DISTRIBUTIVE JUSTICE AND URBAN FORM ADAPTATION TO FLOOD RISKS: A GIS-BASED STUDY FOR THE IDENTIFICATION OF PRIORITY AREAS FOR THE JUST ALLOCATION OF GBIS IN TORONTO

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ABSTRACT

The integration of green and blue infrastructures (GBIs) in urban form, in the name of flood-risk reduction and climate change adaptation, might disproportionately exacerbate the vulnerability of socio-economically disadvantaged groups, leading to climate injustice. Since there is a gap in theoretical and empirical studies that define spatial criteria and/or concepts for the just spatial distribution of GBIs in urban form, we apply a GIS-based multicriteria methodology on Toronto to identify the neighborhoods need to be prioritized in GBIs' provision for adaptation to flood risks. Our GIS methodology, specifically, identify the priority areas by mapping and overlaying six concepts: (1) the spatial distribution of flood sensitive population; (2) the spatial distribution of flood sensitive infrastructure/buildings; (3) the spatial distribution of flood-exposed population; (4) the spatial distribution of flood-exposed infrastructures/ buildings; (5) The spatial distribution of areas with low amounts of GBIs; and (6) the spatial distribution of flood hazards. The results show that GBIs, in Toronto, are not distributed in areas with the high risks of floods. The results, moreover, highlight four neighborhoods need to be prioritized in the allocation of GBIs, namely: Bay Street Corridor, North St. James Town, Kensington-Chinatown, and Milliken.

Keywords: Adaptation, Climate justice; distributive justice; risk framework; Toronto; Urban floods

INTRODUCTION

The increase in precipitation rates, due to the global climate change, and the failure of urban gray infrastructures to manage the extra stormwater have led to the recognition of GBIs as flexible, multifunctional, and reliable measures for adapting cities to the flood risks (Zellner et al., 2016, Soz et al., 2016, Carter et al., 2018). The integration of such infrastructures in urban form, however, might create major challenges of climate justice. The unjust outcomes are the result of the existing power relations and privilege patterns that prioritize those who are already in well-being over those who bear the highest levels of flood risks (in which risk is the result of intersections between hazards, vulnerabilities, low levels of adaptive capacities) (Kabisch et al., 2016, Carter et al., 2015).

To advance climate justice, theoretical debates on climate justice recommend adaptation responses (among which are GBIs) to employ the three pillars of climate justice, namely: distributive justice (which relates to the equity of outcomes); procedural justice (which refers to equal decision-making processes), and recognitional justice (which refers to the legitimization of difference in adaptation responses) (Young, 2011 [1990], Schlosberg, 2001, Fraser, 2009 [1996], Bulkeley et al., 2014, Ambrey et al., 2017). However, the results of a systematic literature review, in which we reviewed 105 peer-reviewed papers on urban climate justice in adaptation, unveil that the existing empirical studies mostly use these pillars as criteria for evaluating urban form adaptive interventions (such as GBIs' provision) rather than employing them in urban form as a means for the advancement of climate justice. Moreover, there is an absence of theoretical studies which bridges the gaps between these pillars and the adaptive measures in urban form, such as GBIs.

To address these empirical and theoretical gaps, the research follows two objectives. The first objective is to suggest a theoretical framework for the just spatial distribution of GBIs in urban areas that need them the most. For this purpose, We combine risk framework (suggested by Mehrotra et al. (2009)) and distributive justice (as one of the pillars of climate justice) to suggest six concepts by which one can identify urban areas that need GBIs the most. These six concepts are: (1) the spatial distribution of flood sensitive population; (2) the spatial distribution of flood sensitive infrastructure/buildings; (3) the spatial distribution of flood-exposed population; (4) the spatial distribution of flood-exposed infrastructures/ buildings; (5) The spatial distribution of areas with low amounts of GBIs; and (6) the spatial distribution of flood hazards. The second objective is to empirically operationalize this theoretical framework on the city of Toronto where the frequency of floods (see: Armenakis and Nirupama (2014)), on one hand, and the socio-economic inequalities (see: Walks et al. (2016)), on the other hand, are increasing. We, specifically, use spatial analysis (using ArcGIS software) to map and overlay the six theoretical concepts, and consequently, to identify the priority neighborhoods for the allocation of GBIs. Our results highlight four neighborhoods in Toronto need to be prioritized in the allocation of GBIs, namely: Bay Street Corridor (76), North St. James Town (74), and Kensington-Chinatown (78), and Milliken (130).

THEORETICAL FRAMING

The adaptation of urban form to climate change is tightly tied with the mitigation of climatic risks, such as flood risks. According to the risk framework, suggested by Mehrotra et al. (2009), the level of climatic risks depends on three components: hazards, vulnerabilities, and adaptive capacity. *Hazards* relate to climatic extreme events (e.g., heat waves, floods, and storm surges), whose trends are increasing in cities. *Vulnerability* refers to the level of sensitivity and exposure of urban systems to climatic hazards. last, *adaptive capacity* relates to the ability of a system to moderate harm from climatic hazards while taking advantage of emerging opportunities (Rosenzweig et al., 2011, IPCC, 2001, Carter et al., 2015, Adger, 2006).

Since the global climate change has already increased the precipitation rates and the frequency of flood hazards, to reduce flood risks, several studies (see for example: Li et al. (2020); Hetz and Bruns (2014); Henrique and Tschakert (2019)) have focused on urban form interventions that advance urban populations' adaptive capacity and which can reduce their vulnerability. Among such interventions that are highly recommended are green and blue infrastructures (GBIs) (see: PLennon et al. (2014); Childers et al. (2015); Depietri and McPhearson (2017)). GBIs are defined as "interconnected networks of green and [blue] spaces" (Benedict and McMahon, 2002), such as parks, green roofs, lakes, and wetlands, that by the integration of ecosystem services in urban form benefit humans (Demuzere et al., 2014). The increased attention to GBIs for adapting to floods might be the result of the shift in storm water management from traditional approaches, which are based on combined/separated urban swage systems, to decentralized approaches, which are based on bio-mimicry hydrological processes (see: Fletcher et al. (2007); Gautam et al. (2010); Coutts et al. (2013)). Among the multifunctional benefits of GBIs for flood risk reduction are storm water retention (such as through forest soils, which infiltrate the extra stormwater), storm water detention (such as through ditches, which reduce the speed of storm water), and discharge control (such as through wetlands, which control downstream discharge) (Liu et al., 2019).

Attention to only these technical issues of GBIs, however, cannot evenly reduce the risk of floods for all people because the allocation of GBIs is influenced by socio-economic patterns of privilege and power imbalance that have shaped and continue to shape cities. To illustrate, to protect urban economies and elite groups' interests against floods, the provision of GBIs might disproportionately advance the adaptive capacity of some privileged groups while excluding and/or imposing costs on the most vulnerable groups who usually have the lowest levels of adaptive capacity (Romero-Lankao and Gnatz, 2019, Moser and Stein, 2011, Miller, 2019). The integration of GBIs in urban form, therefore, in the name of climate change adaptation, might lead to climate injustice. To prevent such unjust outcomes, social and climate justice scholars, such as Young (2011 [1990]), Fraser (2009 [1996]), and Schlosberg (2001), suggest the just spatial distribution of adaptive resources (i.e., distributive justice), which reflects the existence of fair and inclusive decision making processes (i.e., procedural and recognitional justice).

Accordingly, to allocate GBI, adaptation decisions need to recognize, equally include, and prioritize urban areas that experience the highest levels of flood risks. Our framework, therefore, combines the risk framework (which is the result of intersections between hazards, vulnerabilities, and adaptive capacities) with distributive justice (which itself reflects procedural and recognitional justice) to identify the priority areas for the spatial distribution of GBIs. According to these theoretical links, we introduce six concepts by which one can identify urban areas that need GBIs the most for adaptation to flood risks. These six concepts are: (1) the spatial distribution of flood sensitive population; (2) the spatial distribution of flood sensitive infrastructure/buildings; (3) the spatial distribution of flood-exposed population; (4) the spatial distribution of flood-exposed infrastructures/ buildings; (5) The spatial distribution of areas with low amounts of GBIs; (6) the spatial distribution of flood hazards (see Figure 1).

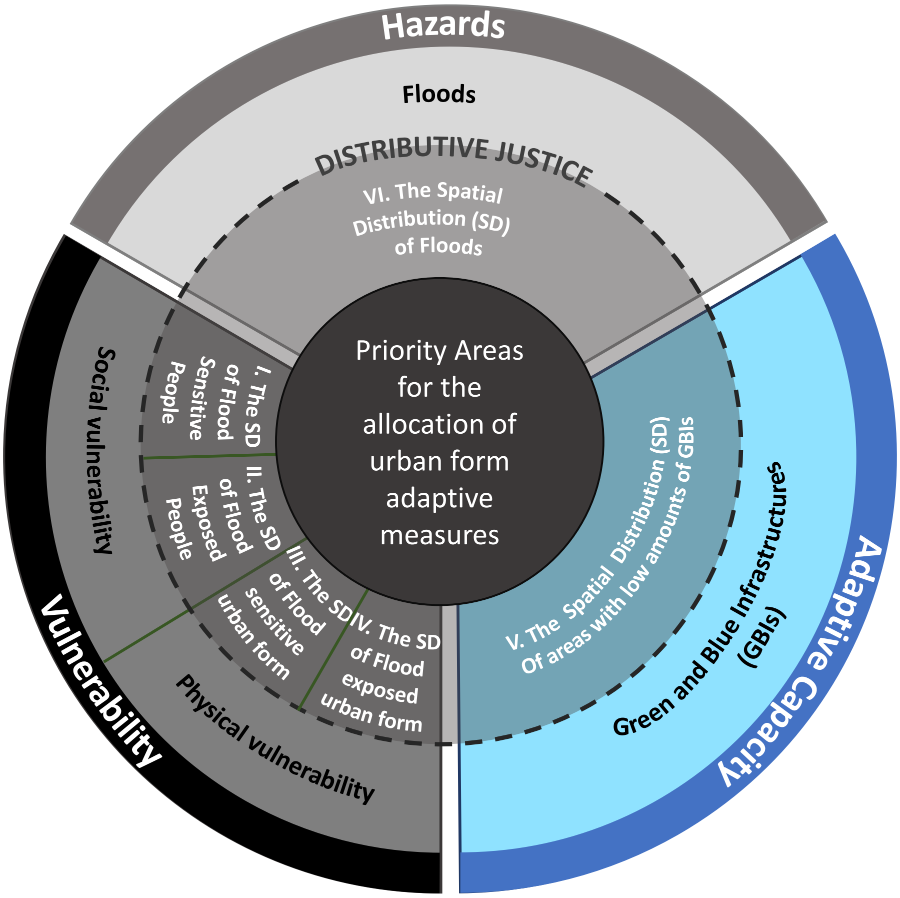

Figure 1. The theoretical framework

METHODOLOGY

We operationalize our framework on the city of Toronto through spatial analysis, using ArcGIS software. For this purpose, we, firstly, suggest spatial indicators and their associated variables to measure each of the concepts of our theoretical framework (see

Table 1). Such indicators (and also variables) are extracted from the previous similar studies as shown in

Table 1.

Table 1. Indicators and their associated variables for measuring the concepts of the framework

The main concepts of the proposed theoretical framework	Indicators	Variables	Sources
I. The spatial distribution of flood sensitive (vulnerable) population	Wealth	1) The percentage of low-income population (those who earn less than 30000 CAD per year) within each neighborhood	(Meerow and Newell, 2017, Li et al., 2020, Cutter et al., 2003)
	Race	2) The percentage of visible minority individuals within each neighborhood	
	Age	3) The percentage under 5 years old and above 65 years old population within each neighborhood	
	Employment	4) The percentage of unemployed population within each neighborhood	
II. The spatial distribution of flood-sensitive infrastructures/buildings	Flood sensitive land uses	5) The density of flood-sensitive land uses (including, commercial and industrial) (per sq.km) in each neighborhood.	(SEPA, 2018, Strom et al., 2013, Meerow and Newell, 2017)
	Building age	6) The density of heritage buildings (per sq.km) in each of the neighborhoods. 7) The density of private dwellings that are built before 1980 (per sq.km) in each of the neighborhoods.	
III. The spatial distribution of flood-exposed population	Population density	8) Population density (per sq.km) in each of the neighborhoods	(Sowmya et al., 2015)
IV. The spatial distribution of flood-exposed infrastructure/buildings	Impervious surfaces	9) The percentage of lands in each neighborhood that are covered by impervious surfaces (such as: buildings', roads, pavements, and other impervious surfaces)	(Armenakis and Nirupama, 2014)
	Infrastructures' density	10) The density of infrastructures (water and sewage pipelines, communications, and power line constructions) (per sq.km) in each of the neighborhood.	
V. The spatial distribution of areas with low amounts of GBIs	Land cover	11) The percentage of lands covered by green and blue spaces in each of the neighborhood.	(Li et al., 2020)
VI. The spatial distribution of flood hazard	Flood frequency	12) The intensity of rainfalls in each of the neighborhoods (per sq.km).	(Kabenge et al., 2017)

		13) The number of times floods and gray infrastructure blockage are reported by the occupants of each of the neighborhoods	

After defining the indicators and variables, to facilitate the analysis, we mapped the variables (using ArcGIS software). We, specifically, used statistical and spatial secondary data provided by the City of Toronto[1] and the Geospatial Center in the University of Waterloo[2]. Such data include: census data (2016); land use and land cover data (2019); precipitation and flood report data (2017); underground infrastructure data (water and sewage pipelines, communications, and power line constructions) (2019); and heritage register data (2019). Once the maps were produced, we overlaid them to create six master maps each of which indicates one concept in the theoretical framework (see Table 1 and Figure 2). The overlaying process consisted of several stages, namely: (1) normalizing the variable values from zero to ten to make each map comparable and combinable to the other maps; (2) calculating the average value for each neighborhood (we used an equal weight for each variable); (3) creating a master map by using those average values. Last, we simply overlaid the master maps to produce a final map, which highlights the priority areas for the allocation of GBIs in Toronto.

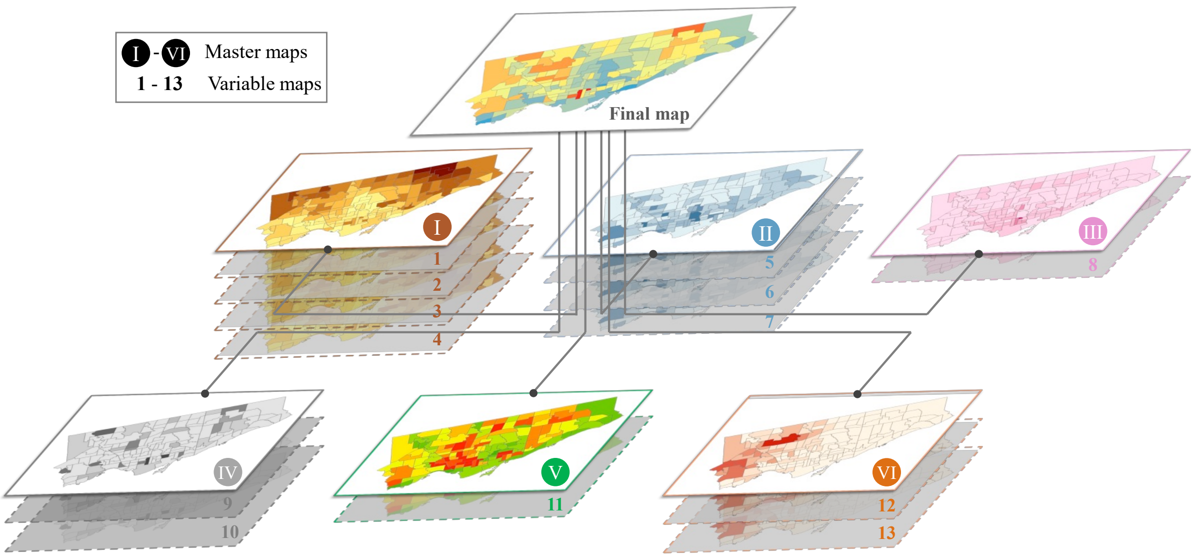

Figure 2. The overlay analysis process

FINDINGS

The results of the spatial analysis show that flood-sensitive population and infrastructures/buildings, flood exposed population and infrastructures, areas with low amounts of GBIs, and flood hazards (see the six concepts in Table 1) follow different, and sometimes contradictory, spatial distribution patterns in Toronto (see Figure 3). To illustrate, while most of the flood-sensitive population live in the Northern neighborhoods of the city (see Figure 3I), flood-sensitive infrastructures and urban neighborhoods with low amounts of GBIs are mostly concentrated in the central urban districts (see Figure 3II and Figure 3V) where the density of buildings and infrastructures is high. Similarly, flood hazards are the most probable in the western neighborhoods (see Figure 3VI) while flood-exposed population and buildings/infrastructures (see Figure 3III and Figure 3IV consecutively) are

[1] https://open.toronto.ca/
[2] https://uwaterloo.ca/library/geospatial/

distributed consistently across the city. These findings highlight the importance of trade-offs between multiple concepts and indicators for the advancement of climate justice in adaptation responses in Toronto.

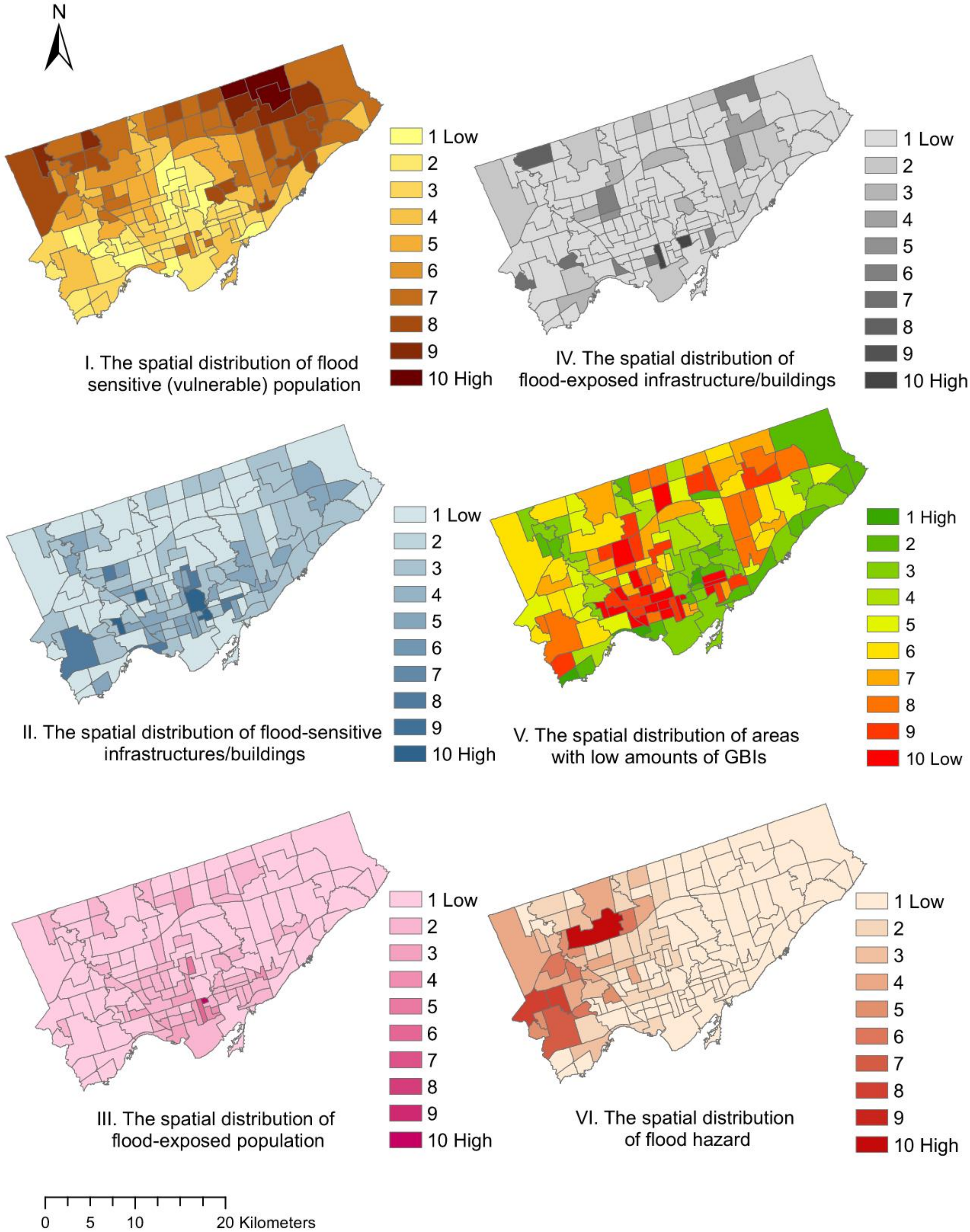

Figure 3. The master maps (representing the six concepts of our theoretical framework)

When we overlay these multiple concepts and their associated maps, the results highlight four neighborhoods need to be prioritized in GBIs provision, namely: Bay Street Corridor (76), North St. James Town (74), and Kensington-Chinatown (78) – all of which are located in the central urban districts – followed by Milliken (130) – which is located in the North (see Figure 4). As shown in Figure **3**, interestingly, all of these areas experience low levels of flood hazards, but they should be prioritized in the allocation of GBIs for flood risk reduction because of other important factors that affect flood risks.

To identify the decisive variables that have largely affected the priority ranking of such neighborhoods, we show the variable values of the neighborhoods in Figure 5. Accordingly, the high concentration of visible minority groups and low-income population (see Figure 5I), the high density of infrastructures/buildings and impervious surfaces (see Figure 5IV), and the low amounts of GBIs (see Figure 5V) were decisive for the high rank of all of these neighborhoods (the rank of such variables for all the neighborhoods is higher than Toronto's average). Similarly, the high population density (see Figure 5III) and the high concentration of heritage buildings (see Figure 5II) seem to be decisive for the high rank of all the neighborhoods except Milliken. In contrast, variables such as the population of children and seniors (see Figure 5I), industrial land uses (see Figure 5II), and flood hazards (see Figure 5VI) seem not to be decisive in the priority ranking of such neighborhoods. Consequently, the allocation of GBIs in these neighborhoods require trade-offs between the more decisive and the less decisive variables.

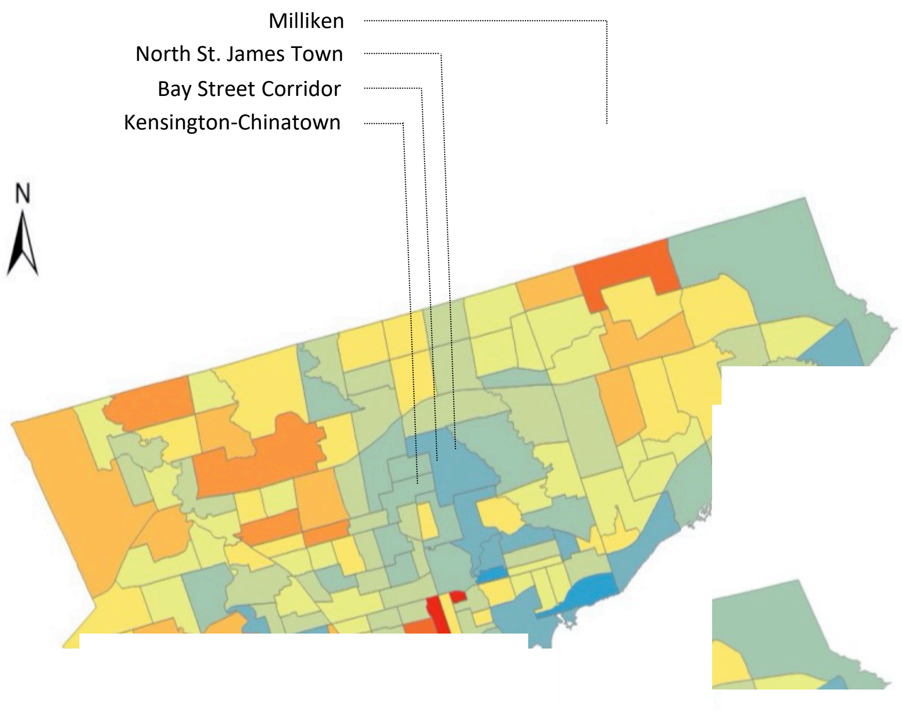

Figure 4. The final map showing the priority areas for the allocation of GBIs

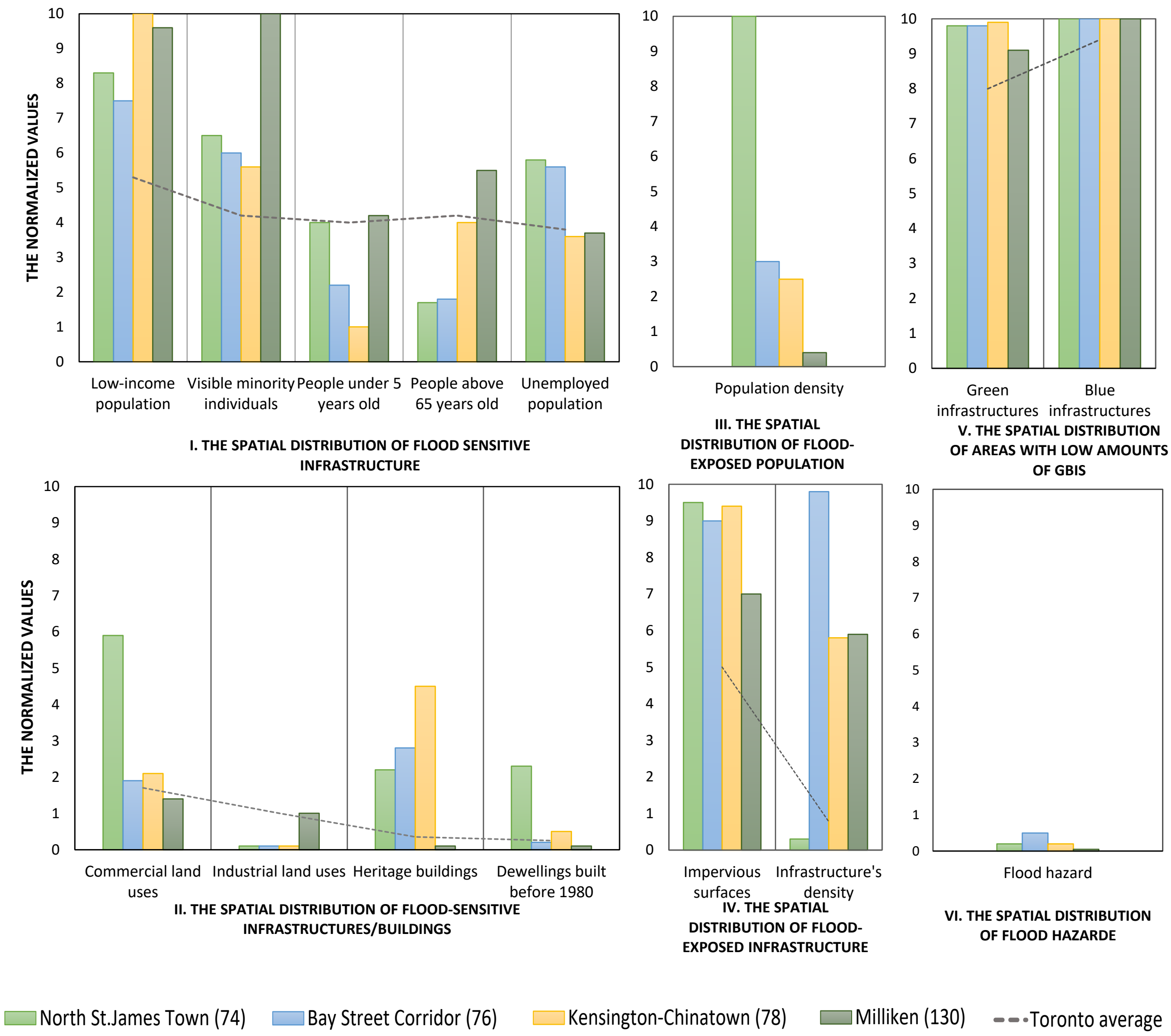

Figure 5. The normalized values of variables (from 0 to 10) for the high-priority neighborhoods

CONCLUSIONS

This study employed spatial analysis, using ArcGIS software, to identify the priority urban neighborhoods for the just spatial distribution of GBIs in urban form, and consequently, for the just adaptation to flood risks. The methodology, specifically, mapped and overlaid six concepts, namely: (1) the spatial distribution of flood sensitive population; (2) the spatial distribution of flood sensitive infrastructure/buildings; (3) the spatial distribution of flood-exposed population; (4) the spatial distribution of flood-exposed infrastructures/ buildings; (5) The spatial distribution of areas with low amounts of GBIs; and (6) the spatial distribution of flood hazards. The results highlighted four neighborhoods need to be prioritized for the allocation of GBIs. The results, furthermore, unveiled several synergies (for example, between the high population density and the low amounts of GBIs) and trade-offs (for example, between visible minority groups and senior groups) in the priority neighborhoods. The existence of such trade-offs and synergies highlights the importance of spatial analysis for maximizing the benefits of GBIs among different population groups, and consequently, for the advancement of climate justice.

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