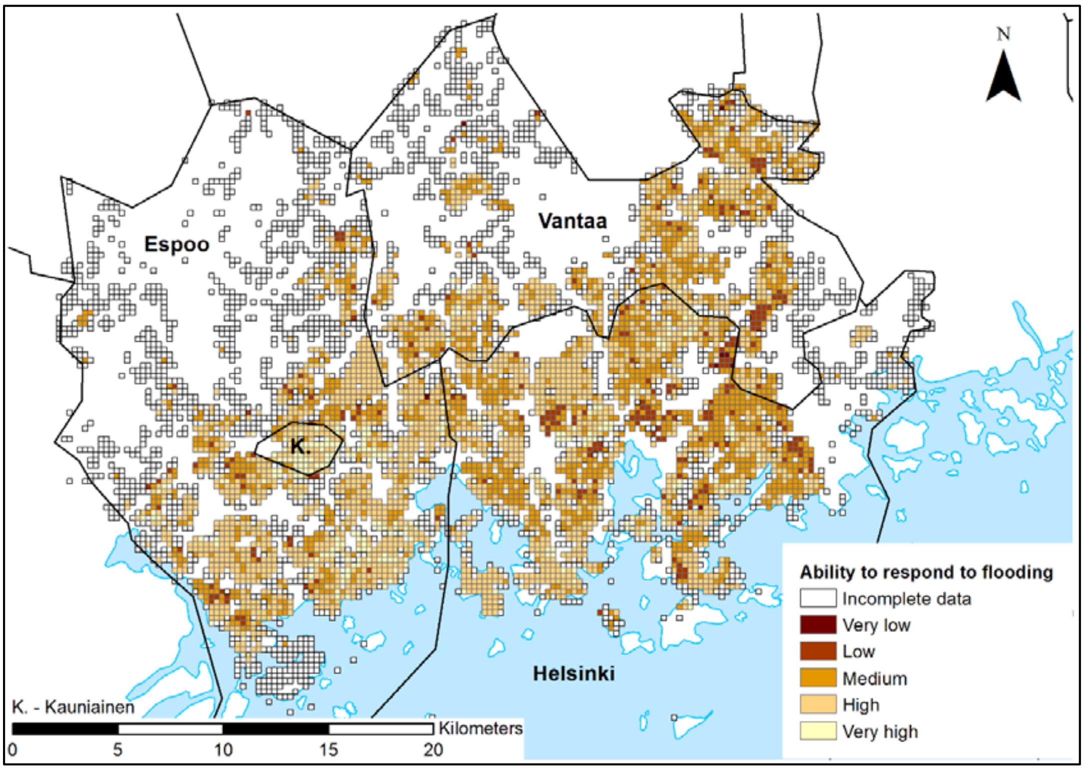

Figure 9. Ability to respond to flooding in the Helsinki Metropolitan Area

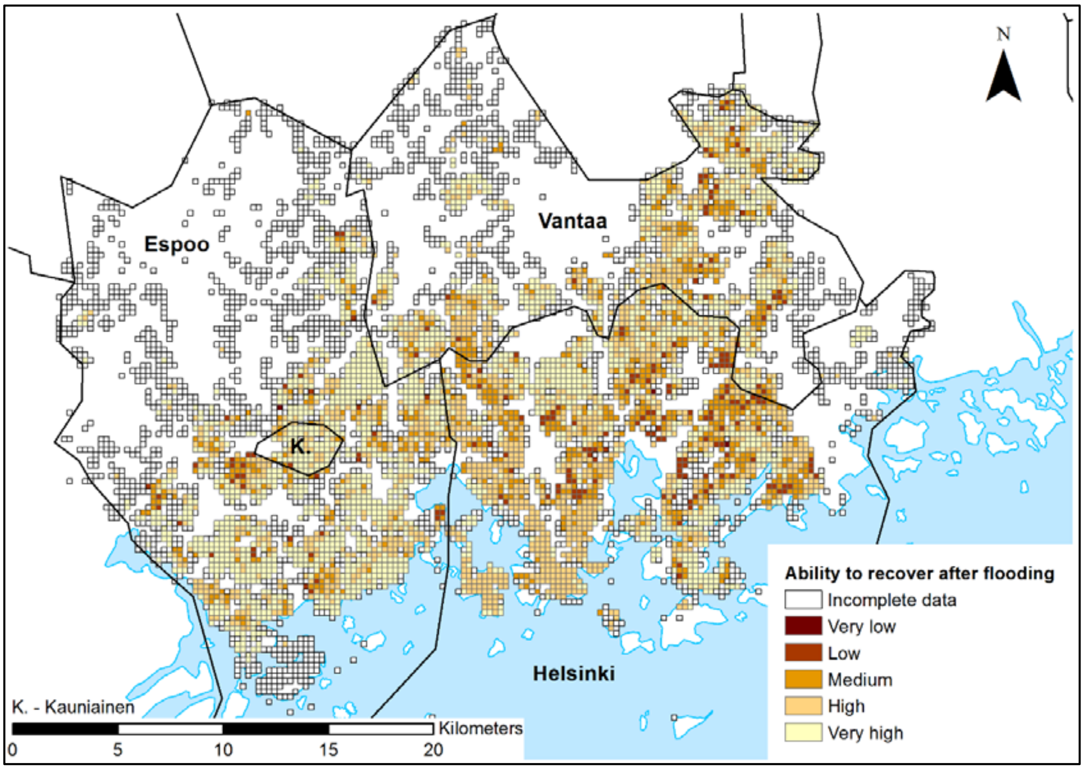

Figure 10. Ability to recover after flooding in the Helsinki Metropolitan Area

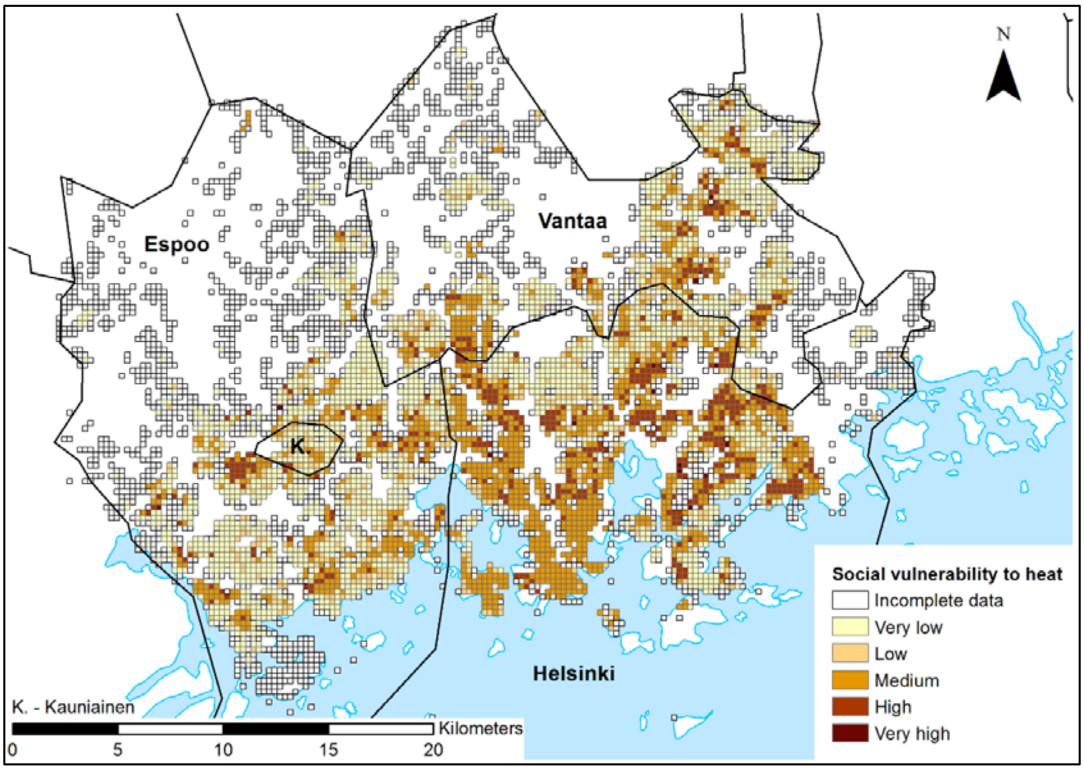

Figure 11. Social vulnerability to high temperatures in the Helsinki Metropolitan Area

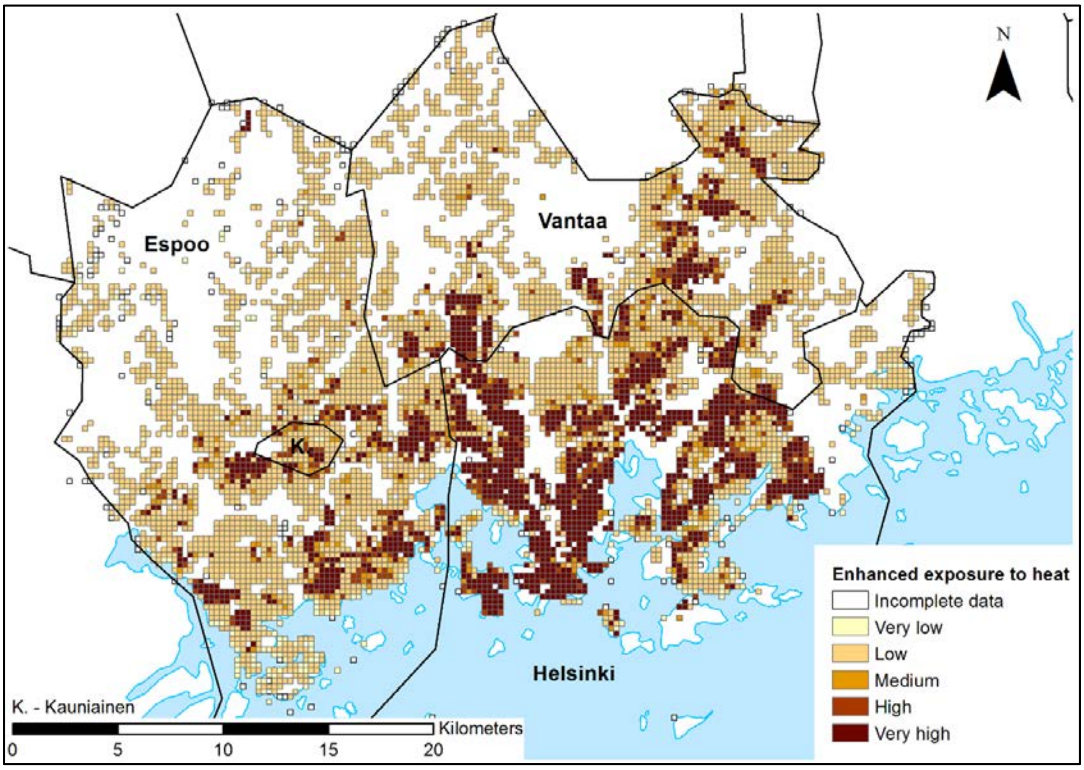

Figure 12. Enhanced exposure to high temperatures in the Helsinki Metropolitan Area

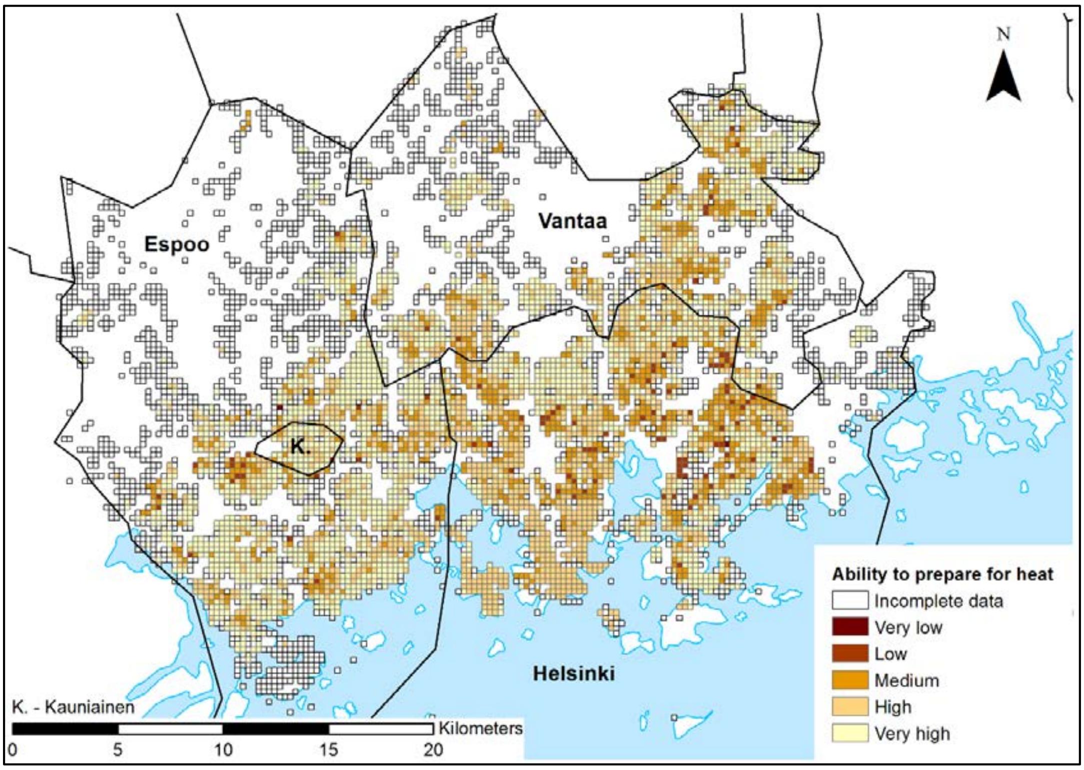

Figure 13. Ability to prepare for high temperatures in the Helsinki Metropolitan Area

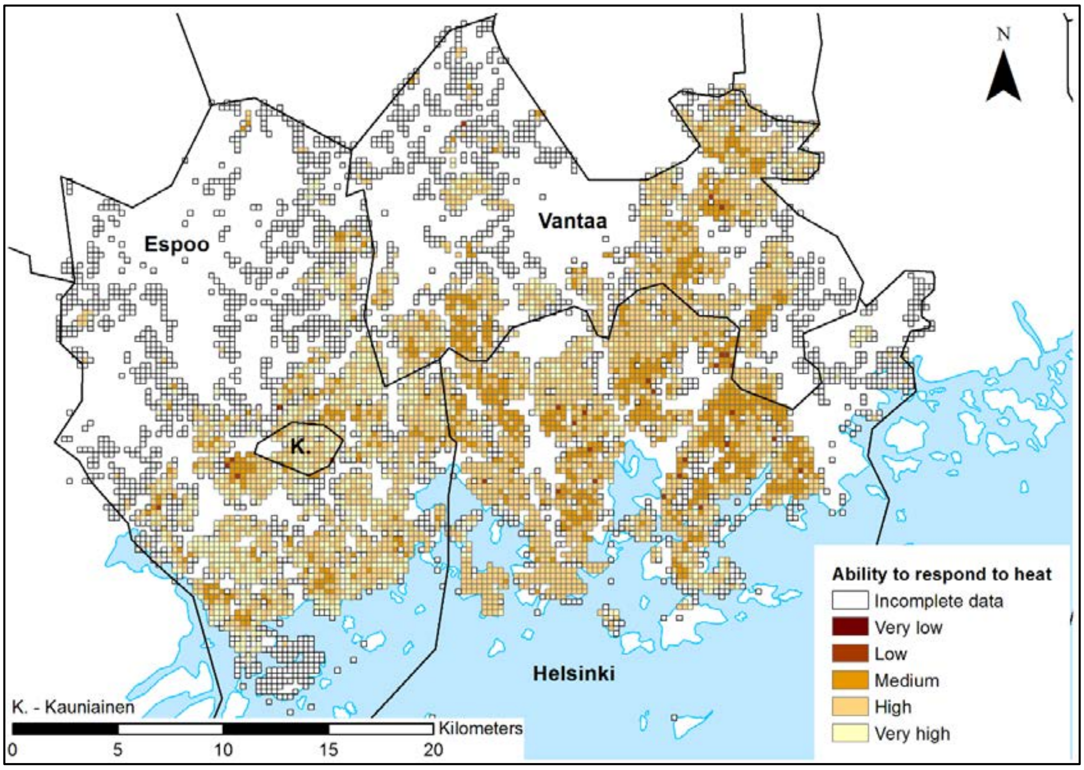

Figure 14. Ability to respond to high temperatures in the Helsinki Metropolitan Area.

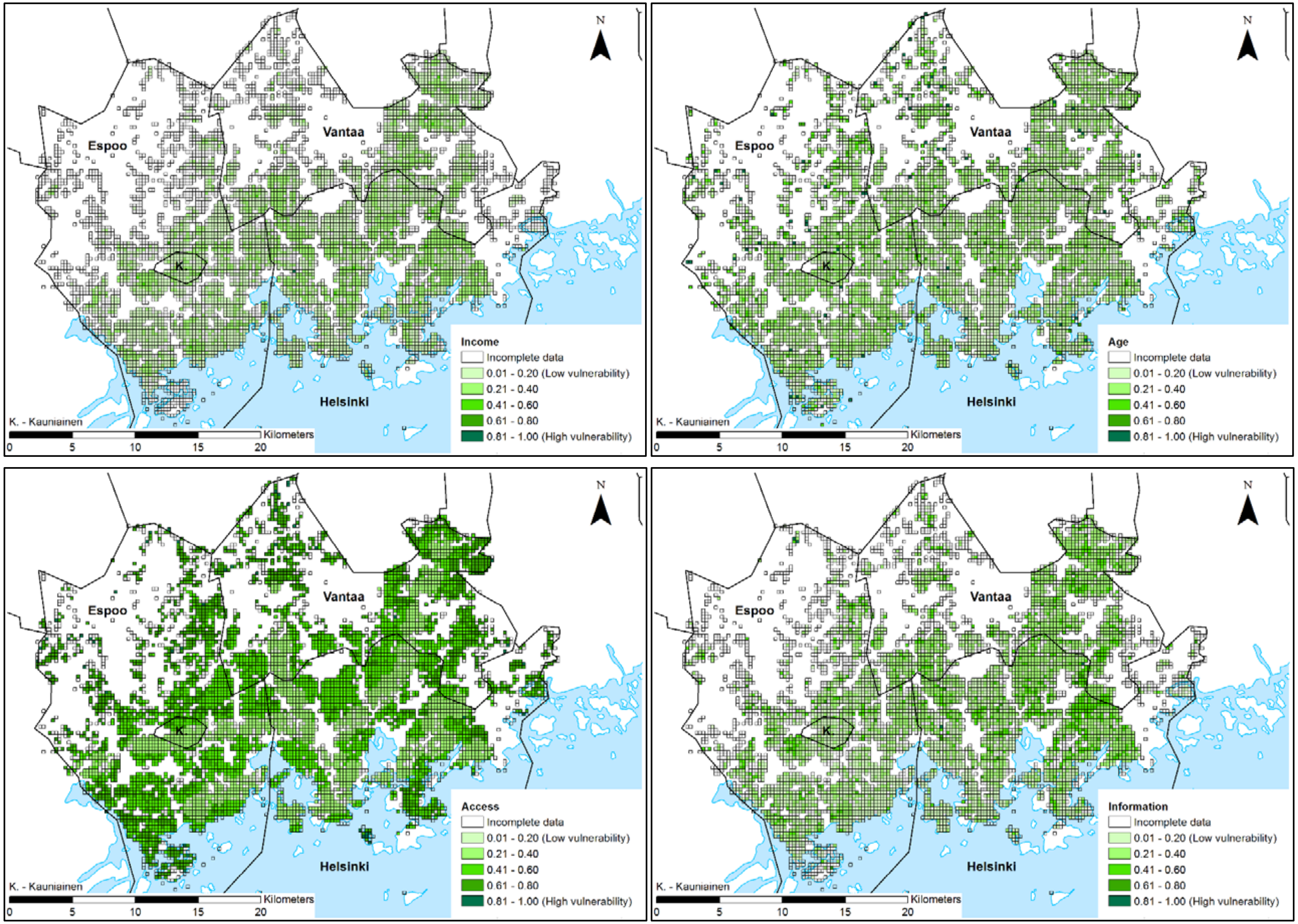

Figure 15. Aspects of social vulnerability to climate change in the Helsinki Metropolitan Area

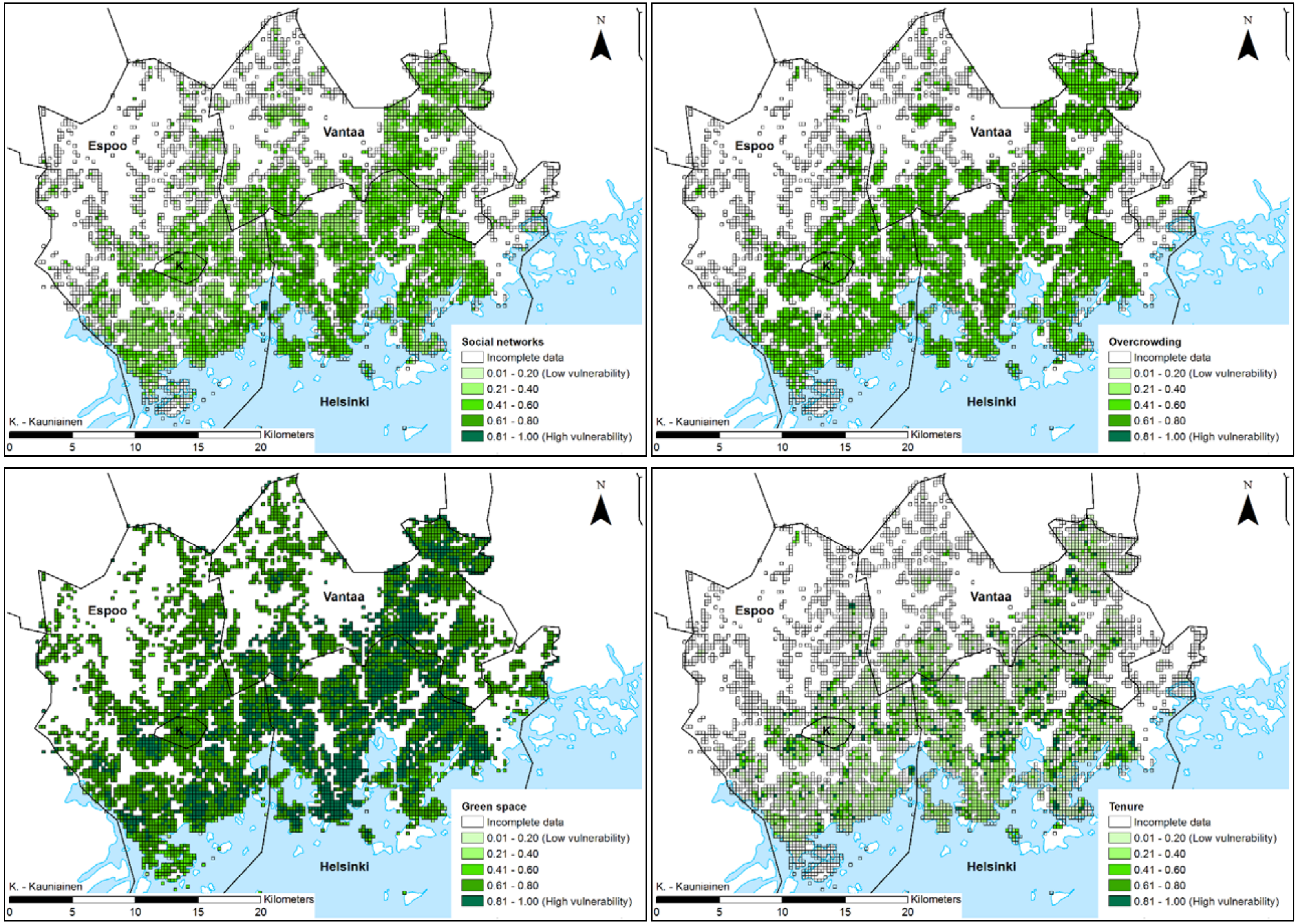

Figure 15 continued. Aspects of social vulnerability to climate change in the Helsinki Metropolitan Area.

9 Combining the index of vulnerability to flooding with the flood hazard

The indices of social vulnerability to climate change provide only the information, where the communities that could be particularly negatively affected by flooding or high temperatures are located. In order to assess, which places are at high risk, or disadvantage, from climate change impacts it is necessary to investigate to what extent high social vulnerability spatially coincides with hazards (see Figure 1).

In the case of this project, the data representing spatial distribution of high temperatures (urban heat island) in the Helsinki Metropolitan Area was deemed insufficient by HSY. However, the presence of data on different types and return periods of flooding has made it possible to assess flood disadvantage.

9.1 Hazard of flooding from river, sea and lakes

The hazard of flooding from rivers, sea and lakes was calculated based on the information on the number of dwellings in grid cells that are potentially exposed to flooding (i.e. which are located within the spatial flood extents) and are not protected from flooding. The percentage of such dwellings in the grid cells in relation to the total number of dwellings (additional data provided by HSY) represents the level of hazard.

Four return periods were considered: 1:20; 1: 50; 1: 100 and 1: 250 years, in order to represent the floods of high likelihood and low magnitude as well as less probable but more severe events.

The hazard indices were standardised again to enable presenting them on the scale 0-1.

9.2 Pluvial flooding hazard

The probability of pluvial flooding was represented in the spatial dataset as 10 classes; classes 0-7 representing different probability of surface water flooding (class 0 being the lowest probability; class 7 – the highest); class 8 being bedrock and class 9 - surface water. Each of the grid cells was described by the area belonging to each of these classes.

The surface water class was excluded from the calculation and the bedrock class was separated by HSY into areas with zero or very little slope (<3%), seen as having high probability of pluvial flooding (class 8) and areas with higher slope, seen as having lower probability of pluvial flooding (class 4).

The formula to assess the combined hazard of pluvial flooding per grid cell used weighted approach (the higher the pluvial flooding probability class, the higher the weight) and was as follows:

Hazard of pluvial flooding = (area of class 0 * 1) + (area of class 1 * 2) + (area of class 2 * 3) + (area of class 3 * 4) + (area of class 4 * 5) + (area of class 5 * 6) + (area of class 6 * 7) + (area of class 7 * 8) + (area of class 8 * 9)

The pluvial hazard index was standardised again to enable presenting it on the scale 0-1.

9.3 Indices of flood disadvantage

The indices of flood disadvantage were calculated for each of the flood hazard types separately as a sum of the index of social vulnerability to flooding and hazard index. The indices were calculated only for the grid cells where two conditions were met:

a) The hazard of flooding was present – if there is no risk of flooding, flood disadvantage cannot be calculated (see section 2);

b) The index of social vulnerability to flooding had valid values.

Due to the limited number of unprotected residential properties at risk of flooding, only a small number of grid cells had valid values of index of hazard of flooding from the sea, rivers and lakes present. In addition, some of the cells where the flooding hazard was present, did not have valid values of social vulnerability index due to e.g. low population numbers. This resulted in a very low number of grid cells with valid values of flood disadvantage (Table 5).

However, in the case of pluvial flooding, the information on the probability of flooding was available for nearly all the grid cells, and the main limitation was the availability of the valid index of social vulnerability to flooding.

The final indices of flood disadvantaged were standardised using range standardisation to present them on a scale 0-1. However, it should be noted that this standardisation method, when applied to a very low number of cells in the case of flooding from rivers, sea and lakes may overinflate differences in the flood disadvantage index between cells with relatively low number of properties exposed to the hazard of flooding.

Code[5]	**Index**	**Number of grid cells with valid index**	**% of grid cells with valid index**
F_DIS_20	Flood disadvantage – rivers, sea and lakes 1:20	13	0.2
F_DIS_50	Flood disadvantage – rivers, sea and lakes 1:50	22	0.3
F_DIS_100	Flood disadvantage – rivers, sea and lakes 1:100	32	0.5
F_DIS_250	Flood disadvantage – rivers, sea and lakes 1:250	68	1.0
F_DIS_PLUV	Flood disadvantage – pluvial flooding	4217	61.9

Table 5. Spatial coverage of flood disadvantage

Due to the low number of grid cells with valid values of flood disadvantage, and their dispersed spatial distribution across the Helsinki Metropolitan Area, it was difficult to present flood disadvantage related to flooding from rivers, sea and lakes. However, the spatial distribution of pluvial flood disadvantage is presented in Figure 16.

[5] As used in the accompanying shapefile.

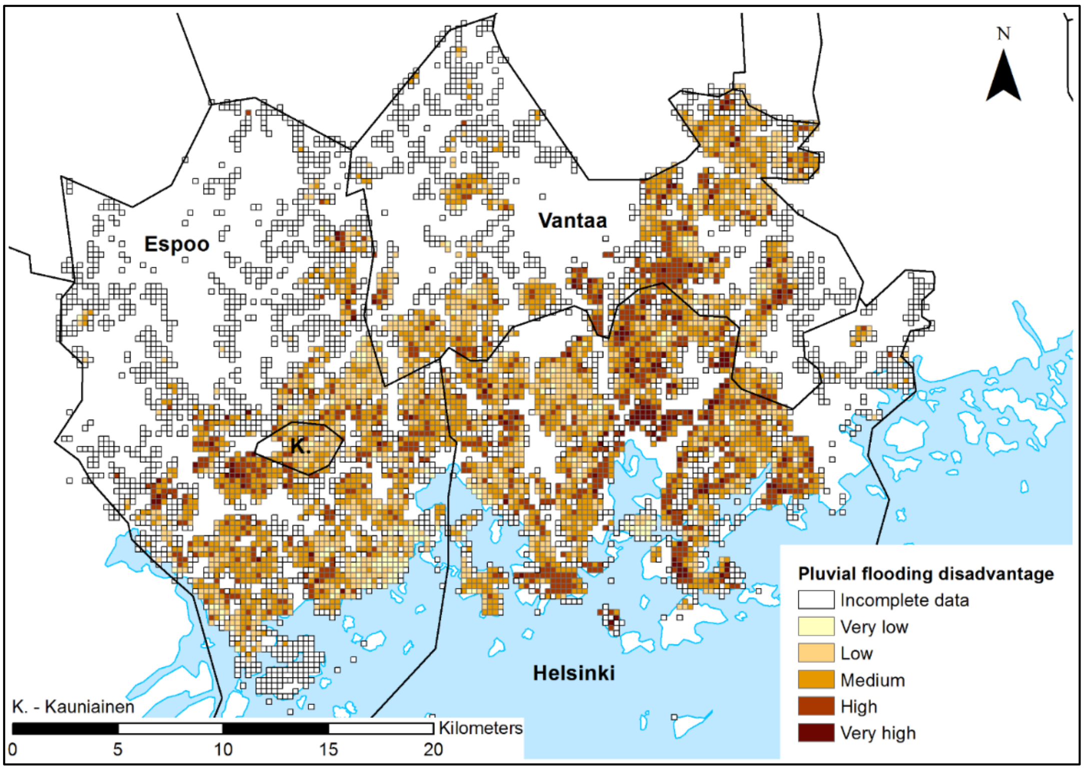

Figure 16. Pluvial flood disadvantage in the Helsinki Metropolitan Area.

Datasets resulting from the project

The project resulted in two datasets:

a) A shapefile containing the final, processed indicators (as per Table 3), indices of social vulnerability to climate change (Table 4) and indices of flood disadvantage (Table 5). The shapefile can be used for producing maps of social vulnerability and disadvantage.

b) A more extensive Excel spreadsheet containing, alongside the indices in the shapefile, the original (unprocessed) indicators (formulas as per Table 1); standardised, log-transformed and reversed indicators. The spreadsheet also includes the hazard indicators (and steps leading to their development), as well as the steps leading to the development of flood disadvantage indices. This dataset is meant to allow replicating the process for more recent datasets as they emerge and including additional datasets.

In both datasets, the hidden or missing values are coded as -1 and -2. It is important to exclude the cells with these values from any calculations.

10 Limitations and strengths of the methods used

The project utilises a conceptual framework which has been used in various projects in the UK since 2011 (Lindley et al., 2011). It was applied in assessing and updating flood disadvantage in Scotland (Lindley and O'Neill, 2013; Kazmierczak et al., 2015) and is currently underpinning the assessment of social vulnerability to climate change in Wales (led by Aleksandra Kazmierczak). The framework has been used as a basis for mapping social climate change in online portals such as ClimateJust[6] or the online ArcGIS platform utilised by the Scottish Government to publicise the results of the 'Mapping Flood Disadvantage in Scotland 2015' project[7]. As a result, the framework has been recognised by local authorities in the UK and various public agencies, e.g. Public Health England or the Environment Agency as a valid approach to understanding the potential for negative impacts of climate change-related hazards. It has also generated interest in other countries such as Slovakia. Therefore, it is justified to use this tried and tested approach in the context of the Helsinki Metropolitan Area.

The main strength of the framework is the disaggregation of the index of vulnerability into the aspects of sensitivity, enhanced exposure, and ability to prepare, respond and recover. This allows planning of specific adaptive actions for different phases of emergency situations (planning, response, recovery) or for particular social or physical environment aspects of vulnerability. At the same time, combining various aspects of social vulnerability to climate change into one index helps to understand the overall potential for losses in health and well-being that may be posed by climate hazards.

However, at the same time, the extensive user consultations in the previous project highlighted some difficulties with understanding the framework, mainly due to the novelty of terms such as 'enhanced exposure' or 'disadvantage'. It has also been pointed out that the framework departs from the definitions of sensitivity, adaptive capacity or vulnerability used by the IPCC in their reports, which may create some confusion. Therefore, it is recommended that the terms used in the framework are consulted with the potential users of the resulting indices and maps, and adjusted as needed. Further, the outputs of the vulnerability assessment should ideally be accompanied by a brief explanation of the framework and its terms (see section 2 and also Lindley et al. 2011 or Kazmierczak et al. 2015).

A major strength of the approach used here is the multifaceted understanding of social vulnerability to climate change, which goes beyond assessing the population characteristics only from the perspective of income or demographics. The indicator set developed in the scope of this project reflects nine different aspects of vulnerability (age, income, access, social networks, information, tenure, overcrowding, housing, physical environment), therefore is quite comprehensive. Table 6 aligns the indicators used in this project with the indicators and thematic domains used in the 'Mapping Flood Disadvantage in Scotland 2015' project (Kazmierczak et al., 2015), which utilised the same conceptual framework.

The table indicates that some of the aspects of vulnerability are well-covered in the current assessment: age, tenure, income, social networks, access and physical environment. In addition, indicators relating to potential overcrowding were added. However, some additional aspects of vulnerability may be worth considering in the future:

[6] http://www.climatejust.org.uk/map
[7] http://www.arcgis.com/home/item.html?id=2061e4a5ba134fe3ba3afb58de2c3079

- The health aspect is not currently represented. Pre-existing health problems make people particularly vulnerable during extreme weather conditions, and areas with concentrations of people who are disabled or in poor health may require considerable support in preparation, response and recovery from flooding and high temperatures.

- The ability of people to understand the presence of risks and to comprehend the relevant information provided by the authorities is currently limited to reflecting their level of education. Including indicators relating to the ability of inhabitants to speak the official language(s) could provide a useful information about the ability to understand and use information. This could also and inform future actions of public agencies, emergency services and other bodies responsible for communicating and addressing climate-related risks (e.g. where to provide leaflets in languages other than Finnish or Swedish).

- Another important aspect to include is the potential for physical damage to houses from flooding. This can be assessed based on their level of their lowest floor as houses with basements are affected the most during flooding.

Indicators used in the 'Mapping Flood Disadvantage in Scotland 2015' project		Relevant indicators used for assessment of social vulnerability to climate change in the Helsinki Metropolitan Area
Domain	Indicator	
Age	% people under 5 years old	% children 0-6 years old (i_6)
	% people over 75 years old	% people over 75 years old (i_7)
Health	% people whose day-to-day activities are limited	-
	% households with at least one person with long term limiting illness	-
Income	% people in routine or semi-routine occupations	-
	% of long term unemployed people	% of long-term unemployed in labor force (i_10)
	% households with dependent children and no adults in employment	-
	Number of Income Support claimants	% economically inactive people in the population (i_9_
	Number of Job Seeker Allowance claimants	% of unemployed in labour force (i_8)
	Number of Pension Credit claimants	-
	Number of families receiving tax credits	-
	-	Median income (i_11)
Information use	% people with <1 year residency in the UK	-
	% people who do not speak English well	-
	-	% people with basic studies (i_5)
Insurance	% new addresses located in flood risk areas	-
	Number of historic flood events	-
Local knowledge	% addresses in Flood Warning Target Areas	-
	% new residents (< 1 year) arriving from outside the local area	-
Tenure	% social rented households	% dwellings rented from ARA (i_23)
	% private rented households	% rented dwellings (i_22)
Mobility	% of Incapacity Benefit/Severe Disablement Allowance claimants	-
	% people living in medical and care establishments	-

Indicators used in the 'Mapping Flood Disadvantage in Scotland 2015' project		Relevant indicators used for assessment of social vulnerability to climate change in the Helsinki Metropolitan Area
Domain	Indicator	
Social networks	% households with no car or van	% households with no car (i_3; Access)
	% children of primary school age	% school age children in the population (i_21)
	Number of voluntary organisations focused on local community	-
	% single pensioner households	% single person households (i_20)
	-	% students in the population (i_19)
Physical access	% people working further than 30km from home	Access in case of emergency (i_4)
	Road density	Accessibility zone (i_2)
	-	Location within 1km from railway station (i_1)
Crime	Number of domestic breakings	-
Access to health services	Travel time to local doctor surgery (private transport)	-
	Travel time to local doctor surgery (public transport)	-
Housing characteristics	% households with the lowest floor level: ground floor	-
	% households with the lowest floor level: basement or semi-basement	-
	% caravans or other mobile or temporary structures	-
	- (due to focus on flooding only)	% of dwellings in flats (i_14)
	-	Occupancy rate (i_12; Overcrowding)
	-	% households containing 7 or more people (i_13; Overcrowding)
Physical environment	% urban land cover	% total green space in the land area (i_16)
	-	% low vegetation in the land area (i_17)
	-	% trees in the land area (i_18)
	-	% water in the grid cell area (i_15)

Table 6. Comparison of the indicators used in this project with the set used in the 'Mapping Flood Disadvantage in Scotland 2015' project (Kazmierczak et al., 2015)

Other currently under-represented aspects of vulnerability include local knowledge, crime levels (in particular domestic break-ins), access to health services and ability to obtain flood insurance (i.e. its cost and availability). It would be interesting to include these themes in future assessments in order to present a more complete picture of social vulnerability. However, it also needs to be remembered that the set of indicators used must reflect the local context. The evidence supporting some of the indicators may be country- or region-specific. This is illustrated by the example of differences in sensitivity of older people to heat by gender from France and USA showing conflicting results (section 6). Therefore, it is recommended that a wider group of stakeholders is consulted in the future to investigate which of the indicators are relevant. The choice of the indicators could also be supported by a literature review on the socio-economic and physical environment factors influencing losses to health and well-being (physical, mental, financial or social) from climate hazards, specifically focused on Finland and other Nordic countries, as the evidence from USA or south Europe may not be relevant.

The majority of the indicators used in the current assessment are relatively up to date, with the oldest data from 2012. There were some minor inconsistencies between e.g. the number of long-term unemployed people and the information on the number of people in labour force (section 6) due to the datasets derived from different sources and being produced at different times. It is recommended that in the future assessments the indicator set is being updated as new data emerges in order to keep it current, and that there is as much consistency as possible in the data sources used and the dates of production.

The spatial unit of assessment used here – the grid of 250 by 250 meters – offers a great potential for spatially-detailed assessment of social vulnerability for climate change. Previous assessment utilising methodologies similar to the one used here were based on census units of population of over a 1,000 people (5,000 – 7,000 in England), in sparsely populated areas stretching over many tens of kilometres squared, which posed questions about applicability of these units in less populous areas. Therefore, having access to data based on a fine-scale grid allows for more nuanced observation of spatial differences.

At the same time, the size of the units used posed problems with confidentiality of some data for grid cells with fewer than 10 people (hidden data). This resulted in the inability to calculate the index of social vulnerability to flooding/heatwaves for nearly 40% of the grid cells (see Table 4) in the Helsinki Metropolitan Area. Therefore, choosing the size of the spatial unit applied can be seen as a balancing act between spatial accuracy and data availability. In the future, it is recommended to either use data for larger grid cells (e.g. 1x1km) which could help to address the problem with high number of missing values but would maintain a level of spatial detail.

The methods of processing the indicators are based on the methods applied by the UK Government in processing of socio-economic data (see ONS, 2015). They also represent a development compared to the processing methods used by Lindley et al (2011) and Kazmierczak et al (2015), where the statistical characteristics of the indicators were investigated in less detail. Range standardisation, following log-transformation, is seen as a more statistically robust method compared to Z-score standardisation (see section 7). However, at the same time, processing of indicators in this manner is not without its flaws. For example, standardised scores are dependent on the range of values. Whilst for most of the indicators the ranges were between 0 and 100%, for some of them narrower ranges were present. This means that, firstly, indicators or indices with narrow ranges may have overemphasised differences between small and large values after standardisation. Secondly, a standardised indicator for the Helsinki Metropolitan Area may have different values than a standardised indicator for just the Helsinki municipality or for a larger region (e.g. the whole of Finland) if they have different ranges. Therefore, any comparisons among the standardised indicator/index values or comparisons with other regions (if such assessments are carried out) should be avoided.

The current assessment is based on the equal importance of vulnerability aspects (e.g. age, tenure, income) and equal importance of indicators within these aspects. However, the weights of the domains and individual indicators can be adjusted to reflect their relative importance. For example, in relation to enhanced exposure to high temperatures, trees are more effective in reducing temperatures in the urban environment than low-level vegetation, therefore to reflect this a higher weight could be assigned to the indicator describing the proportion of area covered by tree canopy in the grid cell. Similarly, income may be less important in assessing the ability to respond to flooding than the extent of social networks or age/health of individuals. Therefore, it is recommended that in the future expert judgement is used to propose alternative weightings of domains and indicators used in this assessment in order to more accurately represent the importance of different vulnerability aspects.

Finally, the maps produced for the purposes of this report offer only one possible manner of categorising the indices. Equal interval classification was used, based on the 0.2 interval width and resulting in five classes, from very low to very high (Table 5). This classification method is very easy to understand, but may result in empty classes, or classes with very few values, if the values of index represented are not evenly spread between 0 and 1. Alternative methods of presenting the data include for example quantiles or standard deviation. Quantile classification results in equal number of values in each class, which is easy to interpret but may result in not obvious thresholds between classes. Standard deviation is best used for normally distributed data. It represents the distance from the mean value, and allows for identification of extreme values, i.e. far removed from the mean (+/- 2.5 standard deviation). However, it is not easy to interpret by lay users and may not be appropriate for severely skewed data. What needs to be remembered is that each of the classification methods will result in a slightly different picture of social vulnerability to climate change across the Helsinki Metropolitan Area.

To date, no methodological ‘best practice’ has been established for the assessment and mapping of social vulnerability to flooding and to climate-related events more broadly. Whilst the underlying causes of social vulnerability to extreme weather events (such as age, health or living conditions) are well-recognised, the selection of indicators, methods of combining them and spatial representation may vary considerably (Kazmierczak et al., 2015).

As an alternative perspective to the assessment of social vulnerability to climate change based on indicators combined into indices and carried out here, Principal Component Analysis may be used to identify composite factors explaining the spatial variation of social vulnerability. This was for example used by Kazmierczak and Cavan (2011) in assessment of vulnerability to surface water flooding in Greater Manchester.

Factor analysis retains some information about the underlying causes of vulnerability, therefore it has an advantage over methods of assessment that develop one cumulative index only. However, the grouping of indicators according to statistical associations between them may result in rather cumbersome indices, grouping a variety of different issues together, which as result are too far removed from the practitioners’ perspective to be easily applicable. The exploratory PCA analysis is presented in Appendix 1; however, the emerging groupings of indicators were not seen as sufficiently clear to use them as the main assessment. Instead, the main approach presented in this report aims to categorise the indicators into topical groups, or domains, which may be easier to decipher by practitioners without losing the richness of data. In the future, it is advised that more research is carried out into alternative methods of representing social vulnerability to climate change.

11 Recommendations for further assessments of social vulnerability to climate change in the Helsinki Metropolitan Area

The main recommendations for future assessments of social vulnerability to climate change in the Helsinki Metropolitan Area can be summarised as follows:

- The indicator dataset could be enhanced by including data pertaining to the aspects of health, house type, flood insurance, ability to speak the official language, local knowledge, crime levels or access to health services (see Table 6). The inclusion of the particular aspects of indicators would ideally be guided by an expert stakeholder group, based on their relevance to the Helsinki Metropolitan Area.

- Stakeholders' input would also be extremely valuable to develop weightings of individual indicators and thematic domains, or aspects, contributing to social vulnerability to climate change. In the future, development of an online tool which would allow the users to freely select the indicators they see as suitable to their vulnerability assessment and enter the weights that are relevant to their locality or area of work is advisable, similar to the 'User-based Climate change Impacts, Adaptation and Vulnerability mapping tool U-C-IAV .

- The assessment of social vulnerability to high temperatures could usefully be combined with data on Urban Heat Island, or other data on geographic distribution of temperatures in the Helsinki Metropolitan Area, when such data becomes available. This would allow development of the index of heat disadvantage.

- The current assessment is based on the snapshot of socio-economic situation and current likelihood of flooding in the Helsinki Metropolitan Region. In order to assess the potential impacts of climate change on health and well-being under the changing climate, a future perspective could be applied. This would require an incorporation of data on likelihood and spatial extent of flooding under different climate change scenarios as well as incorporation of demographic and socio-economic development scenarios in the vulnerability assessment.

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Appendix 1. An exploratory assessment of social vulnerability to climate change with Principal Component Analysis

This appendix summarises results of the exploratory factor analysis - Principal Component Analysis (PCA) carried out to identify underlying factors of social vulnerability to climate change in Helsinki.

The analysis of social vulnerability to flooding was based on 19 indicators and to heat - on 15 indicators (see Table 3). The unprocessed indicators were included in the analysis (values prior to log-transformation, standardisation or reversing of values).

The suitability of both social vulnerability to flooding and social vulnerability to heat datasets for PCA was first ascertained by:

-Checking the pattern of relationships between indicators by reviewing the correlation matrix to identify the coefficient values greater than 0.9 (none found following the initial reduction of indicators described in section 6) and to assessing the number of correlations with significance values greater than 0.05;

- Checking that the value of the R-matric determinant is greater than 0.00001 to avoid multicollinearity;
- Applying the Kaiser-Meyer-Olkin measure of sampling adequacy;
- Applying the Bartlett's test of sphericity.

Both datasets were found to be suitable for PCA analysis.

As the number of variables was lower than 30 and the sample size was greater than 250, the Kaiser criterion of selecting factors with eigenvalues greater than 1 was applied. Varimax rotation was used in order to differentiate more clearly between the individual factors (i.e. maximise or minimise the loadings of variables on factors). All loadings less than 0.3 were suppressed and are not displayed in tables for clarity.

Principal Component Analysis: social vulnerability to flooding

In the case of social vulnerability to flooding, five principal components explaining 67.3% of variance in the data were identified. Table A1 presents the loadings of indicators on the five components.

Principal component 1 ("low income") explains 32.1% of variance in the dataset and groups indicators related to low income, unemployment, rented housing, low education levels and small dwellings including single-person households. This would mean that the social vulnerability to flooding associated with this factor is mainly linked to the financial situation of people and their reliance on landlords for adaptive measures.

In contrast, high values of PC2 (explaining 12.8% of variance) represent "green suburbs", where the incomes are higher, houses are owned rather than rented and presence of green space may to some extent mitigate against flooding. However, these areas have lower accessibility by walking, cycling or public transport and access in case of emergency may be limited due to long average journeys made by residents.

Third principal component, “age” (explaining 9.9% of variance) is associated with higher percentage of older and economically inactive people in the population.

PC4 (explaining 6.5% of variance) can be called “families”. High values represent areas with larger households and higher percentage of children (both very young and of school age). Whilst a high proportion of people is economically inactive, the median income values are positively associated with this factor.

Finally, principal component 5 (explaining 6.0% of variance), reflects the concentrations of students and ARA housing.

Indicators	Principal component				
	1	2	3	4	5
Percentage of people with basic studies	.824				
Percentage of unemployed in labour force	.773				
Percentage rented households	.761	-.331			
Percentage of dwellings rented from ARA	.731				.302
Percentage of households with no car	.627	-.606			
Percentage of single person households	.536	-.523		-.486	
Percentage long-term unemployed in labour force	.532				
Occupancy rate	-.512		.562		
Median household income	-.762	.345		.326	
Accessibility		.903			
Access in case of emergency		.753			
Percentage of green space in land area		.590			
Percentage of school age children in the population		.406		.654	
Location within 1km from a railway station		-.639			
Percentage of people over 75 years old in the population			.778		
Percentage of economically inactive people			.747	.465	
Percentage of children 0-6 years old in the population			-.501	.494	-.365
Percentage of students in the population					.925
Percentage of households containing 7 or more people				.645	

Table A1. Rotated component matrix – social vulnerability to flooding

Figures A1-A5 show the spatial distribution of values of principal components. In all maps, the values of principal components were classified into 5 categories (from low to high) using quantile classification

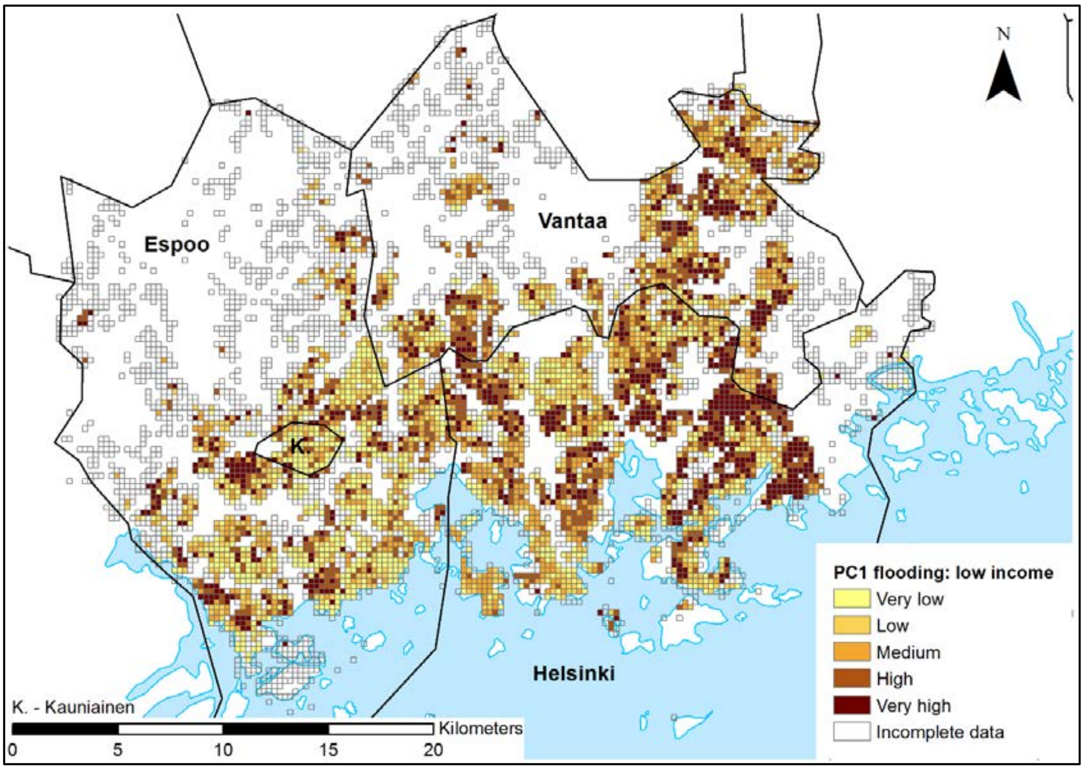

Figure A1. Social vulnerability to flooding, principal component 1: low income

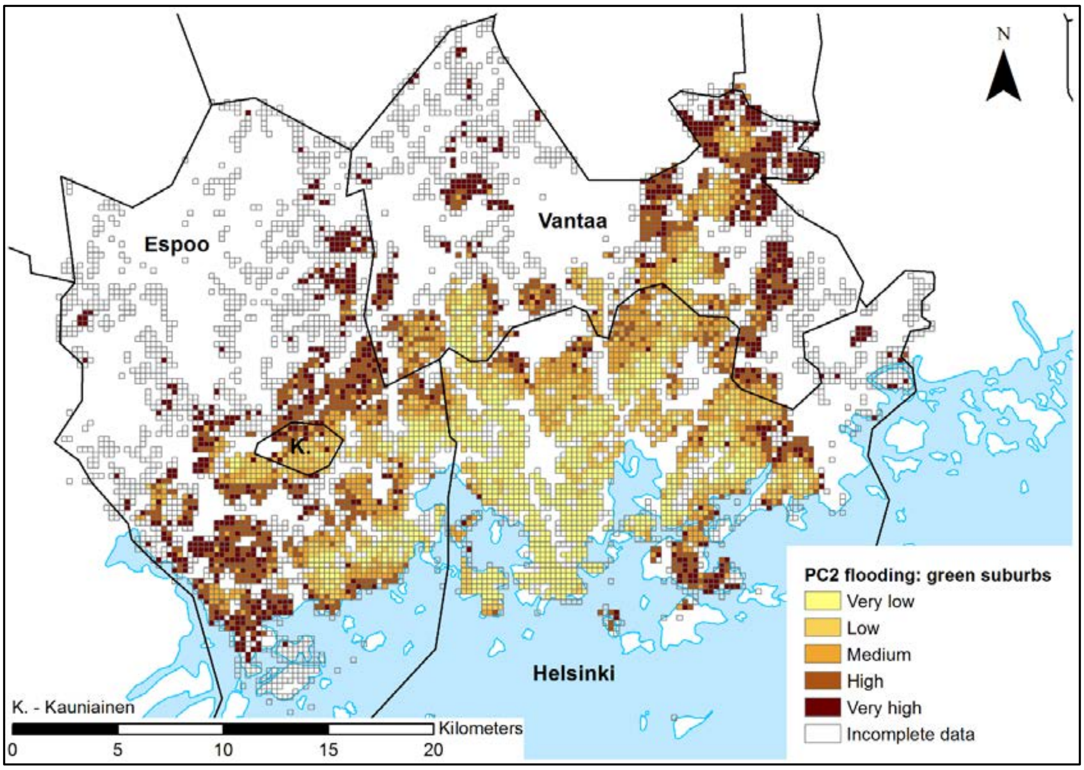

Figure A2. Social vulnerability to flooding, principal component 2: green suburbs

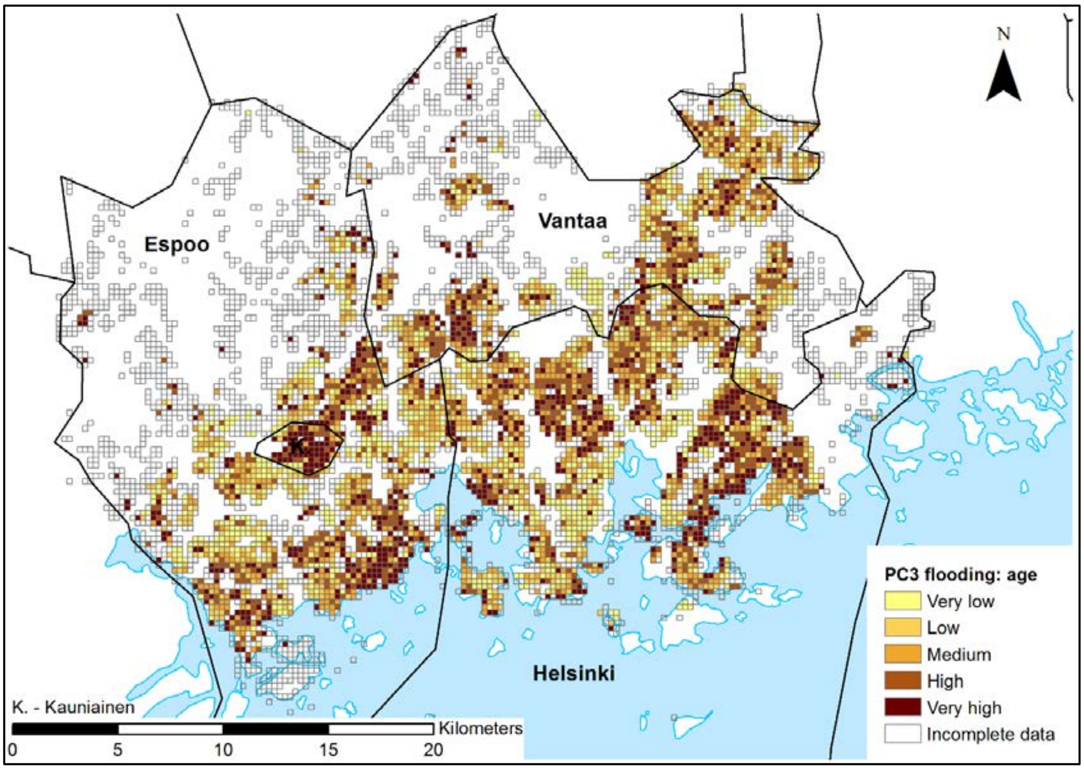

Figure A3. Social vulnerability to flooding, principal component 3: age

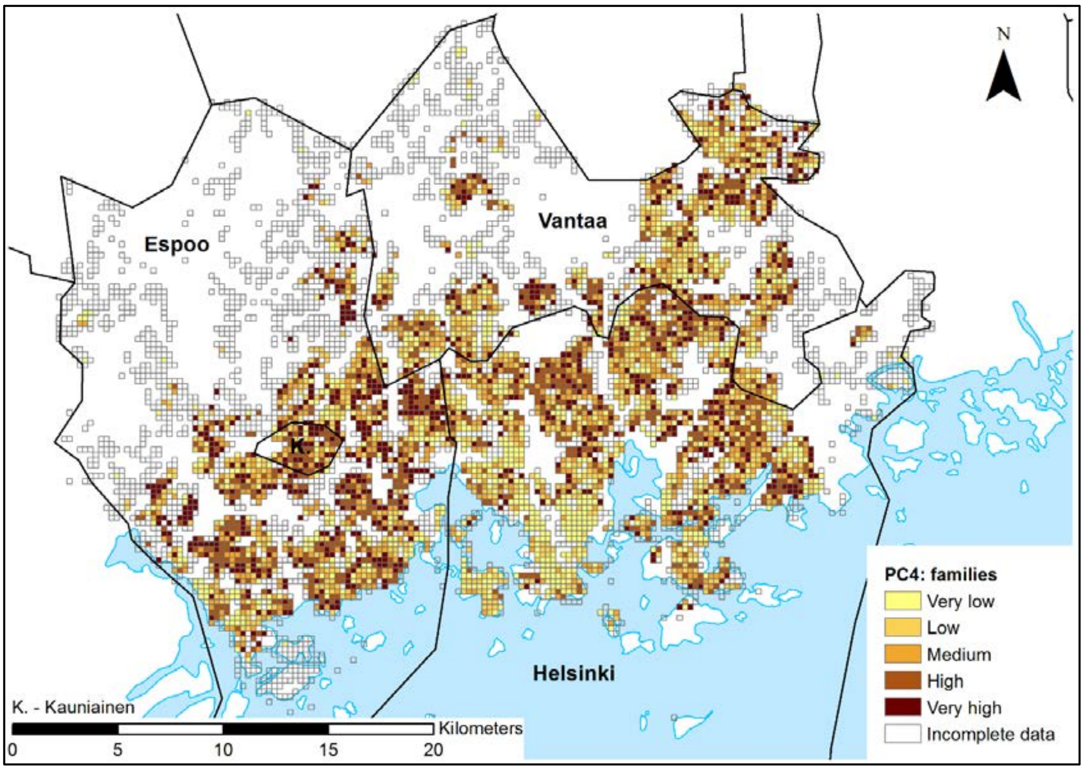

Figure A3. Social vulnerability to flooding, principal component 4: families

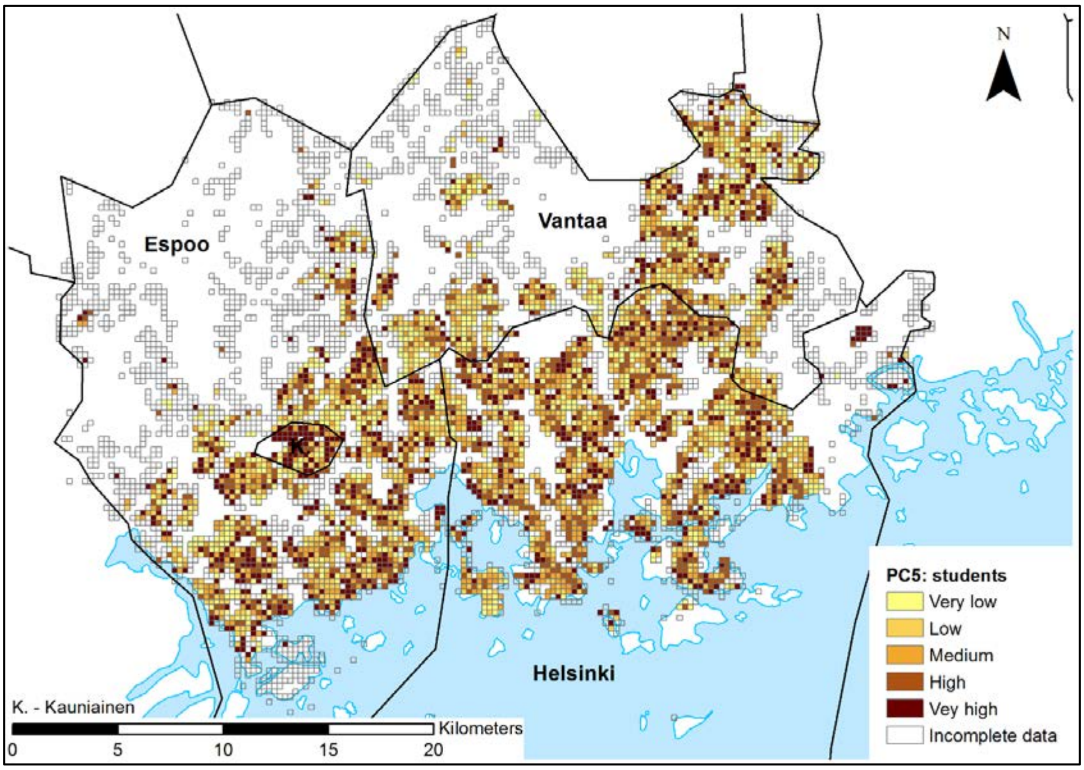

Figure A5. Social vulnerability to flooding, principal component 5: students

Principal Component Analysis: social vulnerability to high temperatures

In the case of social vulnerability to high temperatures, four principal components explaining 65% of variance in the data were identified based on the relationships between the 15 relevant indicators. Table A2 presents the loadings of indicators on the four principal components.

Similarly as in the case of social vulnerability to flooding, principal component 1 reflects “low income”. It explains 33% of variance in the dataset and groups indicators related to low income, unemployment, rented housing, low education levels and small dwellings including single-person households.

Principal component 2 (12.8% of variance) represents “families in green settings”, where the incomes are higher, proportion of children and economically inactive people in the population is higher, houses are owned rather than rented and green space (both low and high vegetation) provides cooling during heatwaves.

Principal component 3 (explaining 11.4% of variance) represents “age”. The indicators reflecting percentage of people over 75 in the population and economically inactive people are loading highly on this factor. The high values of this factor are also associated with presence of water.

Finally, PC4 (which explains 7.8% of variance) – “vegetation” represents differences in land cover – either the presence of low vegetation and water in grid cells (high values) or the high proportion of tree cover (low values).

Indicators	Principal components			
	1	2	3	4
Percentage of dwellings rented from ARA	.799			
Percentage of unemployed in labour force	.764			
Percentage of people with basic studies	.761			
Percentage of rented households	.741	-.406		
Percentage of long-term unemployed in the labour force	.565			
Percentage of dwellings in blocks of flats	.446	-.756		
Percentage of single person households	.393	-.811		
Median household income	-.625	.632		
Percentage of school age children in the population		.789		
Percentage of economically inactive people in the population		.512	.679	
Percentage of children 0-6 years old in the population		.367	-.525	
Percentage of low vegetation in land area		.365		.644
Percentage of trees in land area		.333		-.712
Percentage of people over 75 years old in the population			.847	
Percentage of water in the grid cell			.316	.465

Table A2. Rotated component matrix – social vulnerability to high temperatures

Figures A6-A9 show the spatial distribution of values of principal components. In all maps, the values of principal components were classified into 5 categories (from low to high) using quantile classification.

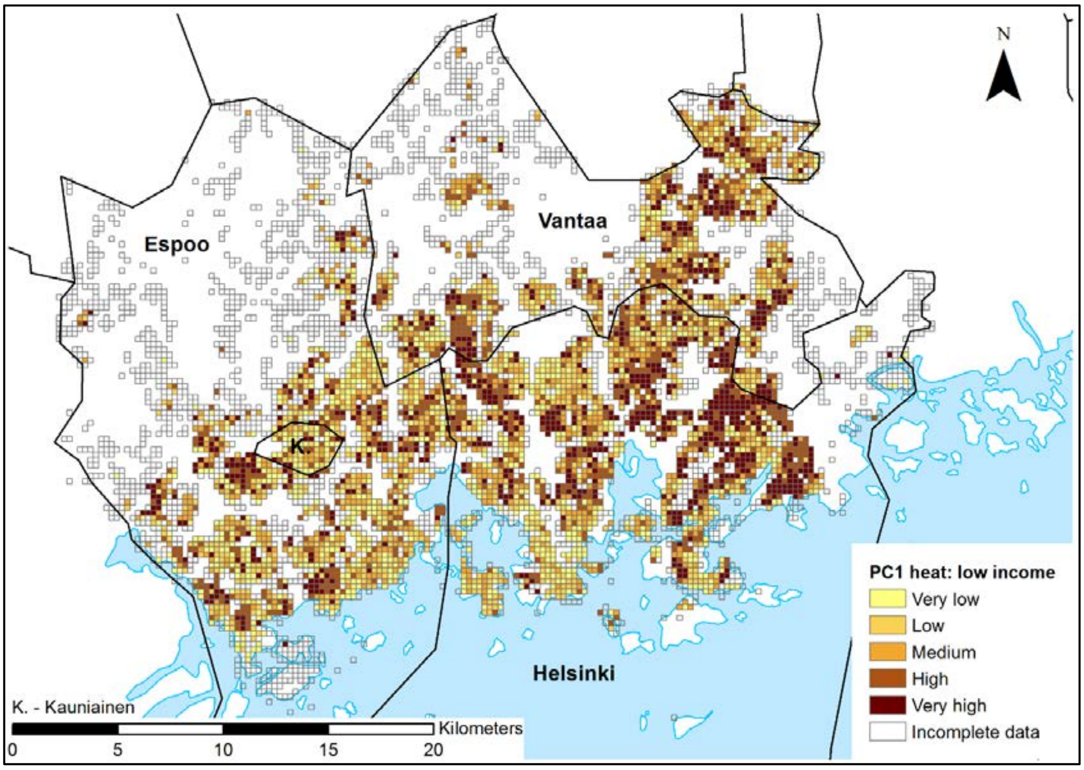

Figure A6. Social vulnerability to high temperatures, principal component 1: low income

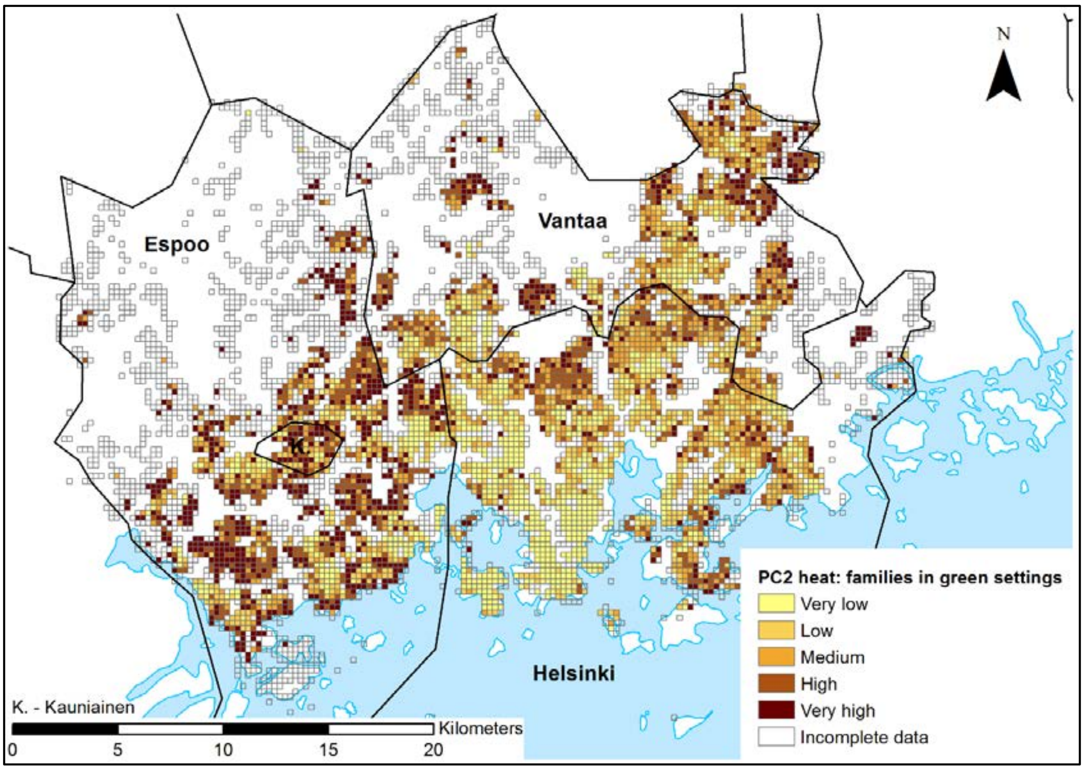

Figure A7. Social vulnerability to high temperatures, principal component 2: families in green settings

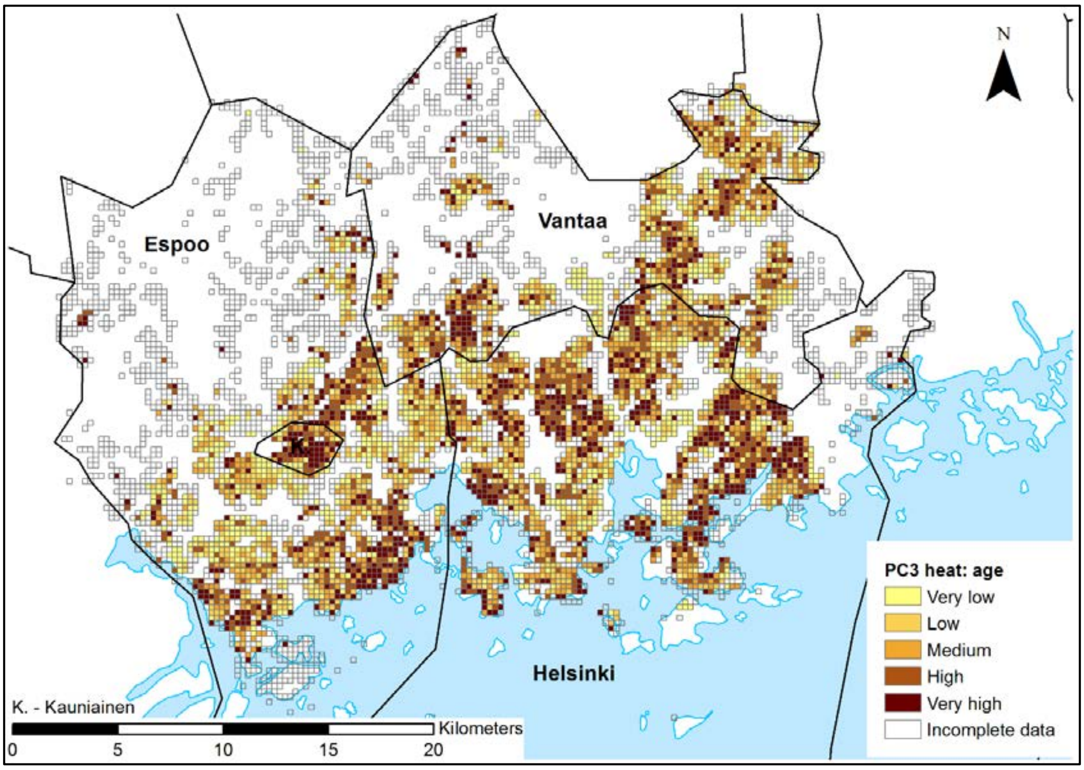

Figure A8. Social vulnerability to high temperatures, principal component 3: age

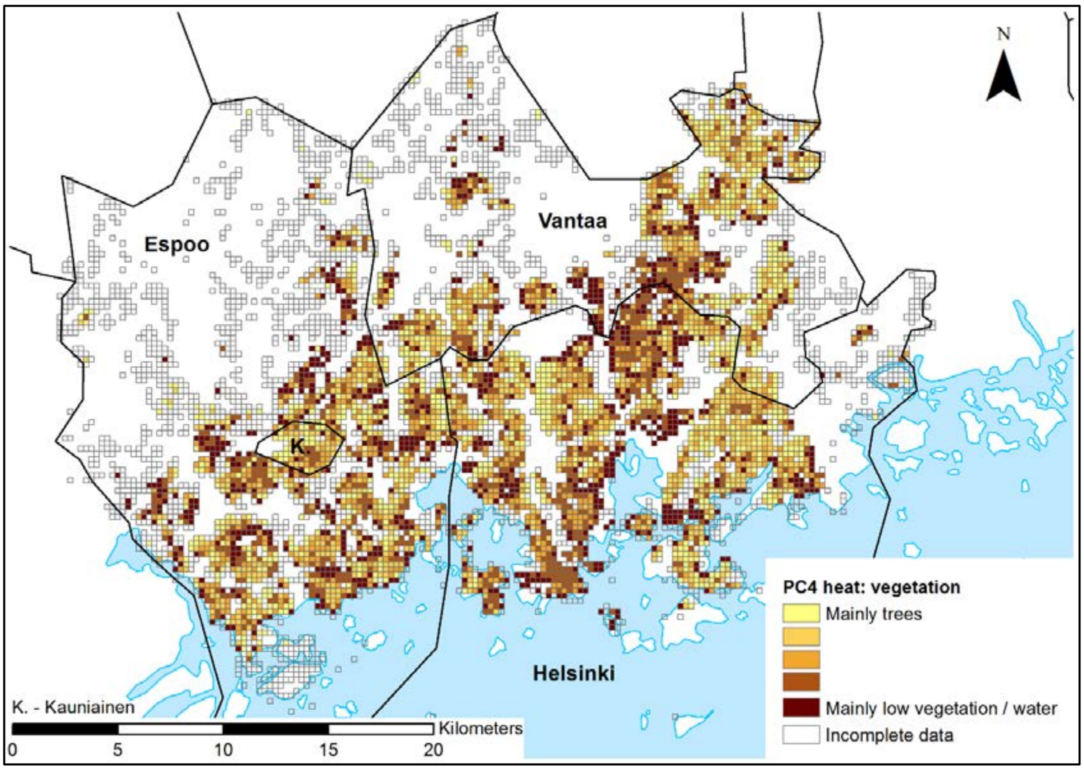

Figure A9. Social vulnerability to high temperatures, principal component 4: vegetation

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