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ESTIMATING AND MAPPING CIGARETTE BUTT LITTERING IN URBAN ENVIRONMENTS: A GIS APPROACH

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Abstract

Background: Cigarette butts are some of the most common form of litter in the World, causing severe environmental damage. Analysing spatial distribution of cigarette butts in the urban environment may lead to useful insights for further interventions to reduce this form of litter. In this study, we present a GIS-based methodology to estimate the density of cigarette butts across a large urban area.

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Contributors: RV, XS, and FE conceived the original idea. RV geocoded and prepared the spatial databases. RV conducted all the fieldwork to collect data on cigarette butt litter in Madrid, with the advice of XS. RV performed GIS and statistical analysis, supervised by FE and XS. RV, XS, JP, and FE designed the validation analyses. All authors contributed substantially to the interpretation of the data and manuscript review and approved its final version.

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Methods: We collected information about discarded cigarette butts in outdoor public spaces by systematic social observation in a diverse sample of areas in Madrid, Spain. We used these data to estimate the density of cigarette butts in public spaces around the entire city by performing GIS analyses based on Kernel Density Estimations. Last, we validated these measures using on-field observations in a set of locations across the city.

Results: Hospitality venues and public transportation stops were the places with the highest concentrations of cigarette butts, followed by the entrances to educational venues and playgrounds. Central districts showed the highest amount of cigarette butts in contrast to peripheral ones. We found that our measure had good validity, with a correlation coefficient of 0.784.

Discussion: This is the first study estimating and mapping cigarette butt litter in a large urban area. We identified a set of outdoor public places with high concentrations of cigarette butts and found geographical unevenness in the distribution of this pervasive form of litter across the study area. Our findings demonstrate the ubiquitous nature of cigarette butts in the urban environment and the need for interventions to reduce its impact on both people's health and the environment.

Keywords

cigarette butts; GIS; Kernel Density Estimation; cigarette butt density

1. INTRODUCTION

The tobacco epidemic is responsible for several of the leading causes of mortality and morbidity including cancer, pulmonary illness, heart attacks, strokes or diabetes among others.(1) Beyond the health implications of smoking, tobacco also involves severe environmental threats through all stages of business cycle including production, distribution and disposal. Tobacco harvesting leads to deforestation and to the use of harmful pesticides to the environment; and the manufacturing and distribution of tobacco products increases green-house gases emissions.(2,3) In addition, once the cigarettes are consumed, they remain in the environment as litter. Cigarette butts contain carcinogenic and toxic substances which can pollute the soil, the water and also damage the biota.(4–6) These environmental harms may last for up to 2 years as the cigarette butts decompose.(7) It is estimated that 6 trillion cigarettes are smoked worldwide every year, and 4.5 trillion of them are discarded in the environment, comprising a yearly waste of 280 billion of centilitres in the World,(4,8,9) and representing approximately 25–50% of the litter collected from roads and streets.(10)

To address this situation, local jurisdictions have assumed high economic costs by cleaning streets, conducting educational campaigns and installing bins or ashtrays in public spaces.(4) In 2011, Schneider and his colleagues estimated that in the city of San Francisco, CA, USA the cost of cleaning up the streets from cigarette butts was \$6 million per year.(11) Further, discarded cigarette butts in public spaces have a detrimental impact on the landscape, worsening the quality of life of the population.(4) Finally, previous research argued that cigarette butts visibility on the environment may contribute to the normalization of smoking. (12,13)

Therefore, there is a great need to study the spatial extent of discarded cigarette butts and their distribution throughout cities, identifying those public places where this waste is concentrated. To date, the existing studies interested in capturing discarded cigarette butts at outdoor public spaces have conducted on-field measures based on systematic social observation;(5,14) or addressed face-to-face interviews(15) and surveys(16) to gather information about the population perspectives related to this issue. Moreover, these studies focused their results on the identification of types of places that may constitute hotspots for cigarette butt litter in outdoor environments (i.e. beaches,(17) parks,(18) public transportation stops(14) or hospitality venues,(19)). However, this earlier work limited their results to these places and overlooked the extent of the exposure in the across wider geographical areas, such as a city. To our knowledge, there is only one report using a methodology based on Geographic Information Systems (GIS) to address this research gap. (20)

GIS provides a set of spatial tools and metrics that enable the study of the distribution of any given issue or event around space. In the current study, we build on previous work in these areas to develop an alternative methodology based on systematic social observation and GIS for estimating the density and then use this information to calculate city-wide estimates of discarded cigarette butts. We further evaluated the validity of our estimations through on-field exposure measurements.

2. METHODS

2.1. Study area and project design

We undertook our study in the city of Madrid, Spain, which has a registered population of 3.2 million inhabitants (Spanish Statistical Office, 2018, <http://www.ine.es/>). According to official data from the City Council, cigarette butt litter constitutes a serious problem of pollution in Madrid since every day more than 500,000 cigarette butts are dropped in the streets.(21) This figure is considerably greater than in other major cities around the World, such as London, where a mean of 16,500 cigarette butts are discarded per day,(22) with a much larger population (8.9 million inhabitants in 2019, Office for National Statistics, UK, <https://www.ons.gov.uk/>).

Figure 1 illustrates the adopted GIS based methodology. First, we collected data about the presence of discarded cigarette butts at outdoor public spaces through systematic social observation around a sample of census tracts within the city ($n=42$, $\approx 2\%$ of total census tracts). We designed a two-step procedure to sample these census tracts which ensured the breadth of the city's socio-economic conditions were represented. In the first step, we chose two neighbourhoods for each district within Madrid ($n=21$, 42 neighbourhoods in total) based on socio-economic indicators (precarious work, educational level, occupation and foreign-born population). Then, we sorted all census tracts within each neighbourhood by population density, business density, percentage of foreign-born, percentage of population older than 65 years old, and educational level. This sampling procedure has been used in previous studies.(23,24) The spatial distribution of these census tracts is shown in the supplementary material (figure S1). Second, we identified a list of the types of places where we observed a high concentration of discarded cigarette butts; we used these data to estimate

the density of cigarette butts and their distribution across the whole city applying GIS tools. Last, we analysed the validity of our results by comparing on-field and estimated measures in a set of 40 random point-locations in the whole city of Madrid.

2.2. Data collection and databases

2.2.1. Measuring cigarette butts in the urban environment—Using systematic social observation, we collected data on all discarded cigarette butts within the selected 42 census tracts (stage 1 in figure 1). The fieldwork was performed by a single and trained data collector from May to September 2016, from Monday to Thursday and between 5 and 9 pm. These times were chosen because previous studies estimated that smoking visibility is highest in the evenings and during the spring and summer months.(19,25) We used an existing audit questionnaire tool(23,26,27) which allowed us to record information about the presence of cigarette butts (yes/no), date, address, time of registry and the type of public space where we found cigarette butts. We integrated the audit questionnaire tool in a smartphone using Open Data Kit (ODK) software (<https://opendatakit.org/use/collect/>). This allowed us to geocode the data and capture pictures.

2.2.2. Other contextual data—Geographic contextual data were collected for analyses and cartographic outputs. We obtained data about administrative boundaries (city, districts, neighbourhoods and census tract borders). We also gathered the public land use areas (suitable for pedestrians) and the location (UTM coordinates and address) of all public spaces and facilities around the city of Madrid, whose data were available. Specifically, we included hospitality venues (bars, restaurants, cafeterias and pubs), public transportation stops (considering bus, metro and train), healthcare and educational centres, supermarkets and food stores, playgrounds and other public buildings (such as post offices, government buildings, retail shops or other service premises). In addition, we procured information about the location of benches as another functional element of the urban assets which characterize public spaces. We performed the data extraction from the retail and business census available at the Open Database website of the Madrid City Council (<https://datos.madrid.es/>) and from the Regional Statistical Institute of Madrid (<http://www.madrid.org/iestadis>) in July 2016.

2.3. Defining places with cigarette butt littering

We identified all types of places where we registered cigarette butts within the 42 census tracts (e.g. bars or supermarket entrances). For each type of place, we calculated the percentage of places that had cigarette butts with respect to the total number of similar places within the 42 census tracts (stage 2 in figure 1).

In addition, we calculated the number of places per square kilometre (sq. km) for each of the types of places with cigarette butts using the point-density tool in ArcGIS 10.4. software (ESRI Inc., Redlands, CA, USA). This analysis showed the spatial distribution of the types of places from which we estimated the density of cigarette butts around each place.

2.4. Extrapolation of data on cigarette butt littering to the entire city

In order to estimate the geographical distribution of cigarette butts throughout the municipal area of Madrid we mapped the location of all types of places where we had observed cigarettes butts in the fieldwork and we conducted a Kernel Density Estimation (KDE) analysis (stage 3 in figure 1). The KDE is a geographical measure that can be used to calculate the density of features in an area (e.g. neighbourhood) around a specified point. KDE creates a smoothed raster surface of the density of specific spatial events (in this study, the selected types of places), based on their location and the distance to the neighbouring ones. These calculations assumed that the value of density is higher at the location of that event and, decreases as a specific function of distance as we move away up to a specific search radius.(28) More details about how KDE works were provided elsewhere.(29–31)

We defined a raster grid of 1×1 meters and weighted density values by the observed probability of found cigarette butts in each public space (i.e. the percentages obtained in stage 2). We used a search radius of 50 meters around each public space. This density value can be interpreted as an approximation of the magnitude of the exposure to cigarette butts; the search radius is defined as the extent of the area around each public place where the associated smokers might drop their cigarettes. Thus, considering a hospitality venue as a place where we could find cigarette butts, our analyses assumed that the estimated density or exposure to cigarette butts would be higher at the entrance to the building, and it would decrease as a function of distance.

Density values were normalized using the equation [1] exposed below:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \times 100 \quad [1]$$

When X' is the new pixel standardized value, X is the old pixel value, and X_{min} and X_{max} are the lowest and the highest pixel value in the map extension, respectively. We used the Natural Breaks method(32) to classify each pixel in the city into 4 categories: null, moderate, high and extreme. The areas that were not considered as public spaces according to the land use classification provided by the Madrid City Council, along with non-built areas (i.e. countryside and non-residential areas), were excluded from the analysis.

Last, we used GIS to estimate the total areas affected by cigarette butt littering. We approximated the population living in areas with exposure to cigarette butts. In brief, we procured census population data obtained from the Open Database of Madrid City Council (<https://datos.madrid.es/>) and transferred this population data from census tracts to residential buildings, weighting this operation by to the number of floors in each building. Then, we add the amount of population who were estimated to live in those residential buildings that were within areas with cigarette butts' exposure. All the analyses were conducted using ArcGIS v.10.4. software.

2.5. Validation

A validation procedure was performed to analyse the validity of our estimations. Specifically, we obtained 10 random addresses within each category of cigarette butts

exposure area (null, moderate, high, and extreme) using ArcGIS 10.4. We excluded those areas covered by the 42 census tracts used for observation. In total, we visited 40 random point-locations within the city of Madrid. A similar procedure to define points for validation has been used in previous studies.(20,24)

At each point-location, we conducted the same measurement procedure as in stage 2. To obtain these measures, we visited each point and collected data on the number of cigarette butts in a 1-meter radius (size of the pixel in the GIS analyses), and in a 3- and 5-meters radius for sensitivity analyses. On-field measures were collected by the same data collector as in stage 1, between July and September 2018, from Monday to Thursday and between 5 and 9 pm.

We then compared the KDE-estimated measures to the newly obtained observed values for the density of cigarette butts (stage 4 in figure 1). We used a correlation coefficient to compare both observed and estimated measures of exposure to cigarette butts. Correlation coefficients were interpreted according the cut-off ranges defined in Mukaka, 2012.(33) All statistical analyses were conducted using Stata v.12. software (StataCorp, College Station, TX, USA).

3. RESULTS

3.1. Descriptive results of observational data (Stage 1)

We found a total of 515 public spaces with a presence of cigarette butts in the observed 42 census tracts (table 1). The presence of cigarette butts was highest around hospitality venues (76.24%), public transportation stops (65.00%), playgrounds (53.10%) and educational centres (39.29%). We also found cigarette butts at the entrances to the supermarkets (8.33%), surroundings of benches (5.61%), at other locations within parks and green areas, and at streets, squares and other public pathways (table 1).

3.2. Types of places considered in the analyses (Stage 2)

We considered these types of places in the KDE analyses: 1) hospitality venues, 2) public transportation stops, 3) entrances to educational centres, 4) entrances to supermarkets and food stores, 5) playgrounds and 6) benches. Since KDE analyses were calculated from specific addresses, observations in types of places that were not recorded by the City Council secondary databases (e.g. elements of the urban furniture, tree-planters) could not be considered in our estimations. In addition, although we geocoded streets and parks data, extrapolation of data obtained in these types of places is controversial. In particular, the characteristics of streets (e.g. sidewalk width) and parks (e.g. land area and amenities) within the city are heterogeneous. This characteristics may be more relevant to the presence of cigarette butts in these public spaces, as compared to the number or density of the public spaces themselves.(24) Conversely, playgrounds were considered in our analyses because all these facilities within the city have homogeneous characteristics and dimensions, following specific guidelines provided by the Madrid City Council.

Thus, we identified 104,120 locations including 16,730 hospitality venues, 5,860 transportation stops, 2,159 educational centres, 14,998 supermarkets, markets and, food

stores, 1,935 playgrounds and 62,438 benches across the city. Figure 2 shows the distribution of these locations around the city. The density of hospitality venues and supermarkets were higher in central areas of the city, while playgrounds and benches were more abundant in peripheral areas. Public transportation stops, and educational centres were more evenly distributed.

3.3. Distribution of cigarette butts across the city (Stage 3)

Our analyses resulted in a complete map showing the estimated distribution of cigarette butt litter across the whole city of Madrid (Figure 3). We observed the highest values of exposure in downtown, “Centro” district (see an image enlargement of this area included at the upper right side of the figure). As indicated in figure 2, we found that the downtown area had the highest densities of hospitality venues, public transportation stops, and commercial venues (i.e. supermarkets, markets and food stores) in the city, which were the types of places with the highest probabilities to have discarded cigarette butts (table 1). Extreme and high values of exposure were also estimated in other central districts of the city (Chamberí, Salamanca, Tetuán and Chamartín), where we also found a high density of hospitality venues, public transportation stops, commercial venues and schools (figure 2).

In contrast, we estimated a lower density of cigarette butts in peripheral districts of the city, which include more residential (e.g. Hortaleza district) and industrial land uses (e.g. Vicálvaro district) and green/park areas. Within these districts, we found specific areas where the density of cigarette butts was high. These areas were around large streets and squares where most of the leisure services were concentrated within the district. Furthermore, we observed a geographical unevenness in the distribution of the density of cigarette butts: southern districts of the city (e.g. Carabanchel and Usera districts) seemed to have higher values of density of cigarette butts than northern ones (e.g. Hortaleza district), where larger areas of null exposure are depicted. Southern districts tended to have a higher density of hospitality venues, public transportation stops, and commercial venues.

Figure 3 (lower right side) represents a detailed zoomed section of the map over a popular square in downtown Madrid (Santa Ana square). This inset showed all public spaces considered in our analyses as places with high probability to have cigarette butts, and the distribution of this phenomena within the square and adjacent streets. Due to the large concentration of places with estimated cigarette butts, there was an extreme density of this form of litter in this square.

Madrid has 58.98 km² of outdoor public spaces within the residential areas, of which 72.88% (42.98 km²) were depicted with at least a moderate exposure to cigarette butts. We calculated that around 2.6 million of inhabitants (82.24% of population) in Madrid lived within these residential areas affected by this form of litter.

3.4. Validation results (Stage 4)

We used Spearman’s correlation coefficient to assess the relationship between estimated and observed values of density of cigarette butts because their distribution was skewed (see supplementary file, figure S2). We found a high correlation between observed and estimated values in a 1m radius from each validation location ($r=0.784$) (figure 3). The coefficients

were slightly lower in the sensitivity analyses at 3m and 5m radius from each location, showing a moderate correlation ($r=0.543$ and $r=0.632$, respectively). The points with dissimilar estimated and on-field values were those mainly categorized in the groups with estimated null or extreme exposure. The distribution of validation points throughout the study area is shown in the supplementary material (figure S1).

4. DISCUSSION

We proposed a methodology to measure and quantify the distribution of cigarette butts over an entire urban area by combining systematic social observation and GIS. We found an overall presence of cigarette butts in the city of Madrid: 72.88% of outdoor public spaces within residential areas were depicted with at least a moderate exposure to cigarette butt litter. 82.24% of the population of Madrid lived in those areas. Similar findings were obtained in Scotland, where a recent study estimated that 75% of the streets in Scottish cities have some smoking-related litter.(34)

Our study identified high concentrations of cigarette butts around hospitality venues, public transportation stops, educational centres, supermarkets, markets and food stores entrances, playgrounds and in the surrounding areas of benches. These types of places were also identified as hotspots of cigarette discarded butts by other studies.(19,27) Some of these places are associated with tobacco sales and consumption such as hospitality venues as suggested Marah and Novotny, 2011.(20) Others might be related to the effect of indoor smoking bans that force smokers to relocate at outdoor venues (e.g. public transportation stops, or supermarkets).(15,35) Furthermore, we found a high concentration of cigarette butts in places where smoking is banned by the Spanish national regulation, such as playgrounds.(36)

The distribution of cigarette butt litter is not uniform throughout the city of Madrid. The central districts, which presented the greatest density of hospitality venues, public transportation stops, supermarkets, and educational centres registered the highest amounts of cigarette butts. These areas are characterized by a broad range of leisure, commercial, business and tourist activities, and have the highest population densities within the city. Moreover, we found that southern districts of the city seem to have higher density of cigarette butts than northern ones. This result may be due to a greater diversification of land uses in southern districts. In addition, these inequalities may be due to the frequency of street cleaning. Overall, the City Council spends less money in street cleaning in the southern districts in comparison to the northern ones (e.g. 36.6€per inhabitant each year in Carabanchel and Usera vs 40.4€in Hortaleza or 46€in Fuencarral-El Pardo).(37)

These findings were validated ($r=0.784$). The dissimilarities observed between the estimated and on-field measures in areas with null exposure in the validation process indicates the overall ubiquitous of discarded cigarette butts around the urban space. Meanwhile, those dissimilarities found in areas with high exposure might be due to the frequency of street cleaning, which is particularly high in central places of the city with a great density of leisure, commercial and touristic activities.(37)

Our results offer policy insights for those tasked with addressing urban refuse concerns as well as tobacco control practitioners. To date, effective interventions to reduce cigarette butt litter(4) and protect population from tobacco(23) include the implementation of smoke-free policies in outdoor environments. Moreover, according to previous studies this regulation receives popular support,(38–40) largely driven by increasing awareness for the serious environmental harms of pollution derived from cigarette butts and interest for “beautification” processes of the city,(41) beyond their implications for population health. In Spain, the existing regulations banning smoking at playgrounds should be enforced and extended to other outdoor settings such as entrances to hospitality venues, educational centres, supermarkets or public transportation stops. Particularly, the prohibition of smoking on beaches (a place not considered in our study since Madrid is not a coastal city) has attracted attention in the literature. Other studies registered a high volume of discarded cigarette butts in these environments.(17) While we found some examples of smoke-free beaches in Spain,(42) this is not universal. Still, the results found in previous studies suggest that beaches may be an important site for policy intervention.

The results will also be of interest to tobacco control practitioners, as the findings offer opportunities for targeted interventions such as educational campaigns or public health messaging (e.g. billboards) in those types of places where we identified high densities of cigarette butts (e.g. entrances to hospitality venues). Furthermore, we have found some policies that aim to provide a greater number of bins or portable ashtrays in those areas where it exists higher density of cigarette butts such as beaches, entrances to public buildings, etc.(10,43,44) However, other studies reject the effectiveness of these measures since they argued that the increase of the number of tobacco-specific refuse collection devices in the environment may encourage and normalise smoking.(23,45)

In terms of methodology, previous studies capturing the extent of the pollution of cigarette butts applied single observational methods which are limited to a sample of places or streets and are not suitable for covering large areas.(5) Beyond these single observational methods, GIS tools enable us to infer the data on the presence of cigarette butts collected in specific types of places to similar settings around the city. Thus, we could extrapolate these data observed in a sample of points across a large geographical area.

Marah and Novotny in 2011 tested a weighted overlay model based on GIS proximity tools to identify zones where high concentrations of discarded butts may be deposited around their study area. This model was underpinned by data collected through a survey of tobacco product waste (TPW) in a set of places with potential high concentrations of these litter forms. That study suggested that the outdoor environment surrounding these high TPW places might be affected by cigarette butt littering, and they defined 10 levels of exposure using straight buffers, which decrease with the distance to these places.(20) By contrast, our study involved extensive fieldwork to define those types of places with high concentrations of cigarette butts and applied kernel density estimations (KDE) instead of buffer-proximity measures. KDE algorithm offers a more updated and sophisticated density method based on the distance of the types of places, which may provide results with higher precision and better spatial resolution (1-meter pixel) than single measures based on proximity.(28) This approach is more advantageous compared to the use of different proximity buffers: KDE

may offer a gravity-based model which represents a gradual (or fuzzier) transition of the density values from the places with cigarette butts littering to the boundary of the search radius, rather than sharp transition obtained from buffer analysis.(30) Moreover, the model tested by Marah and Novotny, 2011, was conducted in a small area within 3 zip codes, while our method was applied to the entire city of Madrid.

Our study has several limitations. Presence of cigarette butts in the urban environment were observed during a specific time slot (during weekdays, between 5pm and 9pm). We did not assess the possible variations of the extent of these forms of litter in the environment during the day (e.g. those produced by the frequency of street-cleaning), across the days of the week (differences between weekdays and weekends), or even at different seasons of the year (e.g. due to the presence of people and activities at outdoor spaces). A potential limitation, especially related to the lack of measurement on weekends, is that we may have underestimated the presence of butts around hospitality venues or other spaces that are more frequently used during leisure time. Moreover, the methodology proposed was conditioned by the availability of data recorded by the secondary databases. Thus, the presence of cigarette butts could be only extrapolated for those places that were registered and georeferenced in secondary databases (e.g. hospitality venues, public transportation stops, supermarkets, etc.). Cigarette butt littering in other unspecific locations in the streets or parks could not be estimated. However, our methodology and findings were successfully validated, and to our knowledge, our study is the first on quantifying and mapping the distribution of cigarette butt litter within a large urban area.

In summary, this study presents a novel and reliable methodological approach to analyse the extent of cigarette butt littering in the urban environment, which may be reproduced in other settings. These results demonstrate the high density of cigarette butts in the urban environment, and pose some interventions to solve this problem, which could be also considered in other cities worldwide.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Drope J, Schluger NW, Cahn Z, Drope J, Hamill S, Islami F, et al. The Tobacco Atlas [Internet]. Sixth Edit Drope J, Schluger NW, editors. Atlanta, GA, USA: American Cancer Society and Vital Strategies; 2018 58 p. Available from: <https://tobaccoatlas.org/>
2. Araújo MCB, Costa MF. From Plant to Waste: The Long and Diverse Impact Chain Caused by Tobacco Smoking. *Int J Environ Res Public Health*. 2019;16:2690–9.
3. Bialous S, Curtis C, Stigler-Granados P, Hendlin Y. Tobacco and its environmental impact: an overview. Geneva, Switzerland: World Health Organization; 2017.
4. Araújo MCB, Costa MF. A critical review of the issue of cigarette butt pollution in coastal environments. *Environ Res [Internet]*. 2019;172(January):137–49. Available from: 10.1016/j.envres.2019.02.005
5. Patel V, Thomson GW, Wilson N. Cigarette butt littering in city streets: A new methodology for studying and results. *Tob Control*. 2013;22(1):59–62. [PubMed: 22821749]
6. Dobaradaran S, Schmidt TC, Lorenzo-Parodi N, Jochmann MA, Nabipour I, Raeisi A, et al. Cigarette butts: An overlooked source of PAHs in the environment? *Environ Pollut*. 2019;249:932–9. [PubMed: 30965545]
7. Bonanomi G, Incerti G, Cesarano G, Gaglione SA. Cigarette Butt Decomposition and Associated Chemical Changes Assessed by 13 C CPMAS NMR. *PLoS One*. 2015;(January):1–16.
8. Curtis C, Novotny TE, Lee K, Freiberg M, McLaughlin I. Tobacco industry responsibility for butts: a Model Tobacco Waste Act. *Tob Control*. 2017;26:113–7. [PubMed: 26931480]
9. Novotny TE, Slaughter E. Tobacco Product Waste: An Environmental Approach to Reduce Tobacco Consumption. *Curr Environ Heal Reports*. 2014;1:208–16.
10. Heaton CG, Michael Cummings K, O'Connor RJ, Novotny TE. Butt really? The environmental impact of cigarettes. *Tob Control*. 2011;20(1 SUPPL):1. [PubMed: 21172855]
11. Schneider JE, Peterson NA, Kiss N, Ebeid O, Doyle AS. Tobacco litter costs and public policy : a framework and methodology for considering the use of fees to offset abatement costs. *Tob Control*. 2011;20(Suppl 1):36–41.
12. Alesci NL, Forster JL, Blaine T. Smoking visibility, perceived acceptability, and frequency in various locations among youth and adults. *Prev Med*. 2003;36(3):272–81. [PubMed: 12634018]
13. Klein EG, Bernat DH, Forster JL. Young adult perceptions of smoking in outdoor park areas. *Health Place [Internet]*. 2012;18(5):1042–5. Available from: 10.1016/j.healthplace.2012.06.002
14. Wilson N, Oliver J, Thomson G. Smoking close to others and butt littering at bus stops: pilot observational study. *PeerJ [Internet]*. 2014;2(1):e272 Available from: <http://www.scopus.com/inward/record.url?eid=2-s2.0-84895727671&partnerID=tZOtx3y1>
15. Kaufman P, Griffin K, Cohen J, Perkins N, Ferrence R. Smoking in urban outdoor public places: Behaviour, experiences, and implications for public health. *Health Place [Internet]*. 2010;16(5):961–8. Available from: 10.1016/j.healthplace.2010.05.012
16. Stigler Granados P, Fulton L, Nunez Patlan E, Terzyk M, Novotny TE. Global Health Perspectives on Cigarette Butts and the Environment. *Int J Environ Res Public Health*. 2019;16:1858–67.
17. Kungskulniti N, Charoenca N, Hamann SL, Pitayarangsarit S, Mock J. Cigarette waste in popular beaches in Thailand: High densities that demand environmental action. *Int J Environ Res Public Health*. 2018;15(4):1–12.
18. Platter HN, Pokorny SB. Smoke-free signage in public parks: impacts on smoking behaviour. *Tob Control [Internet]*. 2017;1–4. Available from: <http://tobaccocontrol.bmj.com/content/early/2017/07/14/tobaccocontrol-2016-053624.abstract>
19. Kaplan B, Grau-Perez M, Çarkoglu A, Ergör G, Hayran M, Navas-Acien A, et al. Smoke-free Turkey: Evaluation of outdoor areas of public places. *Environ Res [Internet]*. 2019;175(April):79–83. Available from: 10.1016/j.envres.2019.05.003
20. Marah M, Novotny TE. Geographic patterns of cigarette butt waste in the urban environment. *Tob Control*. 2011;20(Suppl 1):2010–2.

21. 20 minutos. Manuela Carmena le declara la “guerra” a las colillas. 20 minutos [Internet]. 2016 [cited 2019 Sep 19]; Available from: <https://www.20minutos.es/noticia/2755035/0/carmena-declara-guerra-colillas/>
22. The City of London. Clean Streets Partnership [Internet]. London; 2019 p. 32 Available from: <https://www.cityoflondon.gov.uk/services/transport-and-streets/clean-streets/Pages/Clean-Streets-Partnership.aspx>
23. Sureda X, Bilal U, Fernández E, Valiente R, Escobar FJ, Navas-Acien A, et al. Second-hand smoke exposure in outdoor hospitality venues: Smoking visibility and assessment of airborne markers. *Environ Res*. 2018;165.
24. Valiente R, Escobar F, Pearce J, Bilal U, Franco M, Sureda X. Mapping the visibility of smokers across a large capital city. *Environ Res* [Internet]. 2020;180(108888):1–8. Available from: 10.1016/j.envres.2019.108888
25. Pearson AL, Nutsford D, Thomson G. Measuring visual exposure to smoking behaviours: a viewshed analysis of smoking at outdoor bars and cafés across a capital city’s downtown area. *BMC Public Health* [Internet]. 2014;14(1):300 Available from: <http://bmcpubhealth.biomedcentral.com/articles/10.1186/1471-2458-14-300>
26. Fu M, Fernández E, Martínez-Sánchez JM, San Emeterio N, Quirós N, Sureda X, et al. Second-hand smoke exposure in indoor and outdoor areas of cafés and restaurants: Need for extending smoking regulation outdoors? *Environ Res* [Internet]. 2016;148:421–8. Available from: 10.1016/j.envres.2016.04.024
27. Navas-Acien A, Çarko lu A, Ergör G, Hayran M, Ergüder T, Kaplan B, et al. Compliance with smoke-free legislation within public buildings: a cross-sectional study in Turkey. *Bulletin of World Health Organization*. 2016;94(October 2015):92–102.
28. Silverman B Density estimation for statistics and data analysis [Internet] Chapman and Hall, editor. *Monographs on Statistics and Applied Probability*. London; 1986 22pp. Available from: http://books.google.com/books?hl=en&lr=&id=exsrjsL7WkC&oi=fnd&pg=PR9&dq=Density+Estimation+for+Statistics+and+Data+Analysis&ots=ivSomp7D_q&sig=XfZFIeyzmSO4nm54dgq22EiW9iA
29. Guagliardo MF. Spatial accessibility of primary care: concepts, methods and challenges. *Int J Health Geogr*. 2004;3(3):1–13. [PubMed: 14748927]
30. Thornton LE, Pearce JR, Kavanagh AM. Using Geographic Information Systems (GIS) to assess the role of the built environment in influencing obesity: A glossary. *Int J Behav Nutr Phys Act*. 2011;8:1–9. [PubMed: 21194492]
31. Charreire H, Casey R, Salze P, Simon C, Chaix B, Banos A, et al. Measuring the food environment using geographical information systems: a methodological review. *Public Health Nutr*. 2010;13(11):1773–85. [PubMed: 20409354]
32. Cauvin C, Escobar F, Serradj A. *Thematic cartography and transformations*. John Wiley & Sons; 2010 463 p.
33. Mukaka MM. A guide to appropriate use of correlation coefficient in medical research. *Malawi Med J*. 2012;24(3):69–71. [PubMed: 23638278]
34. Ash Scotland. *Fastfacts: Smoking-related litter* [Internet]. 2016 [cited 2018 Oct 18]. Available from: <https://www.ashscotland.org.uk/media/7613/21Litter.pdf>
35. Sureda X, Martínez-Sánchez J, López M, Fu M, Agüero F, Saltó E, et al. Secondhand smoke levels in public building main entrances: outdoor and indoor PM2.5 assessment. *Tob Control*. 2012;21(6):543–8. [PubMed: 21964181]
36. Parliament of Spain. Ley 42/2010, de 30 de diciembre, por la que se modifica la Ley 28/2005, de 26 de diciembre, de medidas sanitarias frente al tabaquismo y reguladora de la venta, el suministro, el consumo y la publicidad de los productos del tabaco. Vol. 318, *Boletín Oficial del Estado*. 2010 p. 11370–421.
37. El País. Madrid gasta en limpiar los distritos ricos casi el doble que en los pobres. *El País* [Internet]. 2016; Available from: https://elpais.com/ccaa/2016/01/14/madrid/1452776161_125411.html

38. Thomson G, Wilson N, Edwards R. At the frontier of tobacco control: A brief review of public attitudes toward smoke-free outdoor places. *Nicotine Tob Res.* 2009;11(6):584–90. [PubMed: 19359392]
39. Gallus S, Rosato V, Zuccaro P, Pacifici R, Colombo P, Manzari M, et al. Attitudes towards the extension of smoking restrictions to selected outdoor areas in Italy. *Tob Control.* 2012;59–62.
40. Sureda X, Fernández E, Martínez-Sánchez JM, Fu M, López MJ, Martínez C, et al. Secondhand smoke in outdoor settings: smokers' consumption, non-smokers' perceptions, and attitudes towards smoke-free legislation in Spain. *BMJ Open* [Internet]. 2015;5(4):e007554 Available from: <http://www.ncbi.nlm.nih.gov/pubmed/25854974%5Cnhttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4390691>
41. Ueda H, Armada F, Kashiwabara M, Yoshimi I. Street smoking bans in Japan: A hope for smoke-free cities? *Health Policy* [Internet]. 2011;102(1):49–55. Available from: 10.1016/j.healthpol.2011.05.013
42. ABC. Estas son las playas de España donde está prohibido fumar [Internet]. ABC. 2019 [cited 2019 Oct 14]. Available from: https://www.abc.es/sociedad/abci-estas-playas-espanolas-donde-esta-prohibidofumar-201908100224_noticia.html
43. Metcalfe S, Murray P, Schousboe C. A kick in the butt: time to address tobacco waste in New Zealand. *N Z Med J.* 2017;130(1456):65–9.
44. Hoek J, Gendall P, Blank M, Robertson L, Marsh L. Butting out: an analysis of support for measures to address tobacco product waste. *Tob Control.* 2019;0:1–7.
45. Glenn NM. Young adults' experiences of neighbourhood smoking-related norms and practices : A qualitative study exploring place-based social inequalities in smoking. 2017;189:17–24.

HIGHLIGHTS:

- This study presents a reliable and replicable GIS methodology to estimate the extent of cigarette butts' litter in the urban environment.
- Our results showed a ubiquitous and unequal distribution of cigarette butt litter in the environment in our study area.
- Central districts with higher density of hospitality venues and public transportation stops registered higher densities of cigarette butts.
- This study revealed some hints for future interventions to reduce cigarette butt littering in public spaces.

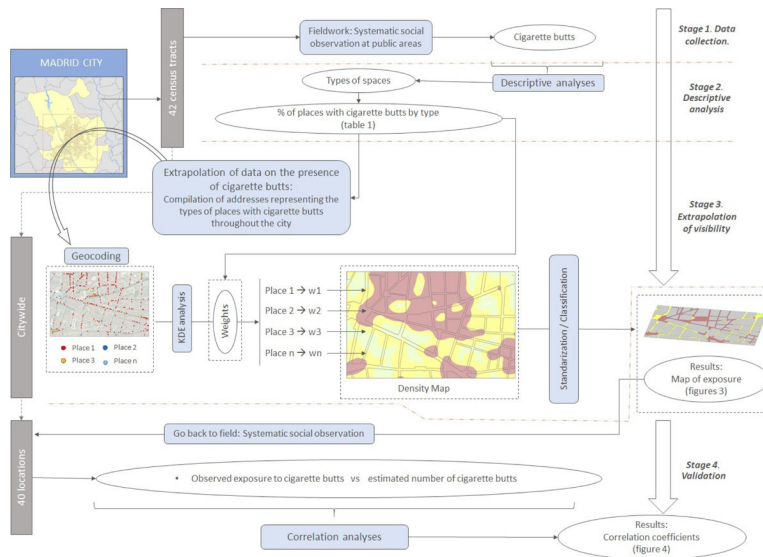


Figure 1. Flow diagram depicting the study designs and methods.

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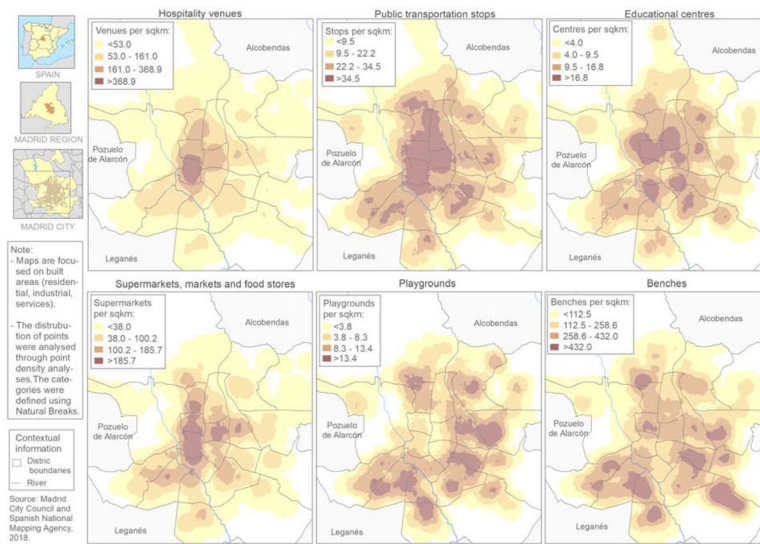


Figure 2. Distribution of the types of outdoor public places with presence of cigarette butts in the city of Madrid, Spain.

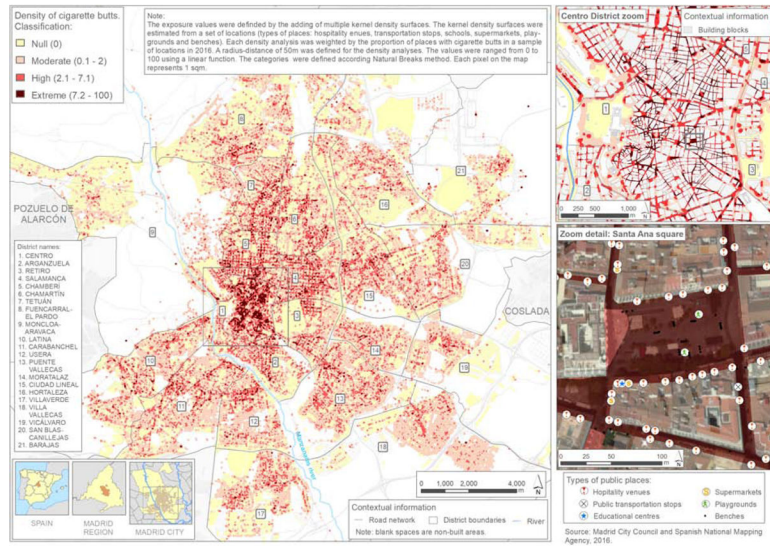


Figure 3:
Density of cigarette butts in public outdoor spaces in the city of Madrid, Spain.

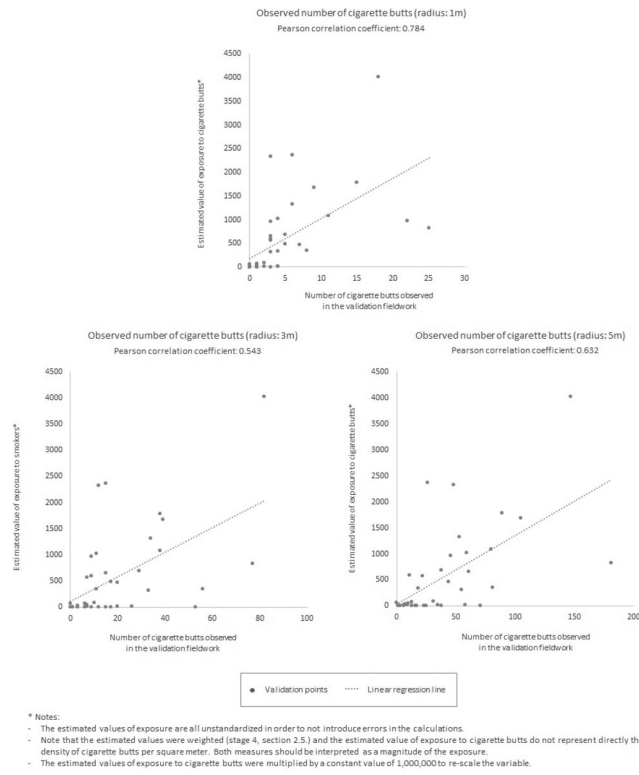


Figure 4:
Correlation between observed and estimated measures of density of cigarette butts

Table 1.

Outdoor public places with presence of cigarette butts collected within 42 census tracts in the city of Madrid, Spain in 2016

Final list of public places observed	Total number of places observed	Total number of places observed with cigarette butts	Percent of places with cigarette butts over the total number of places
Hospitality venues ^a	202	154	76.24%
Public transportation stops	80	52	65.00%
Playgrounds	41	23	53.10%
Entrances to educational centres	28	11	39.29%
Entrances to supermarkets and food stores	240	20	8.33%
Benches	1033	58	5.61%
Parks and green spaces ^b	- ^c	28	- ^c
Streets, squares and, public pathways ^d	- ^c	169	- ^c
Total		515	

^aWe considered only those premises that were opened by the time of observation.

^bThis type of place comprises cigarette butts discarded within parks and green areas, on the park-pathways, on the grass or near the tree planters.

^cThese data could not be estimated. These measures were either related to non-specific addresses which are difficult to concrete as points or to very specific elements which are not registered and geocoded in the secondary databases and could not be counted.

^dThis type of place encompassed cigarette butts dropped on the middle of the streets, squares, car parking's or other public pathways, such as sidewalks, stairways or near the tree planters in the street.