Summary report

Mapping the vulnerability and exposure to extreme heat waves of populations living in housing in Canadian communities

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INTRODUCTION

Climate change is inevitable and can be observed globally [1]. In Canada, the estimated warming rate for the 1948-2016 period was much higher than the global rate (1.7°C compared to 0.8°C) [2]. Thus, the impacts of global warming are being strongly felt across the country, particularly with the increase in the frequency of extremely hot days [3]. This threat weighs heavily on the population's health, as extreme heat is associated with an increase in mortality and the onset of numerous health problems [4-5]. The population's vulnerability and exposure vary over time and space, putting certain groups more at risk than others. The effects of heat waves on the health and well-being of communities are modulated by people's ability to access resources, particularly adequate housing [6]. The main objective of this project is to develop an interactive online mapping application that provides valid information on the geographical distribution of the vulnerability and exposure of populations in 156 urban regions of the country, specifying their intensity at the dissemination area level. The tool is intended for professionals in the field while remaining accessible to the public.

STUDY AREA

The study area covered by our project consists of 156 urban regions: 42 census metropolitan areas (CMAs) and 114 census agglomerations (CAs) in Canada, representing 83.9% of the Canadian population, or over 31 million people [7]. The indicators were calculated at the dissemination area (DA) level, which is the smallest standard geographic area for which all Canadian census data are disseminated. A dissemination area (DA) is composed of 400 to 700 persons. [8]. The 2021 census year was chosen as it is the most recent census. Moreover, since we were seeking to represent the vulnerability of the population at the finest scale possible, i.e., the environment in which individuals live, a dasymetric mapping of the ecumene was applied to the dissemination areas to determine and only represent the inhabited zones.

DASYMETRIC MAPPING

To meet the project's objective, which sought to represent the vulnerability and exposure to extreme heat waves of populations living in housing in Canadian communities, the research team wanted to develop an accurate cartographic representation of the geographical distribution of residential areas. Initially, the entire study area of a CMA is divided into dissemination areas, representing both non-residential and residential areas. To identify and only keep the residential areas, an additional breakdown was carried out using a file (GHS-BUILT-C Functional classification) produced by European Commission's Joint Research Centre (JRC) [9].

The GHS data layer was then validated to ensure that it adequately represents the reality in major Canadian cities. A stratified random sampling plan was used to validate just over 33 000 locations in the geospatial data layer. The results from the validation allowed the team to move forward with the use of this data to produce the map layers. Using an iterative approach, a chain of geoprocesses applied to the GHS layer was developed. It incorporates, among other things, census population data and a hexagonal grid covering the area of each CMA and CA (figure 1). The various calculated indices were then added to this map layer.

Figure 1: Cartographic representation results of residential areas (dasymetric layer). (A) Calgary Area, Alberta. (B) Toronto Area, Ontario. (C) Québec Area, Québec. (D) Halifax Area, Nova Scotia

CONCEPTS

The geographical analysis of the vulnerability and exposure of populations promotes a better understanding of territorial issues and makes it possible to design better impact mitigation strategies. In recent years, the assessment of heat wave vulnerability has progressed, inspiring various adaptation and development strategies at the local, regional, and national levels. Studies on the subject identify several factors (social, economic, physical, and environmental) as components of social vulnerability. The location of the dwelling in which people live can be a predominant factor in modulating the protective capacity it offers to cope with the onset of an extreme heat wave. Within the framework of the project, vulnerability encompasses two dimensions: sensitivity and coping capacity. Moreover, following what was done in the Atlas of Vulnerability project, [10] our team adopted an indicator-based mapping approach to spatially represent the studied phenomenon.

Sensitivity represents the inherent socio-economic characteristics of a population facing a climatic hazard. These are the "intrinsic conditions of an exposed element that make it particularly vulnerable" [11]. Various conditions can make a population more susceptible to consequences during a heat wave; however, it is especially the combination of these conditions that will cause the most impact. In the context of our study, sensitivity refers to conditions that contribute to increasing the vulnerability of people or infrastructure during heat waves.

Coping capacity is an essential element in the analysis of vulnerability to heat waves since it helps reduce negative effects by strengthening the population's resilience to this climatic hazard [12-13]. For our study, coping capacity represents the population's ability to access certain places to cool off during and after a heat wave. These are the factors that help reduce people's vulnerability during heat waves.

Exposure to extreme heat waves refers to situations where individuals, communities, and ecosystems are confronted with extremely high temperatures. The urban heat island phenomenon modulates this level of exposure by increasing the temperatures felt, thus aggravating the risks of overheating, dehydration, and other heat-related medical problems.

It is important to specify here that the data on the maps do not represent the risk of a heatwave occurring in a given area since our approach did not venture to quantitatively assess the number of people affected, the intensity, the frequency, and the duration of the hazard in the final calculation of the indices.

APPROACH

Based on socio-economic, demographic, and the characterization of the built and natural environment data associated with the population's vulnerability and exposure to extreme heat waves, we calculated four indices at the dissemination area level, namely an exposure index, a sensitivity index, a coping capacity index, and a vulnerability index.

1: SENSITIVITY INDEX

The sensitivity index groups together several demographic and socio-economic information estimated at a fine scale. The twelve selected variables are all taken from Statistics Canada's 2021 Census of Population. Like other studies conducted in the field, principal component analyses (PCA) were used to synthesize information for the sensitivity indices (figure 2).

2: COPING CAPACITY INDEX

The coping capacity index is calculated from indicators of proximity to 10 different places and services where it is possible to take refuge during an extreme heat wave, such as shopping malls, parks, and public swimming pools. As with the sensitivity index, the coping capacity index was developed using PCA (figure 2).

3: VULNERABILITY INDEX

The vulnerability index was created by combining the standardized numerical values of the sensitivity and coping capacity indices. To do this, the coping capacity result (factors that make the population less vulnerable) was subtracted from the sensitivity result (factors that make the population more vulnerable). The numerical values of the vulnerability index were then divided into classes (quintiles) by province.

4: EXPOSURE INDEX

The exposure index was calculated using, among other things, information from satellite imagery on the ground temperature and impermeability, vegetation, and the built environment. Data on proximity to water, altitude, and location have also been integrated. For this index, the "random forests" machine learning algorithm was used.

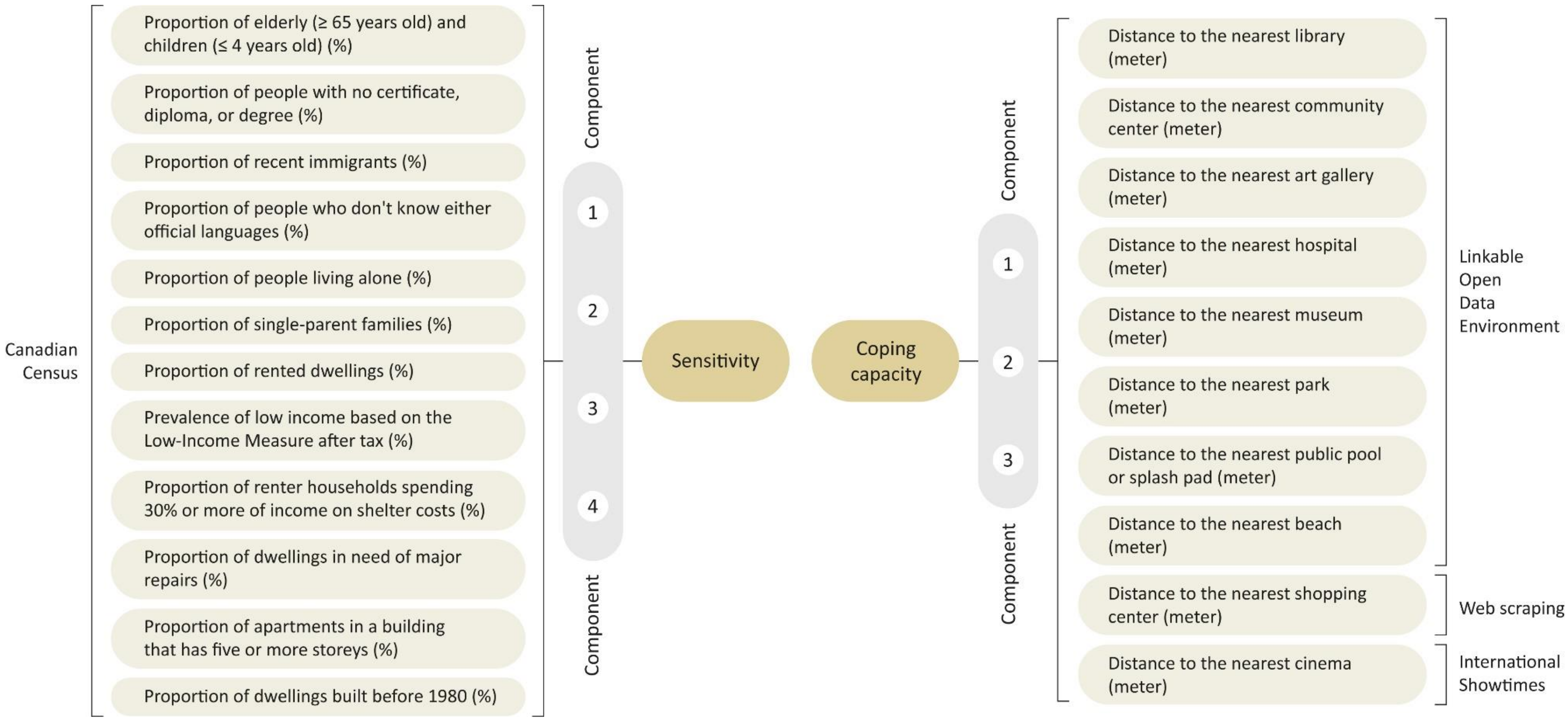

Figure 2: Diagram illustrating the calculation of sensitivity and coping capacity indices using principal component analysis.

DYNAMIC MAPPING

To distribute our results, the six geospatial data layers produced (sensitivity, coping capacity, vulnerability, exposure, vulnerability and exposure, and urban heat islands) were mapped and implemented in the *ArcGIS Experience Builder* module (figure 3).

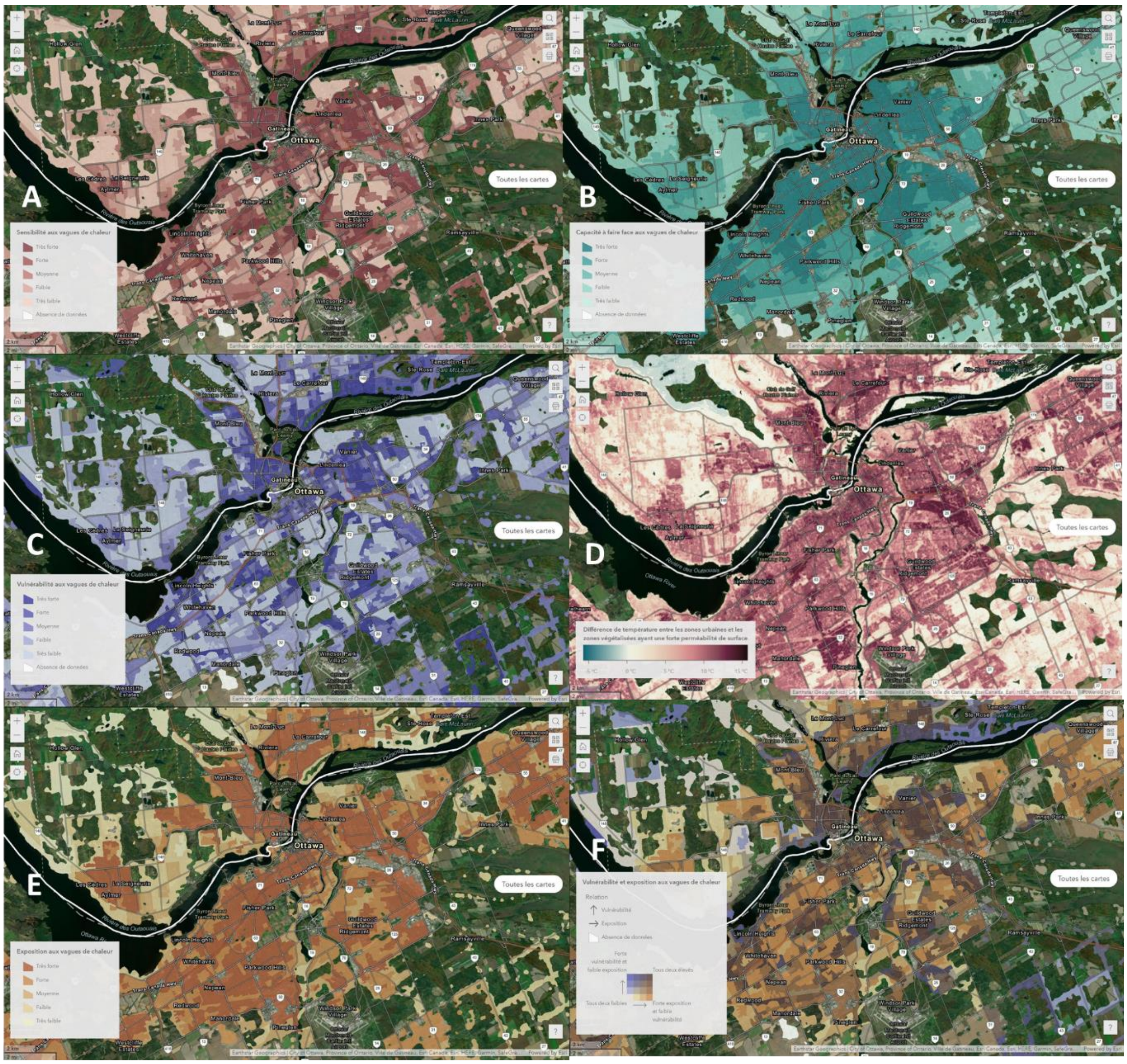

Figure 3: Cartographic representation of: (A) the sensitivity index; (B) the coping capacity index; (C) the vulnerability index; (D) the urban heat islands; (E) the exposure index; and (F) the bivariate map of the vulnerability and exposure indices

For the **sensitivity** and **coping capacity** indices, the numerical value of the indices obtained was classified into 5 quintiles, by province. The classes thus obtained were subsequently labeled as follows: very low, low, moderate, high, very high.

For the **vulnerability** index, a normalization between 0 and 1 of the sensitivity and coping capacity indices was applied, then an arithmetic operation was performed to create the new index so that the range of values of the index extends from 0 to 2. This new result was classified into 5 quintiles for each province and then labeled.

For the **urban heat islands** map, to represent the phenomenon cartographically, a classification (n=22) at equal intervals of the predicted values of relative temperature was carried out on the pixels overlapping the area covered by the model.

For the **exposure** index, the mapping approach consisted in averaging the predicted temperature values relative to the uninhabited areas of the Statistics Canada dissemination areas. The vector data were then classified into quintiles.

Finally, the research team used a bivariate map to display the vulnerability and exposure indices on the same screen. A bivariate map is a thematic map that allows two variables to be represented simultaneously using different colors or patterns. The data classification method used is a cross-tabulation of quartiles estimated at the provincial level for the vulnerability and exposure indices.

The mapping application is integrated into the project website:

heatwaves.ffgg.ulaval.ca

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