SPATIAL DISTRIBUTION OF SOIL CONTAMINATION SITES AND SOCIO-ECONOMICALLY VULNERABLE POPULATION IN MONTRÉAL, QUÉBEC, CANADA

By

Jia Yi Fan

Rachel Ivey

Sophie Kingunza Makasi

Angélique Meyer

Améline Morbelli

Taylor Piotrowski

Report prepared for

Dr. David Kaiser and Geneviève Hamelin

Public Health Department, Centre Intégré Universitaire de Santé et de Services Sociaux du Centre Sud de l'Île de Montréal (CIUSSS)

Under the supervision of

Professor Raja Sengupta

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EXECUTIVE SUMMARY

Across the Island of Montréal, the presence of soil contamination is significant according to federal, provincial and municipal records. This study aimed to examine the spatial distribution of contamination across the city, to identify the distribution of soil contamination and the communities that are most impacted by its potential adverse effects. The purpose of this research was to identify if the distribution of contamination is equally distributed across all ethnic and income groups, or if there is presence of environmental injustice, potentially due to biased government planning and management. This research encompasses both presently contaminated and rehabilitated sites to identify contamination trends across the city and analyze if presence of contamination is skewed.

Research is informed by the presence of contamination and announced government funding of soil decontamination and how these variables are spatially distributed in accordance with the distribution of low-income and minority neighbourhoods in Montréal. The research is primarily guided by the issue of environmental injustice in low-income and minority communities throughout Canada.[1,2] The management of soil contamination and planning of decontamination is further analyzed in a detailed literature review that identifies the motivations and priorities identified through institutional funding of soil decontamination throughout Montréal. The

[1] Laurent Pilon, “Protection des sols et réhabilitation des terrains contaminés: Une politique attendue [Soil protection and contaminated sites rehabilitation policy: an awaited policy],” *Vecteur Environnement,* 2017: 40-41.

[2] Marie-Claude Desjardins et al., “Towards Social Environmental Justice ?” European University Institute, Florence Department of Law, 2014

research showed evidence of environmental injustice for low-income populations. This finding should be used as a mechanism to advise policy-makers to consider and take action to avoid possible contribution to reproducing structural injustices in their decision-making processes and policy outcomes.

Key words: soil contamination, environmental injustice, Montréal, low-income, visible minorities, GIS

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INTRODUCTION

Client

The clients with whom the research is in collaboration with are Dr. David Kaiser and toxicologist Geneviève Hamelin. Both clients work at the “Direction de la santé publique” section of the Centre Intégré Universitaire de Santé et de Services Sociaux du Centre Sud de l'Île de Montréal[3]. The latter regroups medical centers and healthcare facilities in the area and provides social and health services to ensure the population’s well-being is sustained. The CIUSSS is greatly involved in developing and sharing scientific knowledge, making it more accessible by regrouping all the data in one place. The work is made on 3 different levels: neighborhood, municipal and provincial.

The purpose of this research for the client is to combine the available data from different levels of the government to create a map indicating the locations of the contaminated soils on the Island of Montréal in order to help the clients direct their health policies.

Context

Soil contamination is becoming more common in urban environments due to anthropocentric activities such as industrialization and urban sprawl[4]. Prevalent pollutants found in urban soils include carcinogenic heavy metals[5], organic

[3] Centre Intégré Universitaire de Santé et de Services Sociaux du Centre-Sud-de-L’Ile-de-Montréal, “Mission, vision et valeurs”, 2019

[4] Imran Khan, Muhammad Iqbal, and Farad Shafiq, “Phytomanagement of Lead-Contaminated Soils: Critical Review of New Trends and Future Prospects,” *International Journal of Environmental Science and Technology* 16, no. 10 (2019): 6473-88, https://doi.org/10.1007/s13762-019-02431-2.

[5] Khan, Iqbal, and Shafiq “Phytomanagement of Lead-Contaminated Soils,”

contaminants like polycyclic aromatic hydrocarbons (PAHs) and pesticides[6,7]. Such contaminants can be absorbed by plants and impede growth [8], leach into groundwater or other water sources and be ingested by humans and other species in the ecosystem [9]. Consequently, to prevent negative effects on human health and the ecosystem, contaminants must be treated effectively using appropriate remediation methods. Physicochemical remediation methods such as extracting the soil and washing it, electrokinetic remediation, chemical oxidation, nanomaterial and burial may be used to treat heavy metals and sometimes PAHs.[10,11,12] Alternatively, to prevent against potential damages to the soil caused by physicochemical methods[13], biological remediation methods such as microbial remediation, biochar, composting, phytoremediation, and genetic engineering technologies[14] can be used.

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[6] Shaohua Wu et al., "Role of Biochar on Composting of Organic Wastes and Remediation of Contaminated Soils-a Review," *Environmental Science and Pollution Research* 24, no. 20 (2017): 16560-16577, https://doi.org/10.1007/s11356-017-9168-1.

[7] Hussein I. Abdel-Shafy, and Mona S.M. Mansour, "A Review on Polycyclic Aromatic Hydrocarbons: Source, Environmental Impact, Effect on Human Health and Remediation," *Egyptian Journal of Petroleum* 25, no. (2016): 107-123, https://doi.org/https://doi.org/10.1016/j.ejpe.2015.03.011.

[8] Oznur Karaca, Claudio Cameselle, and Krishna R. Reddy, "Mine Tailing Disposal Sites: Contamination Problems, Remedial Options and Phytocaps for Sustainable Remediation," *Reviews in Environmental Science and Bio/Technology* 17, no. 1 (2018): 205-228, https://doi.org/10.1007/s11157-017-9453-y.

[9] Wu et al.,"Role of biochar,"

[10] Abdul G. Khan et al., "Role of Plants, Mycorrhizae and Phytochelators in Heavy Metal Contaminated Land Remediation," *Chemosphere* 41, no. 1 (2000): 197-207, https://doi.org/https://doi.org/10.1016/S0045-6535(99)00412-9.

[11] Shujing Ye et al., "Biological Technologies for the Remediation of Co-Contaminated Soil," *Critical Reviews in Biotechnology* 37, no.8 (2017): 1062-1076, https://doi.org/10.1080/07388551.2017.1304357.

[12] Saranya Kuppusamy et al., "Remediation Approaches for Polycyclic Aromatic Hydrocarbons (PAHs) Contaminated Soils: Technological Constraints, Emerging Trends and Future Directions," *Chemosphere* 168, (2017): 944-968, https://doi.org/https://doi.org/10.1016/j.chemosphere.2016.10.115.

[13] Khan et al., "Role of Plants, Mycorrhizae and Phytochelators,"

[14] Ye et al., "Biological Technologies for Remediation,"

In Quebec, the primary soil contaminants are heavy metals, PAHs and other chemical pollutants.[15] In the province, the owner of the contaminated land, whether private or public, has the responsibility to rehabilitate the soil or if authorized after a risk analysis, can leave some contaminants in the soil.[16] In this regard, governmental guidelines promote *in situ* remediation as being the most durable method and excavation and burying as the least sustainable methods.[17] However, burying is the most common remediation method used in Quebec.[18] This is because it is an easy and low cost method and because there may be a lack of technology to treat certain contaminants and few valorization options for lightly treated or contaminated soils.[19]

The government of Quebec's acknowledgement and efforts to resolve soil contamination issues throughout the province were officially recognized in 1988 with the adoption of the Contaminated Sites Rehabilitation Policy.[20] This research will use the same definitions of contamination and soil contamination that are identified by the Food and Agriculture Organization (FAO); contamination will hereafter be understood as to

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[15] Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), "Contamination des sols en ville [Contamination of Soils in the City]," 2018, https://www.mapaq.gouv.qc.ca/fr/Productions/agricultureurbaine/trucsconseils/Pages/Contamination-des-sols-en-ville.aspx.

[16] Geneviève Hamelin, personal communication, October 8, 2019

[17] Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC), "Politique de protection des sols et de réhabilitation des terrains contaminés : Plan d'action 2017-2021 [Soil Protection and Rehabilitation of Contaminated Sites Policy: Action Plan 2017-2021]," 2017,http://www.mddelcc.gouv.qc.ca/sol/terrains/politique/politique.pdf.

[18] Jocelyne Hébert, and Julie Bernard,"Bilan sur la gestion des terrains contaminés au 31 décembre 2010 [December 31, 2010 Contaminated Lands Report]," 2013, http://www.environnement.gouv.qc.ca/sol/terrains/bilan/bilan2010.pdf.

[19] MDDELCC,"Politique de protection des sols et de réhabilitation des terrains contaminés,"

[20] Mario Cormier, "Federal Contaminated Site Action Plan (FCSAP)," First Nations of Quebec and Labrador Sustainable Development Institute, 2018, http://fnqlsdi.ca/wp-content/uploads/2018/08/2E-Mario-Cormier-ABC-contaminated-sites2.pdf.

the presence of a substance or agent in the soil as a result of human activity.[21] Furthermore, soil contamination is the concentration of a chemical or substance that is greater than background levels but is not necessarily causing direct human harm.[22] According to the government of Canada, a contaminated site is defined as "A site in which the concentration (e.g. soils) of harmful substances (1) is above the natural levels and poses or may pose an immediate or future danger to human health or the environment, or (2) exceeds the levels indicated in the policies and regulations."[23] It is important to understand the Government of Canada's definition because it makes clear that there is an incomplete understanding of the levels and spatial distribution of the contaminants identified in their records, and therefore, the potential present and future effects of soil contaminants on human health are unknown at the time of this research.

Urban soil contamination continues to be an issue around the world, where contamination is largely a result of human activities such as landfill seepage, chemical spills, manufacturing and construction, industrial dumping, pesticide use and local waste disposal.[24] Urban areas are the most sensitive to soil contamination as a result of industrialization, urban expansion, development and gentrification, all of which have been historically significant in Montréal's past and present development.[25] The Soil

[21] "ISO 11074:2015." ISO, 2015, https://www.iso.org/standard/59259.html.

[22] Natalia Rodríguez Eugenio, Michael McLaughlin, and Daniel Pennock, "Soil Pollution: a hidden reality," Food and Agriculture Organization of the United Nations, 2018, http://www.fao.org/3/I9183EN/i9183en.pdf.

[23] Cormier, "Federal Contaminated Site Action Plan,"

[24] Yulia M. Galitskova, and Antonina I. Murzayeva, "Urban Soil Contamination," *Procedia Engineering* 153, (2016): 162–166, https://doi.org/10.1016/j.proeng.2016.08.097.

[25] Willie J. Chevalier, and Cyrille Felteau, "History," Encyclopædia Britannica, accessed, October 9, 2019, https://www.britannica.com/place/Montréal/History.

protection and contaminated sites rehabilitation policy identified that significant soil contaminants resulted from the abandonment of industries that ran during the rapid industrialisation in the 19th and 20th centuries.[26] In fact, the economic potential of Montréal has resulted in development and is also a significant motivator behind the Ministry of Sustainable Development, Environment, and Fight Against Climate Change announcement of the new ClimatSol-Plus program that includes an investment of $55 million to aid urban municipalities with rehabilitating contaminated soils on municipal and privately owned sites.[27] Additionally, the government's 2017-2021 Action Plan is investing $120 million in the rehabilitation of contaminated sites on state-owned land.[28] More specifically, in 2018, Montréal received $75 million from the MDDELCC.[29] Wherein, ClimatSol-Plus announced an investment of $10 million per year for general rehabilitation projects over a period of 3 years, as well as $5 million per year for a period of 5 years towards sites that have "strong economic potential"[30] 2017. Therefore, the government's investments are focused on promoting a green economy by protecting the environment and revitalizing the territory to make land available for further development.

These motivations are skewed towards the economic potential of contaminated land, while showing an apparent lack of focus and action towards the rehabilitation of land that is potentially causing adverse impacts to human health. This research calls

[26] MDDELCC, "Politique de protection des sols et de réhabilitation des terrains contaminés,"
[27] Ibid.
[28] Ibid.
[29] Service Québec, "Le gouvernement du Québec attribue 75 M$ à la Ville de Montréal pour la réhabilitation de terrains contaminés [The Quebec government allocates $ 75 million to the City of Montréal for the rehabilitation of contaminated land]," 2018, http://www.fil-information.gouv.qc.ca/Pages/Article.aspx?idArticle=2603253066.
[30] Pilon,"Protection des sols et réhabilitation des terrains contaminés,"

attention to the lack of investment made to revitalize the soil in low-income and minority areas. Social fragmentation and low social capital are characteristics predictive of many adverse health outcomes and may be more present in minority communities.[31] Thus, the government's efforts to build the green economy and improve land for population densification can further the negative effects of discrimination and promote environmental injustice.

Research identified that pollutants are not evenly distributed in the air, soil, and water, and this inequality of distribution has frequently been found to place underprivileged social groups at heightened risk of exposure. Environmental injustice is defined as "the disproportionate exposure of communities of colour and the poor to pollution, and its concomitant effects on health and environment".[32] The term was popularized by the 1970s protests against the designation of a toxic landfill in North Carolina, home to a majority of Black identifying residents. The environmental justice movement was then led by the people of the United Church of Christ who conducted research to expose other similar cases across the US.[33] Moreover, "environmental racism" is a notion that relates specifically to environmental injustices that Indigenous, Black and other racialized communities experience.[34] Sometimes manifesting as

[31] Elsje van Der Ven et al., "Comparing the Clinical Presentation of First-Episode Psychosis across Different Migrant and Ethnic Minority Groups in Montréal, Quebec," *The Canadian Journal of Psychiatry* 57, no. 5 (2012): 300–308, https://doi.org/10.1177/070674371205700505.

[32] Juliana Maantay, "Mapping Environmental Injustices: Pitfalls and Potential of Geographic Information Systems in Assessing Environmental Health and Equity," *Environmental health perspectives* 110 Suppl 2, no. Suppl 2 (2002): 161-71, https://doi.org/10.1289/ehp.02110s2161.

[33] Brooks Berndt, "A Movement Is Born: Environmental Justice and the UCC," United Church of Christ, 2017, https://www.ucc.org/a_movement_is_born_environmental_justice_and_the_ucc.

[34] Sebastien Caquard, William Cartwright, and Laurene Vaughan, "Mapping Environmental Issues in the City: Arts and Cartography Cross Perspectives," *Lecture Notes in Geoinformation and Cartography*, 2011

institutional indifference, sometimes state-sponsored exploitation, these patterns are the result of colonial structures which uphold neoliberal pursuit of economic growth.[35]

Environmental injustices are found in the unequal distributions of environmental hazards and manifest in the unequal access to investments, benefits, resources aiming to improve environmental conditions, as well as information.[36] These trends often result from the lack of representation of diverse groups of people, particularly people of color, at the governance and decision-making levels of governmental institutions. Historically, urban planning for example has predominantly been governed by urban elites, which has led to the deterioration of some urban areas while benefiting middle-class neighbourhoods. These marginalized areas are prevailing destinations for low-income, racialized and/or immigrant populations. Thus, injustices pervade “in the processes in which neighbourhoods, cities, and whole societies are designed, developed, governed, and experienced".[37]

Informed by trends found across different cities in North America, this study focused on two categories of population in Montréal that are more at risk of disproportionately being affected by environmental injustice. The first group is low-income individuals after deductions with income adjusted by number of people in the household.[38] The second group is visible minorities, which Statistics Canada defines

[35] Goldtooth, Tom B. K., “Environmental Injustice in “Indian Country”, in Robert D. Bullard, Paul Mohai, Robin Saha, and Beverly Wright, “Toxic Wastes and Race at Twenty: 1987-2007,” United Church of Christ 2007: 95-96.

[36] Maureen Baikie et al.“Environmental Justice in Canada? Identifying a role for public health research and practice,” CPHA Annual Conference Workshop, June 2008: 1-11.

[37] Baikie et al.“Environmental Justice in Canada?”

[38] Statistics Canada, "2016 Census of Population," 2016.

as people who do not self-identify as white, Indigenous or mixed raced with an European origin.[39]

Indigenous people were added in the Visible minorities group as this population faces the same, if not more issues than Visible minorities. In fact, Canadian studies have shown that racialized minorities generally face a pay gap compared to White people, and this issue affects Indigenous people more than other Visible minorities.[40,41] In short, the lower resilience and the discrimination patterns justified the choice to include low-income and racialized populations respectively as vulnerability factors.

Looking at the current decontamination plan in Montréal, it is understood that policies are focusing primarily on the decontamination of sites with high economic attractiveness. The aim is to balance government spending with corporate investment to minimise rehabilitation costs. Such policy represents a risk in further marginalizing those who are found to be already experiencing a significant degree of environmental injustice.

RESEARCH QUESTION AND HYPOTHESIS

To target the issue discussed above, this research analyzes the distribution of contamination sites in relation to the presence of visible minority and low-income groups

[39] Statistics Canada, "2016 Census of Population,"

[40] Pendakur, Krishna & Pendakur, Ravi. "Colour My World: Have Earnings Gaps for Canadian-Born Ethnic Minorities Changed over Time?". *Canadian Public Policy-Analyse de Politiques* 28, no. 4 (2002): 489-512, https://doi.org/10.2307/3552211.

[41] Pendakur, Krishna & Pendakur, Ravi., "The Colour of Money: Earnings Differentials among Ethnic Groups in Canada," *Canadian Journal of Economics* 31, no. 3 (1998): 518-48.

across the island of Montréal. The purpose of this research is to assess whether the distribution of contaminated sites in Montréal also demonstrate patterns of environmental injustice. The results will help policy-makers to make equity-driven decisions.

It was anticipated that minority, low-income neighbourhoods will have more contamination sites, mostly due to backfilling on land that had not been previously decontaminated, such as sites that were once quarries, gas stations or landfills.

METHODOLOGY

Sources of data

For this project, secondary data available from federal, provincial and municipal databases was used and most of the data which were provided by the client. The federal data, namely “Federal Contaminated Sites Inventory” was obtained from the Treasury Board of Canada Secretariat.[42] This dataset came with information about ID, reporting organization, latitude/longitude, neighbourhood, type of contaminant, follow-up notes and city name in French and English, but these descriptions were not available for all entries.

The first provincial data is composed of “System of contaminated soil management” and was retrieved from the MDDELCC.[43] This dataset provided the

[42] Treasury Board of Canada Secretariat, “Federal Contaminated Sites Inventory,” 2016, https://open.canada.ca/data/en/dataset/1d42f7b9-1549-40aa-8ac6-0e0302ff2902.

[43] MDDELCC, “Répertoire des terrains contaminés [Repertoire of contaminated soils],” 2019, http://www.environnement.gouv.qc.ca/sol/terrains/terrains-contamines/aide.htm.

address of contaminated sites and the specific types of contaminants present, as well as the latitude and longitude, consistently for all entries. The rehabilitation state was also displayed. The second provincial database included is the "Former quarries and surface deposits location map,"[44] which has information about reporting organization, address, type and nature of contaminant(s). Alternatively, the researchers found a shapefile that was previously made and comprised of seemingly identical information.[45] However, this dataset was not included because it had insufficient information (polygon shapefile without addresses nor geographical coordinates) and only 4 entries overlapped within 100 meters (m) of the data points from the client-approved website.

The municipal data proposed by the client, namely the "List of contaminated lands," was found as a collection of scanned Portable Document Format (PDF) files describing contamination events, sometimes with multiple files stating the contamination, rehabilitation state or usage restriction.[46] Some files were very detailed and included the address, geographical coordinates, name of property owner, type and amount of contaminants, whereas others were missing the description of contaminants. The total number of files that would need to be read and have pertinent information transcribed reached over 1200. Thus, for logistic reasons, the research only use data

[44] City of Montréal, "Carte de localisation des anciennes carrières et des dépôts de surface [Former quarries and surface deposit location map]," accessed October 22, 2019, https://environnementmtl.maps.arcgis.com/apps/webappviewer/index.html?id=eddfe22f7ef54982a6545e8eb3c86a9a.

[45] City of Montréal, "Polygones des anciennes carrières et des dépôts de surface [Former quarries and surface deposit polygons]," accessed October 22, 2019, http://donnees.ville.Montréal.qc.ca/dataset/d332b1ef-95af-42d8-a996-7e451f1c6722/resource/4387f2d6-f437-494f-b840-08e085a492ed/download/anciennes_carrieres_depot_surface.zip.

[46] City of Montréal, "Liste des terrains contaminés [List of contaminated lands]," accessed October 22, 2019, http://ville.montreal.qc.ca/portal/page?_pageid=7237,74643772&_dad=portal&_schema=PORTAL.

from an alternative ready-made “List of contaminated lands” Excel file retrieved from the City of Montréal’s open data portal and their related map.[47] This document has information about ID, reporting organization, address, lot number and neighborhood, but unfortunately lacked information about the rehabilitation state or types of contaminants specified in the PDF reports.

The socioeconomic data, namely indigenous people, visible minorities, and low-income distribution in Montréal, was found through the website Census Mapper, with the original data coming from Statistics Canada’s 2016 census.

Data processing

Socio-economic dataset

As mentioned earlier, Indigenous people were added in the definition of visible minorities used by Statistics Canada as they are considered in this research as key groups who face marginalization due to their ethnicity.

Contamination dataset

The federal and the “System of contaminated soil management” provincial datasets both provided the latitude and longitude for each contaminated site. The “Former quarries and surface deposits” provincial and municipal data did not include this information, but had addresses. For these databases, latitudes and longitudes were

[47] City of Montréal, “Liste des terrains contaminés officiels” [List of official contaminated lands]”, Open data Portal, Service du greffe et Service de l'environnement, April 2018, http://donnees.ville.montreal.qc.ca/dataset/liste-des-terrains-contamines.http://donnees.ville.montreal.qc.ca/dataset/liste-des-terrains-contamines.

determined using the “Geocode by Awesome Table” complementary module in Google Sheets. The same tool was used for visual assessment of locations to validate the accuracy of geocoding. A few entries were found to be in completely different parts of the world, possibly due to the popularity of the street name. The website Geocoder.ca, recommended by the research supervisor, was used to conduct site-specific research and determine the location of incorrect or unfindable coordinates by “Geocode by Awesome Table”. Finally, two entries were erased as they could not be geocoded by either method.

All databases were then merged into a single table. The “Remove Duplicates” complementary module was used to find duplicates. Only duplicates entered under the same name (i.e. private or public owner) were removed. Entries containing the same address but different names were not eliminated as they could represent different contamination cases. This research included all information given across databases, resulting in a table with ID, Name of site owner, Address, Latitude, Longitude, Type of contamination, State of rehabilitation, Level of government, Nature of contaminant and Neighborhood.

The final table was re-separated into its 4 respective sources after having been checked for duplicates, and was exported into ArcGIS together with visible minority, low-income cut-offs and population by dissemination area (DA) in Montréal. DAs are the smallest aggregate units used by Statistics Canada 2016 census and were chosen to ensure maximum precision in results.

Final entries

From the original 447,844 entries country-wide in “Federal Contaminated Sites Inventory,” we retrieved 139 entries for Montréal. For provincial data, 1881 of 1978 entries from “System of contaminated soil management” and 21 of 30 entries from “Former quarries and surface deposits” were included as they were either duplicates or no location information listed.

For municipal data, 479 of 742 entries from the “List of contaminated soils” were also included because of duplicates or no location information.

Quality control

All data used are secondary, thus, there is a need to ensure accuracy. For contamination, it is acknowledged in this research that it is unrealistic to test for the presence of contaminants in all the sites listed. Since most are accompanied with a report of the contamination event, including location, contaminants in question and follow-ups, written by diverse levels of government, the research assumes that these official organizations acted in favour of the population they served. Moreover, releasing these reports to the public shows their consideration for transparency. A buffer around each site will be created to account for the possibility of pollutant displacement and for location imprecision, as some addresses provided in the datasets were quite imprecise (e.g: “400 m west of the 83rd avenue, close to Perras boulevard”[48]). To ensure the appropriateness of the buffer, a sensitivity analysis with a 100, 200, 400 meters buffer

[48] MDDELCC, Québec, "Répertoire des terrains contaminés,"

will be conducted. These numbers were decided based on empirical evidence of pollutant travel distances, which are impacted by duration in the ground as well as soil and pollutant properties. For instance, a 10 days leach pit experiment showed that the smallest distance travelled by a hypersaline solution was in a clay-silt soil (2.055 m), whereas a sand-gravel had the largest record (10.200 m).[49] For a longer deposit duration, wood tar was found 60 m from its starting point[50] and garbage dump leachate was recorded 445 m away.[51,52]

Selecting for only the whole Montréal island, 3202 DAs were identified. There were some DAs that were then deleted if they were missing data for at least one variable (low-income or racial minority) or there was an error code from the data provider (e.g.: indicating that publishing the data would constitute a breach of privacy due to the low population in a certain DA), giving 3150 DAs. Of this number, 8 DAs were found to contain a low-income population of over 100%. As this is obviously impossible, the 2 DAs that had percentages close to 100% (102 and 103%) were rounded down to 100% while the remaining 6 DAs (121-316%) were excluded from analysis. Thus, the number of DAs used in the final analysis totaled 3144.

[49] Goutam Banerjee, "Underground Pollution Travel from Leach Pits of on-Site Sanitation Facilities: A Case Study," *Clean Technologies and Environmental Policy* 13, 2011, no. 3 (2011): 489-497, https://doi.org/10.1007/s10098-010-0331-3.

[50] Robert G. Butler, Gerald T. Orlob, and Percy H. McGauhey,“ Underground Movement of Bacterial and Chemical Pollutants,” American Water Works Association 46, no. 2 (1954): 97-111, https://www.jstor.org/stable/41253595

[51] A. Lang, "Pollution of Water Supplies, Especially of Underground Streams, by Chemical Wastes and by Garbage," Z. Gesundheitstech. u. Stadtehyg.(Ger.) 24, no. 5 (1932).

[52] NB: The full name of A. Lang is unfindable.

Mapping

After cleaning and formatting all databases in a consistent way data was selected from points falling inside the island of Montréal. Then the Comma Separated Value (CSV) layer was opened as point data in ArcMap using entries' latitude/longitude. All layers' were defined as geographic coordinates to World Geodetic System (WGS) 84 and projected them to North American Datum (NAD) 83 Modified Transverse Mercator (MTM) zone 8. The provincial data set had some problems when trying to display the latitude/longitude. It was found that 10 points did not include any location information (address or latitude and longitude), explaining why the data couldn't be displayed. These points were deleted from the CSV layer, but the provincial data still would not display the latitude as it was stored as string data. The CSV therefore had to be saved as a dBASE in order to add a double format field for latitude.

The 4 layers (municipal, 2 provincials, federal) were merged together to compute a single layer of contamination point data. By doing that, the number of entries went from 2519 to 2508 entries. This reduction of 11 entries indicates that some overlapping points got merged into one because of matching latitude/longitude. This modification did not have a negative effect on the project because of the working buffer zones, which would not change whether there was an overlap or not. However, this is something to take into account if one was to work with density of contamination points.

Visible minority, Indigenous people and low-income data were joined based on DA identifier. This socio-economic layer was then clipped by each of the 100, 200 and

400 m contamination buffer layers.It resulted in 6 maps, from Figure 1 to 6 in the Results subpart.

The percentage of low-income and minority groups inside each buffer and standardization by area was determined as follows. The proportion of DA area inside a buffer over the total DA area was multiplied by the proportion of Visible minorities (VM) inside the same buffer over the total number of VM:

$$\%\ \text{VM within 100 m buffer} = \left(\frac{\text{Area of DA inside 100 m buffer}}{\text{Total area of DA}}\right) \times \left(\frac{\#\text{VM in buffer}}{\text{Total population inside DA}}\right)$$

This was completed for all 3 buffers, and repeated for the indigenous and low-income data. The average in Montreal for Visible minorities was then calculated:

$$\text{Average VM within Montreal} = \frac{\text{Total VM}}{\text{Total population of Montreal}}$$

The same calculation was repeated for Indigenous people and Low-income populations. The percentages of Indigenous and Visible minorities because the number of people surveyed was different in the two cases was added. A comparison was then made between the average Visible minorities and Low-income population in Montréal and the percentage of these socio-economic groups within each buffer area. The results are presented in tables 1 and 2.

RESULTS

Tables

Table 1: *Percentage of Visible minority/Indigenous people and Low-income (%) within a 100, 200 and 400 m buffer around a contamination point on the Island of Montréal*

	Buffer distance (m)		
Percentage of vulnerable people inside the buffer (%)	100	200	400
Visible or Indigenous (%)	33,2	33,8	34
Low-income (%)	18,5	18,2	17,2

Table 2: *Average percentage of Visible minority/Indigenous people and Low-income (%) on the Island of Montréal*

	Visible Minorities and Indigenous People	Low Income
Percentage of Montréal population (%)	33,67	15,99

Maps

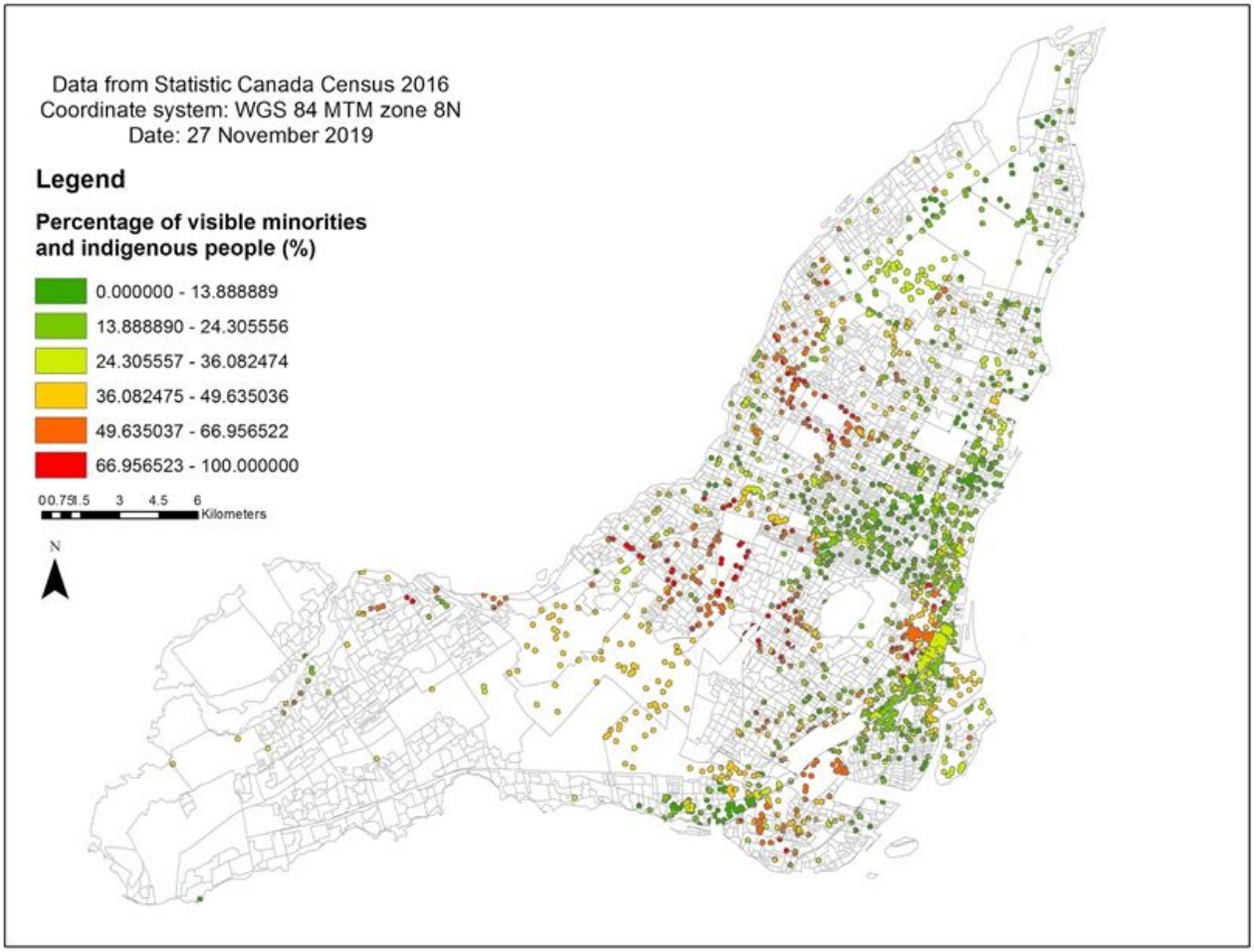

Figure 1. *Visible minorities and Indigenous people within 100 m of a contamination point in Montréal*

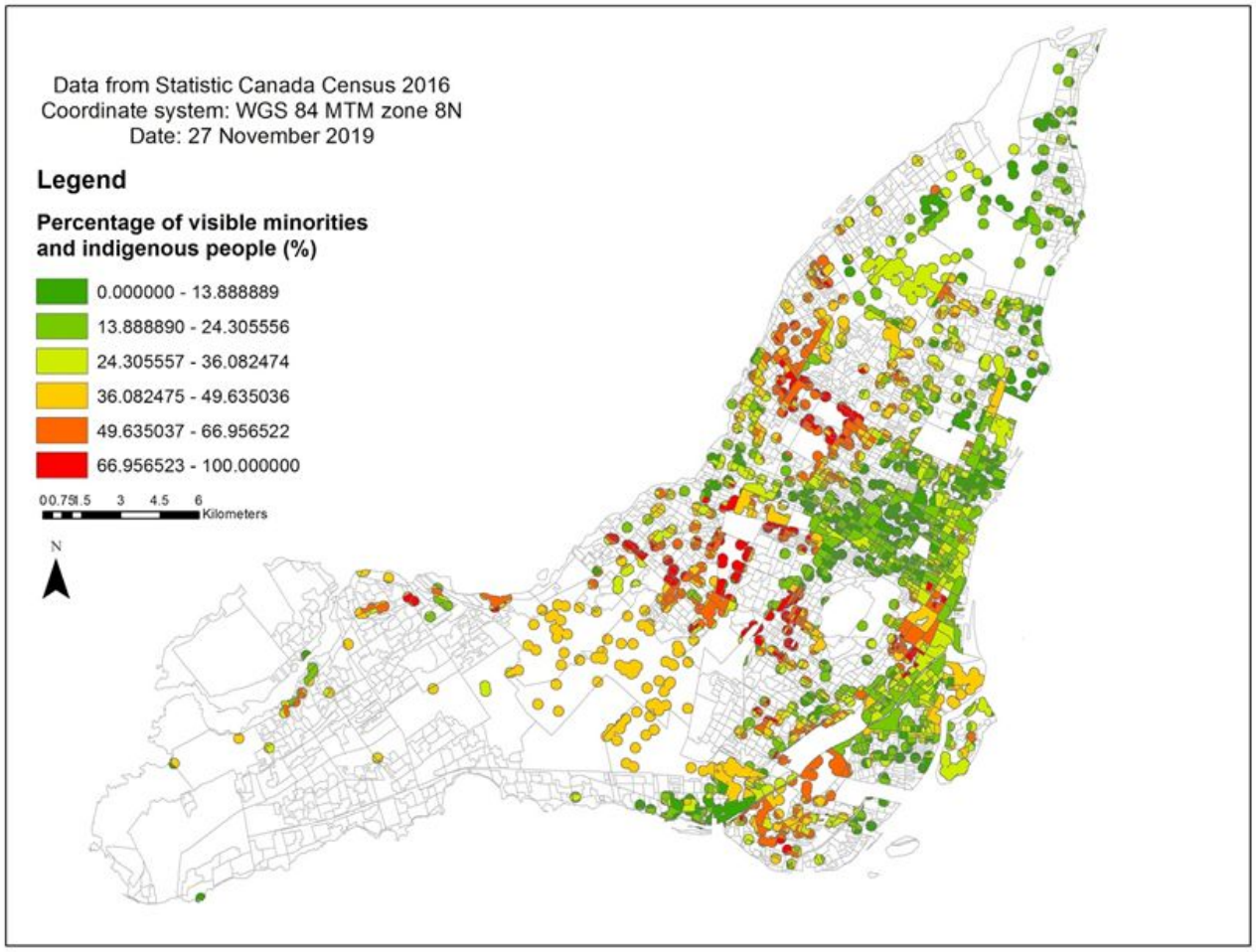

Figure 2: *Visible minorities and Indigenous people within 200 m of a contamination point in Montréal*

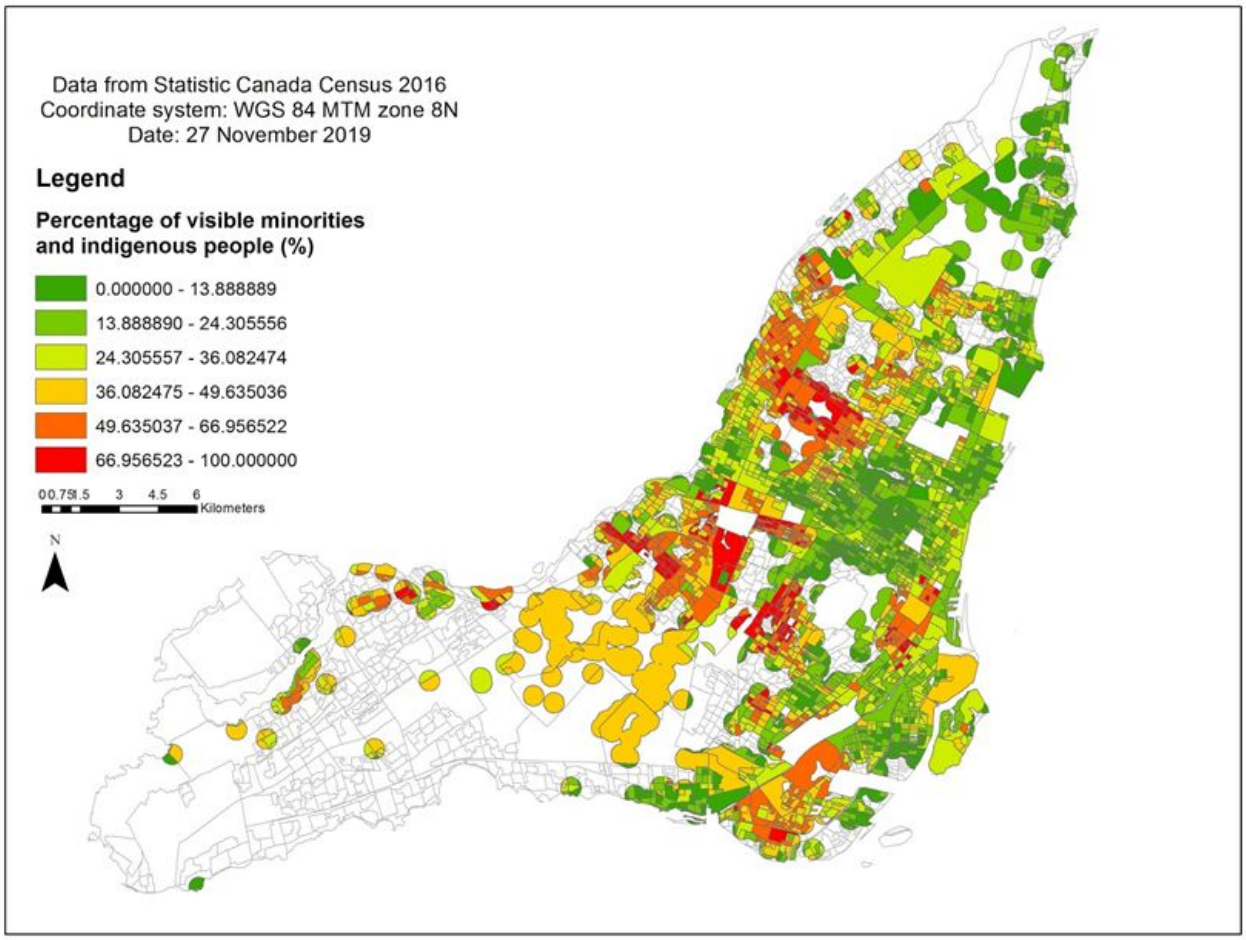

Figure 3: *Visible minorities and Indigenous people within 400 m of a contamination point in Montréal*

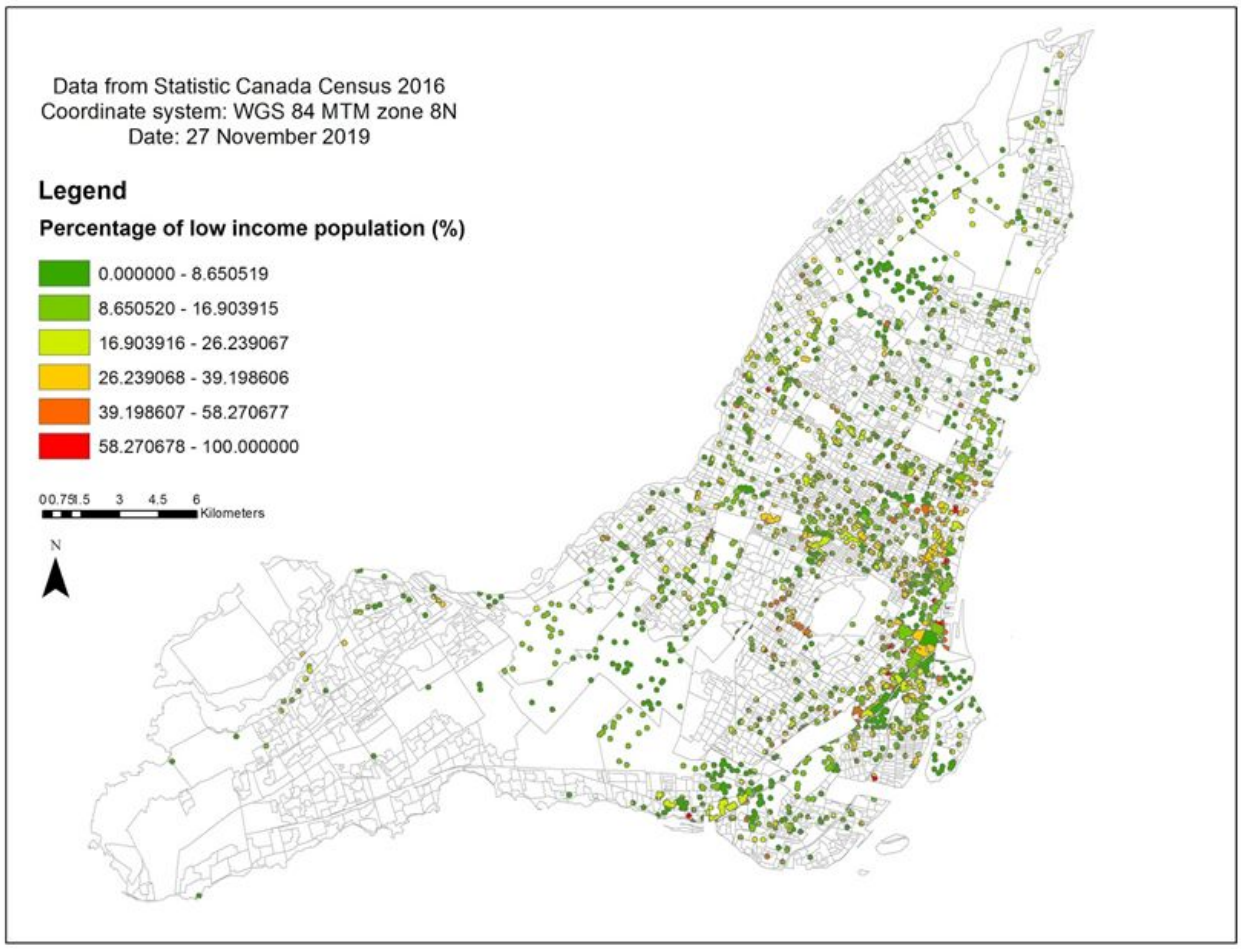

Figure 4: *Low-Income people within 100 m of a contamination point in Montréal*

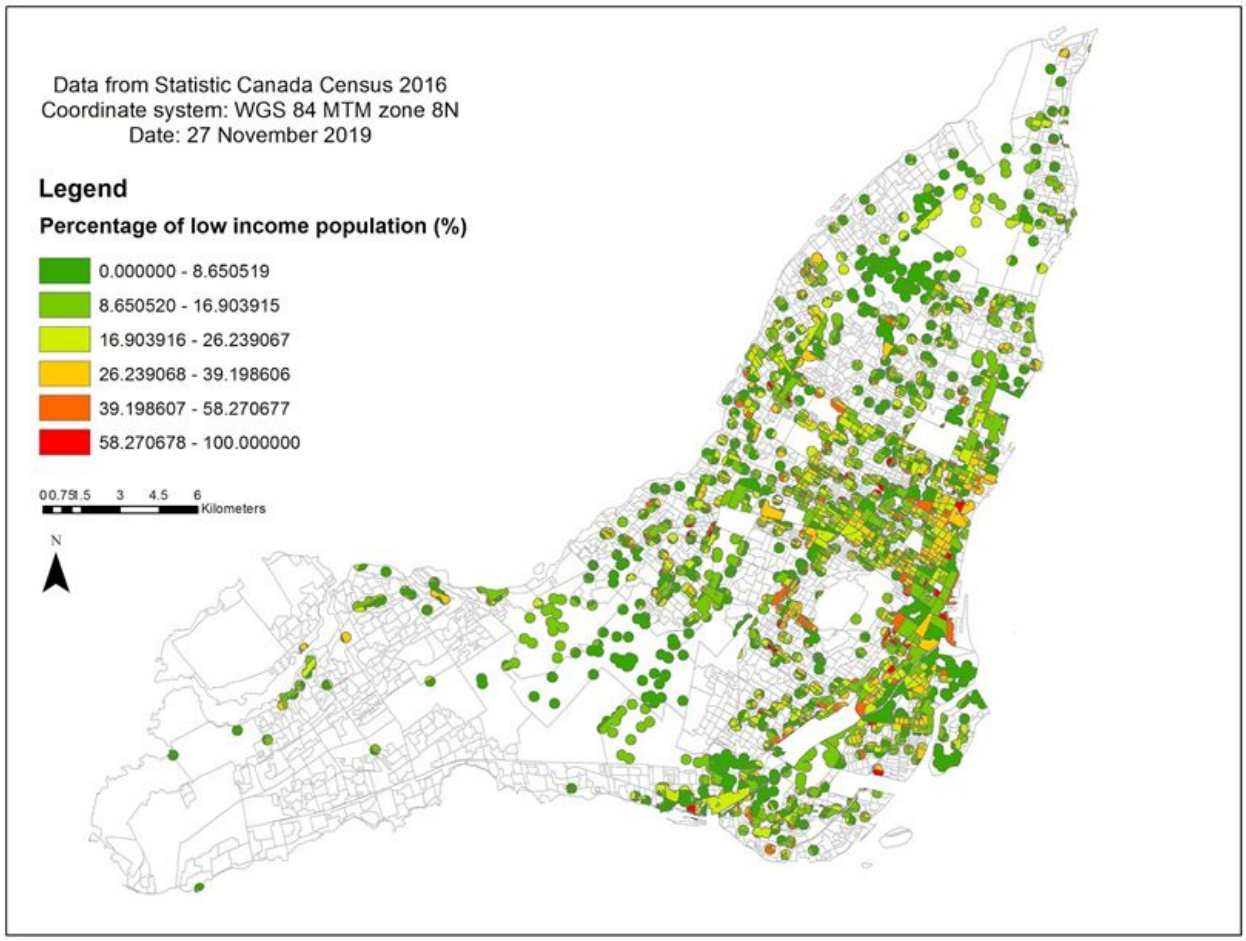

Figure 5: *Low-Income people within 200 m of a contamination point in Montréal*

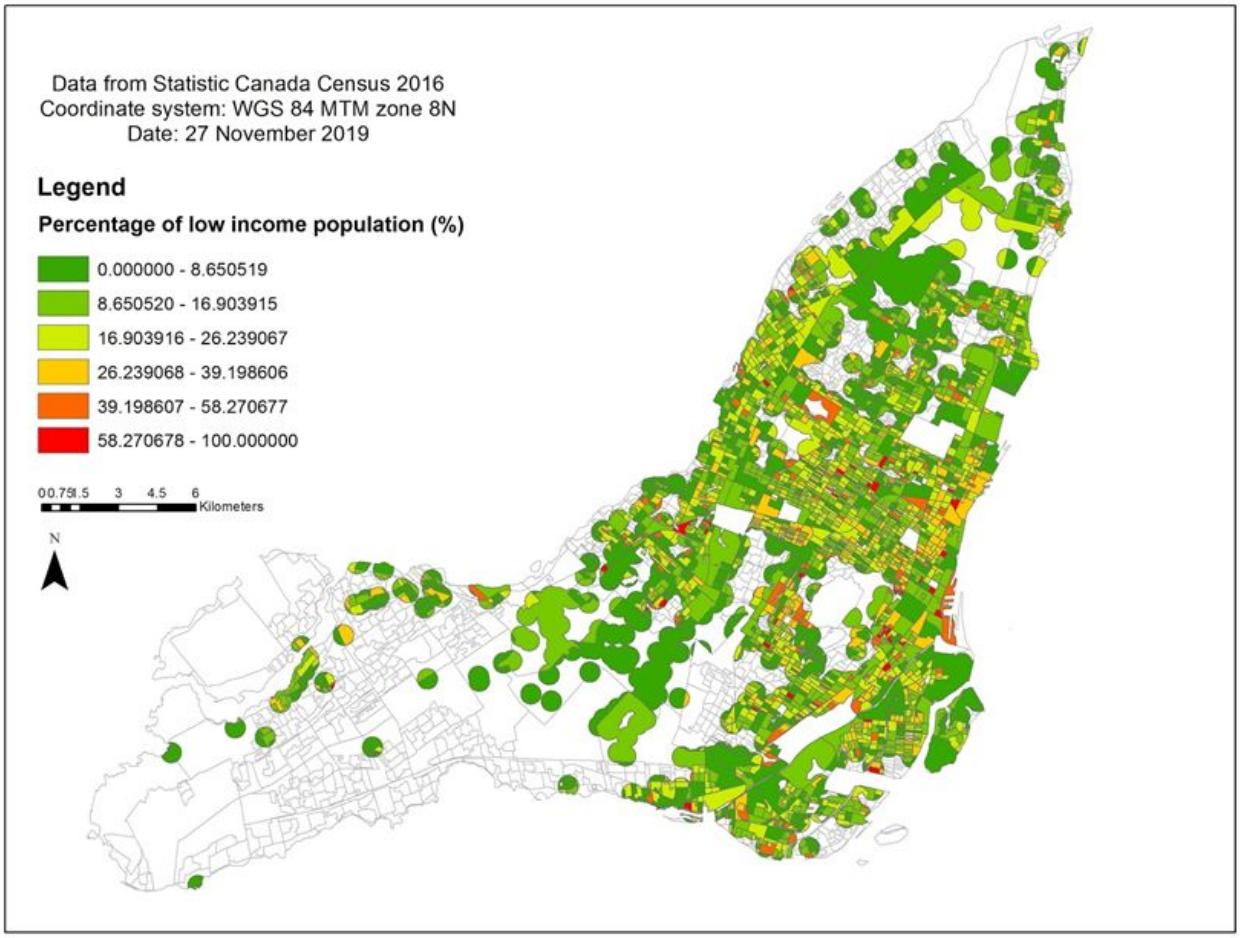

Figure 6: *Low-Income people within 400 m of a contamination point in Montréal*

ANALYSIS

This research is pertinent because humans can come in direct contact with urban soil contaminants through ingestion, skin contact and by inhalation, and these interactions can lead to the development of various health problems such as metal poisoning, cancers, mental retardation, etc.[53] Consequently, to ensure a healthy living environment, significant investments are being put into the rehabilitation of contaminated sites in Quebec and Montréal in particular. Thus, to support effective management of funds and advocate for the distribution of rehabilitation initiatives that do not reinforce health inequalities across the population, this research compares the spatial distribution of contamination sites with the location of low-income and visible minority groups in Montréal.

The results illustrate that the hypothesized trend of low-income and visible minorities residing closer to contaminated soil sites was only partially accurate. This research indicates that there is a disproportionate number of low-income households located in the smallest buffer zone of 100 m, and as the buffer zone increases to 200m and 400m, the population of low-income decreases. This finding supports the initial hypothesis that more low-income households are located closer to contaminated soil sites. This result can be explained through the literature review as an effect of income segregation where those of low-income groups are often residing in cheaper, less

[53] Gang Li et al., "Urban Soil and Human Health: A Review," *European Journal of Soil Science* 69 (2018): 196-215, https://doi.org/10.1111/ejss.12518.

developed neighbourhoods which tend to be subject to receiving less investment.[54] Furthermore, this trend could be a result of low-income households being pushed out of more affordable neighbourhoods as the housing crisis unfolds, condo development increases and more expensive residences are built, which drives up the price of living for surrounding homes and buildings.[55] According to Ley,[56] there has been a trend where low-income neighbourhoods in Montréal are subjected to gentrification; these include Saint-Henri, Pointe-Saint-Charles and Le Plateau. This scenario of low-income household segregation can be further explained by examples coming from the United States of America where the issue of urban poverty and polarization within cities has previously resulted in the formation of 'underclass' neighbourhoods in cities that are increasingly becoming more global in their demography and economy.[57] This is something that Badcock[58] described as a result of combined global economic pressures and labour market adjustments which result in more polarized societies due to the spatial patterning of poverty. This is a likely issue in Montréal since the research indicates that more low-income residences are located near contaminated soil sites. Within the city, there is a possibility that this trend is a consequence of recent

[54] Baikie et al.,"Environmental Justice in Canada?"
[55] Canada Mortgage and Housing Corporation (CMHC), "Examining Escalating House Prices in Large Canadian Metropolitan Centres," 2018, https://www.cmhc-schl.gc.ca/en/data-and-research/publications-and-reports/examining-escalating-house-prices-in-large-canadian-metropolitan-centres.
[56] David Ley, "Past Elites and Present Gentry: Neighbourhoods of Privilege in the Inner City," In *Changing Social Geography of Canadian Cities*, edited by Larry S. Bourne, and David F. Ley, 214-33: McGill-Queen's University Press, 1993.
[57] Blair Badcock, "Restructuring and Spatial Polarization in Cities," *Progress in Human Geography* 21, no. 2 (1997): 251–62, https://doi.org/10.1191/030913297670500369.
[58] Badcock,"Restructuring and Spatial Polarization in Cities,"

unemployment rates fluctuating from 6.9 in November 2019 to 9.2 in November 2019.[59] The rise in unemployment rates results in income contraction and the need for bigger mortgages when combined with rising housing and rental prices. Furthermore, recent reports from the Canadian Real Estate Association (CREA) stated that Montréal housing prices were recorded as the fourth largest year-on-year rise of 4.37 % in Canada.[60] This can result in the directed shift of households from their increasingly more expensive neighbourhoods to more affordable areas.[61]

The second half of the research results indicate the opposite effect occurring for those identifying as a visible minority. The findings suggest that the initial hypothesis was incorrect and that there was rather an increasing number of visible minorities as buffer zones increased from 100 m to 400 m. This result is novel compared to the existing research as there are a multitude of variables that could affect this trend. One potential variable could be the fact that visible minorities may not be highly represented in underdeveloped and low-income housing neighbourhoods where soil contamination is high. However, this hypothesis needs to be tested by further research. Although Montréal does present many “discrete cultural neighbourhoods [...] as well as several regions of concentrated poverty,” current research suggests that there are very few marginalized ethnic ghettos compared to those found in other large American cities.[62]

[59] Institut de la Statistique du Québec, “Labour Market Characteristics, Seasonally Adjusted Monthly data[1], Montréal and All of Québec, November 2018 to November 2019, December 2019, http://www.stat.gouv.qc.ca/statistiques/profils/profil06/societe/marche_trav/indicat/tra_mens06_an.htm.
[60] Global Property Guide, “Is Canada's Amazing House Price Boom Coming to an End?” March 2019, https://www.globalpropertyguide.com/North-America/Canada/Price-History.
[61] CMHC, “House Prices in Large Canadian Metropolitan Centres,”
[62] Caquard, “Mapping Environmental Issues in the City,“

The research thus shows novel results when looking at the trends of low-income households being disproportionately located in proximity of contaminated soil sites than those of visible minorities. It also presents the need for further investigations on the types and concentration levels of soil contamination throughout Montréal since the current risks to human health and well-being are understudied. As it pertains to investments in soil rehabilitation, this research indicates that investments should consider human health and well-being equally across demographics, especially since the results show that low-income housing is more concentrated near contaminated soil sites.

The decision to use buffer instead of polygon or centroid containment was motivated by a will to respect the contaminant travel pattern and keep consistent distances across buffer zones for all contamination points.[63] The 2 other techniques, consisting of including a zone if more than 50% of its area or if its center falls inside the buffer, are better suited if certainty about the number of people inside zones is important and if people live close to the center of an aggregation unit respectively.[64] To remediate these methods' downfalls, additional analysis of dasymetric mapping, i.e. aggregation based on land lots, is recommended.[65]

[63] Jayajit Chakraborty, Juliana A. Maantay, and Jean D. Brender, "Disproportionate Proximity to Environmental Health Hazards: Methods, Models, and Measurement." [In eng], *American journal of public health* 101 Suppl 1, no. Suppl 1 (2011): S27-S36, https://doi.org/10.2105/AJPH.2010.300109.
[64] Chakraborty, Maantay, and Brender, "Disproportionate Proximity to Environmental Health Hazards,"
[65] Ibid.

Limitations

A major obstruction encountered in this project concerned data availability. Currently, the available information on soil contamination sites in Montréal is underrepresented.[66] According to the client, contaminated urban lots in Montréal are not automatically declared or even characterized.[67] Thus, many contaminated sites are missing from the analysis, and the results obtained may underestimate reality.

The level of details provided by the various sources of data varied, so completeness was another obstacle. To avoid positional uncertainty, we had to exclude events without any geographical identifier (e.g.: address or geographical coordinates) or with incomplete addresses (e.g.: only a street name). Single event entries with multiple addresses (e.g.: 1000 Ottawa street, 140,150 and 156 Ann street, 175 Shannon street) [68] were separated into new individual entries to facilitate the process of geocoding and determining duplicates. Also, addresses entered as a range (e.g. 4200-4220 Poirier boulevard)[69] were replaced by a midpoint address. Spatial dependence such as this one can lead to spatial error, which happens when the error of an observation affects the errors of its neighbours.[70] Indeed, this could have lead to the introduction of non-existent addresses, which may explain why some locations could not be identified by any of the geocoding software we tried.

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[66] Geneviève Hamelin, personal communication, November 7, 2019.
[67] Hamelin, personal communication
[68] City of Montréal, “Liste des terrains contaminés officiels,”
[69] City of Montréal, “Liste des terrains contaminés officiels,”
[70] Sebastian Bauhoff, "Spatial Error," *Social Science Statistics Blog - Harvard University,* 2005, accessed December 20, 2019, https://blogs.iq.harvard.edu/spatial_error_1.

Finally, because of the inconsistency across databases, we were not able to distinguish all the rehabilitated sites from the contaminated ones. Hence, for the analysis, it is assumed that all the sites were still contaminated. Also, due to data incompleteness, the analysis was limited. We could not examine the categories of soil contaminants, and find out if vulnerable populations of interest are affected by a different level of toxicity compared to the average Montrealer. This would have provided relevant information for the client who is a provider of health services.

Another limitation relates to dubious addresses, i.e. when the intersection of more than 2 roads was reported. For this problem, we had to assess the accuracy of the location by verifying the associated coordinates over a street view basemap. If an approximate correct location could be pinpointed, we would adjust the address. .

Potential displacement of soil contaminants can also lead to positional uncertainty. Thus, to account for this possibility and for slight location imprecisions, we applied a buffer around each site. In this regard, we recognize that soil contamination is not limited to a fixed point but occurs over an area. However, using points was the only choice given the available data and limited resources. This could mean that duplicates were removed because of identical addresses even if they represent different sections of a contaminated area. To remediate this, further studies should represent contamination entries as polygon instead of point data.

Furthermore, despite best efforts to prevent positional uncertainty, we acknowledge that the nature of Geographic Information System (GIS) is prone to have

data uncertainty.[71] Consequently, inaccuracies and errors could have been introduced when inputting and analyzing the data. This could have happened when we input the data into the ArcGIS software or overlayed multiple datasets (i.e. superimposition of the contamination sites and the demographic datasets), which could have increased the amount of error.[72] Additionally, the geocoding process might have introduced additional inaccuracies since the "Geocode by Awesome Table" and the Geocoder.ca website produced slightly different coordinates.

Finally, the Modifiable Areal Unit Problem (MAUP) was a major limitation inherent to the research. Indeed, when analyzing questions of environmental justice, the MAUP is known to greatly influence the research outcomes.[73] There is a "scale effect"[74] where results across different spatial scale can vary.[75,76] For our research, DAs were chosen to have maximum precision, but socio-economic data at other aggregation levels such as Census Tracts and neighborhood were available. Larger aggregations are more suitable to look at spread out vulnerable populations but may miss isolated and local environmental injustice instances. To determine the best level for Montreal, further research should repeat our methodology at different scales and see if the trend maintains. Also, we assumed that individuals were uniformly spread across the DAs.

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[71] Stan Aronoff, "Geographic Information Systems: A Management Perspective," *Geocarto International* 4, no. 4 (1989): 58-58, https://doi.org/10.1080/10106048909354237.
[72] Aronoff, "Geographic Information Systems,"
[73] Michael T. Most, Raja Sengupta, and Michael Burgener, "Spatial Scale and Population Assignment Choices in Environmental Justice Analyses," *The Professional Geographer* 56 (2004): 574-86, https://doi.org/10.1111/j.0033-0124.2004.00449.x.
[74] David W. S. Wong, "The Modifiable Areal Unit Problem (MAUP)," In *Worldminds: Geographical Perspectives on 100 Problems: Commemorating the 100th Anniversary of the Association of American Geographers 1904–2004*, edited by Janelle Donald G., Barney Warf and Kathy Hansen, 571-75. Dordrecht: Springer Netherlands, 2004.
[75] Most, Sengupta, and Burgener, "Spatial Scale and Population Assignment Choices,"
[76] Wong, "The Modifiable Areal Unit Problem,"

However, groups such as Indigenous people or Visible minorities might cluster in a small section of the DA that falls outside of the chosen buffer zones. Thus, because of the MAUP, this subtlety might not have been captured in the final analysis.

CONCLUSION AND RECOMMENDATIONS

In this report, the presence of soil contamination on the Island of Montréal was investigated. The research team decided to look at the spatial distribution of contamination across the city and determine if some communities were disproportionately impacted, and thus more prone to potential adverse effects.

Soil contamination is indeed a global problem that is largely due to human activities. Urban areas are more sensitive to it because of manufacturing, construction, industrial dumping and so on, and Montréal is no exception to this rule.

Several official rehabilitation plans were put in place for Montréal, but those focused mostly on promoting a green economy and revitalizing territories to make land available for more development. These plans specifically focused on strong economic potential sites, and ignored potential adverse effects on human health. These types of governmental policies can further add on to the negative effects of discrimination and promote environmental injustice. The latter occurs when certain segments of the population are disproportionately exposed to pollution and its concomitant effects on health and the environment. This problem can be further worsened with institutional indifference or state-sponsored exploitation. Therefore, the research is focused on the

distribution of two categories of vulnerable people, the low-income group and the visible minority group, the latter including Indigenous people. Montréal soil pollution data was obtained from federal, provincial, and municipal datasets that were provided by the client and through governmental authorities' websites. Contamination points as well as the distribution of the two groups were used to create maps with ArcGIS. From the results, percentages of the two groups falling within predetermined buffers around contamination points were found.

It was discovered that there is a significant percentage of low-income households in the smallest buffer (100 m) around the contamination points and this proportion decreases as the point moves further away from the contamination center. This trend was not repeated for visible minorities. In order to prevent reproducing environmental injustices in the distribution of rehabilitation projects, it is recommended that a soil protection and rehabilitation policy should revolve around public health and well-being. Such an approach could be more appropriate and effective in addressing the issue of unequal exposure to soil contamination as well as associated matters such as safe living and working conditions, adequate nutrition, shelter and sanitation in order to create socially and environmentally sustainable as well as equitable communities. Moreover, decision-making processes must include a greater diversity of stakeholders to ensure that marginalized voices can be represented. Indeed, "at a more fundamental level, environmental justice is also about maximizing opportunities for full democratic participation in the governance of a healthy and sustainable society."[77]

[77] Baikie et al., "Environmental Justice in Canada?"

The various data limitations encountered in this project indicate the need for more advanced and accurate soil contamination record keeping. This improvement will provide consistent and standardized databases across different levels of government, as well as clear and accessible information on the exact location, types and potential health risks of soil contamination in all sites throughout Montréal. This method will make sure that all contaminated urban lots are declared and characterized. It is also recommended that specific structures should be put in place to avoid this problem as vulnerable populations have limited choices and lower resilience. For instance, ensuring a minimum of environmental cleanliness in Montréal could decrease the exposition of poor neighbourhoods to unsafe levels of contamination. Furthermore, the distribution of environmental hazards is only one out of a multitude of ways in which environmental injustices can manifest. Further research can be conducted on issues relating to unequal access to information and resources aiming to improve environmental conditions, as well as representation in governance, in order to deepen the analysis and understanding the complexity of the issue in Montréal.

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