6TH INTERNATIONAL CONFERENCE
ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

AN APPROACH TO DEVELOPING A COMPOSITE MEASURE FOR HUMAN HEALTH AS AN INPUT TO ADYNAMIC SYSTEMS MODEL FOR INVESTIGATING CITY RESILIENCE

Lannigan R. [1], Owrangi A.M. [2], and Simonovic S. P. [2]

1. *Schulich School of Medicine. Department of Pathology, Western University. London. Ontario. Canada*
2. *Department of Civil and Environmental Engineering, Western University, London, Ontario, Canada.*

ABSTRACT: The Coastal Cities at Risk project (CCaR) is a multidisciplinary team project involving 4 cities: Manila (Philippines), Bangkok (Thailand), Lagos (Nigeria) and Vancouver (Canada). The major focus of the project is to develop a system dynamics model to assess the resilience of the cities in the face of sea level rise, storm surges, riverine flooding and extreme precipitation events. The model is capable of accepting multiple inputs. This paper addresses the approach taken to develop a human health input and summarizes the progress to date for Vancouver. Maps are shown that demonstrate how this methodology can be used both as an input for the modeling exercise as well as for “stand alone” investigations.

Key Words: Climate Change, Coastal Cities, Extremes, Resilience, Human Health

1. INTRODUCTION

In the face of climate change, more frequent and severe extreme weather events are predicted to be the expected pattern (IPCC 2013, IPCC 2013(a)). Tools and information to aid planners and policy makers in the development of effective mitigation and adaptation strategies have been based on the analysis of previous events and usually address a single component such as human health, socio-economic or impacts on physical infrastructure. While there are many such analyses relating to a variety of extreme weather events, flooding, secondary to extreme precipitation, sea level rise and tidal surges are prominent in the literature (WHO 2002, Hajat *et al*., 2003). The most vulnerable areas identified are coastal megacities situated in river deltas where large human populations reside. Not only do these cities harbour large human populations vulnerable to the immediate and aftermath effects of flooding but also they have major economic activities and associated infrastructure that are vulnerable as well. The concept of the resilience of a city, which is defined as how rapidly it can return to a level of functionality comparable to what existed prior to the extreme event, is gaining in popularity as a means of informing policy makers and disaster planners on total city vulnerabilities (Simonovic and Peck, 2013). Resilience takes into account not only the inclusion of multiple factors but allows their interaction with one another to be investigated. The Coastal Cities at Risk (CCaR) project is a inter-disciplinary, multi-national effort involving the cities of Vancouver (Canada), Lagos (Nigeria), Manila (Philippines) and Bangkok (Thailand). One of the objectives is to develop a system dynamics model of coastal city resilience in the event of flooding due to extreme precipitation events, sea level rise and storm surges. The model itself is described elsewhere (Simonovic and Peck, 2013). This paper describes the progress to date of the method used to develop the input to the model for the human health impact of flooding for the city of Vancouver (Canada). So far we have used the method to establish the baseline state of human “health” of the city.

The input can be used to develop insight into health impact dynamics and their contribution to overall city resilience. Using the resilience of a city as a measure for comparison the model will be able to select among the set of health adaptation options those that will contribute the most to the increase in the resilience. Future efforts will focus on refining and adapting the input for this purpose.

The data for the baseline state lends itself to the development of maps which can be layered and show, in a stand-alone fashion, the areas of the city where the greatest impact on human health is likely to occur in the event of flooding. These maps are not necessarily the final inputs to be used in the resilience model. Some data such as population over 65 years and under 4 years as well as total family income were included only to demonstrate that such data could be incorporated as part of the health impact analysis. The other research team members are working on detailed social vulnerability and economic model of the Vancouver city and therefore we would not be including this data in the health input to eliminate potential double counting. Rather, we have included them to demonstrate that it is possible to do so in this context. We have termed this composite map a human health impact map and it is included as part of this paper as a demonstration of the visual output of the presented methodological approach to disaster health impact analysis. Other inputs used in the resilience model might lend themselves to similar outputs related to socio-economic and physical parameters in a stand- alone fashion. The baseline health estimation can be further modified for each site with local knowledge of the city as well as local available data, making it possible to provide inputs to the resilience model for their own city in addition to creating impact maps which may help inform on vulnerabilities due to flooding events.

2. MATERIALS AND METHODS

2.1 Health Impacts of Flooding

A major component of the CCaR project is to develop a system dynamics model to simulate the resilience of a city in response to various adaptation and mitigation measures. The results of resilience simulation will inform policy makers and planners where adaptation and mitigation measures may have the greatest value in the face of natural disasters. The natural disasters that are considered include flooding due to sea level rise, tidal surges and extreme precipitation events under a changing climate. At the current level of development the following units of resilience are considered: physical, health, economic, social and organizational (Simonovic and Peck, 2013). A resilient city is a sustainable network of physical (constructed and natural) systems and human communities (social and institutional) that possess the capacity to survive, cope, recover, learn and transform from disturbances by: (i) reducing failure probabilities; (ii) reducing failure consequences (for example material damage); (iii) reducing time to recovery; and (iv) creating opportunity for development and innovation from adverse impacts.

This paper describes the progress to date in the development of a human health input that addresses the Metro Vancouver site specifically but does have the capability of being used in the context of the other cities in the CCaR project.

The impact of flooding on the health and wellbeing of humans has been studied extensively as flooding is the most common natural disaster globally. Reports of such events and the impacts on human health around the world in both developed and less developed nations are readily available as comprehensive, systematic reviews (Alderman *et al*. 2012, Doocy *et al*. 2013). While it is recognized that the health of human populations is much more broadly defined than the presence or absence of disease, the inherent burden of disease within a given human population is a major component of its health and how this burden of disease is affected by flooding has been a major focus of concern. The diseases present in a population are usually broken down, for the sake of simplicity, into three major categories: diseases that are communicable or non-communicable and injuries. The spectrum of diseases in each of these categories varies, depending on the geographic location of the population, particularly in the case of the communicable diseases.

An estimation of the baseline burden of disease in each city is an important first step in the development of a health input for the resilience model. In order to establish this we chose to use the standard measure of DALYs. Although this measure is at best a crude estimate it has the advantage of being available from the WHO data repository in many formats, including an age standardized version which we chose to use, and is available for most countries in the world. Although specific diseases are addressed in each of the 3 categories (WHO 2004) they are rolled up into communicable, non- communicable and injury categories so that a total burden of each category type can be obtained. It is a population based measure (based on 100,000 population units) and in most countries population estimates are available, to a greater or lesser degree of reliability, so a baseline value of the burden of disease in DALYs can be obtained for each of the three disease categories in the city. This input is numerical and lends itself well as one important component of city resilience measure..

2.2 Mapping Health Impact

The variables that are selected to be included in mapping the impact of human health are: (i) land elevation (description of the physical conditions), (ii) total population, (iii) population above 65 years of age, and (iv) population under 4 years of age. These variables are integrated with burden of disease data by major category (communicable disease, non-communicable disease and injuries) expressed as the Disability-Aadjusted-Life-Year (DALY) per 100,000 populations. DALY combines the number of years of healthy life lost due to premature mortality and disability. Summary measures of population health, such as the DALY, provides one possible health impact quantification framework. The DALY measures health gaps as opposed to health expectancies. It measures the difference between a current situation and an ideal situation where everyone lives up to the age of the standard life expectation, and in ideal health. Based on the life tables, the standard life expectancy at birth is set at 80 years for men and 82.5 for women. The DALY combines in one measure the time lived with disability and the time lost due to premature mortality (Prüss-Üstün, 2003).

The individual variable spatial data is then integrated using the GIS to generate the final health impact map according to:

$$\textit{Health Impact (HI)} = f(\text{physical conditions, disease conditions, social conditions}) \qquad [1]$$

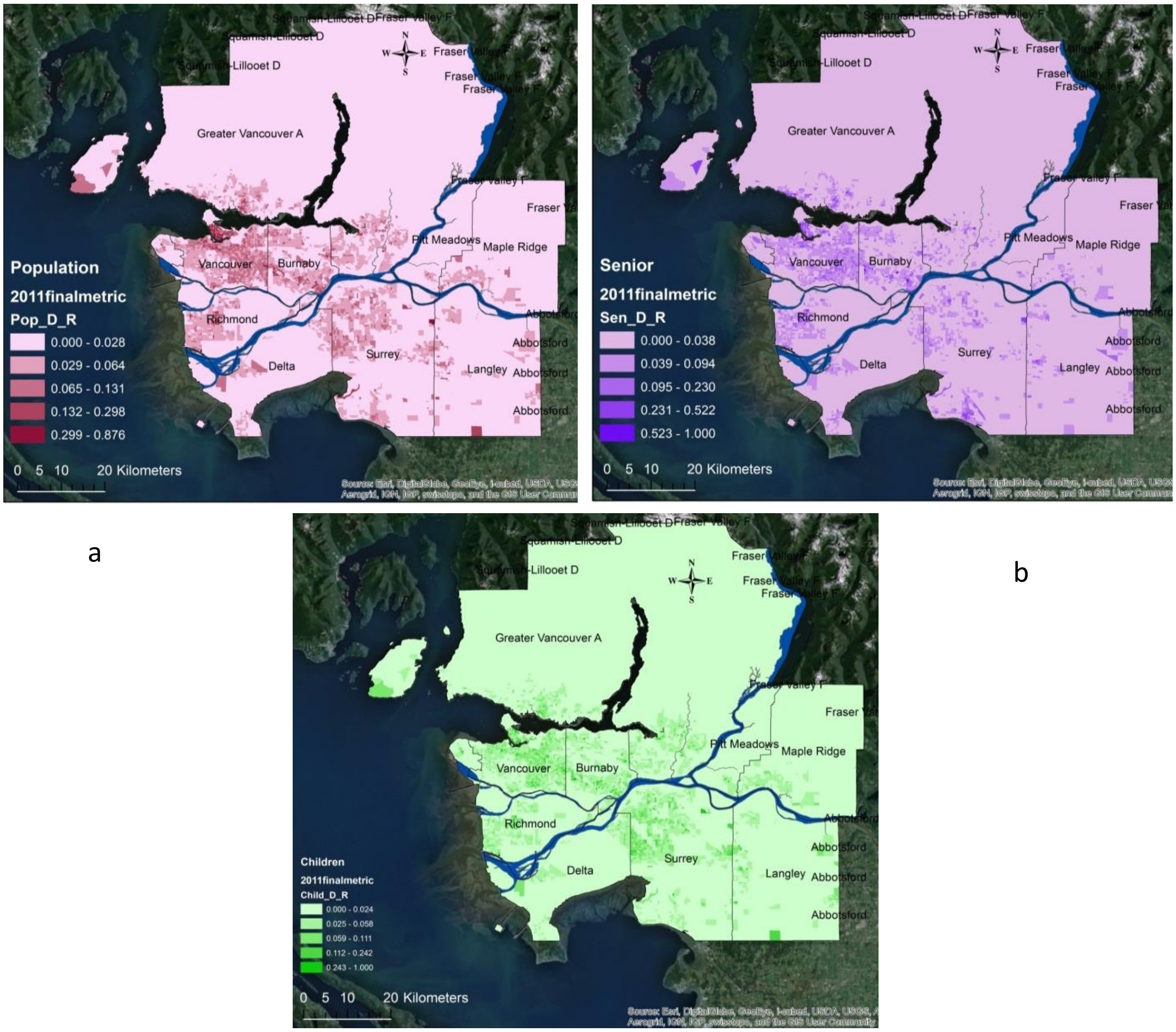
All input variables are normalized in order to deal with different measurement units. Normalized variables are integrated using:

$$\text{HI} = \alpha_1 \left[\frac{\sum_1^n \text{Wi}*\text{NPi}}{\sum_1^n \text{Wi}}\right] + \alpha_2 \left[\frac{\sum_1^m \text{Wi}*\text{Pi}}{\sum_1^m \text{Wi}}\right] \qquad [2]$$

where NP is the notation for nonphysical data, Wi is the weight for each variable considered, P is the notation for the physical data, and α_1 and α_2 are weights for non-physical and physical variables, respectively. Introduction of a double weighting scheme allows for active participation of decision makers in the development of a health impact map. Selection of different weights can be used to (a) represent different preferences of decision makers and (b) assess their impact on the final health impact outcome.

3. RESULTS

The results of the health impact mapping are shown for the City of Metro Vancouver (British Columbia, Canada). Metro Vancouver includes 24 local authorities situated in the southwest corner of mainland British Columbia. Municipalities located along the coastline or on the Fraser River Delta are vulnerable to sea level rise and riverine flooding. Figure 1 shows three social variables (a) the population density, (b) population density of 65 years and older, and (c) population density of children under age 4. The population data is obtained from the most recent Stats Canada census data (Stats Canada 2012).



a

b

c

Figure 1: The Metro Vancouver: a) Population Density, b) Density of Population 65 Years and Older, and c) Density of Population under 4 Years of Age

Figure 2 shows the normalized values of health variables (.a) communicable diseases (based on national averages, and local information about population within each spatial unit), (b) non-communicable diseases (carrying a higher and more widespread burden than communicable diseases), and (c) injuries.

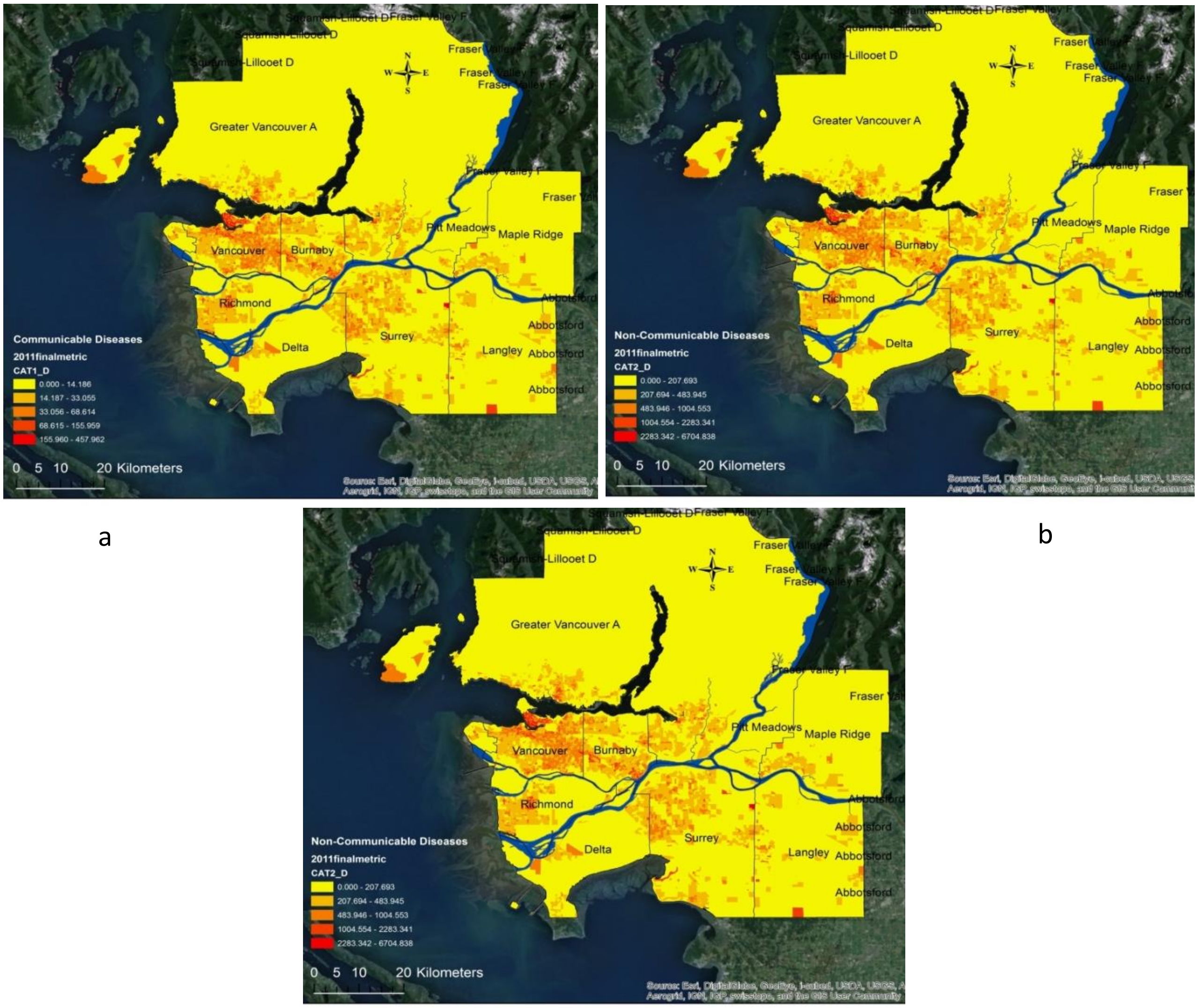
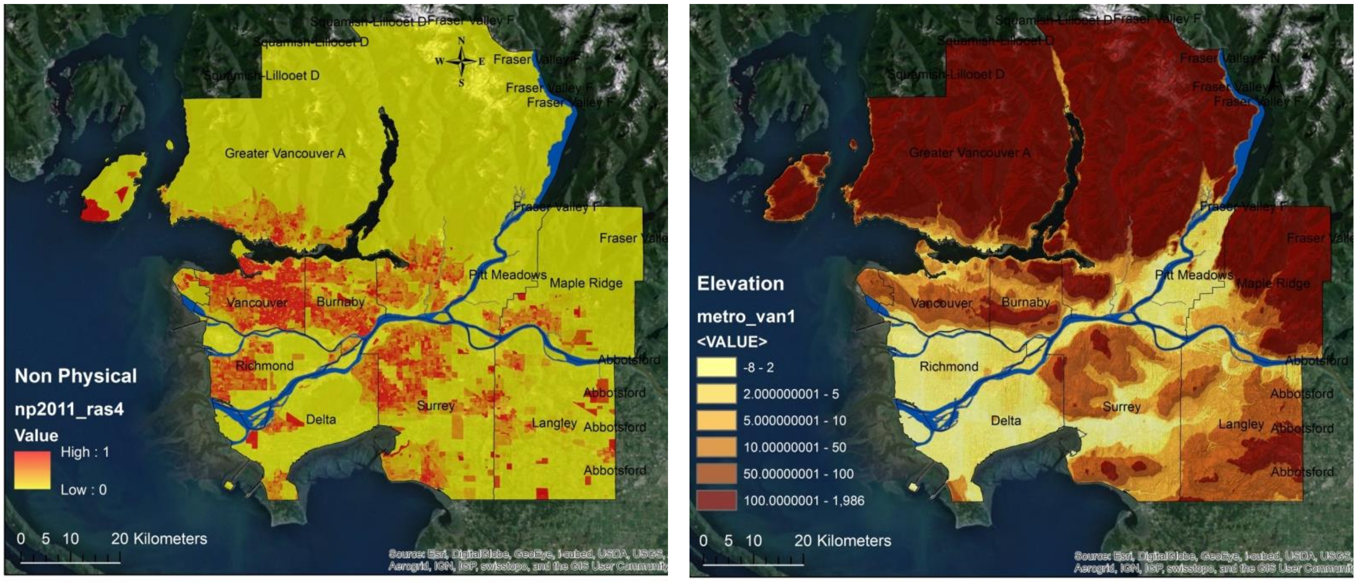


Figure 2: The Metro Vancouver: Normalized Value of a) Communicable Diseases, b) Non-communicable diseases and c) Injuries

Normalized health conditions (Figure 2) and social conditions (Figure 1) are integrated into one map. The resulting map helps in identifying non-physical vulnerable regions in the City of Metro Vancouver. Figure 3a shows the map that integrates all social and health variables. This map is also normalized and rasterized so that can be later integrated with the elevation map that describes the physical conditions that may affect spatial distribution of health impacts (Figure 3b).



a b

Figure 3: The Metro Vancouver: a) Non-physical Health Impact Map, b) Elevation Map

The final step in the presented methodology combines the two maps in Figure 3 using Equation (2) into the final heath impact map as shown in Figure 4. The values in this map are also normalized between 0 and 1. This map demonstrates that Richmond, Delta and Surrey are more vulnerable compared to other municipalities in terms of flooding related to climate change with the greatest impact on human health.

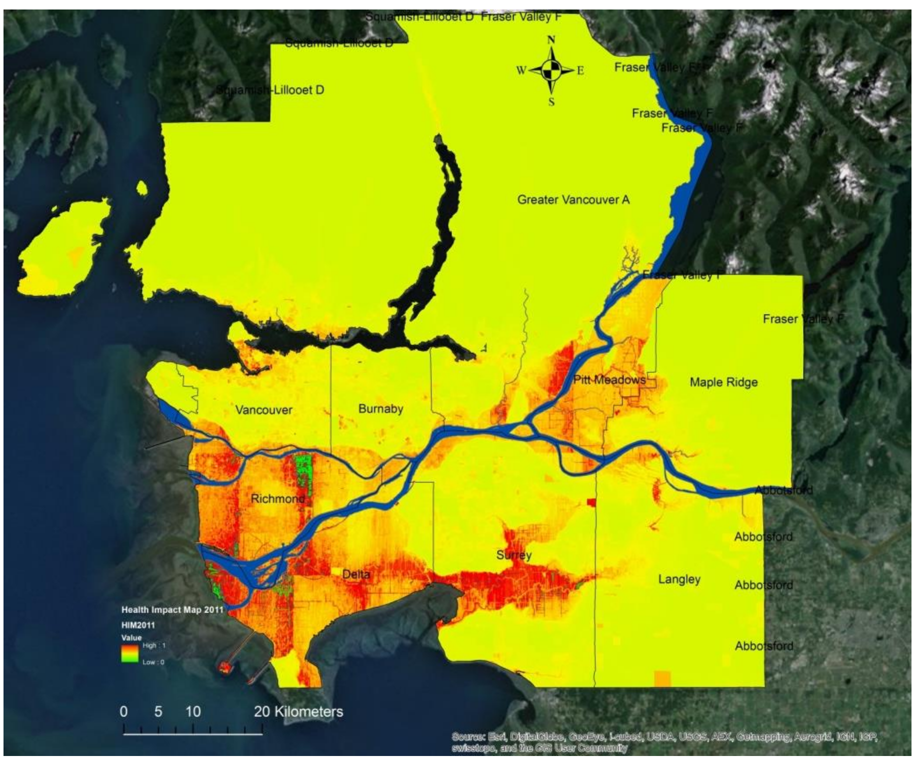


Figure 4: The Metro Vancouver: Health Impact Map

4. DISCUSSION

The paper demonstrates the procedure for the development of health impact map for use with the city resilience system dynamics simulation model. The main thrust of the presented methodology is in the use of DALY estimates as a measure of the baseline burden of disease. The major shortcomings of this measurement are easily apparent and include: the DALY estimates are for the country as a whole and not specific for an urban population however human populations now reside mainly in urban settings and local knowledge of diseases that occur in higher numbers than the national average in the urban setting could be used to modify the input.

The data is based on population numbers and the accuracy of this parameter varies from city to city depending on the country, for example Vancouver has more accurate population data than Lagos but we wanted to use the same method for calculation of the burden of disease in all the CCaR project cities to allow for comparison of resilience in the future.

The main advantage of this approach is its feasibility and that the data is available for all the CCaR project cities. The results provide an informative picture of the baseline burden of disease in three major disease categories.

The dynamic aspects of the resilience model allows for the inputs to be both temporal and spatial. As the burden of disease is population based we used an original mapping technique to provide a spatial distribution of the population and hence the burden of disease. The population figures were obtained from the most recent Stats Canada census data (Stats Canada 2012). In future we plan to use previous population census data sets to provide the temporal input.

In order to demonstrate that this input could be used as a stand- alone visual representation of the areas in Metro Vancouver where flooding would have the greatest impact on human health we created a series of maps that when layered, provide what we have termed as a health impact map. The layers selected for analysis were: burden of disease in the three categories of communicable, non-communicable and injuries, total population, population of children under 4 years of age, population of seniors over 65 years of age, and elevation.

5. CONCLUSION

This paper describes the progress to date of the development of a human health input for the CCaR system dynamics resilience simulation model designed to inform policy makers and planners on potential adaptation and mitigation measures that may improve city resilience in the event of flooding.

6. REFERENCES

Alderman K, Turner L R, Tong S., 2012: Floods and Human Health: A systematic review. *Environment International.* 47 (2012) p.37-47.http://www.ncbi.nlm.nih.gov/pubmed/22750033

Doocy S, Daniels A, Murray S, Kirsch T.D. PLOS 2013: *The Human Impacts of Floods: a Historical Review of Events 1980-2009 and Systemic Literature Review.* http://currents.plos.org/disasters/article/the-human-impact-of-floods-a-historical-review-of-events-1980-2009-and-systematic-literature-review/

Hajat S, et al. 2003: The human health consequences of flooding in Europe and the implications for public health: a review of the evidence. *Applied Environmental Science and Public Health*, 1(1):13-21. (http://www.openmindjournals.com/EnvSci1-1-Hajat.pdf. Accessed 10 December 2004)

IPCC, 2013: Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2013(a): *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker,T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)].Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Prüss-Üstün A, et al., 2003: *Introduction and methods: assessing the environmental burden of disease at national and local levels.* Geneva, World Health Organization, (WHO Environmental Burden of Disease Series, No. 1).

Simonovic, S.P., and A. Peck, 2013: "Dynamic Resilience to Climate Change Caused Natural Disasters in Coastal Megacities - Quantification Framework", *British Journal of Environment and Climate Change*, 3(3): 378-401.

Statistics Canada., 2012: Greater Vancouver, British Columbia (Code 5915) and British Columbia (Code 59) (table). Census Profile. Statistics Canada Catalogue no. 98-316-XWE. Ottawa.

WHO, 2004: Death and Daly tables (select “all ages”): http://www.who.int/healthinfo/global_burden_disease/estimates_country/en/index.html

WHO,2002: Europe.Floods: Climate Change and Adaptation Strategies for Human Health. https://www.wmo.int/pages/prog/wcp/wcasp/meetings/documents/floodresult.pdf