Environment & Climate Maps

Heat Vulnerability in Toronto

Where will rising summer temperatures impact Torontonians the hardest, and what can be done about it?

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Toronto is experiencing more severe Urban Heat Islands than ever before

Extreme heat can cause illnesses like heat exhaustion and heat stroke, but it can also contribute to other cardiovascular illnesses

like heart attack and stroke. According to the National Weather Service, extreme heat is the largest weather-related killer in the United States [1].

Despite the fact that many of these deaths are preventable, the problem **is only getting worse**.

Urban Heat Islands

A major contributing factor to worsening extreme heat related health outcomes is the Urban Heat Island effect. This is when urban elements like asphalt surfaces, lower amounts of vegetation and high air conditioning usage causes locally hotter temperatures.

Urban Heat Islands are very local. The severity of the effect can vary from neighbourhood to neighbourhood - even street to street.

Which parts of Toronto are at highest risk?

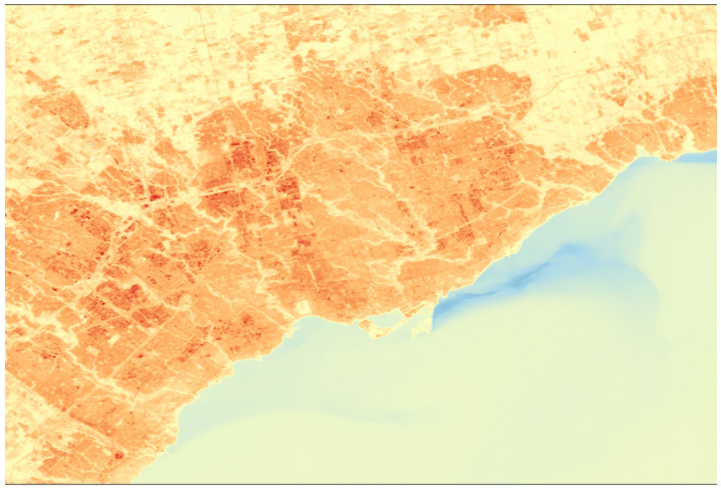
This analysis will use satellite imagery of Toronto (taken August 2024) and 2021 census data to breakdown where urban heat islands are appearing, which areas of Toronto have more residents who are at risk of worse heat related health outcomes.

Land Surface Temperature

Data from satellite imagery can be used to tell the temperature of the surface of the earth - which is often different and more

localized than the air temperature that may be seen on the weather forecast. In areas with especially large amounts of pavement without trees or water nearby, the surface can be 20° C hotter than the local air temperature.

This was calculated from spectral band data - *more info here*.



The Land Surface Temperature (LST) in the Greater Toronto Area (Landsat 8, Collection 2, August 13th, 2024 [2])

In the map above, especially red areas are locations where there are Urban Heat Islands. There are cooler zones around the lake and the rivers, as well as in areas with high amounts of vegetation. The hottest surface in the image is 45°C!

From the image we can see which parts of the city are experiencing extreme heat the worst. The neighbourhoods with the highest

average surface temperature are:

1. Humber Summit
2. Junction-Wallace Emerson
3. Weston-Pelham Park
4. Dovercourt Village
5. Briar Hill-Belgravia
6. Corso Italia-Davenport
7. Yorkdale-Glen Park
8. Oakwood Village
9. Palmerston-Little Italy
10. Trinity-Bellwoods

With the surface temperature mapped, the next important consideration is how temperature affects people differently.

Heat Sensitivity Factors

Heat affects us differently. Some factors may make people more vulnerable to negative health outcomes related to heat.

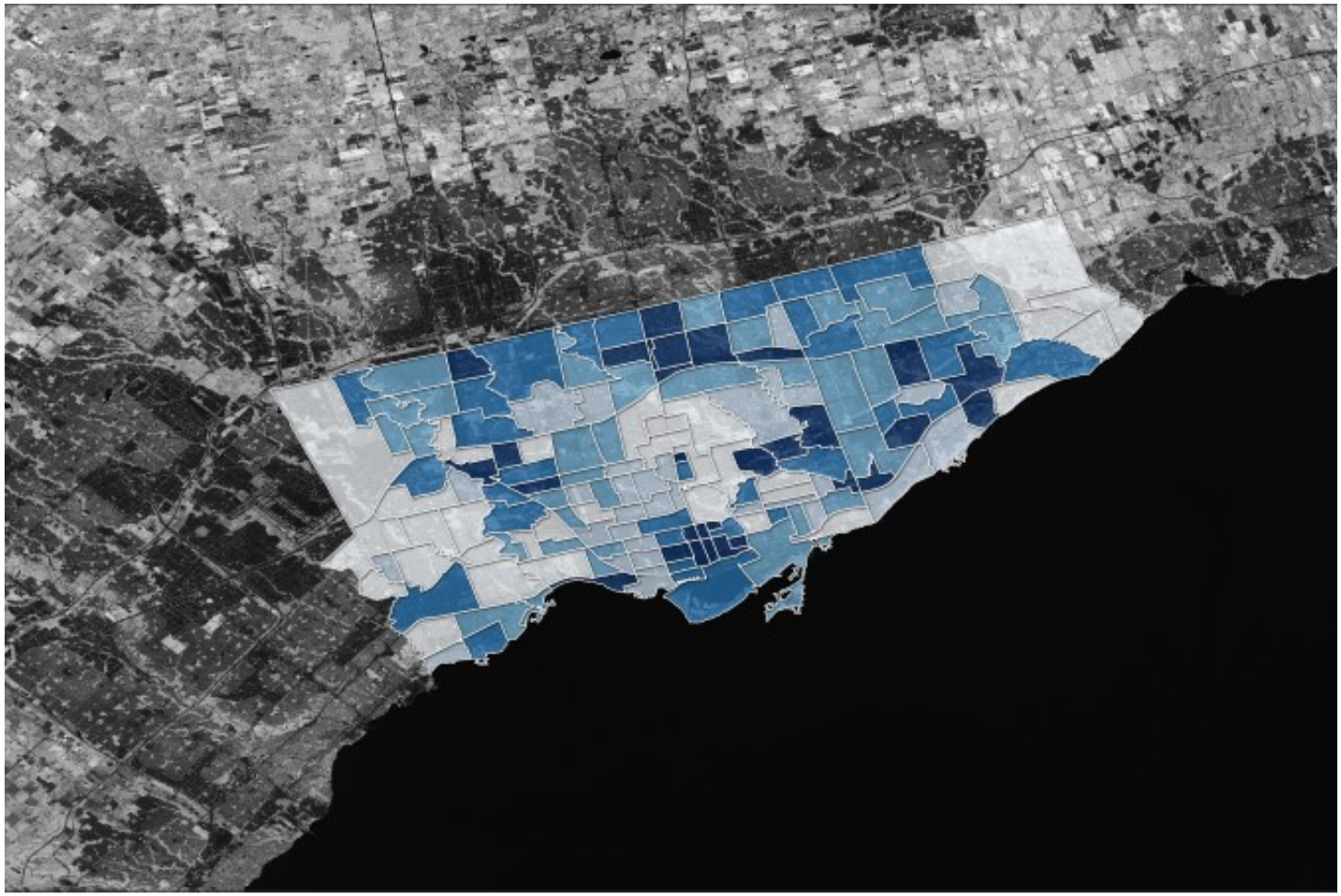
All data for demographic factors was taken from the 2021 Canadian Census [3].

Age

% Population over 65 years of age

The first is age. As risk for cardiovascular disease rises with age, the risk of extreme heat exacerbating those illnesses also rises.

(More yellow = higher % population over 65 yrs)
*(**Maximum**: 29%, **Minimum**: 3%)*



Income

% Prevalence of Low Income status

People with lower income have fewer resources at their disposal to help deal with heat and help prevent other negative health outcomes.

Based on the Low-Income Measure After-Tax (LIM-AT), defined in the Canadian Census [4].

(More blue = higher % of residents who are low income)
*(**Maximum**: 29%, **Minimum**: 4%)*

Unsuitable Housing

% of Households deemed 'Unsuitable'

(Or, too many people per room)

According to the National Occupancy Standard (NOS), housing may be unsuitable if there are not enough bedrooms for the number of people living in the house (depending on their relationships to each other) [5].

A common-law or married couple may use one bedroom suitably, but two unrelated roommates above a certain age may be unsuitable.

Sharing bedrooms or living space generally can make households more sensitive to extreme heat.

(More orange = higher rate of housing unsuitability)
*(**Maximum**: 42%, **Minimum**: 2%)*

Immigration

% Immigrants or Non-Permanent Residents

People of different origins or backgrounds may experience overall worse health outcomes as a result of language barriers, extent of social networks and other factors of marginalization - and can therefore be at higher risk during extreme heat events.

(More purple = higher % immigrants or NPRs)

*(**Maximum**: 77%, **Minimum**: 22%)*

Outdoor Commute

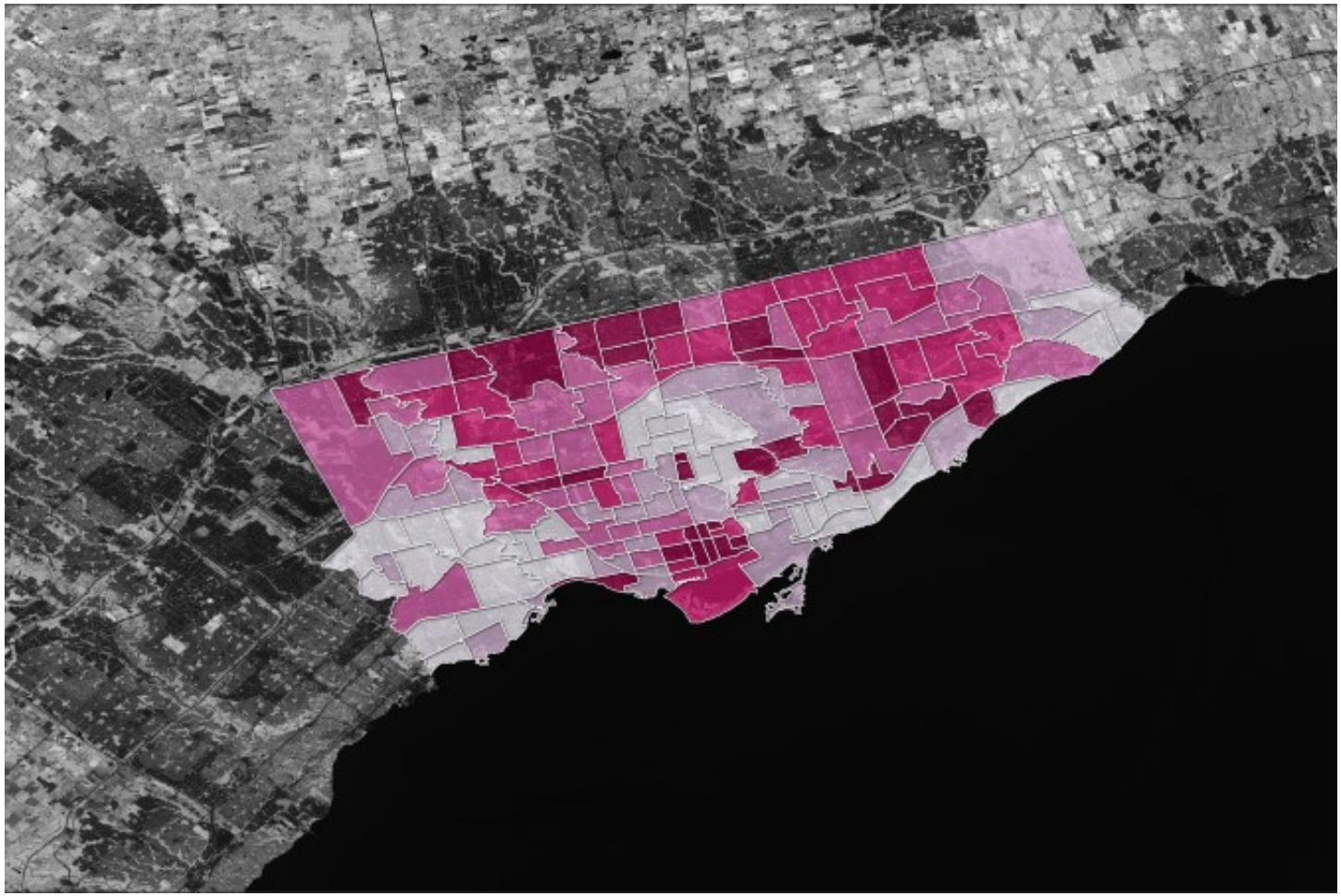
% of people commuting not by private automobile

Commuting by personal car typically means air conditioning door to door. Residents who commute by transit often must walk to/

from a station, and can experience excess heat on public transit itself.

Residents who commute primarily by walking, cycling or taking public transit are more exposed to extreme heat and therefore are at higher risk.

(More green = higher % of outdoor commuters)
*(**Maximum**: 81%, **Minimum**: 17%)*



Overall Sensitivity Factors

Normalized index of above factors

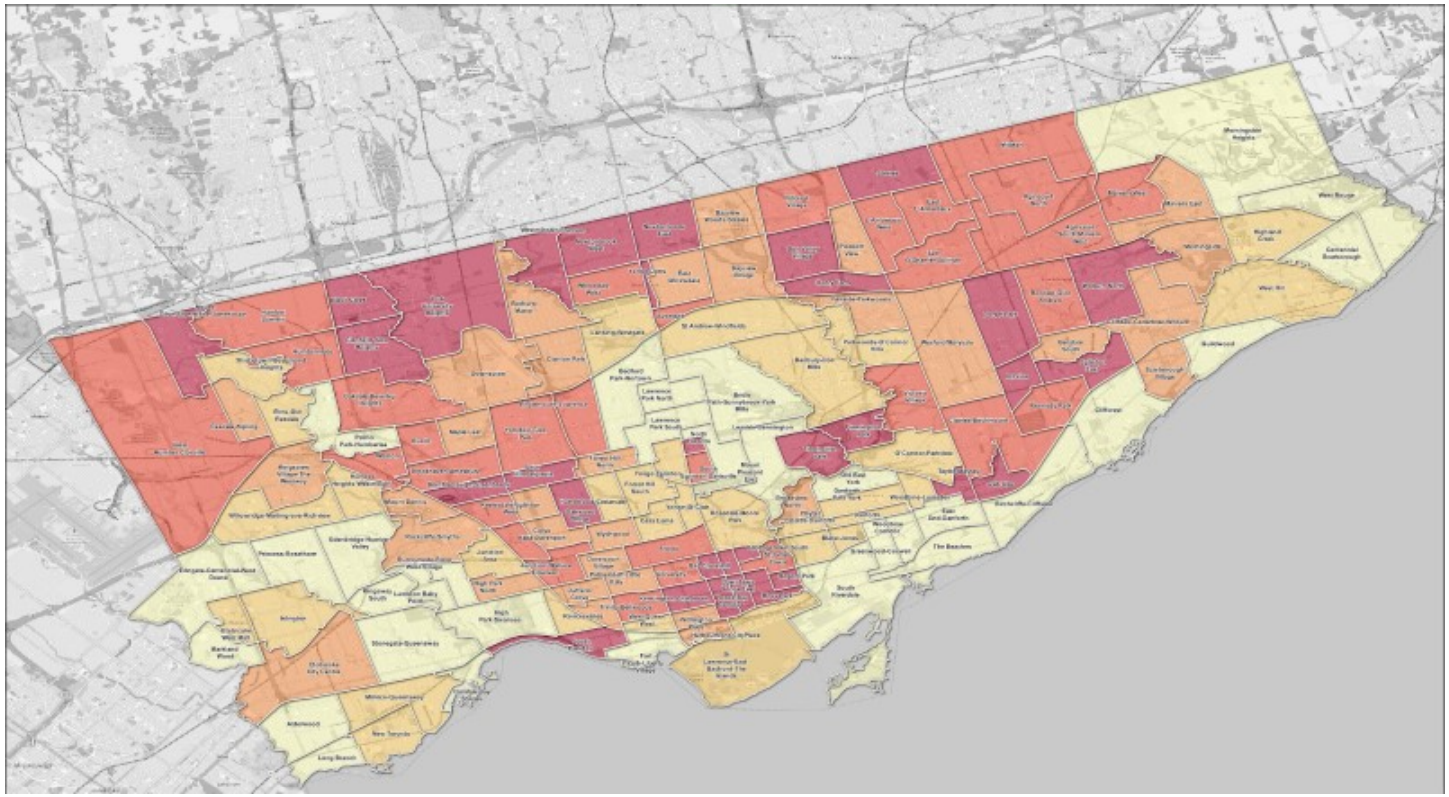
There is not currently one standard way to measure the sensitivity of a person or region to extreme heat exposure. The sensitivity was calculated using a normalized average of the factors above, although there are certainly other more specific factors that can have an impact.

These are the regions with populations most vulnerable. Below, it will be combined with the regions that experience the worst urban heat islands.

***NOTE**: This is not a fully extensive* sensitivity *index. Other potential factors: language, educational background, building age, access to pools & parks, access to hospitals, etc.*

Overall Heat Vulnerability

The **surface temperature** representing the heat islands combined with the **sensitivity** can give us "**Heat Vulnerability**", or how different areas of the city on average will experience overall worse outcomes from the increased frequency and intensity of urban heat islands.



Overall Heat Vulnerability - where the worst heat islands occur combined with demographic data to represent which areas of the city are at most risk of heat related negative health outcomes.

The map shows us that several downtown neighbourhoods as well as several suburban neighbourhoods are most at risk.

The areas most **heat vulnerable** are:

1. Thorncliffe Park
2. North St. James Town
3. Kensington-Chinatown
4. Bay-Cloverhill

5. Yonge-Bay Corridor
6. Church-Wellesley
7. Yonge-Doris
8. Newtonbrook West
9. York University Heights
10. Black Creek

***NOTE**: This analysis only uses land surface temperature data calculated from one day of satellite imagery - a more full analysis could include time series analysis of months/years.*

How to mitigate the heat islands

Slowing climate change would reduce the severity and frequency of heat islands, but that is a complicated problem requiring institutional change of nation-states and corporations.

Thankfully, solutions at a local level can be very effective at reducing the urban heat island effect during heat waves. These include:

1. Expand the urban tree canopy (and plant more vegetation generally)
2. Replace pavement with more permeable surfaces
3. Use higher albedo surface coverings
4. Use passive cooling
5. Add or expand water features
6.

As well as those **geographic solutions** that address the heat island effect, there are **social solutions** can help to mitigate harm for those most at risk - including (but not limited to):

1. Increasing supply of affordable suitable housing
2. Increasing access and removing barriers to receiving healthcare
3. Reducing marginalization

◆ ◆

When the city gets too hot, look for the signs of heat islands - and help your community take steps to keep us all a bit cooler.

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Appendix: How Land Surface Temperature (LST) is calculated

To get the land surface temperature in the first part of this analysis, calculations had to be done on the raster bands from the Landsat 8 images.

Top of Atmosphere Spectral Radiance (TOA)

The numbers (DN) recorded at the Landsat 8 satellite first need to be scaled to represent the emitted, reflected and scattered radiation. The result is the

$$L_\lambda = \mathrm{ML} \times Q_{\mathrm{cal}} + \mathrm{AL}$$

ML, AL: Multiplicative and additive scaling factors (from sensor metadata)

Qcal: The number (DN) read by the

amount of radiant energy reaching the sensor from the Earth and atmosphere.

sensor

Brightness Temperature (BT)

The brightness temperature is derived from the TOA radiance using the sensor's thermal imaging band using the sensor's specific calibration parameters.

$$T_{\mathrm{BT}} = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

K1, K2: Thermal conversion constants (from sensor metadata)
L: TOA Radiance (from above)

Fractional Vegetation Cover (FVC) & Normalized Difference Vegetation Index (NDVI)

Fractional vegetation cover reflects the density of vegetation within a region.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

NIR: Near-infrared band (Band 5 for Landsat 8)
Red: Red band (Band 4 for Landsat 8)

It is derived from NDVI, which is a measure that estimates the vegetation of a region of a remote image based on the difference in reflectance observed in healthy plants between the red wavelengths and near-infrared wavelengths of light.

$$f_v = \left(\frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}\right)^2$$

f: Fractional vegetation cover

Emissivity

This is a measure of a surface's efficiency in emitting thermal radiation. It depends on the qualities of the surface, and dense vegetation tends to have higher emissivity. The measure is based on fractional vegetation cover.

$$\epsilon = \epsilon_v \cdot f_v + \epsilon_s \cdot (1 - f_v)$$

Vegetation emissivity (ϵv): Typically 0.98 for dense vegetation.
Soil emissivity (ϵs): Typically 0.92 for bare soil
f: Fraction vegetation cover (from above)

Land Surface Temperature (LST)

Finally, LST measures the temperature at the surface of the Earth, estimated based on the brightness temperature and emissivity.

This was done using raster calculation in QGIS.

$$LST = \frac{BT}{1 + \left(\frac{\lambda \cdot BT}{\rho} \cdot \ln(\epsilon)\right)}$$

BT: Brightness temperature (from above)
Lambda: Wavelength of emitted radiation
p: Radiation constant, derived from Planck's constant
ϵ: Emissivity (from above)

From left to right: TOA radiance, NDVI, Emissivity

Thank you for reading

[1] Weather Related Fatality and Injury Statistics - **US National Weather Service**	https://www.weather.gov/hazstat/
[2] Landsat 8 Remote Imagery - **USGS, Collected with Earth Explorer**	https://earthexplorer.usgs.gov/
[3] Toronto 2021 Census Data - **Toronto Open Data**	https://open.toronto.ca/dataset/neighbourhood-profiles/

[4] Dictionary, Census of Population (Low Income Measure After Tax) - **Statistics Canada**	https://www12.statcan.gc.ca/census-recensement/2021/ref/dict/az/definition-eng.cfm?ID=fam021
[5] Dictionary, Census of Population (Housing Suitability) - **Statistics Canada**	https://www12.statcan.gc.ca/census-recensement/2021/ref/dict/az/definition-eng.cfm?ID=households-menage029
Toronto Neighbourhood Boundaries - **Toronto Open Data**	https://open.toronto.ca/dataset/neighbourhoods/

About the author

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