

Article

# Risk and Resilience: A Case of Perception versus Reality in Flood Management

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**Abstract:** Canada's vast regions are reacting to climate change in uncertain ways. Understanding of local disaster risks and knowledge of underlying causes for negative impacts of disasters are critical factors to working toward a resilient environment across the social, economic, and the built sectors. Historically, floods have caused more economical and social damage around the world than other types of natural hazards. Since the 1900s, the most frequent hazards in Canada have been floods, wildfire, drought, and extreme cold, in terms of economic damage. The recent flood events in the Canadian provinces of Ontario, New Brunswick, Quebec, Alberta, and Manitoba have raised compelling concerns. These include should communities be educated with useful knowledge on hazard risk and resilience so they would be interested in the discussion on the vital role they can play in building resilience in their communities. Increasing awareness that perceived risk can be very different from the real threat is the motivation behind this study. The main objectives of this study include identifying and quantifying the gap between people's perception of exposure and susceptibility to the risk and a lack of coping capacity and objective assessment of risk and resilience, as well as estimating an integrated measure of disaster resilience in a community. The proposed method has been applied to floods as an example, using actual data on the geomorphology of the study area, including terrain and low lying regions. It is hoped that the study will encourage a broader debate if a unified strategy for disaster resilience would be feasible and beneficial in Canada.

**Keywords:** disaster; risk; perception; community; resilience; Canada

## 1. Introduction

The impacts of geo-hydrologic hazards in the last two decades of the 20th century were felt by three-quarters of the population worldwide [1]. Since the 1900s, the most economically damaging disasters from natural causes in Canada were floods, wildfires, drought, and extreme cold. Recent research has linked specific flooding events, as well as a general rise in the intensity of wet weather in the northern hemisphere, to the effects of rising greenhouse gas levels and global climate change [2]. Past studies intended to focus on disaster response founded on a top-down approach, but the focus has now shifted to a community-based approach [3–9] that stresses resilience building. After the Hyogo Framework for Action (HFA), 2005–2015 [10] launched a movement for building the resilience of nations and communities to disasters. The Sendai Framework for Disaster Risk Reduction (SF-DRR) 2015–2030 [11] serves as a continuum to the commitment supported by the United Nations Office for Disaster Risk Reduction (UNDRR). The SF-DRR notes the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability, and hazard characteristics, as well as the strengthening of disaster risk governance [11]. Potential variations in the understanding of risk,

resilience, susceptibility, and coping capacity allow for interpretations and applications in managing disasters. Scholars have analyzed and explained perceptions of risk, as a component of the social factors, which interacts with the geographic context to create vulnerability [12], as part of the cultural arrangements of society to cope with flood events [13], and as determinants of vulnerability [14,15].

The role of risk perceptions in improving the resilience of people and communities is widely recognized as an essential component [16]. While it is not possible for societies and citizens to directly influence the natural sources of hazards, much can be done to mitigate their risk by understanding and managing the consequences they could experience should a disaster occur—this is addressed by resilience [17]. The idea of disaster-resilient communities goes beyond estimating monetary losses alone but also accounting for multiple dimensions, including technical, organizational, social, and economic facets [18]. The world risk index (WRI) focuses on the understanding of risk, which is defined as the interaction of physical hazards and the vulnerability of exposed elements [19]. It also demonstrates through the assessed risk for 173 countries that the vulnerability of a society or a country is not the same as exposure to natural hazards [19].

The most comprehensive definition of resilience is developed by the UNDRR, “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.” Communities or systems that can creatively reorganize themselves in the wake of disruptive events are considered resilient [20,21]. Studies have argued that community resilience is one of the main priority mechanisms for disaster risk reduction [22–27].

Coping capacity is deeply intertwined with resilience building and is a component of the broader term “capacity” that includes capacity assessment and capacity development [28]. It is the ability of people, organizations, and systems, using available skills and resources, to manage adverse conditions, risk, or disasters. The capacity to cope requires continuing awareness, resources, early warnings, and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities relate to complex inter-linked factors, including coordination between institutions designed to provide support in disasters and consolidation of knowledge and methodologies to assess and deal with the identified risks at the local and national levels [11].

Disaster resilience has been the main focus in disaster-prone regions in recent times [29–36]. The latest emergency management (EM) strategy for Canada [37] also focuses on disaster resilience in the wake of intensifying natural disasters in the country [38,39] and recommends prioritizing resilience building, disaster prevention, and mitigation activities. According to this program, the concept of resilience is defined as “the capacity of a system, community or society to adapt to disturbances resulting from hazards by persevering, recuperating or changing to reach and maintain an acceptable level of functioning.” The EM strategy [37] identified five priority areas and activities approved by federal/provincial/territorial (FPT) governments in Canada to strengthen overall resilience:

- i. Enhance whole-of-society collaboration and governance to strengthen resilience.
- ii. Improve understanding of disaster risks in all sectors of society.
- iii. Increase focus on whole-of-society disaster prevention and mitigation activities.
- iv. Enhance disaster response capacity and coordination and foster the development of new capabilities.
- v. Strengthen recovery efforts by building back better to minimize the impacts of future disasters.

The EM strategy supports the FPT governments’ vision to strengthen Canada’s EM capabilities to prevent/mitigate, prepare for, respond to, and recover from disasters, to reduce disaster risk and increase the resiliency of all individuals and communities in Canada. Frequent flooding is a serious concern in Canada, as was evident from the recurring spring floods in Ontario, Quebec, and Toronto Islands during 2017–2019. Previous recent significant floods include the 2013 southern Alberta floods, the 2013 Toronto urban flood, the 2014 Saskatchewan and Manitoba floods, the 2011 Manitoba flood,

and the 2017 British Columbia flood. A potential flooding concern for Toronto Islands is in place in 2020 as Lake Ontario levels may rise in spring.

Although the importance of community perception of risk in the decision-making process has been extensively discussed in the literature [4,8,40–44], the concept has not been applied in practice in a significant way across disciplines. Some of the reasons for that include difficulty in measuring the perception of different actors in the system, assessing the impact of the inclusion of opinion in risk assessment and disaster risk reduction (DRR) policy, and, most of all, designing and collecting relevant data. Perceived resilience is key to comprehend and estimate as it relates to how people perceive risk (exposure to hazards), vulnerability (susceptibility), and their capacity to cope including the institutional support. In survey-based qualitative research, it has been established that post-disaster experiences of affected communities show their preference for coping actions align with their individual personalities [3,45–48]. It is clear that pre-disaster preparedness and capacity building very much depends on how people “feel” about the probability of another disaster to occur in their community [3,49]. A recent study has used a questionnaire survey to evaluate risk perception for risk awareness and to increase resilience in schools [50]. It is worth noting here that people’s participation in community-based disaster management must not merely be an illusion of inclusion [51,52].

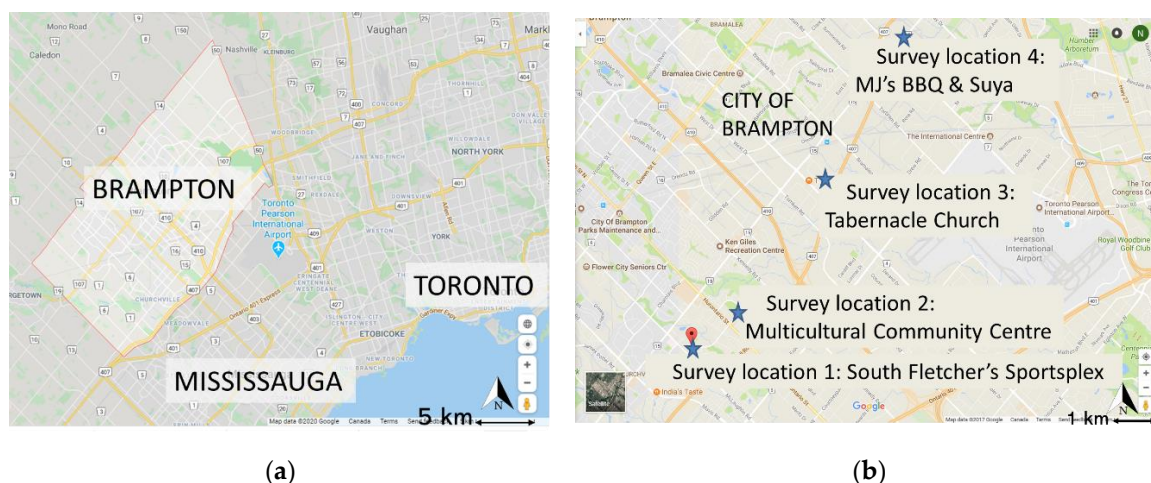
There is considerable interest in disaster resilience as a mechanism for mitigating the impacts on local communities, yet the identification of metrics and standards for measuring resilience remains a challenge [53]. By measuring baseline characteristics of communities, changes in disaster resilience over time can be monitored by estimating the individual drivers of the disaster resilience (or lack thereof)—social, economic, institutional, infrastructure, and community capacities [53]. Conventionally, quantitative methods for disaster risk assessment are better understood and also preferred as they tend to be based on numbers and indices [19,54–57]. However, interactions between the makeup of the communities, their priorities, and general vulnerabilities, and the geomorphology of the region are natural and must be integrated holistically in risk and resilience assessment [12,58–64]. On the other hand, qualitative methods are generally based on surveys, focus groups, questionnaires, and interviews. The data collected from these methods is then examined, thematized, and analyzed for the understanding and interpretation of a variety of phenomena [65–67]. Qualitative techniques are useful for measuring the impact of policy, needs-assessment of communities, and understanding of people’s behaviour and preferences during and post-disaster [68,69]. While the most common approach in research is to apply one of the two methods, quantitative or qualitative, this study integrates both techniques with the intent to capture people’s perception as well as the reality on the ground. Therefore, the focus of this study is to explore how to evaluate and incorporate people’s perceptions of risk, exposure, susceptibility, and coping capacity to realize gaps between perceived disaster resilience and objectively assessed disaster resilience. Once these gaps are identified, mitigation measures, coping capacity building efforts, and adaptivity initiatives can be developed and implemented with greater success. Based on these principles, a national strategy must be considered and prepared for a more comprehensive application for disaster risk management. The following sections outline the data used in the study, the methodology developed and used on a Canadian city, discussion of the results, and concluding remarks.

## 2. Materials and Methods

The method proposed in this study is an adapted and extended version of the world risk index (WRI) method [19]. While the WRI measures disaster resilience only objectively, the technique proposed here evaluates people’s perception of disaster resilience (function of exposure, susceptibility, and coping capacity) and incorporates their opinion into the assessment of perceived resilience. Previous studies have shown that a questionnaire survey is a useful tool to capture risk awareness and perception of the population to help plan future risk management efforts and encourage a resilience culture in the community [47,50]. In this study, objective and perceived resilience are being evaluated and compared, gaps between perceived and actual resilience are identified, and an integrated resilience is calculated,

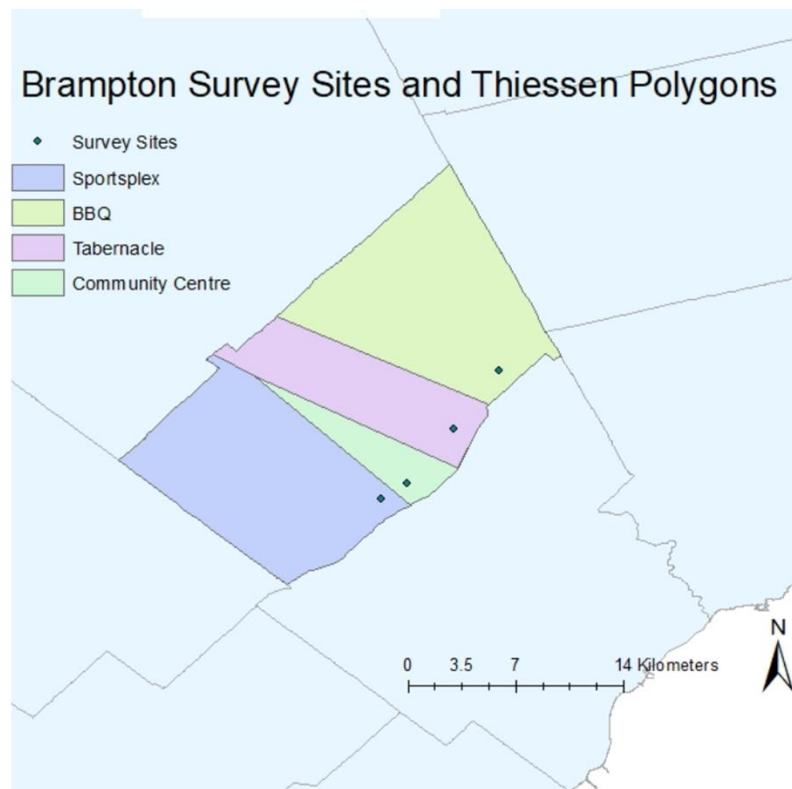
as well. Community participation is essential in effective and successful disaster management in communities, and this point has been validated by various studies that are based on simulation-based planning tools, basically to engage stakeholders in a user-friendly manner [55,70].

**Perceived measurements**—In order to incorporate people’s perceptions, we have used questionnaire surveys to collect data from four different locations in the City of Brampton in the Greater Toronto Area (GTA) of Canada (Figure 1). The selection of the survey sites was made based on a good representation of the community. Specifically, a sports and community centre (survey location 1) that also houses the public library and a swimming pool, a multicultural community centre (survey location 2), a church (survey location 3), and a restaurant (survey location 4), are places regularly used by the community. We received 100 responses to the questionnaire consisting of 29 questions designed to reflect people’s perceptions of threats from natural hazards, how they would cope in emergencies, their background, and how they engage in their local environment. We explained the nature and intent of the study to each participant, including what is meant by risk, how it is a function of different elements, including exposure to hazards. However, it should be noted that at the time of the survey, the exact buffer zones to estimate exposure had not been determined and, therefore, were not communicated to the survey participants. The precise nature of the questions and how they relate to model parameters is given later in this section. People’s perceptions are treated as representative of the entire city for demonstrating the methodology leading to the perceived assessment of community resilience (Table 1).



**Figure 1.** (a) Part of the Greater Toronto Area (GTA) for perspective purposes showing the City of Mississauga and the City of Toronto in the south and southeast of Brampton; (b) the four survey locations in Brampton: survey location 1: South Fletcher’s Sportsplex community centre, survey location 2: Brampton multicultural community centre; survey location 3: New Birth Tabernacle, a non-denominational faith gathering center; and survey location 4: a local restaurant.

We have used the Thiessen polygons method to aggregate the surveyed areas for the entire city by dissemination areas (DAs)—areas of equal density of population, for perceived assessment of the parameters used in the methodology (Figure 2). The Thiessen polygon technique appropriately assigns areal significance to each survey site by constructing perpendicular bisectors to the lines joining each site with those immediately surrounding it. These bisectors form a series of polygons, each polygon containing one site. The data collected at a site gets assigned to the whole area covered by the enclosing polygon.



**Figure 2.** The City of Brampton survey sites and Thiessen polygons (TP) for perceived parameters' assessment. The TP technique appropriately assigns areal significance to each survey site.

It is worth noting here that two survey locations, BBQ and Tabernacle church, shown in Figure 1b, were lumped together as one entity, "BBQ and Tabernacle" for calculations in GIS. The reason being, the total number of responses collected from the two locations combined was rather small (14) compared to the other sites.

As demonstrated in Table 1, three parameters, namely exposure, susceptibility, and lack of coping capacity, are appropriately extracted from the responses to the survey questions by assigning binary values to them. Each parameter is comprised of several variables, representative of the parameter [19,71–73]. Although we have presented a select set of variables to represent each of the three parameters to demonstrate the method, these should not be taken as exhaustive. Disaster types, geomorphology, landuse of the region, and demographics of the population must be taken into account in the determination of these variables. The three parameters are allocated weights according to their assumed influence in this particular case study [55]. The weights can vary depending on the impact of each parameter on community resilience. For example, a known dangerous environment (high exposure), a prosperous and educated neighbourhood (low susceptibility), and an accessible network of emergency services (high coping capacity) must guide how the parameters can be weighted. For example, the residential development in the Barker reservoir in Houston, Texas, that got flooded during Hurricane Harvey [74], will have a high exposure. Table 1 summarizes the proposed process, including a guide to assigning binary values to individual variables as part of the methodology developed to account for people's input in the process of resilience assessment. For example, the parameter exposure is based on dangerous locations such as:

- River (flood risk)
- The transportation network (risk from derailment, explosion, oil spill)
- Chemical plants and hazardous industries
- Transmission lines (elevated health risk from high voltage corridors)

- Oil and gas pipelines (toxic spills)
- Garbage dumpsites (a potential failing of large piles, health, and environmental hazard)

The parameter, susceptibility, comprises the following seven variables:

- Ownership/renting status of the residence
- Crowdedness factor based on the number of members in the household
- Language ability—English or French
- Employment status
- Job satisfaction
- Age—assuming that the very young and the very old would be more susceptible to the exposure to the disaster risk
- Persons with disability

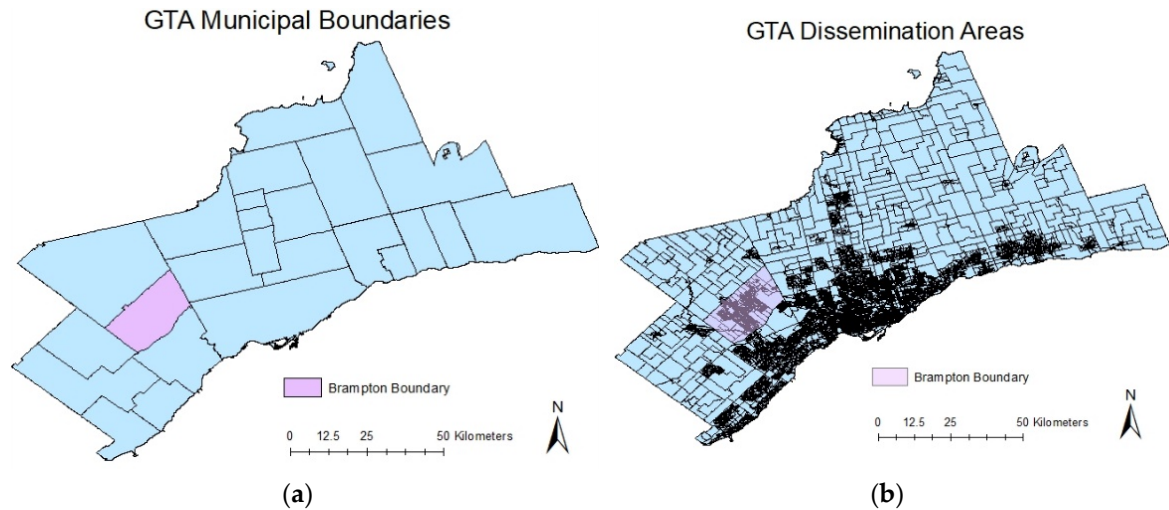
Similarly, the parameter, lack of coping capacity comprises the following variables:

- Level of education
- Family income
- Means of transportation (personal or public)
- Social network support
- Disaster experience by family or friends
- Importance of disaster preparedness
- Engagement in local politics as a proxy of participation

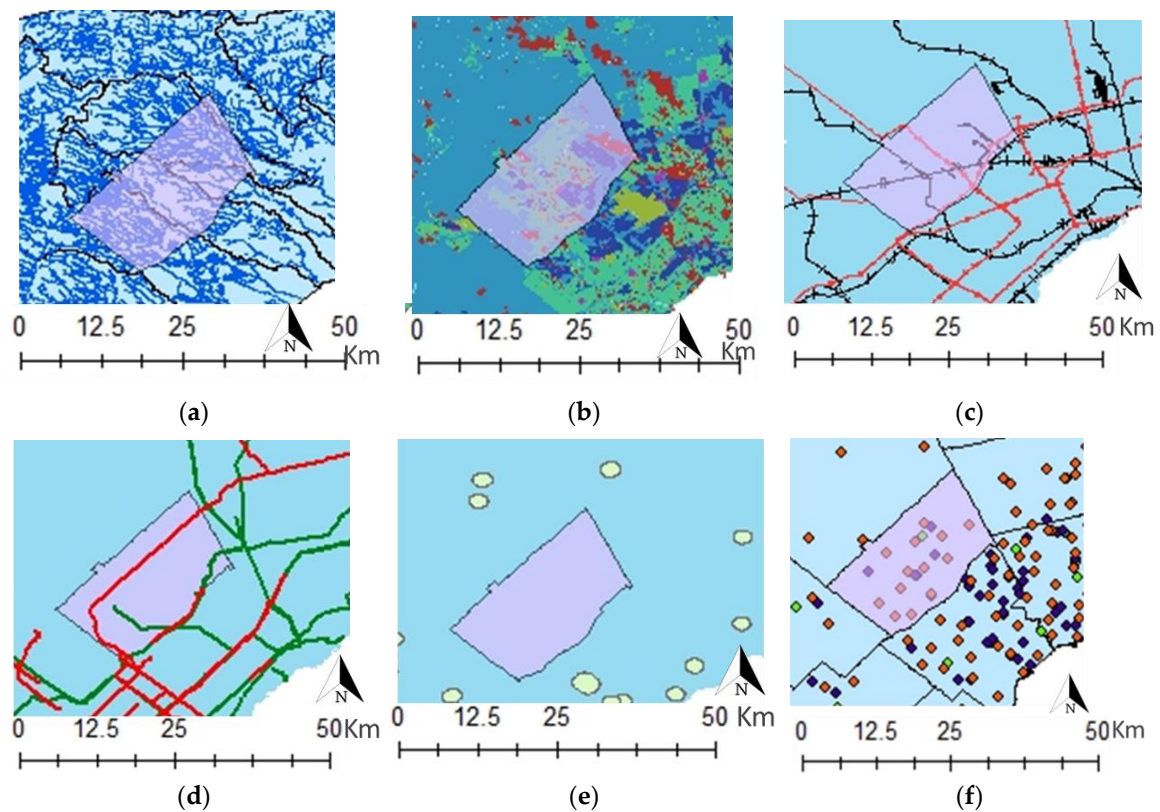
Objective measurements—We have used the 2011 census of Canada for demographic information, Municipal Property Assessment Corporation (MPAC) average property values, slopes and terrain of the region, and landuse. The landuse data is valuable for determining the location of critical infrastructure and critical facilities for the assessment of objective parameters. The GIS software, ArcGIS, is used for data processing and analysis according to the dissemination area (DA) map of the study area. Appendix A lists all the data sources. Figure 3 shows the municipal boundaries and dissemination areas in the GTA. Figure 4 presents datasets, cropped for the City of Brampton, used for parameters estimation proposed in this method.

**Table 1.** Information extracted from the four surveys toward perceived resilience along with assigned weights and binary values, where the total of all assigned weights  $\sum W_i = 1$ .

Parameter	Guidance for Assigning Binary Values 0 or 1 Based on Response to the Survey			
	Question	Binary value = 0	Binary value = 1	Remarks
Exposure Weight $W_1$	I live near a hazardous situation such as a river, chemical plant, etc.	If false	If true	Add all binary numbers to get total exposure
	Question/variable	Binary value = 0 if response is as below	Binary value = 1 if response is as below	Remarks
Susceptibility Weight $W_2$	My home is	Owned	Rented or other	Add all binary numbers to get total susceptibility
	# members in household (crowdedness)	<4	>4	
	Language (English)	very well/good	moderate/poor/blank	
	Employment	Full time/self-employed	Part time/retired	
	Job satisfaction	Very satisfied/satisfied	Somewhat satisfied/not satisfied/blank	
	Age	>20 and <65	<20 and >65	
	Disability	No	Yes	
Lack of Coping Capacity Weight $W_3$	Question/variable	Binary value = 0 if response is as below	Binary value = 1 if response is as below	Remarks
	Education	College and higher	Less than college	Add all binary values to get total lack of coping capacity
	Income	>50 K	<50 K	
	Transportation	Personal vehicle	Public/rideshare	
	Social network	Very important	Important/somewhat/other	
	Disaster experience	Yes	No/blank	
	Disaster preparedness option	Family/friend	Public shelter/blank	
Voted in the past election	Yes	No/blank/n/a		



**Figure 3.** (a) GTA municipal boundaries, and (b) dissemination areas. City of Brampton is shown in purple.



**Figure 4.** Objective datasets for the City of Brampton (purple boundary): (a) watercourses, (b) landuse, (c) pipelines in red and transmission lines in green, (d) the highways in red and the railways in black, (e) dumpsites in yellow circles, and (f) emergency services.

The landuse data in Figure 4b includes residential (green), commercial (dark purple), government and institutional infrastructure (green), industrial (dark blue), parks and recreational (red), and open area (blue). Similarly, in Figure 4f, emergency services include fire stations (red), police stations (dark blue), and hospitals in green. It should be noted that none of the dumpsite buffers fall within the boundary of the city and, therefore, do not contribute toward exposure in this case study.

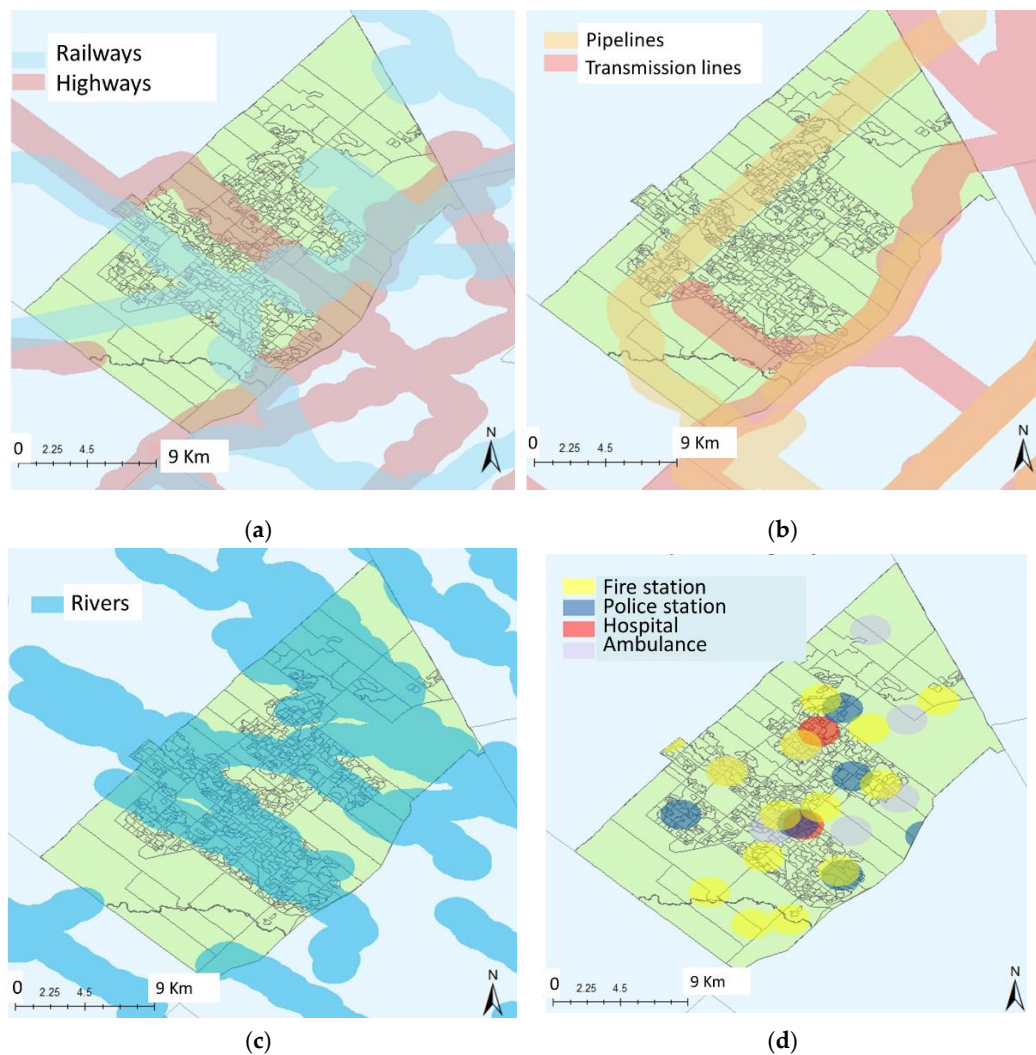
Table 2 summarizes the process of quantifying individual variables within each of the three parameters as part of the methodology. Real datasets explained and illustrated in Figure 4 earlier have been used in the measurement of the model parameters: exposure, susceptibility, and lack of coping



capacity. Some of the processed data are shown in Figure 5. For example, exposure is determined based on whether or not a resident is located in proximity of (within a kilometer of) a highway, railway, river, industrial site, pipeline, transmission line, oil and gas facility, or dumpsite. Similarly, objective assessment of susceptibility is derived from census data, including the residence type, the age of its construction, the property value, language skill, employment status, and disability rate. The lack of coping capacity is derived from census and GIS data; it includes, income, education, a distance of more than one kilometer from emergency services, a fire station, police service, or ambulance service. See Figure 5 for the visuals of the buffer zones.

**Table 2.** List of parameters and variables for the objective assessment of community resilience. The total of all assigned weights  $\sum W_i = 1$ .

Parameter	Criteria to Assign Binary Values to Variables			Remarks
	Variable	Binary value = 0	Binary value = 1	
Exposure Weight $W_1$	Highways, Railway tracks, River and creeks, Industries, Oil and gas pipelines, Dumpsites–stockpiles, Low lying areas (terrain/slope)	If no exposure to a potential hazard	If within 1 km buffer zone of any of the potentially hazardous situations	Add all binary assigned values to get total exposure
	Variable	Binary value = 0	Binary value = 1	
Susceptibility Weight $W_2$	Residence type	Detached/semi	Rented apartment	Add all binary assigned values to get total susceptibility
	Age of property construction	Post-1980	Pre 1980	
	Language	very well/good	moderate/poor/blank	
	Employment	Full time/self-employed	Part time/retired	
	Age	>20 and <65	< 20 and >65	
	Disability	No	Yes	
	Property value	>400 K	≤400 K	
Lack of Coping Capacity Weight $W_3$	Variable	Assign value = 0	Assign value = 1	Add all binary assigned values to get total lack of coping capacity
	Education	College and higher	Less than college	
	Income	>50 K	≤50 K	
	Disaster preparedness: Hospital	≤1 km	>1 km away	
	Disaster preparedness: ambulance service	≤1 km	>1 km away	
	Disaster preparedness: Health emergency services	≤1 km	>1 km away	
	Disaster preparedness: Police station	≤1 km	>1 km away	



**Figure 5.** The City of Brampton: dissemination areas superimposed (a) with buffer zones of 1 km around the transportation network, railways in blue and highways in pink; (b) transmission lines in pink and gas pipelines in blue; (c) rivers in blue to demarcate exposure zones; and (d) buffer zones of 1 km around emergency services to assess lack of coping capacity including fire stations in yellow, police stations in blue, hospitals in red, and ambulance services in a light purple.

The overall resilience is calculated using Equations (1) to (6), derived from the WRI method [19]. Precisely, Equation (1) calculates the Lack of Resilience using objective data for the three parameters that are individually normalized. The parameters can be weighted using weights thought to be appropriate for this case study for demonstration purposes. The weights ( $W_1$ ,  $W_2$ ,  $W_3$ ) are open to adjustment in individual cases depending on the potential influence of the parameters, as well as the objective of the study. For example, a vulnerable community is perceived as more susceptible in comparison to an affluent neighbourhood. Residential development well outside of flood zones indicates a lower level of exposure even though the population may be regarded as vulnerable. If the community is at a substantial distance from a healthcare facility, it may reflect a lack of coping capacity in emergencies. Therefore, in this scenario, it will make sense to allocate a lower percentage of weight to “Exposure” and higher percentage to “Lack of Coping Capacity” and “Susceptibility.” For the application and demonstration of the methodology, we have assigned weights to the parameters as given in Equation (2) for both objective and perceived calculations.

Equation (3) gives the estimate of Resilience using objective data, Equation (4) estimates Resilience using perceived data, and Equation (5) determines the combined Resilience by summing up the

perceived and objective Resilience estimates. We propose here that the combined Resilience is a way to account for perceived and real measures of community resilience.

$$\begin{aligned} \text{Lack of Resilience}_{\text{Objective}} &= W_1 \times \text{Exposure}_{\text{Objective}} + W_2 \times \text{Susceptibility}_{\text{Objective}} \\ &+ W_3 \times \text{Lack of Coping Capacity}_{\text{Objective}} \end{aligned} \quad (1)$$

where  $\sum W_i = 1$

$$\begin{aligned} \text{Lack of Resilience}_{\text{Objective}} &= 0.2 \times \text{Exposure}_{\text{Objective}} + 0.4 \times \text{Susceptibility}_{\text{Objective}} \\ &+ 0.4 \times \text{Lack of Coping Capacity}_{\text{Objective}} \end{aligned} \quad (2)$$

$$\text{Resilience}_{\text{Objective}} = 1 - (\text{Lack of Resilience})_{\text{Objective}} \quad (3)$$

$$\text{Resilience}_{\text{Perceived}} = 1 - (\text{Lack of Resilience})_{\text{Perceived}} \quad (4)$$

$$\text{Resilience}_{\text{combined}} = \text{Resilience}_{\text{Perceived}} + \text{Resilience}_{\text{Objective}} \quad (5)$$

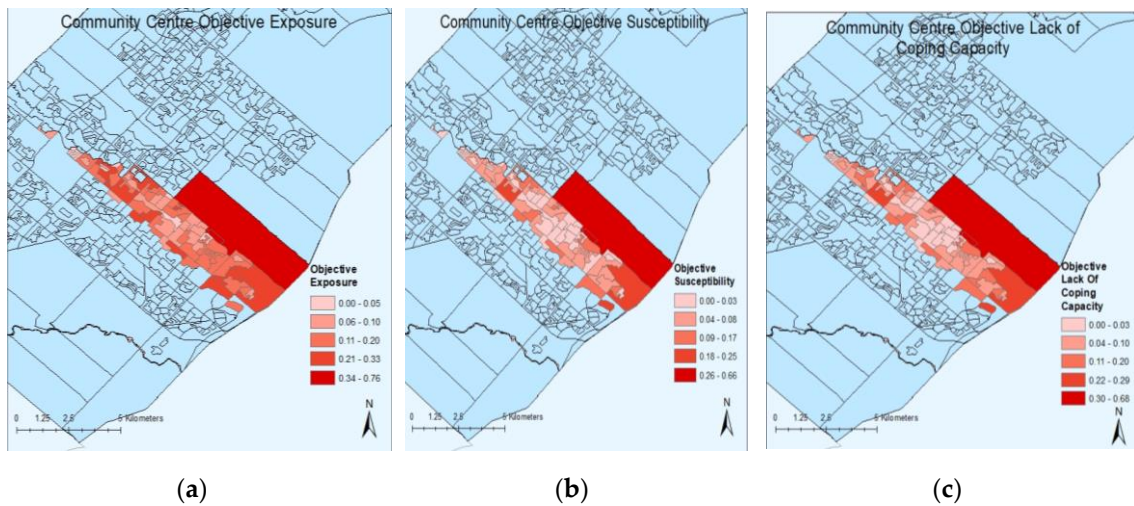
The estimated total resilience has been calculated by normalizing the combined resilience estimates using Equation (6):

$$\text{Resilience} = \frac{\text{Resilience}_{\text{combined}} - \text{MIN}(\text{Resilience}_{\text{combined}})}{(\text{MAX}(\text{Resilience}_{\text{combined}}) - \text{MIN}(\text{Resilience}_{\text{combined}}))} \quad (6)$$

It is noteworthy that Equations (3) and (4) were calculated using normalized and unweighted individual parameters in Equation (2), leading to an adjusted maximum total value of perceived (and objective) Resilience. The objective and perceived resilience calculations are done using the same formula.

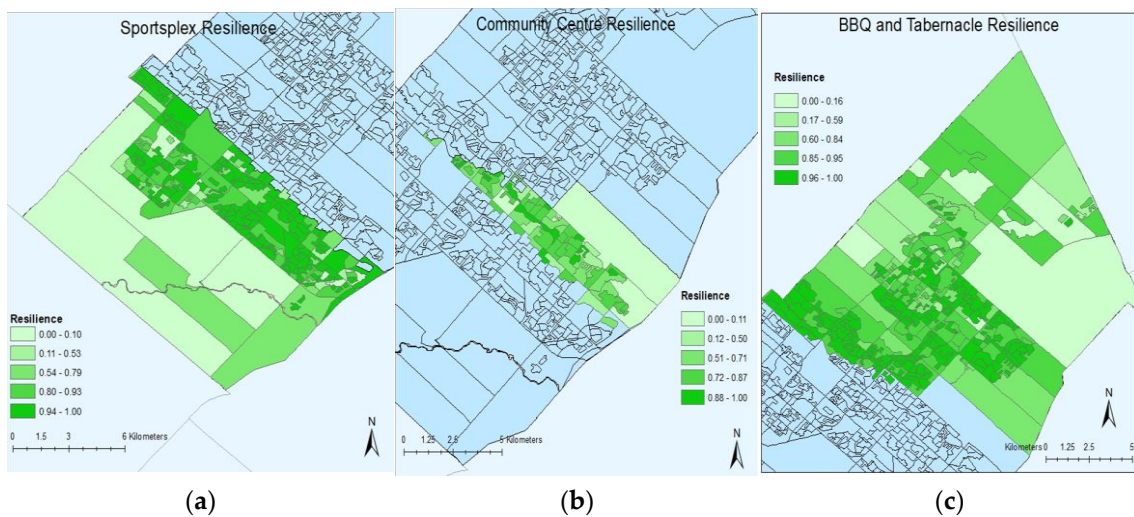
### 3. Results

The findings of the research are illustrated through Figures 6–8. Objective and perceived measures were made for the survey sites. The actual datasets on the geomorphology of the study area, including rivers and low lying regions, indicate that the method has been applied to a flooding scenario as an example. As mentioned earlier, two survey locations, namely, BBQ and Tabernacle church, were lumped together as one entity, “BBQ and Tabernacle” for calculations in GIS due to the small number of responses from the two locations. Each of the three parameters was calculated separately to achieve perceived and objective estimates of them for each survey location. Figure 6 shows objective measures of the three model parameters, namely, Exposure, Susceptibility, and the Lack of Coping Capacity calculated for survey location 2, the Community Centre. Similar maps were obtained for perceived measures of the three parameters. Also, similar maps were developed for other survey locations. In total, 12 maps were obtained for objective and perceived estimates of the three parameters for the three survey locations. Although it may be desirable for the readers to visualize the step-by-step development of these maps, to avoid overcrowding of illustrations, selected graphs are presented here.

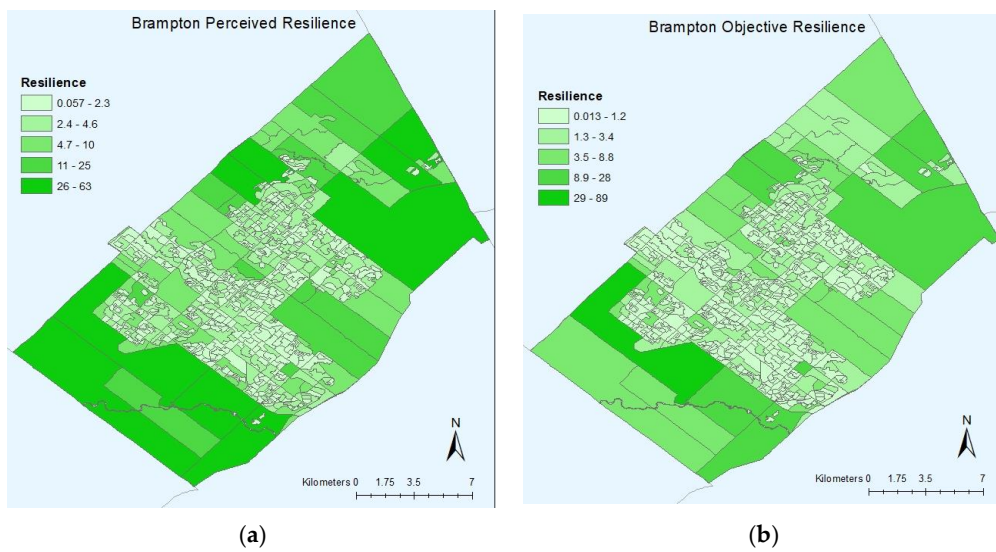


**Figure 6.** Objective measures of the three parameters for one of the three survey areas: (a) exposure, (b) susceptibility, and (c) lack of coping capacity. Similar maps were obtained for the other two survey areas but are not shown here.

Figure 7 shows the integrated (perceived plus objective) measure of Resilience for the three survey locations, separately. Figure 8 is a picture of the perceived and objective Resilience measures for the entire City of Brampton, and Figure 9 represents the integrated resilience map for the city. Each of the three parameters was normalized before being weighted in Equation (1). Therefore, as can be seen in Figure 8, the two resilience maps show estimates of up to 63 for perceived Resilience and up to 89 for the objective Resilience. It is noteworthy that the method suggests the ideal resilience value to be 100. Therefore, objective resilience gives a better level of resilience in the study area as compared to perceived measure of resilience. In essence, the maximum value of objective resilience is higher than perceived resilience, and the higher the value of resilience, the better in each case scenario.

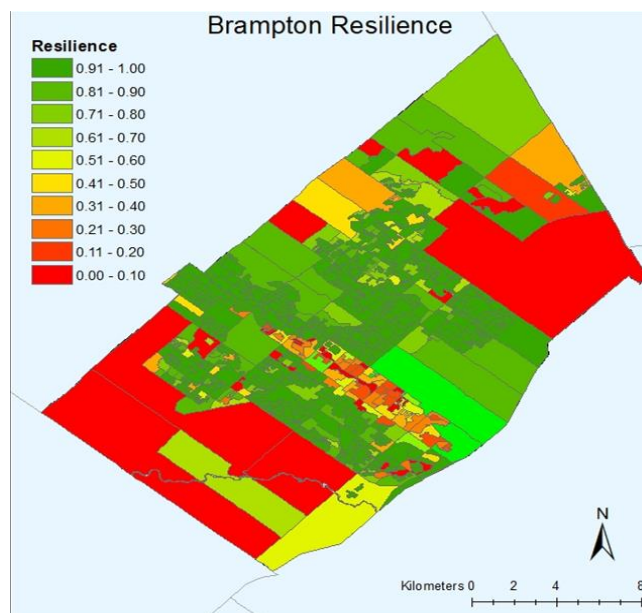


**Figure 7.** The measure of total resilience (perceived plus objective) for the three survey sites: (a) Location 1, (b), Location 2, and (c) Location 3.



**Figure 8.** Resilience maps aggregated for the City of Brampton (in percentage): (a) perceived, and (b) objective.

Although Figure 8 is the key outcome of this study, Figure 9 has been arrived at by combining the two resilience measures, showing the regions of variable resilience. It is useful to see how the two measures of resilience may have aligned with each other, positively or negatively. In future research, it would be helpful to subtract the two resilience measures from each other and visualize where the gaps are between the public perception and the reality on the ground. The shades of green indicate levels of resilience of the community, the darker, the better. The shades of yellow and parts of red are in regions where rivers and creeks flow. The areas shown in red indicate low resilience due to a variety of reasons such as industrial areas, flood zones, low lying areas, and a dense network of watercourses.



**Figure 9.** Integrated resilience map for the City of Brampton (normalized); higher resilience value indicates a higher level of resilience.

#### 4. Discussion and Conclusions

The core objective of this study was to develop a methodology to capture community perceptions of flood hazard risk based on their exposure, susceptibility, and lack of coping capacity, and incorporate

those perceptions into estimating community resilience. Inspired by the world risk index (WRI), we have successfully demonstrated that the WRI determinants can be used to explain the difference between how risk is perceived and the factual picture presented by the objective data. We estimate objective resilience using actual data related to exposure (dangerous locations), susceptibility (derived from demographic data), and lack of coping capacity (derived from a combination of census and landuse data). The two resilience measures, perceived and objective, were combined by adding them and normalizing the resulting combined resilience. It should be noted that the perceived and objective parameters were normalized at the unweighted stage that justifies the similar treatment of the two (perceived and objective). The study should be used as a decision-making tool to enhance the resilience of communities based on their circumstances.

We used a questionnaire to engage people, but it should be noted that some of the nuances of the methodology were under development at the time of the survey. The randomly selected respondents were residents of the City of Brampton, as reflected by their use of the community centre, sports centre, the church and the restaurant used as survey locations. We acknowledge the small sample size of 100 participants that may have led to a rather underwhelmingly visual difference in the perceived and objective resilience measures. The reason for that to happen could be the fact that a small sample from each survey site was used to represent an entire region determined by the Thiessen polygon method. Furthermore, with a limited representation of the community in the study area, the perceived data estimates are bound to have uncertainties that can be addressed with extensive survey data. The determination of the buffer zones for different exposure variables was made by treating the variables such as highways and rivers in a similar manner. However, this aspect needs to be improved by allowing different buffer zones for various variables.

In summary, this research makes a reasonable preliminary attempt toward achieving a better representative measure of the resilience of a community in the context of disasters and emergencies. Future research is recommended for examining current disaster mitigation policies in Ontario, engaging representative communities to capture their perceptions, and looking at how specific changes can be made in those policies to improve their relevance and outcome for a diverse population. Solutions to disaster risk reduction and preparedness strategies lie in meaningful consultation with stakeholders, no matter how insignificant some may seem. We recommend future research to refine the methodology along with its various aspects presented here. The approach should also be user-friendly for a broader application. In Canada, the most frequent hazard, flooding, and other disasters are managed by the local authorities first; the province assists if local capacities prove to be insufficient; and eventually, the federal government helps if the consequences are too severe. In many cases, the federal help arrives when it is too late due to unclear guidance, inconsistent messaging, political and ideological differences among actors, and conflicting priorities. There is a need, now more than ever before, to develop a national strategy for resilience to all disasters to enable an environment of swift impact assessment of events and allocation of resources across the nation.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A List of Data Sources

Data	Source
<b>Exposure</b>	
Highways	DMTI Spatial, 2015 <a href="http://geo.scholarsportal.info/#r/details/_uri@=2347499980">http://geo.scholarsportal.info/#r/details/_uri@=2347499980</a>
Rail Lines	Ontario Ministry of Natural Resources, 2012
Industrial Sites	Canada, Federal Government Open Data Program, created by request, 2016
GTA Pipes, Transmission Lines	DMTI Spatial, 2014
Slope and DEM	DMTI Spatial, 2015 (retired)
Major Rivers	Provided by Toronto and Region Conservation Authority
<b>Susceptibility</b>	
Home Ownership	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Age of Construction	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Language Skills	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Employment	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Age	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Disability	Statistics Canada, by request, 2017
Property Value	online real estate listings (ReMax), geocoded by address in ArcGIS Online
<b>Coping Capacity</b>	
GTA Fires Stations	<a href="http://geo.scholarsportal.info/#r/details/_uri@=3739967620">http://geo.scholarsportal.info/#r/details/_uri@=3739967620</a>
GTA Police Stations	<a href="http://geo.scholarsportal.info/#r/details/_uri@=3739967620">http://geo.scholarsportal.info/#r/details/_uri@=3739967620</a>
GTA Hospitals	<a href="http://geo.scholarsportal.info/#r/details/_uri@=3570906326">http://geo.scholarsportal.info/#r/details/_uri@=3570906326</a>
Ambulance Stations	Addresses gathered from publicly available information at municipal websites, Wikipedia, and Google; geocoded using ArcGIS Online
Income	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Education	Statscan, 2011 census data via <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
<b>Miscellaneous</b>	
Watercourses	Ontario Ministry of Natural Resources, 2011
Watersheds	Ontario Ministry of Natural Resources, 2011
Dissemination Areas	University of Toronto Census Analyzer <a href="http://dc1.chass.utoronto.ca/census/">http://dc1.chass.utoronto.ca/census/</a>
Land Use	DMTI Spatial, 2014 <a href="http://geo.scholarsportal.info/#r/details/_uri@=2785150059\$DMTI_2014_CanMapRL_Topo_LUR_ALL_PROV">http://geo.scholarsportal.info/#r/details/_uri@=2785150059\$DMTI_2014_CanMapRL_Topo_LUR_ALL_PROV</a>
Census Tracts	University of Toronto Census Analyzer <a href="http://dc1.chass.utoronto.ca/cgi-bin/census/2011nhs/displayCensus.cgi?year=2011&amp;geo=ct">http://dc1.chass.utoronto.ca/cgi-bin/census/2011nhs/displayCensus.cgi?year=2011&amp;geo=ct</a>
GTA Municipalities	DMTI Spatial, 2014 <a href="http://geo.scholarsportal.info/#r/details/_uri@=4044335176\$DMTI_2014_CanMapRL_Streets_MUN_ALL_PROV">http://geo.scholarsportal.info/#r/details/_uri@=4044335176\$DMTI_2014_CanMapRL_Streets_MUN_ALL_PROV</a>
Education	DMTI Spatial, 2015 <a href="http://geo.scholarsportal.info/#r/details/_uri@=4062179246">http://geo.scholarsportal.info/#r/details/_uri@=4062179246</a>

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