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ORIGINAL ARTICLE

# Spatiotemporal Trends in Discarded Needle Reports Near Schools in Boston, Massachusetts, between 2016-2019

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**ABSTRACT**

*Background:* Childhood exposures to discarded needles pose a direct risk for infection with blood-borne pathogens and psychological trauma for caregivers and children. Little is known about environmental predictors of discarded needles relative to areas where children are frequent, such as schools.
*Objective:* We investigated spatiotemporal trends in discarded needle reports and the density near schools in Boston, Massachusetts, between 2016 and 2019.
*Methods:* We used the kernel density estimation (KDE) and a relative risk function (RRF) to explore their spatial distribution and temporal changes of discarded needles reported through the 311 service request system in Boston. The density of needle pick-up requests around schools was investigated by using Thiessen polygons.
*Results:* Between January 2016 and December 2019, 18,272 discarded needle reports were made. Publicly reported discarded needles in Boston sharply increased over the 4 years and the highest density of needles was found in 2 central neighborhoods. The density of reports of discarded needles near schools increased among the majority of schools. About 30% of schools demonstrated an increase of 100% or more in reports of discarded needles.
*Conclusion:* This analysis provides insight into potential risk of exposure to needle stick injuries for children based on utilizing publicly available crowd-sourced data. Monitoring the density of discarded needles near schools may be a novel approach to improve public health efforts to distribute safe needle disposal locations and reduce injection drug use in public.

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## Introduction

In the United States and many countries around the globe, opioid use disorder is an escalating public health crisis(1–3). In 2018, there were 67,367 drug overdose deaths in the United States(4) and between 2010 and 2015, opioid overdose deaths increased by 156%(1). Massachusetts ranks in the top five states for opioid-involved overdose deaths with 29.3 deaths per 100,000 persons(5).

Community-associated exposure to discarded needles causes anxiety for caregivers and children(6–8) and can reduce quality of life for residents(9). Needlestick injuries have been associated with psychiatric disorders similar to other trauma-related conditions(10). Although the actual risk for infection from an injury related to a non-medical needlestick injury is extremely low(11), community-based needlestick incidents require medical management and elevate public concern(12).

Childhood exposures to discarded needles pose a direct risk for infection with blood-borne pathogens and psychological trauma for caregivers and children, and may indirectly impact quality of life and use of public space through associated social distress and public anxiety(13). Environmental correlates of discarded needles are emerging and include the accessibility and exposure of acquisition and potential public injection sites(9). However, little is known about environmental predictors of discarded needles relative to areas where children are frequent, such as schools.

Municipal service request systems, such as '311,' which allow residents to report nonurgent safety concerns, have high temporal and spatial resolution. Publicly available 311 databases are being used to understand the spatiotemporal distribution of challenging neighborhood conditions within a city(14,15). 311 requests have been associated with opioid overdose events(16). Prior analyses of 311 data have identified increasing requests for needle pick-up over time and established associations between needle report density and neighborhood indicators of poverty and homeless shelters(17,18). Prior analyses of Boston 311 data have documented increasing rates of discarded needles, as

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well as hot spot clusters in the South End and Roxbury neighborhoods(18). To our knowledge, spatiotemporal patterns of discarded needles relative to schools have not been explored.

We sought to investigate spatiotemporal trends in discarded needles across the city of Boston and trends in the density of discarded needles near schools. We investigated the spatial and temporal association between reports of discarded needles and schools in Boston, MA, by exploring changes in density of discarded needle reports. Specifically, we aimed to identify schools that experienced a disproportionate degree of risk for exposure to discarded needles. This study adds to the existing literature by applying a novel approach to utilizing publicly available databases of crowdsourced, municipal requests to explore geospatial trends in density of discarded needles near schools.

## Methods

As this study uses publicly available secondary data of city service request, ethics approval and consent to participate are not required. The study analyzes needle pick-up requests in the city of Boston between January 2016 and December 2019, specifically with a kernel density estimation (KDE) and a relative risk function (RRF) to explore their spatial distribution and temporal changes, respectively. Then, needle pick-up requests are allocated to their corresponding closest schools, and their spatial densities and temporal changes are examined relative to the closest schools. The dataset for needle pick-up requests was obtained from the 311 service request database publicly available via the Analyze Boston website(19), which was also the source of the school data. Needle pick-up requests are submitted by calling Boston 311, website, or mobile app. The initial dataset contained 18,272 incidents, but 695 invalid cases were excluded from the analysis, and 3,067 incidents were also excluded due to incorrect addresses. The school dataset includes 123 public and 82 nonpublic schools from pre-kindergarten to high schools. Schools with different names sharing the same address are considered as the same school.

First, the spatial densities of needle pick-up requests on a yearly basis from 2016 to 2019 are estimated using KDE, which is a widely used method to summarize and visualize spatial patterns of incidents and event(20). The density value at a location $(x, y)$ can be estimated with

$$\hat{f}(x,y) = \frac{1}{nh_1^2}\sum_{i=1}^{n} k_1\left(\frac{x-x_i}{h_1}, \frac{y-y_i}{h_1}\right), \quad (1)$$

where $k_1(\ldots)$ is a kernel density function, $h_1$ is the bandwidth, and $n$ is the number of incidents. The selection of a bandwidth size and a kernel function has a critical impact on KDE results. The size of a bandwidth primarily determines the degree of smoothness on a density surface. Specifically, a large bandwidth generally produces a smoother surface than a small bandwidth. This analysis estimates an optimal bandwidth size for the needle pick-up requests based on Scott's plug-in estimation(21). The plug-in method estimates optimal bandwidths for a multivariate productive kernel by minimizing the asymptotic mean integrated square errors from orthogonal multivariate normal distributions. The plug-in method can obtain optimal bandwidths ($\hat{h}_i$) in the dimension of $i$ as

$$\hat{h}_i = n^{-1/(3+d)} \cdot \hat{\sigma}_i, \quad (2)$$

where $\hat{\sigma}_i$ is the standard deviation and $d$ is the number of dimensions. When the $d$ value is 1, the plug-in method can be considered as simplified Silverman's rule of thumb(20). For a spatial context, the $d$ value is 2. The plug-in method generally generates a smooth KDE surface by estimating a relatively large bandwidth. This analysis uses a Gaussian density function to emphasize a more general trend in the study area because the density function produces smoother surfaces than other functions, for example, quadratic and negative exponential functions(22). The underestimation of KDE at the boundary of the study area is adjusted using Berman and Diggle's method(23).

Second, the annual changes of needle pick-up requests are explored using RRFs. Initially, RRF was developed to find significant spatial clusters by comparing the densities of cases and controls(24), but it can also effectively capture the temporal increase and decrease in spatial densities(25). RRF used in this study can be represented by the ratio of KDEs in two different time periods,

$$\hat{r}(x,y) = \ln\frac{\hat{f}_{t2}(x,y)}{\hat{f}_{t1}(x,y)}. \quad (3)$$

The logarithm of the ratio is used to reduce the effects of outliers(26). Significant clusters of increasing and decreasing densities are verified with a permutation test, which shuffles incidents between two time periods (27). This study obtains the significant clusters at the 5% significance level in both sides from 999 repetitions of permutation steps. The bandwidth sizes and kernel density functions in RRF are determined using the same methods in the KDE process, and additionally the same edge correction method is utilized.

Finally, the relationship between schools and needle pick-up requests is investigated by allocating the requests to their closest schools using Thiessen polygons(28). All needle pick-up requests within a Thiessen polygon of a school are closer to that school than all other schools(29), and thus, needle pick-up requests could be assigned to only one school based on their proximities. The numbers of needle pick-up requests and density (request counts within a Thiessen polygon/square km) at each school on a yearly basis from 2016 to 2019 are collected to estimate vulnerable schools. The temporal changes of needle pick-up requests and density are also calculated to examine the changes in their surrounding environments.

## Results

### *Geospatial distribution of needle pick-up requests*

Between January 2016 and December 2019, the number of needle pick-up requests in the city of Boston has increased by more than 400%. More than 70% of the requests are made by Citizens Connect App (BOS:311), 28% reported by phone calls, and less than 1% through social media. In all years, the highest rates of requests are observed in August, September, and October, except in 2018 when May, July, and August showed the highest rates.

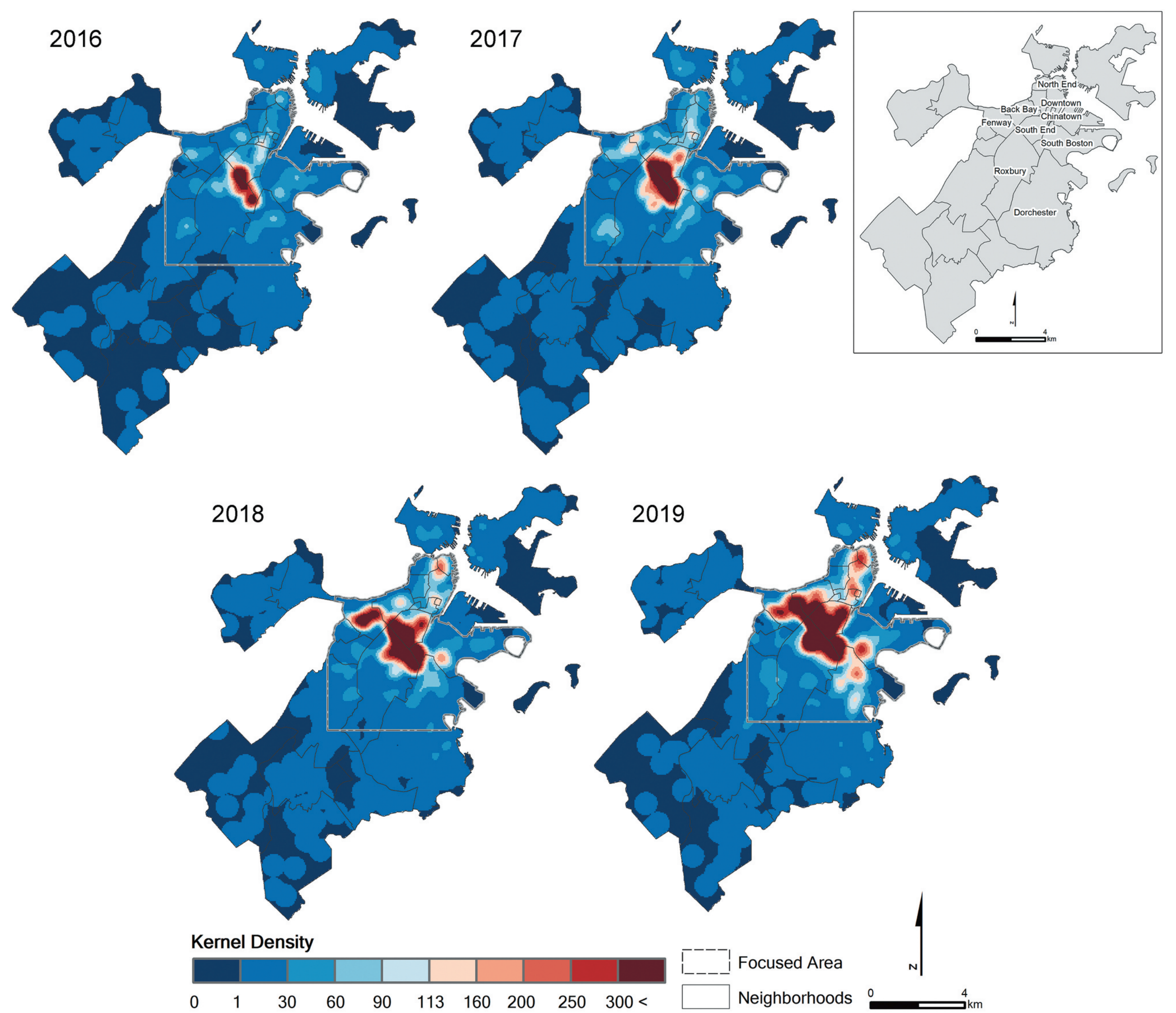


**Figure 1.** Density estimation for needle pick-up requests in the city of Boston (2016–2019): both the number and geospatial distribution of areas with concentrated reports of improperly discarded needles increased citywide between 2016 and 2019.

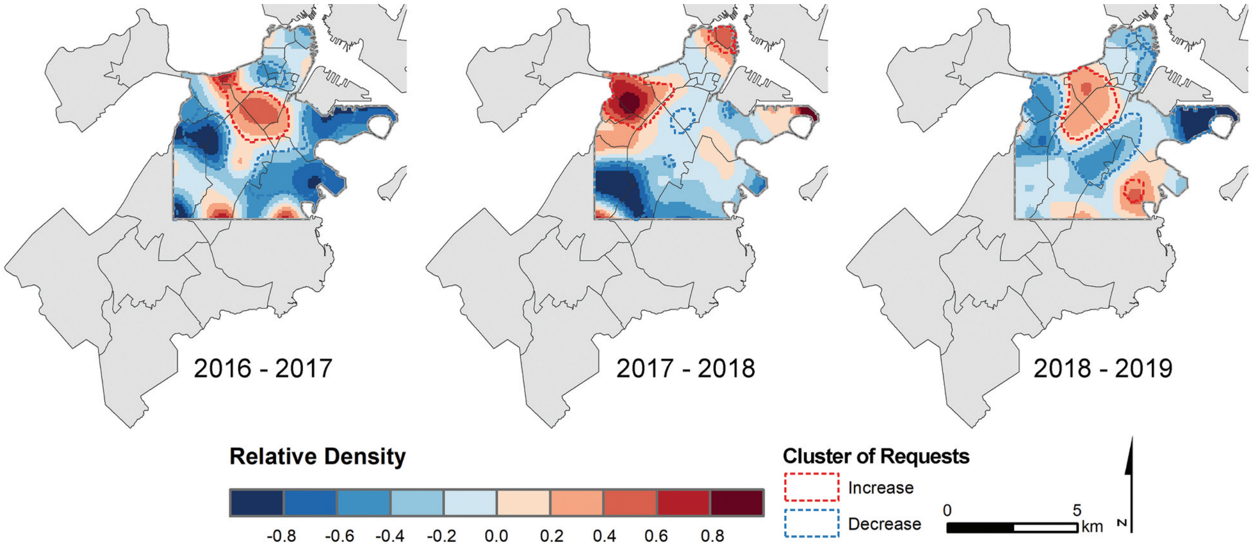


**Figure 2.** Relative density of annual needle pick-up requests in the previous year in a focused area in the city of Boston: the dotted areas denote statistically significant changes in densities with a 99% confidence level.

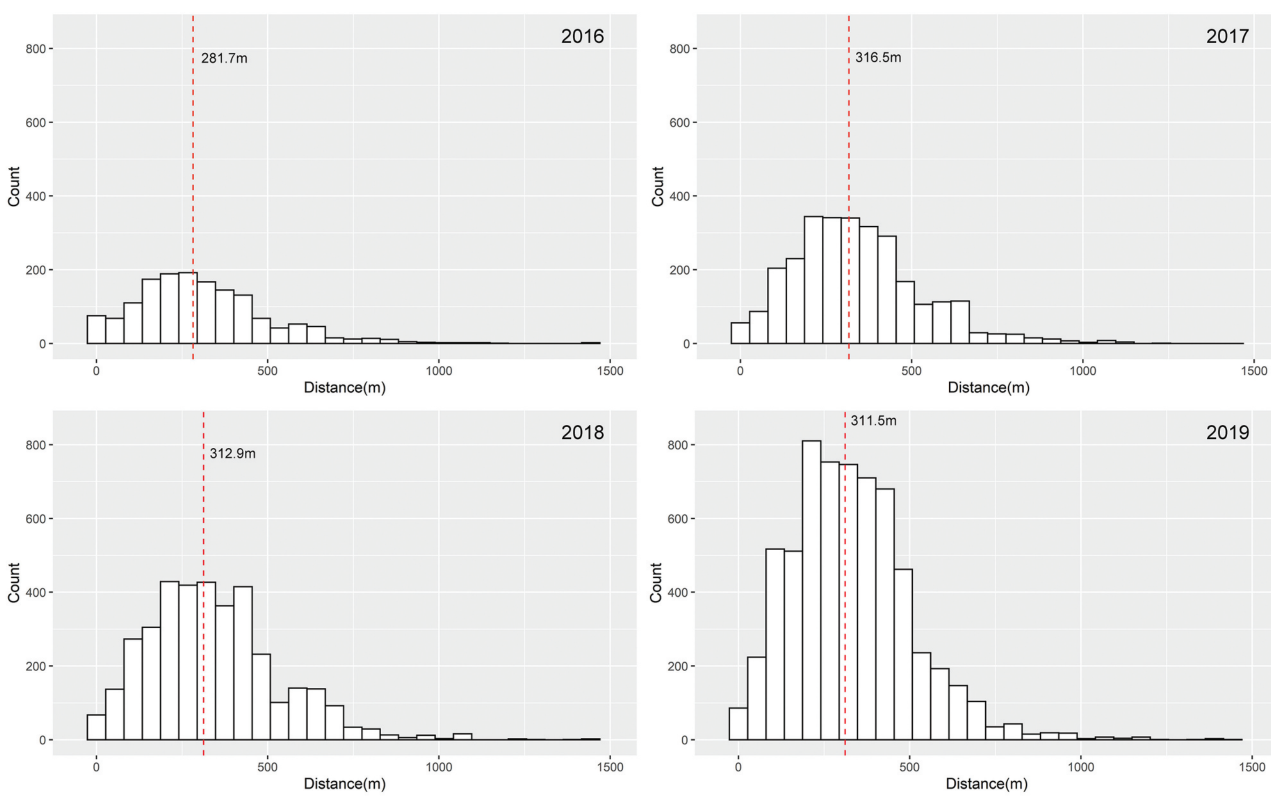


**Figure 3.** The distances from needle pick-up requests to their corresponding nearest schools (2016–2019): the median distance of all years = 310.5 meters.

The density surface of needle pick-up requests, generated by KDE with a bandwidth of 497.2 meters based on the 2016 data when the reporting number was the lowest, presents the spatial pattern of reports of discarded needles from 2016 to 2019 (Figure 1). The cluster is considered as the density higher than

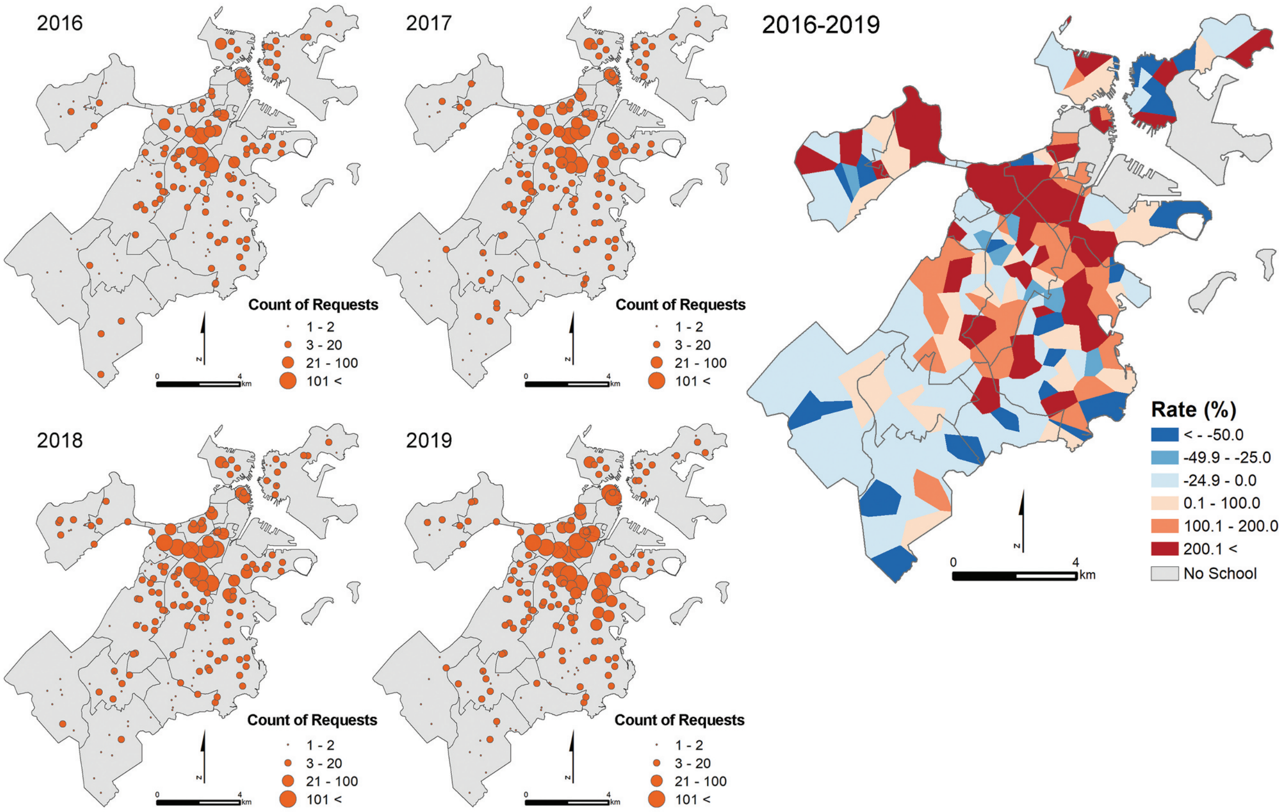


Figure 4. Count of needle pick-up requests near schools each year along with percentage change from 2016 to 2019 in the city of Boston: (on the left) circles indicating the location of schools in each year; (on the right) percentage change over the 3-year period indicated by Thiessen polygons.

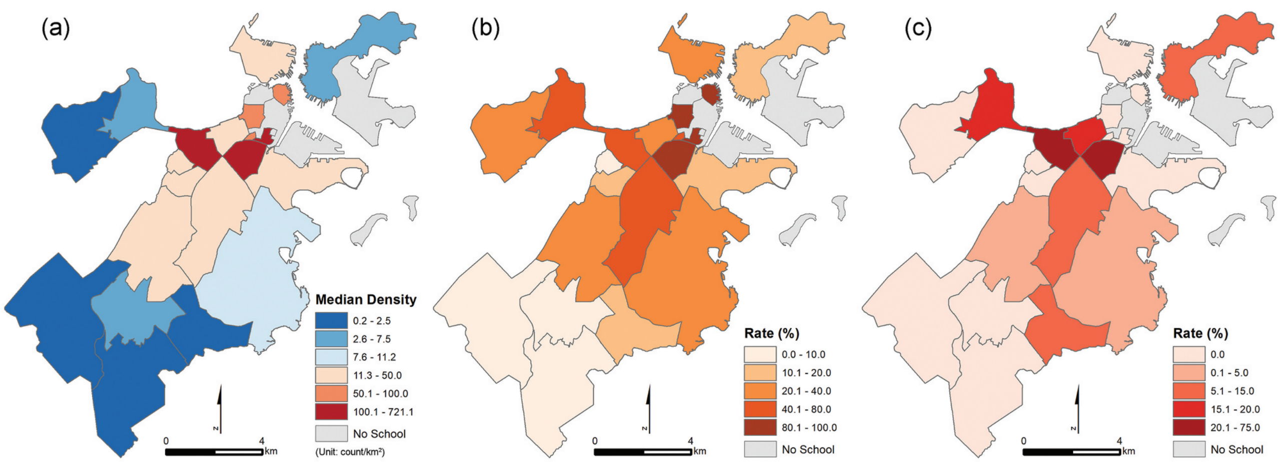


Figure 5. Density of needle pick-up request near schools and percentage of schools with more than 100% and 500% increase in the density at the neighborhood level in the city of Boston: (a) median density of needle pick-up request near schools in 2019 (count/km$^2$); (b) and (c) percentage of schools with more than 100% and 500% increase in the density, respectively, between 2016 and 2019.

the average density of the needle pick-up requests in the city of Boston (113 reports per square km). In 2016, a cluster is mainly observed in South End and adjacent Roxbury neighborhoods. These sites are near the corridor around Massachusetts Avenue and Melnea Cass Boulevard, known as 'the Methadone Mile' due to an open-air drug market and concentration of social services for substance misuse and homelessness, also known as the Mass and Cass corridor(30). As has been documented in other studies, our findings indicate that needle disposal in public places is mainly associated with spaces where drugs are likely to be obtained and used(9). We also observed a new cluster in the Fenway area in 2018. By 2019, clusters are observed in South End, Fenway, Back Bay, Roxbury, Chinatown, Downtown, North End, and northern part of Dorchester. This indicates that while the number of reports of discarded needles substantially increased citywide between 2016 and 2019, the geospatial distribution of areas with concentrated reports also enlarged.

Relative density, each year's density of needle pick-up requests with respect to the density from the previous year, is shown in Figure 2. The focused area is limited to where kernel density is higher than 30 as the relative density values become sensitive when the reference density values are too low. The dotted areas with 99% confidence interval in the series of relative density maps indicate that locations of clusters in discarded needle reports have changed over time. While increased clusters are observed in South End and Back Bay around the Mass and Cass corridor in 2017 compared to 2016, increased clusters show mainly in the Fenway and North End neighborhoods in 2018 compared to 2017, indicating that locations with an increased cluster of cases are not limited to the neighborhoods near the Mass and Cass corridor. In 2019, increased clusters appear more in South End, Roxbury, Back Bay, and Dorchester neighborhoods compared to 2018; however, most of the change from 2018 to 2019 was negative.

### *Density of needle pick-up requests near schools*

As the clusters of needle pick-up requests show growing trends in the city of Boston, we examine the needle pick-up requests in proximity to schools to assess children's risk of exposure to needle stick injuries in a public place around schools. The distances from needle pick-up requests to their corresponding nearest schools are positively skewed in all years investigated (2016–2019). The median distance across all years investigated is 310.5 meters (Figure 3).

Figure 4 shows the summaries of pick-up requests to their nearest schools based on Thiessen polygons. It indicates that the Boston neighborhoods with schools (no school location in Downtown, South Boston Waterfront, and West End, including the airport area) are not insusceptible to exposure to discarded needles and have become more susceptible over time. Compared to 2016, the overall number of schools with more than 100 needle pick-up requests reported has increased in 2019. Also, a majority of schools demonstrate more than 100% increase in the number of reports of discarded needles in their proximity over three years. Even schools with a relatively small number of reports in 2016 have seen a substantial increase in 2019. Schools already in the areas with concentrated needle pick-up requests in 2016 are continuously experiencing a stark increase in the number of reports.

Figure 5(a) shows median density of needle pick-up requests near schools in 2019 while taking into account the different sizes of areas around schools as illustrated by Thiessen polygons. Chinatown, Fenway, and South End near the Mass and Cass corridor demonstrate median densities higher than 116 discarded needle reports per square km, which is the 90th percentile. Figure 5(b) presents the percentage of schools with more than 100% increase in the density of needle pick-up requests near schools between 2016 and 2019 at the neighborhood level, experienced by 33% of schools in Boston. Also, Figure 5(c) shows that nine neighborhoods have schools (8% of all Boston schools) with more than 500% increase in the density during that time. A number of schools in Fenway, Roxbury, and South End demonstrate particularly high density of reports on discarded needles in proximity (max = 297.7, 1019.2, and 3,617.2, respectively; Table A1).

## Discussion

We identified a dramatic increase in the number of needle pick-up requests across the city of Boston: more than 400% between 2016 and 2019. Areas with concentrated requests in the South End and its nearby Roxbury neighborhoods continued to enlarge over time and reach other neighborhoods. Overall needle pick-up requests in proximity to schools have increased over time, yet, the considerably growing reports of discarded needles disproportionately affect some of the schools located in South End and Roxbury areas (e.g. Hurley K-8, Blackstone Elementary, City on a Hill Charter Public School Dudley Square, Orchard Gardens K-8, and the Carter School). This suggests that while childhood risk for exposure to discarded needles in public areas near school increased overall, some schools and therefore children experience a disparate risk.

Our findings lend greater evidence to past calls for 'safer environment interventions' to reduce discarded needle-related harm. While there are 46 safe needle disposal locations, including 4 van needle drop-off sites and 26 Boston public library locations(31–33), more sites, perhaps near schools, may be needed to effectively respond to rapidly increasing numbers of discarded needles in public places that could jeopardize children's safety. The Boston City Council recently passed a law mandating large pharmacies that sell the syringes to provide needle returning kiosks or programs(34). As the policy is expected to expand the safe needle disposal sites to 100 locations across the city, its impact could be evaluated by future research.

There are some limitations to this study. As the data only include needle pick-up requests reported to the Boston 311 Service Requests, they may not represent all needles or syringes discarded in public places. While 311 data are regarded as a measure of aggregate demand for public services, the micro-level determinants of 311 data are not well-understood. It is possible that 311 data are associated with unobserved differences in neighborhoods and could be impacted by frequent users of the system. Specifically, the number of unique reporters relative to total reported requests is not known. Given the absence of information about the reporter, propensity to contact 311 is unknown (14). Reporting bias is a significant limitation of 311 service data, given the knowledge of the 311 service and use may vary geographically and over time. Also, more than 70% of the requests come from a mobile app, and reports by younger residents and those who have access to smartphones may have been overrepresented. As accurate response time is not available, risk of children's exposure to discarded needles is not assessed at a more granular level. Additionally, since schools are represented as point locations, school boundaries that are likely to be larger than point locations are not considered in the analysis. Finally, since this study does not consider other public places such as parks, relationship between school locations and other public places is not examined.

Despite these limitations, this study presents a new perspective to explore spatial patterns of needle pick-up requests by focusing on school locations to assess children's potential risk of exposure to needle stick injuries. This study indicates that about 30% of schools have faced more than 100% increase in the number of needle pick-up requests nearby between 2016 and 2019. Moreover, schools in the neighborhoods that are close to the Mass and Cass corridor are experiencing disproportionate risk of children's exposure to discarded needles.

While the city of Boston is implementing new laws to expand safe needle disposal sites, our findings may be useful to inform the design of other environmental measures, such as street sweeping services, to effectively respond to needles or syringes discarded in public places particularly around schools to improve children's safety. As proposed by Rhodes et al (35), this analysis lends support to calls for a greater focus on 'safer environment interventions' to reduce injection drug use in public areas. Additional public health interventions for schools and community settings are needed to reduce risk of childhood needlestick exposure. Publicly available, 311 service request data have high temporal and spatial precision and this information that can be incorporated in geographic information system (GIS) maps and offers the opportunity to respond to community dynamics and modify interventions in real time(36).

## Conclusion

This study is the first published report of spatiotemporal trends in the density of discarded needles with respect to schools. Our findings indicate an increasing density of reports of discarded needles near the majority of Boston schools. Utilizing 311 service request data to monitor changes in the density of discarded needles near schools may be a novel public health approach to reduce risk for childhood exposure to needlesticks. These data may help better target resources to discourage needle discards, improve safe disposal, or reduce injection drug use in public, high contact areas for children, such as schools.

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## Appendix

**Table A1.** Density of needle pick-up requests near schools (2019) and its percent increase (2016–2019) by neighborhood in the city of Boston.

| Neighborhood | Number of school locations | Number of schools with more than 3rd quartile of needle pick-up requests density (30 counts/km$^2$) in 2019* | Density of needle pick-up requests near schools in 2019 (counts/km$^2$)* | | | Number of schools with more than **100%** increase in the density of needle pick-up requests near schools between 2016 and 2019 | Number of schools with more than **500%** increase in the density of needle pick-up requests near schools between 2016 and 2019 |
|---|---|---|---|---|---|---|---|
| | | | Median | SD | Range | | |
| City of Boston | 205 | 53 | 11.2 | 136 | 0–3617.2 | 68 | 16 |
| Allston | 6 | 0 | 4.9 | 8.9 | 0–21.1 | 3 | 1 |
| Back Bay | 5 | 3 | 46.7 | 98.4 | 9.2–221.5 | 2 | 1 |
| Bay Village | 2 | 2 | 99.8 | 50.1 | 64.3–135.2 | 1 | 0 |
| Beacon Hill | 2 | 2 | 60.3 | 36.7 | 34.4–86.3 | 2 | 0 |
| Brighton | 9 | 0 | 1.3 | 3.7 | 0–11.1 | 2 | 0 |
| Charlestown | 5 | 0 | 18 | 2.9 | 15.9–23.8 | 2 | 0 |
| Chinatown | 1 | 1 | 127.1 | NA | 127.1–127.1 | 1 | 0 |
| Dorchester | 44 | 9 | 9.9 | 45.1 | 0–218.1 | 17 | 2 |
| East Boston | 15 | 2 | 5.8 | 13.7 | 0–49.8 | 3 | 1 |
| Fenway | 5 | 4 | 147.4 | 125.7 | 0–297.7 | 4 | 3 |
| Hyde Park | 14 | 0 | 2.4 | 2.6 | 0–7.1 | 1 | 0 |
| Jamaica Plain | 20 | 4 | 23.5 | 17.3 | 0–67.9 | 8 | 1 |
| Longwood | 2 | 0 | 12.8 | 18.2 | 0–25.7 | 0 | 0 |
| Mattapan | 7 | 0 | 1.2 | 4.1 | 0–11.6 | 1 | 1 |
| Mission Hill | 6 | 2 | 20.1 | 17.1 | 7.2–51.5 | 1 | 0 |
| North End | 3 | 3 | 89.4 | 66 | 72.6–194.3 | 3 | 0 |
| Roslindale | 10 | 0 | 3.8 | 3.5 | 0–12.4 | 0 | 0 |
| Roxbury | 24 | 11 | 26.3 | 268.8 | 0–1,019.2 | 11 | 3 |
| South Boston | 11 | 6 | 39.3 | 55 | 1.6–152.1 | 2 | 0 |
| South End | 4 | 4 | 721.1 | 1,569 | 245.6–3,617.2 | 4 | 3 |
| West Roxbury | 10 | 0 | 0.2 | 0.8 | 0–2.5 | 0 | 0 |

*The areas of Thiessen polygons around schools range between 0.07 and 3.06 km$^2$