CANADIAN JOURNAL of
URBAN RESEARCH
REVUE CANADIENNE de RECHERCHE URBAINE

Spatial analysis of discarded needles and dropbox locations in Calgary, Canada

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Abstract
Concomitant with the rise in the number of people who inject drugs has been an increase in unsafely discarded needles and injection debris. While the scholarly literature indicates that harm reduction programs reduce needle debris, the news media often report otherwise. Using geographic information systems (GIS) software ArcGIS Desktop 10.8 (Esri 2020), we analyzed geospatial data pertaining to needle debris in Calgary (Canada), correlating debris with available needle dropboxes, outreach education, overdoses, and changes over the COVID pandemic. Needle debris was most dense in two central neighbourhoods: Beltline and Downtown Commercial Core. The city's central neighbourhoods contributed to 83% of all needle discards, which accounted for 73% of discrete locations. Additionally, 51% of discarded needles were collected from the Beltline (40%) and Downtown Commercial Core (11%) neighbourhoods, accounting for 85% of clusters and 71% of hotspots. Overdoses were positively correlated with needle debris. COVID-19 pandemic restrictions were linked to a spike in the number of discards. Needle debris is a complex social, environmental and public health issue that requires a multifaceted approach. GIS mapping is a powerful tool that can locate hotspots so that resources can be deployed.

Keywords: public injection, overdose, substance misuse, improperly discarded needles, homelessness, supervised consumption services (SCS), geographic information systems, COVID-19

Résumé
Parallèlement à l'augmentation du nombre de personnes qui s'injectent des drogues, il y a eu une augmentation des aiguilles et des débris d'injection mis au rebut de manière non sécuritaire. Alors que la littérature scientifique indique que les programmes de réduction de risques réduisent les débris d'aiguilles, les médias rapportent souvent le contraire. À l'aide du logiciel de système d'information géographique (SIG), nous avons analysé les données géo-spatiales relatives aux débris d'aiguilles à Calgary (Canada), en corrélant les débris avec les boîtes de dépôt d'aiguilles disponibles, programme de sensibilisation et d'éducation, les surdoses et les changements au cours de la pandémie de COVID. Les débris d'aiguilles étaient les plus denses dans deux quartiers centraux : Beltline et Downtown Commercial Core. Les quartiers centraux de la ville ont contribué à 83 % de tous les rejets d'aiguilles, qui représentent 73 % des emplacements discrets. De plus, 51 % des aiguilles jetées ont été recueillies dans les quartiers Beltline (40 %) et les quartiers de

Canadian Journal of Urban Research, Summer 2022, Volume 31, Issue 1, pages 1–15.

ISSN: 2371-0292

Downtown Commercial Core (11 %), représentant 85 % des grappes et 71 % des points chauds. Les surdoses étaient positivement corrélées avec les débris d'aiguilles. Les restrictions liées à la pandémie de COVID-19 étaient liées à une augmentation du nombre de rejets d'aiguilles. Les débris d'aiguilles sont un problème social, environnemental et de santé publique complexe qui nécessite une approche multidimensionnelle. La cartographie SIG est un outil puissant qui peut localiser les points chauds afin que les ressources puissent être déployées.

Mots-clés : injection publique, surdose, abus de substances, aiguilles au rebut de manière non sécuritaire, sans-abris, services de consommation supervisée (SCS), systèmes d'information géographique, COVID-19

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Introduction

Many cities are observing an increase in unsafely discarded needles and injection debris. Using geographic information systems (GIS) software, we analyzed one western Canadian city's geospatial data pertaining to needle debris, identifying both the spatial distribution of needle debris and hotspot locations and clusters. Our findings showed a clear link between the distribution pattern of needle debris to the presence of needle dropboxes and services like homeless shelters and supervised consumption services (SCS). In this paper, we report on the findings of this study from Calgary, Alberta, Canada.

Background

Injection drug use is an increasingly ubiquitous public health concern. Concomitant with the rise in the number of people who inject drugs (PWID) has been an increase in unsafely discarded needles and injection debris (Shah et al. 2020; Costa et al. 2017). Several factors are associated with the improper discarding of used needles: being of no fixed address, the stigma attached to accessing supervised injection facilities, lack of access to safe disposal methods, desire to conceal drug use from the community, lack of access to treatment, and perceived legal risks associated with collecting and transporting syringes (Navarro and Leonard 2004; de Montigny et al. 2011; Cleland et al. 2007). Practicing safer injection and syringe disposal have been shown to reduce public health care expenditure and improve public safety (Devaney and Berends 2008). Although supervised consumption services (SCS) have been shown to reduce improper disposal of needles (Wood et al. 2004), many PWID consume substances in other public and private places (Navarro and Leonard 2004; de Montigny et al. 2011). The unrestricted use of needles outside of a dedicated facility can lead to occasions of improperly discarded used needles in public.

Improperly discarded needles present a risk to public health and safety through accidental needlestick injuries and possible exposure to bloodborne infections (Kordy et al. 2017; O'Leary and Green 2003). Even in the rare confirmed case of transmission of hepatitis C due to needlestick injuries (Res and Bowden 2011), needlestick injuries are associated with substantial social, psychological, and health care costs to injured individuals, their families, and the health care system due to the extensive follow-up required (Mannocci et al. 2016; Kordy et al. 2017; Moore 2018), although the risk of seroconversion is considered very low (Papenburg et al. 2008). Because of the risk of injury and infection, which can result in deleterious health effects over the long term, improperly discarded used needles are a public health problem that requires a multifaceted intervention (Costa et al. 2017).

de Montigny et al. (2011) described the ecology of public injecting and discarding as consisting of three physical environments: spaces for drug acquisition, injection, and needle disposal. The authors concluded that discards are associated with drug use spaces and spaces where an injection was likely to occur. Potential solutions to address the problem of publicly discarded needles include: implementing SCS (Wood et al. 2004; Stoltz et al. 2007; KPMG and NSW Health 2010); replacing the current needle designs with a retractable needle (Perry et al. 2012; Kermode, Harris, and Gospodarevskaya 2003); increasing awareness about the potential risks and disposal methods associated with a discarded needle (Moore 2018; Costa et al. 2017); increasing the availability and accessibility of public needle dropboxes (de Montigny et al. 2010); and, establishing a formal needle collection program in high debris areas.

While the scholarly literature indicates that SCS and needle exchange programs (NEP) reduce needle debris on the street (Wood et al. 2004; KPMG and NSW Health 2010; Tookes et al. 2012), the public news media at times reports otherwise (Potkins 2019; Hudes 2019; Bell 2019; Sakaki 2017), suggesting that improperly discarded needles are a significant public concern around SCS. Therefore, the purpose of our study was to analyze the spatial pattern and variation of discarded needle distribution throughout the city of Calgary, located in the western Canadian province of Alberta (see area map in Figure 1). A significant number of unsafely discarded needles have been observed and noted in Calgary, the most populous city in Alberta, with an average of 3,567 needles collected each month by agencies and departments to whom this responsibility is assigned. In our study we explored the proximity of needle dropboxes to hotspot locations, the link between discarded needles and overdoses, the impact of the COVID-19 pandemic on the volume of discarded needles, and the spatial distribution of needle discards by neighbourhood and in reference to the SCS.

For this study, we used GIS software ArcGIS Desktop10.8 (Esri 2020), a powerful tool used to understand community-based efforts to monitor and enhance public health (Cromley and McLafferty 2011). GIS has also been used to understand vulnerabilities to the drug crisis and locate services in the most affected communities (Davidson, Scholar, and Howe 2011; Bearnot, Pearson, and Rodriguez 2018; Schneider, Carlson, and Rosenthal 2020). GIS has been applied in many areas of substance abuse issues, ranging from tracking overdose deaths (Marshall et al. 2017) to opioid-substitution program mapping (Le 2019). For example, de Montigny et al. (2011) identified the physical and social environmental correlations of discarded needles based on samples taken from Montreal, Canada, and Fozouni, Khan, and Bearnot (2021) studied spatiotemporal trends in the distribution of needle reports.

Method

Setting

This study took place in the western Canadian city of Calgary (Figure 1). According to the 2019 civic census, Calgary has a population of 1,285,711, which grew from 1,237,656 in 2016 (Statistics Canada 2016), representing a 1.45% growth rate. The population density is 1501/km^2, and the population's average age is 37.6 years (Statistics Canada, 2016). Our study focused on the entire city, breaking down the data to individual neighbourhoods (Figure 1) in the analysis. A SCS, located in Calgary's central Beltline district, opened on October 30, 2017 and operated out of the Sheldon Chumir Health Centre. On average, 133 unique PWID visited the Calgary SCS every day (Government of Canada 2020). [At the time of this writing, a recent media report shows the government of Alberta's plan to relocate the current SCS site to two new unannounced sites (CBC News, May 27, 2021).]

Data Collection

Prior to January 2019, the City of Calgary's fire department responded to calls from city residents regarding improperly discarded needles. As of January 2019, Calgary Alpha House Society (CAHS), a non-profit agency serving vulnerable individuals experiencing homelessness and substance use, was contracted by the Government of Alberta to collect and dispose of needle debris and engage with communities and neighbourhoods through outreach and education. In the present study, we accessed the agency's spatial datasets of discarded and destroyed needle debris over 21 months (January 1, 2019, to September 30, 2020). The needle debris team retrieved discarded needles through two methods. First, the team received calls about discarded needles found on the ground or when individuals want to empty their sharps bins. Second, in consultation with former and current PWID, the team drove to commonly known city locations where discarded needles are often found. Calls for retrievals came from several sources: members of the public, the city's fire department and by-law officers, transit officers, and peer support groups comprised of former substance users who are now employed by CAHS. The CAHS outreach manager trained the retrieval crew in using the data collection platform on both smartphones and tablets. Regardless of the source of information about needle debris location, the crew captured the data upon retrieval.

Data was collected through Survey123 for ArcGIS for Desktop (Esri 2020), and digitized maps from government reports and the Calgary geospatial database. Survey123 for ArcGIS for Desktop is a web-based data-gathering platform that enables data collection in real-time with predefined questions and embedded GPS that can be exported to ArcMap for analysis (Esri 2020). Using Survey123 for ArcGIS, we analyzed citywide geospatial data pertaining to needle debris, identifying the spatial distribution of needle debris, tracking mitigation programs, identifying hotspot

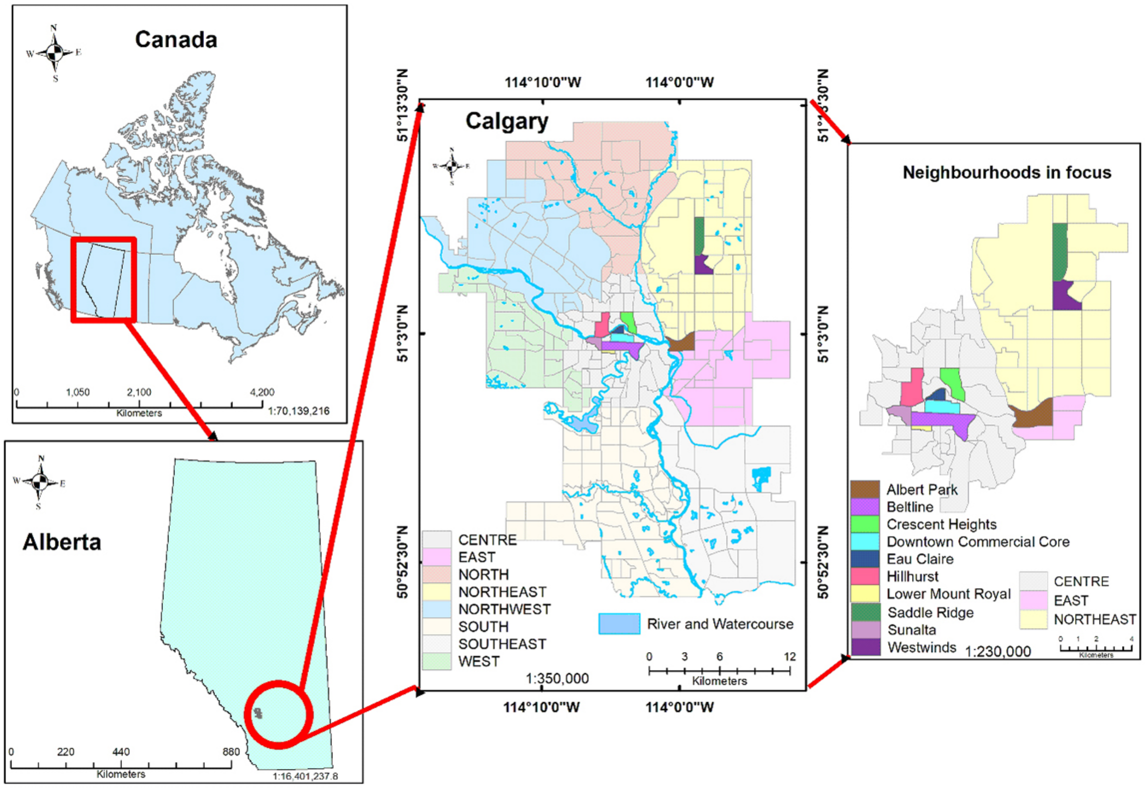

Figure 1
Neighbourhood map of Calgary, Alberta

locations, and relating the distribution pattern to needle dropboxes and outreach education about the safety of needle debris as well as to social and health services. Due to the study's timeframe, we were also able to analyze the relationship between COVID-19 restrictions, needle debris and overdose deaths across the city.

Data Analysis

The needle debris, outreach, and public education data were downloaded from Survey123 for ArcGIS Online, the spatial distribution of dropboxes and overdose were digitized, and other shapefiles obtained from the Calgary geospatial database were analyzed via ArcMap 10.8. All analyses were performed using ArcMap tools. To address identified objectives, we overlayed the city's spatial data of population census and locations of needle dropboxes, overdoses, outreach and public education to analyze relationships with the needle debris dataset. Our analysis utilized descriptive spatial statistics, dispersion, bivariate analysis, and point pattern analysis (nearest neighbor approach, spatial autocorrelation, cluster /outlier analysis and hot spot analysis) of discarded needles. This spatial analysis is based on Tobler's first law of geography (Oyana and Margai 2016) which states that things that occur near each other are more alike than things that occur far apart (Allen 2009, 336). After finding the presence of patterns in the data (Spatial Autocorrelation [Morans I]), we proceeded to examine the location of clusters via cluster and outlier analysis tools. We then conducted a hotspot analysis to identify statistically significant spatial clusters of high and low values.

To assess the centrality of discarded needle distribution, we generated descriptive spatial statistics. The spatial mean generated the central point of spatial distribution by averaging the X and Y values of needle debris distribution by summing up all X and Y values separately and dividing by the total number of needles collected. These values were weighted by the number of needle debris items collected in each location. While the spatial mean is affected by outlier observations (Oyana and Margai 2016), the spatial median offsets this limitation (Pimpler 2017). Spatial measures of dispersion were assessed, including the standard distance, which measures how needle debris is dispersed around the spatial mean. It is a valuable statistic for understanding how compact needle debris is distributed around the mean center (Pimpler 2017; Oyana and Margai 2016). We used correlation analyses (Oyana and Margai 2016) to assess the nature of the relationship between needle debris and overdose incidents. We conducted a spatial pattern analysis of needle debris to determine whether the observed distribution was a random or non-random distribution pattern and whether the pattern was random, clustered or dispersed (Oyana and Margai 2016).

We used the nearest neighbor tool to compute the average distance between nearest neighbours in a point distribution (observed distance) and compare it to a theoretical pattern (expected distance) (Oyana and Margai 2016) to determine if needle debris showed a statistically significant level of cluster and dispersion. The final result is the average neighbour ratio (R), the ratio of the observed distance divided by the distance from random data (Allen 2016). When R=1, the distribution of events is perfectly random; when R=0, the distribution of events is entirely clustered; and, if R>1, the distribution of events tends toward uniformity (Oyana and Margai 2016).

Spatial autocorrelation (Moran's I) determines whether there is an underlying geographical clustering of needle debris based on both location and attribute value for a series of distances (number of needles collected at each point location) (Oyana and Margai 2016). The Moran's I tool determines if the pattern of values is clustered, random, or dispersed (Allen 2016). The values are considered clustered if the average difference between neighbouring features is less than all the features (Allen 2016). The spatial autocorrelation coefficient statistically tests how clustered/dispersed features lie in space concerning its attribute values (Oyana and Margai 2016). The Moran's I value ranges from -1 (representing a perfect negative correlation in which neighbouring values are dissimilar and dispersed) through zero (complete spatial randomness) to +1 (perfect positive correlation that represents spatial patterns in which similar values are clustered in space) (Oyana and Margai 2016, 220). The spatial autocorrelation (Morans I) tool outputs a Moran's I index value along with a z-score and a p-value (Pimpler 2017). This tool only helps to decide the presence or absence of clustering; however, it cannot pinpoint the location of clustering patterns. This gap is addressed through cluster and outlier analysis, Ansellin Local Moran's I, and Getis-Ord hot spot analysis or GI (clustering of high and low values) (Allen 2009).

The cluster and outlier analysis (Anselin Local Morans I) tool identifies the distribution of clusters and outliers with its significance level through generating a COType field that distinguishes between a statistically significant ($p<0.05$) cluster of high values (HH), a cluster of low values (LL), a high outlier value surrounded primarily by low values (HL), and a low outlier value surrounded primarily by high values (LH) (Allen 2016, 382). We extracted HH values to identify high needle debris cluster neighbourhoods.

We used the hotspot analysis tool to examine needle debris to identify statistically significant cold spots and hotspots using the Getis-Ord Gi* statistics. It displays clustering of high, low, and not significant values on the map. Each feature is assigned as a hotspot, cold spot, or not significant. If the neighbourhood values are significantly higher than the study area, the feature will be marked as a hotspot; if the neighbourhood values are significantly lower than the values of the study area, a feature is considered a cold spot. If neither is the case, the feature is marked as not significant (Pimpler 2017).

We utilized other ArcMap analysis tools included data management, editing, analysis, conversion, spatial analyst, and spatial statistics. Some of the specific tools utilized include extract, proximity, statistics, feature class, features, fields, joins, layers and table views, projections and transformations, analysing patterns, mapping clusters, measuring geographic distributions, modeling spatial relationships (ordinary least square (OLS)) and utilities. We used the buffer analysis tool to analyze the distribution of discarded needles around water sources such as rivers and other water bodies. Spatial distributions of overdoses and dropboxes were digitized from the paper maps. A temporal and spatial differential of discarded needles and COVID-19 pandemic were analyzed using spatial statistics tools.

Results

A total of 74,900 discarded needles were collected from 4,470 discrete locations (i.e., 4,470 retrievals) between January 2019 and September 2020. Of the 4,470 locations, only two discrete locations (0.045%) had missing data and were subsequently excluded from the analysis. Most needle collection retrievals originated from the field team (n=4,045, 90.5%) with the remaining calls for service originating from calls to the fire department (9-1-1) (n=378, 8.46%), City by-law officers (n=26, 0.58%), and public transit officers (n=21, 0.47%).

First, we explored the geographic distribution of needle debris. Needle debris was most dense in the Beltline neighbourhood (Figure 2). The spatial mean (16.76) and median (2) distribution of discarded needles is in the Downtown Commercial Core and Beltline neighbourhoods, respectively (Figure 3). To maintain numeric consistency across differently populated areas, such as Fish Creek Park which lacks a residential population but had needle

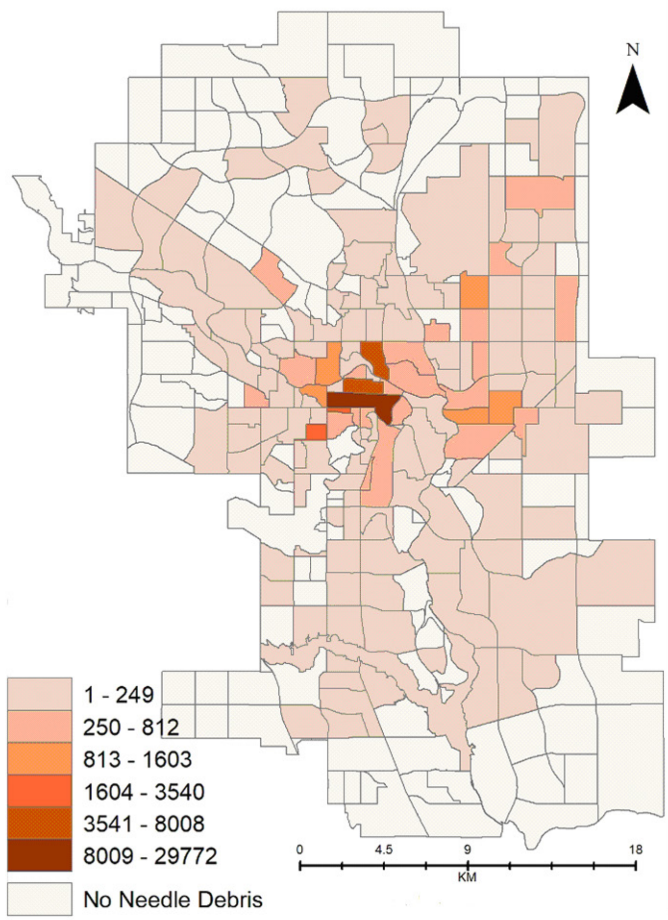

Figure 2
Discarded needle distribution by neighbourhood

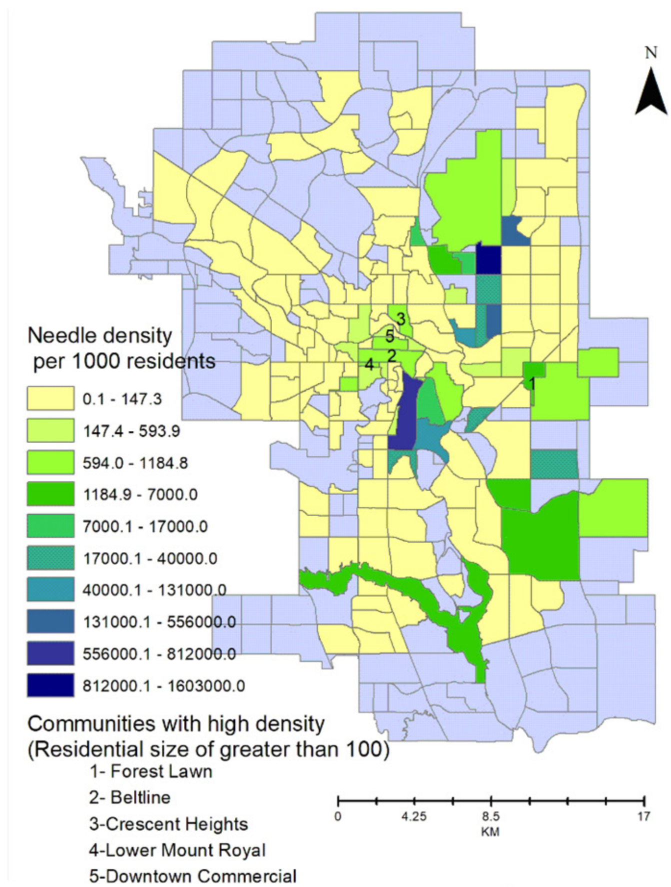

Figure 3
Needle density per 1000 residents, by neighbourhood

debris retrieved, we used one as a residential count for all neighbourhoods with no population count.

The SCS is located in the centre of the Beltline neighbourhood, where the geometric median distribution of the collected needle debris and Central Memorial Park is located. This concentration depicts the role of the SCS as a centre of needle disposal, and the buffer analysis of needle debris collected shows that 10% (n=7,667) of collected needles were within 300 m of the SCS, 16.8% (n=12,608) were within a 500-m buffer from the facility, and 43% (n=32,472) within 1-km buffer from the facility. A 1-km buffer from the SCS accounts for 2,273 out of the 4,470 retrieved locations of discarded needles, that is, 48% of the discarded needles' discrete locations. The maps used in this article have a projection of transverse mercator (TM) and coordinate system of NAD 1983 3TM 114 for Calgary and NAD 1983 10TM AEP Forest for Alberta, and sources of other shapefiles are from the Calgary geospatial database and Alberta's Spatial Data and Imagery Infrastructure (Altalis).

The standard distance tool measures the degree to which features are concentrated or dispersed around the geometric mean centre (Pimpler 2017). The result shows that 92% (69,087) of the needles collected from 4,003 discrete locations were within 2SD from the geometric mean equivalent to a 6.6-km buffer, and 75.5% (56,557) collected within the 1SD from the geometric mean, which was in a 3.4-km buffer. Almost 98% (n=73,688) of all needles collected were within 3SD from the geometric mean (9.8-km buffer). The directional distribution of needle debris also showed a northeast to southwest distributional pattern.

There was a spatial variation in discarded needles collected across the city. The collection and disposal cover 159 neighbourhoods, which is 53% of the 300 Calgary neighbourhoods. It has a wide variation from 1 to 29,772 (M= 250; SD=1847). The city's central neighbourhoods contributed to 83% of all needle discards, which account for 73% of discrete locations (Figure 2). It shows that 51% of discarded needles were collected from the Beltline (40%) and Downtown Commercial Core (11%) neighbourhoods.

We also analyzed the density of discarded needles as a function of the population size in by neighbourhood. According to the 2019 Census upon which our analysis is based, Calgary has a wide range of residential counts across neighbourhoods. Since the census is based on the residential count, it may be a poor indicator of the number of homeless people in the area. For example, needle debris was collected from industrial areas with no residential count. These areas might be ideal for people wishing to conceal drug use from the public. Among the neighbourhoods from which needle debris was collected, residential counts ranged from zero (predominantly industrial areas) to 25,129 (Beltline). Unlike the total count of discarded needles in neighbourhoods, discarded needles per resident offer an overview of the contribution of residential count on the number of discarded needles collected.

We calculated the number of needles discarded per 1000 population at the neighbourhood level (Figure 3), analyzing neighbourhoods with more than 100 residents. We found that Forest Lawn, Beltline, Crescent Heights, Lower Mount Royal, and Downtown Commercial Core are the first, second, third, fourth and fifth most needle-population density rates, respectively. The two neighbourhoods (Beltline and Downtown Commercial) with the highest number of needles collected have a lower ranked second and fifth in needle-population density rate, respectively (Figure 2).

We analyzed the average nearest neighbor ratio (ANN) and spatial autocorrelation to measure any significant distribution patterns. The average nearest neighbor ratio (ANN) is a measure of the observed/expected frequencies in which a value greater than one indicates dispersed patterns and a value of less than one indicates a clustered data pattern (Pimpler 2017). The discarded needles distribution's ANN ratio is 0.303, indicating a clustered distribution pattern ($p < 0.001$).

We analyzed spatial autocorrelation to determine the presence of clusters and dispersion, using Moran's I index value together with a z-score and a p-value. Moran's I values fall between -1.0 and +1.0, in which 0 indicates a random spatial pattern. Clusters occur when similar values are close together, and a dispersed pattern reflects different values close together. The spatial autocorrelation of the data revealed Moran's I = 0.015569 ($p<0.001$), Z score value of 9.778, implying a clustered pattern (C.I.=99%). Thus, the distribution of needle debris is clustered, and we conclude the presence of patterns in the data. We conducted a buffer analysis which showed that 90% of hotspot locations and 76% of all needle discards fell within a 1-kilometre buffer from the city's waterways. Moreover, 56% of hotspots and 43% of discards were within the 500-metre buffer (see Figure 4).

We then conducted a clusters and outlier analysis to find outliers and clusters in the data. The cluster and outlier tool separate features and neighbourhoods from the study area, examining each feature against every other feature to see whether it is significantly different (Pimpler 2017). The map in Figure 5 identifies a statistically significant ($p<0.05$) cluster of high values (HH), low-value clusters (LL), outlier values surrounded by low values (HL), and an outlier low value surrounded by high values (LH). We extracted the HH (High-High) value to show the high value surrounded by high-value clusters. Our analysis revealed 106 high-high clusters at a high significance level ($z=4.853$; $p < 0.001$). Of the 106 HH values, the city's centre has 101 clusters: Beltline and Downtown Commercial Core neighbourhoods accounted for 90 HH clusters, 85% of HH clusters. Other neighbourhoods that have HH clusters in the centre of the city include Eau Claire (2), Sunalta (2), Crescent Height (2), Lower Mount Royal (2), and Hillhurst (3). Saddle Ridge (2) and Westwind (2) neighbourhoods in the northeast have four clusters. The remaining cluster is located in the Albert Park neighbourhood in the city's east (refer to Figure 1).

We then conducted a hotspot analysis to identify statistically significant spatial clusters of high values (hotspots) and low values (cold spots) at a determined significance level. There were 80 hotspot locations (CI ≥95%). Of the hotspot locations with a bin value of ≥2 (CI ≥95%), 57 of the 80 hotspots are in the two central neighbourhoods: 42 in Beltline and 15 in Downtown Commercial Core neighbourhoods (Figure 6). These two areas accounted for 71.3% of highly significant hotspot areas, and 90% of significant hotspot locations are in the center of the city (72 out of 80 hotspots).

One of the factors that creates spatial variation in the number of discarded needles in public places is the availability, accessibility, and proximity of needle dropboxes to the people who need them, specifically in hotspot locations. There were 23 needle dropboxes located and functioning in the central neighbourhoods in the city. In our analysis, the average distance between the hotspot locations and a dropbox was 573m. Moreover, the average distance between all discarded needles to all needle dropboxes was 1316.7m. Of the 80 hotspot locations across 19 Calgary neighbourhoods (see Figure 7), needle dropboxes were located in six of these neighbourhoods; a total of 13 hotspot neighbourhoods were not equipped with a needle dropbox. Moreover, of the three areas with a high number of discard hotspots (Beltline, Downtown Commercial Core and Sunalta), the Sunalta neighbourhood ranked third in the number of hotspots but did not have any needle dropboxes (see Figure 8). Figure 7 shows the extracted hotspot,

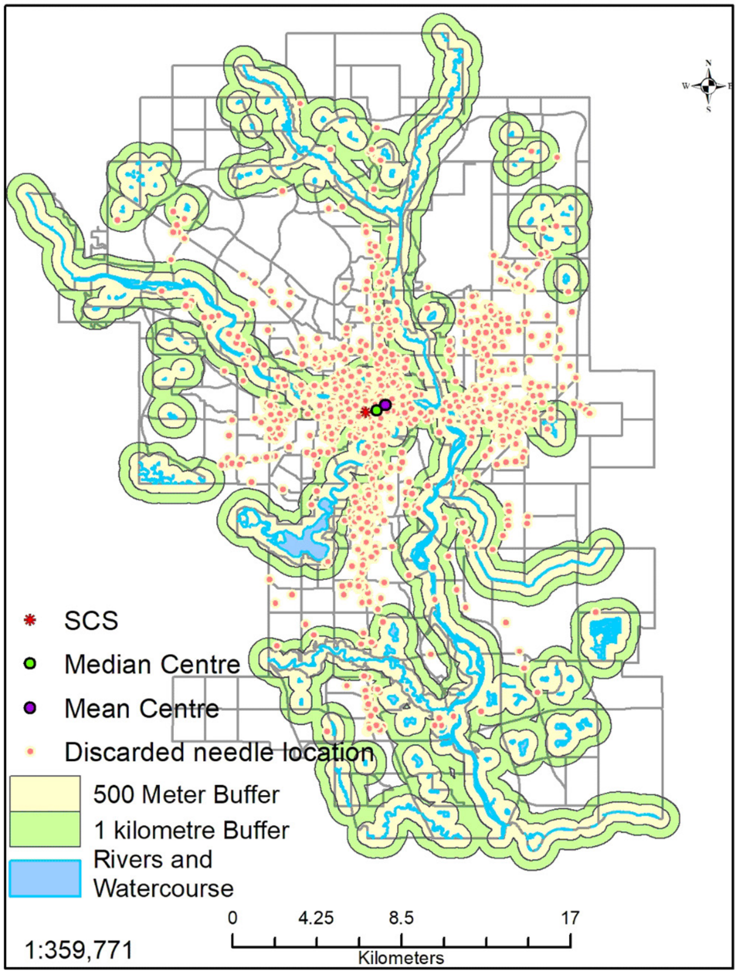

Figure 4
Needle discard (mean and median) pattern waterways

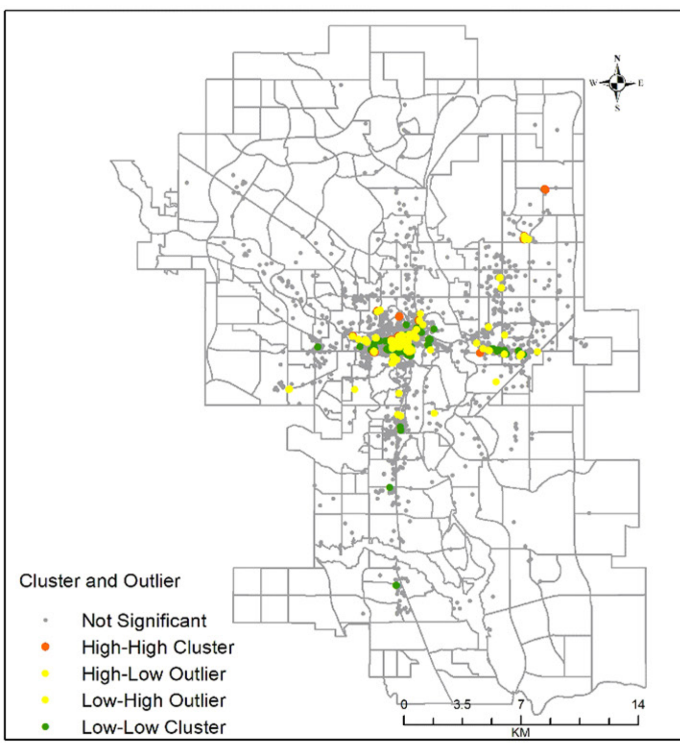

Figure 5
Cluster and outlier map

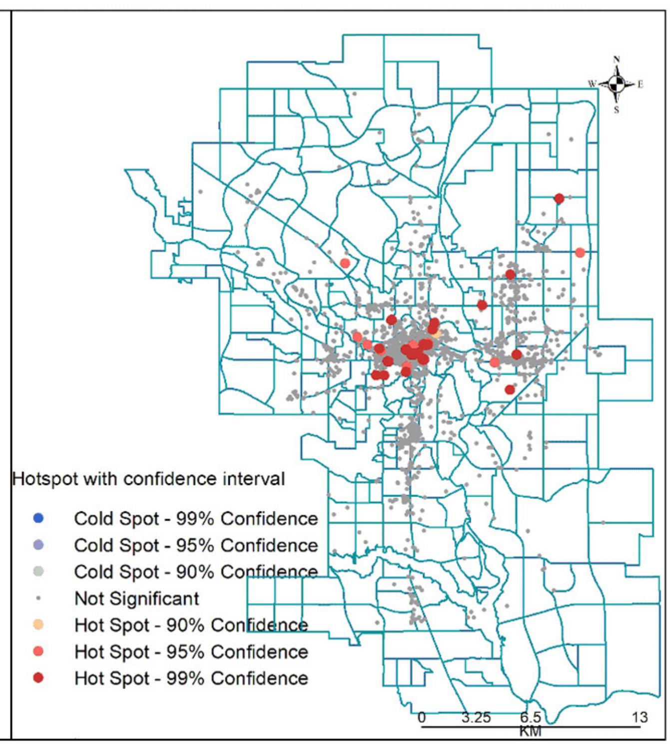

Figure 6
Hotspot analysis with confidence interval

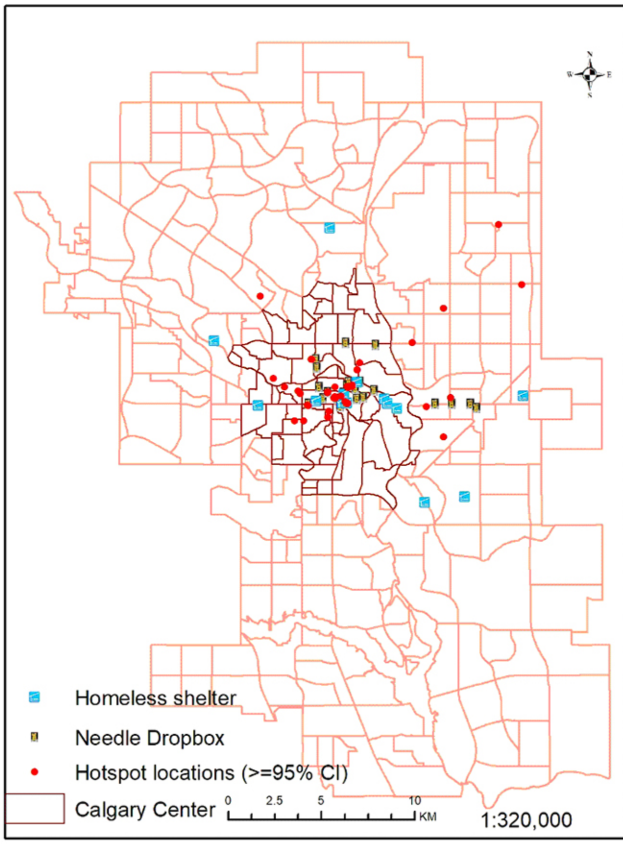

Figure 7
Spatial distribution of needle dropboxes, homeless shelters, and discarded needle hotspots

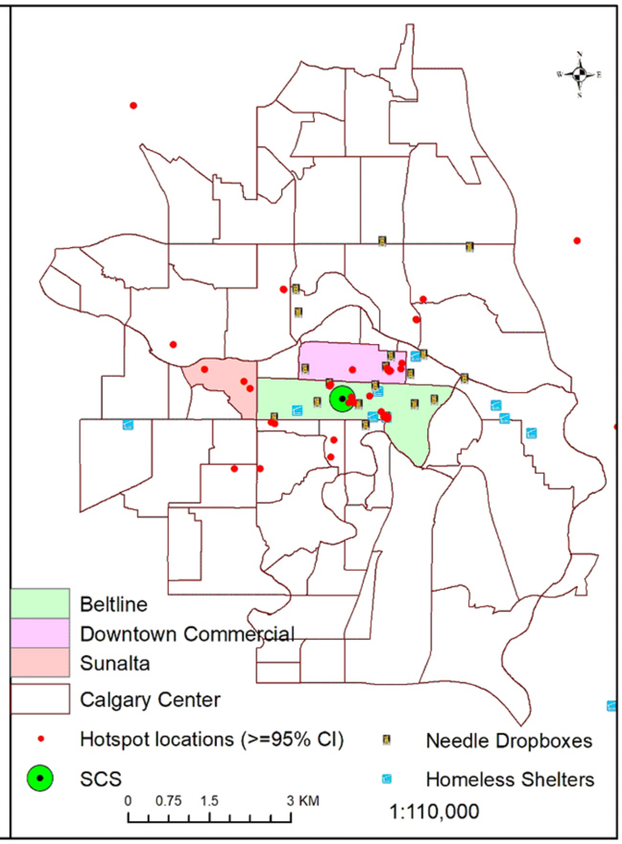

Figure 8
Discarded needles, hotspots, dropboxes, SCE, Homeless shelters in central Calgary

needle dropbox, and homeless shelter locations. It shows that all of the needle dropboxes and most of the homeless shelter services are located in areas characterized by a high density of hotspots in the centre of the city. Figure 8 shows the clipped map of the central quarter of Calgary, where the communities with a higher number of hotspot locations, needle dropboxes, SCS location, and homeless shelters.

We then assessed alterations in needle debris collection after the onset of COVID-19. On March 15, 2020, in response to the escalating COVID-19 pandemic, the City of Calgary declared a state of local emergency that required the temporary closure of most non-essential businesses and services. In the six months prior to the COVID-19 restrictions, there were 16,830 discarded needles collected. In the six months after March 15, there were 37,180 needles collected, resulting in a 120.92% increase in the number of discarded needles collected during the first six months of the COVID-19 restriction.

Next, we explored the relationship between drug overdoses and discarded needles. At least one discarded needle was collected in 62 of the 74 neighbourhoods in the city. Additionally, 15 of the 74 neighbourhoods with at least one overdose death reported are within the hotspot locations. The Beltline and the Alberta Park neighbourhood (see Figure 1) had the highest number of overdose deaths reported by the Government of Alberta (2020) between January 1, 2020, and June 30, 2020. We found a positive relationship between overdose death count and hotspot locations, with a higher number of overdose deaths concentrated in hotspot locations. Although the correlation between overdose reported and needle debris collected is weak (adjusted $R2= 0.388685$, $p<0.001$), there is a positive correlation (Figure 9).

Lastly, we analyzed outreach and public education data about discarded needles safety, a program freely provided to interested individuals and organizations on an as-requested basis. A total of 501 awareness training sessions about needle debris safety were provided to 951 individuals across the city. On average, two individuals participated in each training. Over two-thirds (69%) of outreach education participants were from businesses and commercial organizations, and 10% were from either educational services or non-profit organizations. Just under a third (31.5%)

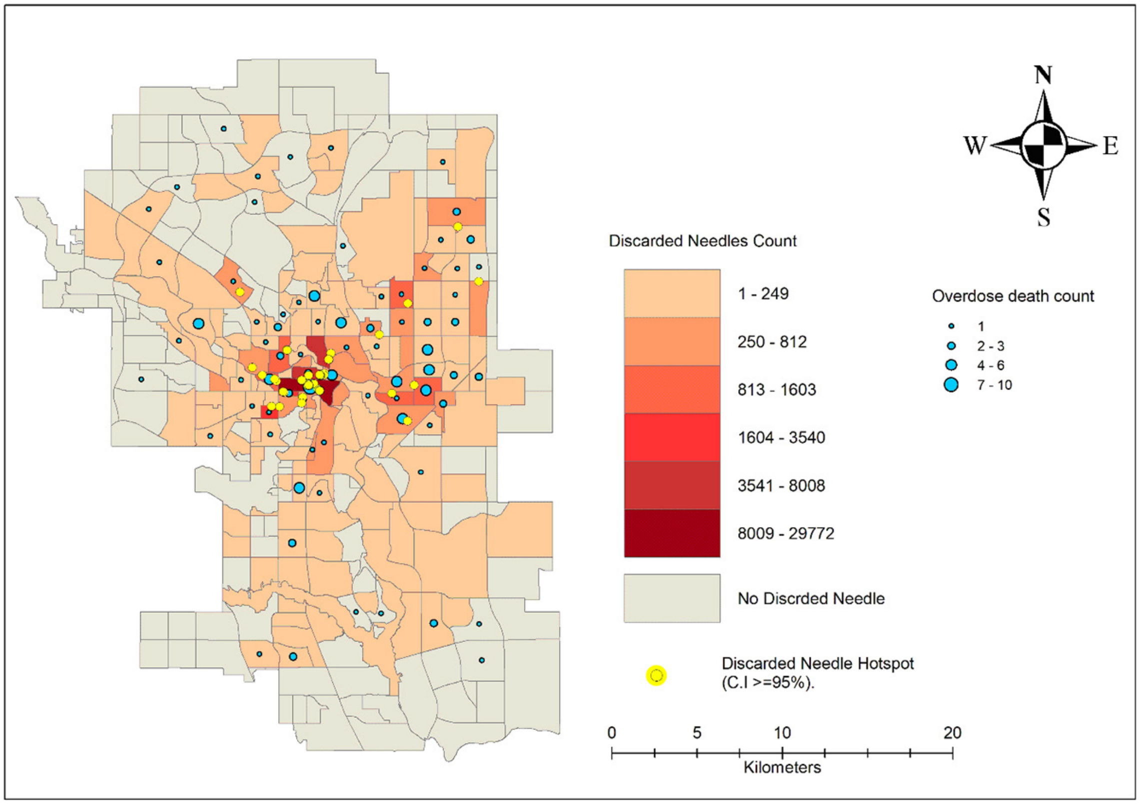

Figure 9
Discarded needles, hotspots, and overdose deaths

of outreach education around needle debris was provided to the two neighbourhoods (Beltline and Downtown Commercial Core) that accounted for 51% of the needle debris.

Discussion

We used the conceptual framework of the ecological model developed by de Montigny et al. (2011) to explore the physical characteristics of discard locations. We focused our analysis on the opportunity spaces and disposal options as put forward by that model. These components complemented the spatial variation of discards and disposal options across neighbourhoods in Calgary.

Our research shows that proximate location of physical features like rivers and watercourses, homeless shelters, and SCS are some of the possible opportunity spaces that attract PWID as a suitable place to inject (and then discard). It is possible that the waterways attracted PWID as a suitable place to inject because of its relative privacy and being away from social control. Like de Montigny et al. (2011), we found that commercial space was associated with discards because these areas often attract PWID (perhaps due to the other area amenities) more than residential neighbourhoods.

There is no consensus in the literature on the link between the location of homeless shelters and discards. Navarro and Leonard (2004) found that homelessness was a strong predictor of public injecting, which naturally links to discards in place. On the other hand, de Montigny et al. (2011) found no association between discards and shelter location. Our study found that two-thirds of the city's homeless shelters are in the central neighbourhoods, accounting for 90% of discarded hotspots and 83% of all discarded needles. This finding is consistent with the literature associating discarded needles with harm reduction programs and homeless shelters (Fozouni, Khan, and Bearnot 2021). This association may be due to the fact that many homeless shelters have policies banning even concealed needles, leaving these items at risk of being either confiscated or discarded unsafely outside of the shelter. Additionally, given that homelessness and substance use are often co-occurring, this association was unsurprising.

Calgary's needle discard problem was most pronounced in the geographical area around a SCS, which in our view, raises more questions than it answers. Unfortunately, digital GIS data was not available prior to the SCS opening, and as a result, conclusions cannot be drawn about the historical impact of the SCS on discard patterns. Whether the SCS has contributed to the problem of needle discard or merely exposed it, or whether the SCS is exactly where it needs to be (i.e., where people using these services already are), is beyond the scope of this research. While some research has found that areas surrounding dropboxes and SCS have a high needle discard density (Fozouni, Khan, and Bearnot 2021), other research has not found this to be the case (Wood et al. 2004). This discrepancy in findings highlights the need for quasi-experimental before-and-after studies, as well as the need for consistent use of geospatial technology for data collection.

Needle exchange programs (NEP) were initially implemented as one-for-one exchanges, with an emphasis on a strict interpretation of exchange. This type of restrictive program was insufficient to reduce bloodborne infection rates, and needle distribution programs were proven to be more effective (Hyshka et al. 2012; Bluthenthal, Ridgeway, et al. 2007; Kral et al. 2004; Sherman et al. 2015; O'Keefe et al. 2017). One of the goals of needle exchange programs, in addition to public health goals, was to reduce inappropriately discarded needles (Hyshka et al. 2012). It is possible that an unintended consequence of moving away from a strict medium of exchange to a system of distribution may be that needles lost their extrinsic (but not intrinsic) value and may thus be increasingly discarded away from a distribution or exchange program. However, this theory is not borne out in the academic literature (Bluthenthal, Anderson, et al. 2007).

Overall, we found that needle dropboxes insufficiently covered the city's most needed hotspots, with publicly available dropboxes only available in 32% of all hotspot neighbourhoods. The remaining 68% of hotspot neighbourhoods lacked dropboxes entirely. In the two neighbourhoods with the highest number of discarded needles, Beltline and Downtown Commercial Core neighbourhoods were responsible for 71% of the hotspot locations but had only 48% of publicly available needle dropboxes. This deficiency represents a significant service gap.

The data also indicates that a PWID must walk hundreds to over a thousand metres (average of 537 to 1317 metres for hotspot and all discard locations, respectively) to access the nearest dropbox. Furthermore, individuals who want to dispose of their needles appropriately may find it impractical due to being under the influence of the substance they have just injected. A 200m buffer zone around the available dropboxes covered only a third of the discrete locations of discarded needles (area coverage) and 46% of the volume of discarded needles. This "dropbox desert" calls for the installation of more dropboxes to enhance ease of access. de Montigny et al. (2010) concluded that 98% of needle debris discarded in public places could be reduced by installing needle dropboxes within 200 m of hotspots.

We analyzed the hotspot locations to ascertain their proximity to social and health service facilities. We identified three schools, 47 parks, 12 playgrounds, and three recreational facilities within the 200m buffer zone from the hotspot locations. Two parks (Central Memorial Park and Olympic Plaza Park) that are located within Beltline and Downtown Commercial Core neighbourhoods are the hotspot centres. One of the parks had a needle dropbox, but none of the identified facilities had a needle dropbox within a 200m buffer distance. (The 200m buffer was chosen based on de Montigny et al. (2010).

Outreach education aimed to reach both PWID and other Calgarians to improve safety around discarded needles and provide instruction on proper disposal. The importance of outreach education is well supported (Kordy et al. 2017; Moore 2018), and it is one of the methods to foster behavioural changes around discarded needles precautions and disposal (de Montigny et al. 2010). In our study, only a third of all training was provided to members of the general public, in whose neighbourhoods more than half of all discarded needles were collected. Since most hotspot locations were in business and commercial districts, most awareness training participants were from these organizations. Since most community needlestick injuries affect children, educating parents and schoolteachers about discard safety is recommended (Butsashvili et al. 2011). Overall, the training's effectiveness needs to be further evaluated in terms of its ability to decrease discarded needle and needlestick injuries.

After the COVID-19 pandemic was declared, there was a dramatic increase in discarded needles. This sudden and marked increase may be due to lockdown preventing businesses from cleaning up the area or because lockdown resulted in fewer opportunities to dispose of needles in the usual places. Alternately, substance use may have increased or become more visible during COVID-19 (Zaami, Marinelli, and Varì 2020; Vasylyeva et al. 2020).

There was a spatial link between the number of discarded needles, the number of overdose deaths, and COVID-19 in a neighbourhood. The number of overdose deaths was higher in the neighbourhoods of hotspot locations. While Fozouni, Khan, and Bearnot (2021) established a link between discarded needles and the risk of overdose, our findings linked discarded needles with the actual count of overdose deaths. We also found that COVID-19 restrictions and the lockdown were spatially linked to an increase in overdose deaths and a spike in the number of discarded needles. Some reports show a doubling of overdose deaths during the pandemic and deaths are expected to spike across the province (Smith 2020; Herring 2020).

Addressing public health and safety through the provision of needle dropboxes and siting of supervised consumption services is the responsibility of both the provincial and municipal government. The provincial health care system, municipal urban planners and community infrastructure departments must work together to ensure that harm reduction principles are integrated into urban planning. The siting (or moving) and operations of supervised consumption services must be based on evidence and best practices.

Limitations

The needle debris collected by CAHS using Survey123 for ArcGIS Desktop may not be conclusive about Calgary discarded needles, as it is possible that some discarded needles were not identified or were disposed of by a third party. Furthermore, some retrievals were in batches and could not be counted individually (for example, needles in a sealed sharps container). Due to the time shortage and inaccessibility of other spatial data, we only overlayed spatial feature data sets of overdose, needle dropboxes, shelter, water sources, and outreach education over the needle discard feature data set. We encourage future research to overlay other spatial data to get a complete picture of discarded needles and other correlates. Due to a backlog in provincial data we were not able to overlay provincial spatial data regarding calls for emergency medical services to reverse overdoses, which may have been beneficial to compare the location of discards with the location of calls for service.

Conclusion

This study aimed to identify the geospatial distribution of needles discarded in public areas in Calgary. Our study is the first to use ArcMap tools to identify hotspots with known confidence interval locations and proximity to dropbox and other social and recreational services. The spatial analysis shows spatial heterogeneity in the distribution of needle debris. We believe these findings are useful to develop further public health interventions. Analysis of discarded needles can help target the opioid overdose epidemic since there is a direct link between discards and active injection. Overdose deaths in neighbourhoods with several hotspots suggest that PWID faces barriers to access SCS. Thus, there is an opportunity to alter the delivery of these services to enhance access by the people who need them. Identifying discarded needle hotspot locations could also indicate potential sites to expand services. With the wide availability of GIS mapping tools, tracking needle debris and targeting hotspots can be a first step in creating safer communities for all.

Acknowledgements

The authors would like to acknowledge the Calgary Alpha House Society for permission to use the needle debris data.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Allen, D. W. 2016. *GIS Tutorial 2: Spatial Analysis Workbook*. Redlands, CA, USA: Esri Press.

Bearnot, B., J. F. Pearson, and J. A. Rodriguez. 2018. Using publicly available data to understand the opioid overdose epidemic: Geospatial distribution of discarded needles in Boston, Massachusetts. *American Journal of Public Health* 108(10): 1355–1357.

Bell, R. 2019. Cleanup time: Social disorder rampant around city's only safe consumption site. *The Calgary Sun*, 2019, 6-7.

Bluthenthal, R. N., R. Anderson, N. M. Flynn, and A. H. Kral. 2007. Higher syringe coverage is associated with lower odds of HIV risk and does not increase unsafe syringe disposal among syringe exchange program clients. *Drug and Alcohol Dependence* 89(2-3): 214–22. https://doi.org/10.1016/j.drugalcdep.2006.12.035.

Bluthenthal, R. N., G. Ridgeway, T. Schell, R. Anderson, N. Flynn, and A. H. Kral. 2007. Examination of the association between syringe exchange program (SEP) dispensation policy and SEP client-level syringe coverage among injection drug users. *Addiction* 102(4): 638–46. https://doi.org/10.1111/j.1360-0443.2006.01741.x.

Butsashvili, M., G. Kamkamidze, M. Kajaia, G. Kandelaki, and N. Zhorzholadze. 2011. Circumstances surrounding the community needle-stick injuries in Georgia. *Journal of Community Health* 36(6): 1050–1052. https://doi.org/10.1007/s10900-011-9408-0.

Cleland, C. M., S. Deren, C. M. Fuller, S. Blaney, J. M. McMahon, S. Tortu, D. C. Des Jarlais, and D. Vlahov. 2007. Syringe disposal among injection drug users in Harlem and the Bronx during the New York State expanded syringe access demonstration program. *Health Education & Behavior* 34(2): 390–403. http://www.jstor.org/stable/45056652.

Costa, M. D., C. Rapparini, C. A. S. Schmaltz, M. Tuyama, L. de Mello Lauria, V. Saraceni, and P. F. Barroso. 2017. Danger in the streets: Exposures to bloodborne pathogens after community sharp injuries in Rio de Janeiro, Brazil. *Brazilian Journal of Infectious Diseases* 21: 306–311.

Cromley, E. K., and S. L. McLafferty. 2011. *GIS and Public Health*. 2nd ed. New York, New York, NY: The Guilford Press.

Davidson, P. J., S. Scholar, and M. Howe. 2011. A GIS-based methodology for improving needle exchange service delivery. *International Journal of Drug Policy* 22(2): 140–144. https://doi.org/https://dx.doi.org/10.1016/j.drugpo.2010.10.003.

de Montigny, L., A. V. Moudon, B. C. Leigh, and S-Y. Kim. 2011. A spatial analysis of the physical and social environmental correlates of discarded needles. *Health & Place* 17(3): 757–766. https://doi.org/10.1016/j.healthplace.2011.01.013. http://www.sciencedirect.com/science/article/pii/S1353829211000219.

———. 2010. Assessing a drop box programme: A spatial analysis of discarded needles. *International Journal of Drug Policy* 21(3): 208–214. https://doi.org/10.1016/j.drugpo.2009.07.003. http://www.sciencedirect.com/science/article/pii/S0955395909001108.

Devaney, M., and L. Berends. 2008. Syringe disposal bins: The outcomes of a free trial for city traders in an inner-city municipality Australia. *Substance Use & Misuse* 43(1): 139-–53. https://doi.org/10.1080/10826080701212352.

Esri. 2020. ArcGIS Software. Author. www.esri.com.

Fozouni, L., S. Khan, and B. Bearnot. 2021. Spatiotemporal trends in discarded needle reports in San Francisco over a 10-year period, 2010-2019. *International Journal of Drug Policy* 87: 103018. https://doi.org/10.1016/j.drugpo.2020.103018. http://www.sciencedirect.com/science/article/pii/S095539592030356X.

Government of Alberta. 2020. *Alberta COVID-19 Opioid Response Surveillance Report: Q2 2020*. Edmonton, AB: Author.

Government of Canada. 2020. *Canadian Supervised Consumption Sites Statistics — 2017 to 2019*. Ottawa, ON, Canada: Author.

Herring, J. 2020. Opioid deaths more than double in Alberta during COVID-19 pandemic. *Calgary Herald*, 23 Sept. 2020 https://calgaryherald.com/news/local-news/opioid-deaths-more-than-double-in-alberta-during-covid-19-pandemic.

Hudes, S. 2019. Council earmarks $1 million for safety near drug site. *Calgary Sun,* 5 March 2019.

Hyshka, E., S. Strathdee, E. Wood, and T. Kerr. 2012. Needle exchange and the HIV epidemic in Vancouver: Lessons learned from 15 years of research. *International Journal of Drug Policy* 23(4): 261–70. https://doi.org/10.1016/j.drugpo.2012.03.006.

Kermode, M., A. Harris, and E. Gospodarevskaya. 2003. Introducing retractable needles into needle and syringe programmes: A review of the issues. *International Journal of Drug Policy* 14(3): 233–239. https://doi.org/10.1016/S0955-3959(03)00074-4. http://www.sciencedirect.com/science/article/pii/S0955395903000744.

Kordy, F., A. Petrich, S. E. Read, and A. Bitnun. 2017. Childhood exposures to discarded needles and other objects potentially contaminated with blood-borne pathogens in Toronto, Canada. *Paediatrics & Child Health* 22(7): 372–376. https://doi.org/10.1093/pch/pxx110.

KPMG, and NSW Health. 2010. *Further evaluation of the Medically Supervised Injecting Centre during its extended Trial period (2007-2011).* Final Report. NSW, Australia: Author.

Kral, A. H., R. Anderson, N. M. Flynn, and R. N. Bluthenthal. 2004. Injection risk behaviors among clients of syringe exchange programs with different syringe dispensation policies. *Journal of Acquired Immune Deficiency Syndromes* 37(2): 1307–12.

Le, P-P. 2019. Patient access to opioid substitution treatment pharmacy and medical service providers in South Australia: Geospatial mapping. *Australian Journal of Primary Health* 25(2): 125–130. https://doi.org/10.1071/PY18099.

Mannocci, A., G. De Carli, V. Di Bari, R. Saulle, B. Unim, N. Nicolotti, L. Carbonari, V. Puro, and G. La Torre. 2016. How much do needlestick injuries cost? A systematic review of the economic evaluations of needlestick and sharps injuries among healthcare personnel. *Infection Control and Hospital Epidemiology* 37(6): 635–646. https://doi.org/10.1017/ice.2016.48. https://pubmed.ncbi.nlm.nih.gov/27022671. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4890345/.

Marshall, B. D. L., M. S. Krieger, J. L. Yedinak, P. Ogera, P. Banerjee, N. E. Alexander-Scott, J. D. Rich, and T. C. Green. 2017. Epidemiology of fentanyl-involved drug overdose deaths: A geospatial retrospective study in Rhode Island, USA. *International Journal of Drug Policy* 46(Supplement C): 130–135. https://doi.org/10.1016/j.drugpo.2017.05.029. http://www.sciencedirect.com/science/article/pii/S0955395917301330.

Moore, D. L. 2018. Needle stick injuries in the community. *Paediatrics and Child Health* 23(8): 532–538. https://doi.org/10.1093/pch/pxy129.

Navarro, C., and L. Leonard. 2004. Prevalence and factors related to public injecting in Ottawa, Canada: Implications for the development of a trial safer injecting facility. *International Journal of Drug Policy* 15(4): 275–284. https://doi.org/10.1016/j.drugpo.2004.03.003. http://www.sciencedirect.com/science/article/pii/S0955395904000283.

O'Keefe, D., A. McCormack, S. Cogger, C. Aitken, L. Burns, R. Bruno, J. Stafford, K. Butler, C. Breen, and P.Dietze. 2017. How does the use of multiple needles/syringes per injecting episode impact on the measurement of individual level needle and syringe program coverage? *International Journal of Drug Policy* 46:99–106. https://doi.org/https://doi.org/10.1016/j.drugpo.2017.05.055. http://www.sciencedirect.com/science/article/pii/S0955395917301597.

O'Leary, F. M., and T. C. Green. 2003. Community acquired needlestick injuries in non-health care workers presenting to an urban emergency department. *Emergency Medicine Australasia* 15(5-6): 434–40. https://doi.org/10.1046/j.1442-2026.2003.00498.x.

Oyana, T. J., and F. M. Margai. 2016. *Spatial Analysis: Statistics, Visualization, and Computational Methods*. New York, USA: Taylor & Francis.

Papenburg, J., D. Blais, D. Moore, M. Al-Hosni, C. Laferriere, B. Tapiero, and C. Quach. 2008. Pediatric injuries from needles discarded in the community: epidemiology and risk of seroconversion. *Pediatrics* 122(2): e487–92. https://doi.org/https://dx.doi.org/10.1542/peds.2008-0290.

Perry, J., J. Jagger, G. Parker, E. K. Phillips, and A. Gomaa. 2012. Disposal of sharps medical waste in the United States: Impact of recommendations and regulations, 1987-2007. *American Journal of Infection Control* 40(4): 354–8. https://doi.org/10.1016/j.ajic.2011.04.328.

Pimpler, E. 2017. *Spatial Analytics with ArcGIS: Build powerful insights with Spatial Analytics*. Birmingham, UK: Packt.

Potkins, M. 2019. 'We're basically at war': Sheldon Chumir's zone of overdoses, needles and fear. *Calgary Herald*, 14 February, 2019.

Res, S., and F. J. Bowden. 2011. Acute hepatitis B infection following a community-acquired needlestick injury. *The Journal of Infection* 62(6): 487–9. https://doi.org/10.1016/j.jinf.2011.04.002.

Sakaki, G. 2017. Community isn't sold on safe-consumption site. *Nanaimo Bulletin*, 30 May 2017.

Schneider, R., L. Carlson, and S. Rosenthal. 2020. Mapping the opioid epidemic in Rhode Island: Where are we missisng resources? *Rhode Island Medical Journal* 103(1): 46–50.

Shah, M., R. Wong, L. Ball, K. Puka, C. Tan, E. Shojaei, S. Koivu, and M. Silverman. 2020. Risk factors of infective endocarditis in persons who inject drugs. *Harm Reduction Journal* 17(1): 35. https://doi.org/10.1186/s12954-020-00378-z. https://doi.org/10.1186/s12954-020-00378-z.

Sherman, S. G., S. A. Patel, D. V. Ramachandran, N. Galai, P. Chaulk, C. Serio-Chapman, and R. M. Gindi. 2015. Consequences of a restrictive syringe exchange policy on utilisation patterns of a syringe exchange program in

Baltimore, Maryland: Implications for HIV risk. *Drug & Alcohol Review* 34(6): 637–44. https://doi.org/https://dx.doi.org/10.1111/dar.12276.
Smith, A. 2020. Alberta's opioid deaths soar during COVID-19 pandemic in deadliest year ever. *Calgary Herald*, 19 December 2020. https://calgaryherald.com/news/politics/opioid-overdose-deaths-soar-in-alberta-marking-the-deadliest-year-ever-recorded.
Statistics Canada. 2016. *Census Profile, 2016 Census*. Author. https://www.statcan.gc.ca/eng.
Stoltz, J-A., E. Wood, W. Small, K. Li, M. Tyndall, J. Montaner, and T. Kerr. 2007. Changes in injecting practices associated with the use of a medically supervised safer injection facility. *Journal of Public Health* 29(1): 35–9. https://doi.org/https://dx.doi.org/10.1093/pubmed/fdl090.
Tookes, H. E., A. H. Kral, L. D. Wenger, G. A. Cardenas, A. N. Martinez, R. L. Sherman, M. Pereyra, D. W. Forrest, M. LaLota, and L. R. Metsch. 2012. A comparison of syringe disposal practices among injection drug users in a city with versus a city without needle and syringe programs. *Drug and Alcohol Dependence* 123(1-3): 255–9. https://doi.org/10.1016/j.drugalcdep.2011.12.001.
Vasylyeva, T. I., P. Smyrnov, S. Strathdee, and S. R. Friedman. 2020. Challenges posed by COVID-19 to people who inject drugs and lessons from other outbreaks. *Journal of the International AIDS Society* 23(7).
Wood, E., T. Kerr, W. Small, K. Li, D. C. Marsh, J. S. Montaner, and M. W. Tyndall. 2004. Changes in public order after the opening of a medically supervised safer injecting facility for illicit injection drug users. *Canadian Medical Association Journal* 171(7): 731–4. https://dx.doi.org/10.1503/cmaj.1040774.
Zaami, S., E. Marinelli, and M. Rosaria Varì. 2020. New trends of substance abuse during COVID-19 Pandemic: An international perspective. *Frontiers in Psychiatry* 11: 700. https://doi.org/10.3389/fpsyt.2020.00700.