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Temporal considerations for an effective sampling of personal protective equipment litter derived from the COVID-19 pandemic

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ABSTRACT

Personal protective equipment (PPE) has become a new pollutant derived from the COVID-19 pandemic. Much of the efforts to characterize PPE litter has focused on its spatial distribution (i.e., trying to identify hotspots of PPE litter), however, such efforts have been limited in the temporal domain, which might result in under- or overestimations in annual projections. Here, using 55 continuous days of sampling in an urban and tropical neighborhood in southeast Mexico, I show that in order to have a robust and defensible average and variance values it is needed at least 22 days of random sampling. Nonetheless, this minimum number might change in different ecosystems and land use areas of the built environment due to the temporal variability of the human behavior and activities related to the surveyed areas, as well as the influence of weather conditions that might affect the mobility of people. Furthermore, I discuss how it is recommended to report the daily average density of PPE litter (items m$^{-2}$ day$^{-1}$) and its variability (i.e., 95 % confidence intervals), rather than only the density of PPE litter (items m$^{-2}$) in order to facilitate annual estimates of PPE litter disposal.

1. Introduction

There is a growing concern worldwide about plastic pollution (MacLeod et al., 2021). The weathering of plastics might represent a planetary boundary since plastics are ubiquitous over the Earth and are not readily reversible (Arp et al., 2021). Thus, increasing efforts should be made to understand and quantify the standing stocks and accumulation rates of the plasticsphere. However, the pulses of plastic litter are influenced by anthropogenic and natural rhythms, and the type, occurrence, and abundance of plastics released to the natural and built environment can change depending on the spatial (e.g., land use) and temporal (e.g., a pandemic) context, which has to be considered in order to have robust and defensible inventories of plastics.

The COVID-19 pandemic brought with it new forms and items of consumption, especially personal protective equipment (PPE), including face masks. During the early stages of the COVID-19 sanitary emergency the use of face masks was suggested and even mandatory in the vast majority of the globe, particularly in the indoor settings. It has been estimated that the disposal of face masks increased >80-fold due to the COVID-19 pandemic (Roberts et al., 2021).
There is a new body of scientific research showing how PPE has been accumulating across different types of ecosystems, including the built environment. However, the main focus of those investigations has been to elucidate the spatial variability of PPE litter (i.e., comparing different urban areas (Ammendolia et al., 2021), or different recreational beaches (De-la-Torre et al., 2021)), while the temporal variability has not been taken into account, although there are a few examples (Kutralam-Muniasamy et al., 2022), ranging from 33 to 112 days of sampling. The temporal variability of the occurrence of PPE litter should be influenced by human activities and behavior, such as working days versus weekends (Hassan et al., 2022), major public events (Kutralam-Muniasamy and Shruti, 2022), or the relaxation of the COVID-19 lockdown due to the presence of vaccines (Ribeiro et al., 2022), and by consequence, influencing the occurrence and abundance of PPE litter.

Taking into account the temporal variability of PPE litter and how it influences its spatial variability could be solved by increasing the number of sampling days, however, it implies the increase in labor and inherent logistics costs. Thus, it is needed to estimate a minimum number of sampling days, in order to maximize resources, and to have a defensible, robust, and accurate PPE litter inventory to provide reliable annual estimates.

Here, my overarching goal was to determine the minimum number of sampling-days required to have a representative survey of face masks in an urban environment. Despite that there is a plethora of PPE types, face masks were selected since this kind of PPE is proportionally the most abundant in PPE surveys (Aragaw et al., 2022; Hatami et al., 2022; Kutralam-Muniasamy and Shruti, 2022; Rakib et al., 2021). This objective was achieved by daily sampling of a fixed path (2.5 km) during 55 consecutive days in an urban and tropical neighborhood in south east Mexico.

2. Material and methods

2.1. Study site

The personal protective equipment (PPE) survey was done in the neighborhood of Atasta de Serra, Villahermosa, Tabasco, México. This neighborhood is a complex mosaic of different land uses (Fig. 1). The different land uses include urban parks and green areas (showed in green in Fig. 1), habitation areas (showed in yellow in Fig. 1), and commercial areas (showed in red in Fig. 1) which include: small family-owned restaurants (e.g., taquerías, bakeries, cake shops, pizza shops), banks, tire shops, paint shops, convenience grocery shops, hair salons, car washes, and a funeral home.

2.2. Personal protective equipment survey strategy

Daily surveys in a delimited area (28,905.8 m²) were done from August 13th 2022 to October 6th 2022. During the week of August 7th to August 12th, face masks in the surveyed area were collected and disposed to avoid an initial spike due to the standing stock of PPE litter. The daily surveys were initiated between 6:00–7:00 am, and between 7:00–8:00 pm local time, and lasted between 45 and 60 min. Furthermore, these periods were also chosen because those are the times for my pet-walking. For the identification of face masks, I followed a similar approach used in a metropolitan city in Canada (Ammendolia et al., 2021). Briefly, during the daily...
surveys the presence of face masks were visually identified and recorded taking photographs using a cellphone (OnePlus 7 Pro). Face masks were identified and collected on the sidewalk, as well as on the first ~5 m from the closest edge of the sidewalk when traffic allowed; if a face mask was visible under a car it was recorded. In the urban parks and green areas the complete area was surveyed. Each photograph represented one face mask; when two or more face masks were present, two or more photographs were taken. After the photograph was taken, the face masks were collected and disposed properly in order to avoid duplicated counting.

2.3. Data analyses

In order to test the minimum number of surveys needed to obtain a representative sampling, the cumulative average and variance were calculated by randomly selecting surveyed days without replacement and progressively adding samples. This procedure was iterated 55 times that represents the same number of surveyed days. The minimum number of surveys was determined as the point where all curves converged within the 95 % confidence interval of the full set of samples. All analyses were done in R (V 4.0.1). Raw data can be found as Supplementary material.

3. Results and discussion

During the surveyed days a total of 704 face masks were found, with a daily average of 12.8 ± 5.2 items day$^{-1}$ (average ± standard deviation; Fig. 2). The minimum number of face masks was 3 recorded on September 21st, while the maximum number of face masks was 28, recorded on August 28th and October 2nd, both being maximum values in Sundays.

By randomly selecting surveyed days without replacement, progressively adding samples and iterated 55 times, I found that in order to have a representative average value of face masks (items days$^{-1}$) within 95 % confidence intervals (CIs) 22 sampling days are required, while for having a variance (items days$^{-1}$) value within 95 % CIs 18 sampling days are required (Fig. 3).

The research of PPE litter monitoring is an emerging field derived from the COVID-19 pandemic. I recognize that previous research was limited due to the lockdown measures and it has provided invaluable information; however, as the field grows and gets consolidated, methodological considerations should be taken into account in order to provide reliable estimates of PPE litter to decision makers. This might be alleviated also by creating international databases of PPE litter inventories, such as the Marine Debris Tracker (Jambeck and Johnsen, 2015) or Litterati (https://www.litterati.org/), with clear data needs and well documented metadata, following the FAIR principles (Wilkinson et al., 2016).

Here, I showed that for an urban and tropical neighborhood in south east Mexico the minimum number of random surveyed days should be 22 and 18 for having an average and variance values within 95 % CIs, respectively; however, those minimum numbers might change in different ecosystems and land use areas of the built environment due to the temporal variability of the human behavior and activities related to the surveyed areas, as well as the influence of weather conditions that might affect the movility of people (e.g., rainy/snowy days, extreme heat conditions). Thus, further research is needed to estimate and establish good practices for monitoring PPE litter. Integrating and synthesizing current existing information and research efforts should guide future PPE litter surveys.

The consequences of not reaching a sufficient sampling could result in over- or underestimation of annual projections. While an overestimation might be not as perjudicial in mitigation and prevention actions, the efficiency of those actions is likely to be low (i.e., a high effort for a small problem); while underestimated projections might provoke lower insights and leverage of the necessity for taking action to prevent and mitigate PPE litter pollution and its derivatives, such as secondary microplastics and the release and leaching of toxic chemical pollutants across different ecosystems (Kutralam-Muniasamy et al., 2022).

On the other hand, it has become a popular way to report PPE litter as a measure of density (i.e., items m$^{-2}$) (Kutralam-Muniasamy et al., 2022); however, the density of items by unit of area has been reported as cumulative (i.e., the total items found by area), not taking into account the number of surveyed days. For example, in this study the total density of PPE litter is 0.02435494 items m$^{-2}$, however, in order to have an annual projection of PPE litter the temporal component is missing. Thus, it will be beneficial for the community interested in PPE litter research to communicate and report the daily average density of PPE litter (items m$^{-2}$ day$^{-1}$); in this study the daily average density of PPE litter (face masks) was 4.428171 × 10$^{-2}$ items m$^{-2}$ day$^{-1}$, which would result in 0.1616282 items m$^{-2}$ year$^{-1}$, that equals to 4672 item year$^{-1}$ for an area of 28,905.84 m$^2$. It is noteworthy to mention that average values can be biased if the distribution of data does not follow a Gaussian distribution; thus, depending on the skewness, the distribution of data, and sampling size, the median value could be also reported.

While it is important to report robust average values, it is also important to provide measures of its variability in order to have upper and lower bounds of confidence. In this study, the daily 95 % CIs PPE density (estimated as the daily average density of PPE ± [1.96 × daily standard deviation]) was from 9.014672 × 10$^{-2}$ to 7.954875 × 10$^{-4}$ items m$^{-2}$ day$^{-1}$, resulting in upper and lower bounds of 0.03290355–0.2903529 items m$^{-2}$ year$^{-1}$, respectively, that would result between 951.1 and 8392.9 items year$^{-1}$ for the area surveyed. Thus, there is an order of
magnitude of uncertainty in the annual estimation of face mask litter in this urban and tropical neighborhood in south east Mexico, making evident that representing the temporal variability is as important as representing the spatial variability of the occurrence and abundance of PPE litter.

4. Conclusions

Long-term surveys are necessary to elucidate the complex socio-environmental variability that regulates the occurrence and abundance of PPE litter, as well as other plastic litter types. Such long-term monitoring will result in more precise and reliable annual estimates of PPE litter, providing fundamental information for decision makers. While across the world the mandates for wearing face masks are relaxing, the information created and experiences gained during the COVID-19 pandemic should help for future similar scenarios. Furthermore, while this analysis focused on face masks, the approach I used can be easily replicated to other kinds of PPE, as well as the diverse types of items of plastic pollutants.

It is noteworthy to mention that at the end of the sampling period (October 6th 2022), the use of face masks in the state of Tabasco, Mexico, changed from being mandatory to suggested in indoor facilities, and this measure might change the abundance and occurrence of PPE litter, but it should be further monitored.

CRediT authorship contribution statement

Alejandro Cueva: Conceived and designed the analysis, Collected the data, Contributed data or analysis tools, Performed the analysis, Wrote the paper.

Data availability

Data is presented as Supplementary Material

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.160047.

References

Ammendolia, J., Satunro, J., Brooks, A.L., Jacobs, S., Jambeck, J.R., 2021. An emerging source of plastic pollution: environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city. Environ. Pollut. 269, 116160.

Aragaw, T.A., De-la-Torre, G.E., Teskager, A.A., 2022. Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic along the shoreline of Lake Tana, Bahir Dar, Ethiopia. Sci. Total Environ. 820, 155261.

Arp, H.P.H., Kühnel, D., Rummel, C., MacLeod, M., Potthoff, A., Reichelt, S., Roije-Nieto, E., Schmitt-Janssen, M., Sonnenberg, J., Toornam, E., Jahske, A., 2021. Weathering plastics as a planetary boundary threat: exposure, fate, and hazards. Environ. Sci. Technol. 55, 7246–7255.

De-la-Torre, G.E., Rakib, M.R.J., Pizarro-Ortega, C.I., Dines-Salinas, D.C., 2021. Occurrence of personal protective equipment (PPE) associated with the COVID-19 pandemic along the coast of Lima, Peru. Sci. Total Environ. 774, 145774.

Hassan, I.A., Younis, A., Al Ghamdi, M.A., Almarzouq, M., Basahi, J.M., El Sheekh, M.M., Abouelkhair, E.K., Haiba, N.S., Alhussaini, M.S., Hajjar, D., Abdel Wahab, M.M., El Maghraby, D.M., 2022. Contamination of the marine environment in Egypt and Saudi Arabia with personal protective equipment during COVID-19 pandemic: a short focus. Sci. Total Environ. 810, 152046.

Hatami, T., Rakib, M.R.J., Madadi, R., De-la-Torre, G.E., Idris, A.M., 2022. Personal protective equipment (PPE) pollution in the Caspian Sea, the largest enclosed inland water body in the world. Sci. Total Environ. 824, 153771.

Jambeck, J.R., Johnsen, K., 2015. Citizen-based litter and marine debris data collection and stewardship. Sci. Data 3, 160018.

Kutralam-Muniasamy, G., Shruti, V.C., 2022. The case of the Catholic holy site in Mexico City, Mexico. Sci. Total Environ. 821, 153424.

Kutralam-Muniasamy, G., Pérez-Guevara, F., Shruti, V.C., 2022. A critical synthesis of current peer-reviewed literature on the environmental and human health impacts of COVID-19 PPE litter: new findings and next steps. J. Hazard. Mater. 422, 126945.

MacLeod, M., Arp, H.P.H., Tekman, M.B., Jahske, A., 2021. The global threat from plastic pollution. Science 373, 61–65.

Rakib, M.R.J., De-la-Torre, G.E., Pizarro-Ortega, C.I., Dines-Salinas, D.C., Al-Nahian, S., 2021. Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in Cox’s bazar, the longest natural beach in the world. Mar. Pollut. Bull. 169, 112497.

Ribeiro, V.V., De-la-Torre, G.E., Castro, J.B., 2022. COVID-19 related personal protective equipment (PPE) contamination in the highly urbanized southeast Brazilian coast. Mar. Pollut. Bull. 177, 113022.

Roberts, K.P., Phang, S.C., Williams, J.B., Hutchinson, D.J., Kolstoe, S.E., de Bie, J., Williams, I.D., Stringfellow, A.M., 2021. Increased personal protective equipment litter as a result of COVID-19 measures. Nat. Sustain. 5, 272–279.

Wilkinson, M.D., Dumontier, M., Altamirano, I.J.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., de Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brookes, A.J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C.T., Finkers, R., González-Beltrán, A., Gray, A.J.G., Groth, F., Goble, C., Grethe, J.S., Herison, J., Hoen, P.A., Hood, R., Kuhn, T., Kok, J., Lusher, S.J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Wagenomerter, A., Wittenburg, P., Wolstenholme, K., Zhao, J., Mona, B., 2016. The FAIR guiding principles for scientific data management and stewardship. Sci. Data 3, 160018.