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Strength in numbers: How citizen science can upscale assessment of human exposure to plastic pollution

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Abstract
Plastic pollution is ubiquitous, and the presence of plastic particles available for human uptake is documented, for example, in air, foodstuffs, and drinking water. Meanwhile, researchers, organizations, and policy agencies call for large-scale analyses of plastic pollution exposure. Doing precisely this in neighboring research fields, we argue that citizen science (CS) can contribute to close knowledge gaps for human exposure. We reviewed the recent literature (2019-present) on the assessment of human exposure to plastic pollution using CS to document the state-of-the-art and only found a single study. We discuss the strength of citizen-generated evidence regarding the most prominent exposure routes, and we present an example of a future, large-scale CS project assessing plastic exposure via drinking water.

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Keywords
Citizen science, Human exposure, Plastic pollution, Public participation, Microplastic, Crowd sourced data.

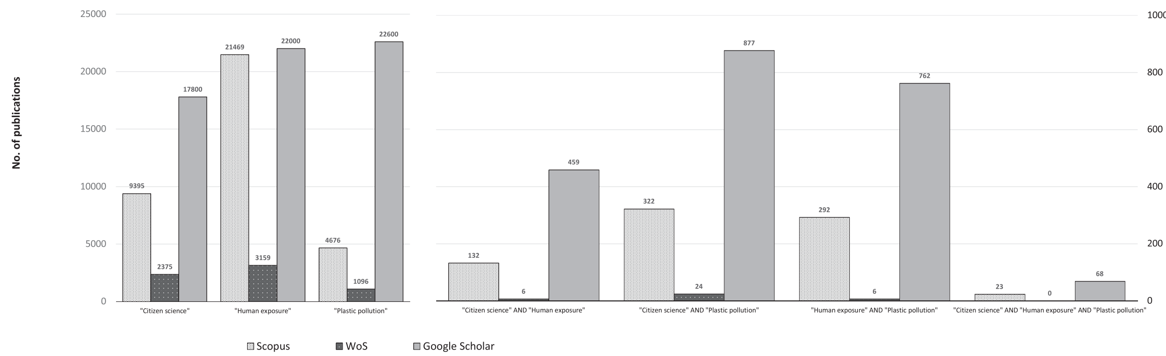
Introduction

Citizen science (CS), a term in the scientific literature, has gained footing in the past decade, yet participatory knowledge generation in the context of informal science education can be traced back to the early years of published science [1]. Whether project objectives are expertly driven or stem from local needs, the core of CS is a bilateral commitment to engaging and empowering people to learn about their surroundings, while creating access to unique data for research purposes. Public participation is particularly embodied in research fields where the power of observation equals that of experimental expertise, including archaeology, astronomy, and ecology [2];, where monitoring is key. In the same way, CS has interdisciplinary potentials in the social sciences [3]. Recently, CS has been acknowledged internationally as a research tool for policy purposes, for example, by the United Nations for measuring the sustainable development goals [4]. Environmental research has profited from large data sources, where a major part of marine plastic debris monitoring is carried out by citizen scientists raising awareness on environmental issues caused by plastic pollution while simultaneously feeding into transnational databases such as the European Environment Agency's Marine LitterWatch database [5–8]. Following the increased focus on plastic pollution and its negative effects on the environment, concerns for human exposure and effects are growing [9];. However, large knowledge gaps with regards to population-wide studies create obstacles for human health risk assessment [10]. Herewith, offering momentum for CS as a large-scale, cost-effective data collection tool to uncover the state of human health exposure to plastic pollution. The present review examines the current literature on how human exposure to plastic pollution has been assessed using CS. We highlight significant research hotspots for implementing CS procedures and suggest how these could be executed with attention to low-hanging fruits and potential pitfalls.

Current state of the art

Literature searches were carried out on three databases, Scopus, Web of Science and Google Scholar to ensure inclusion of all relevant published research for the two years 2019–2021, using the search string ‘citizen science’, ‘human exposure’ and ‘plastic pollution’ separately and in combination as illustrated in Figure 1. CS in relation to plastic pollution yielded the most hits across all three databases, further highlighting the prevalent use of the method in environ-

Figure 1



Literature search across three databases; Scopus, Web of Science (WoS), and Google Scholar, combining the search terms "'citizen science", "'human exposure" and "'plastic pollution". Searches were carried out on 10 June 2021 for the period from 2019 to the present.

mental sciences. Likewise, human exposure to plastic pollution yielded the second-most hits strongly indicating a rising awareness of exposure and effects especially of micro- and nano-sized plastic [9,10]. Interestingly, we found a very limited among of studies addressing human exposure to plastic pollution using CS, Figure 1.

12 articles were found allegeable for examination, and only one of these had applied actual CS in a study involving plastic and human exposure. Namely, Soltani et al. [11], who studied the presence of microplastics in the indoor environment of Sydney (Australia) homes. 32 citizens collected samples over one month period in 2019 and completed a questionnaire on their household characteristics. Samples were subsequently analyzed using a stereomicroscope, a fluorescent microscope, and micro-Fourier transform infrared spectroscopy for their color, size, shape, and composition. Inhalation and ingestion rates were subsequently modeled using the United States Environmental Agency's (US EPA) exposure factors. Uncertainties with regards to data reliance and quality were discussed involving the CS methodology but were conjured away with references to their training program and clear protocols [11]. Relevant for current review [12], scrutinized the current data on microplastics in commercially harvested fish species of North America. The review concludes, for example, that to further advance the knowledge of the occurrence and effects of microplastics in commercial fish, more rapid, and cost-effective sample processing methods are needed. One study included in the review, namely Liboiron et al. 2016, used CS to investigate the ingestion rate of plastic in the Atlantic cod (*Gadus morhua*). Commercial and recreational fish harvesters from Newfoundland, Canada, provided gastrointestinal tracts of their caught cods. A total of 205 gastrointestinal tracts were sampled, which were then subsequently analyzed for plastic in the laboratory. Several studies indirectly address human health issues by use of CS in environmental sampling of marine debris while stating that marine debris constitutes a human health problem in addition to its environmental damages (e.g. [13,14]). CS is suggested multiple times as a means to cost-efficiently access baseline data on a large scale and also as a method to increase public knowledge on sources of human exposure [15–17]. Indirect exposure assessment studies are identified, for instance,the study by Syberg et al. [8] who conducted a national mapping of plastic litter in Denmark using young citizen scientists to determine quantity and plastic types in different nature compartments. These types of mappings may unveil how society functions, people's behaviors and ultimately where and how they are exposed to plastic pollution.

Scientific knowledge gaps

Standing in the way of accurately assessing human risk are the extensive knowledge gaps between plastic pollution exposure and human health impacts, where the three most important might be (i) air pollution, (ii) food contamination and (iii) drinking water contamination [18], scrutinizes the available scientific data on microplastic available for human consumption and highlights the two essential routes of exposure namely ingestion (i.e. food and drinking water) and inhalation (air/dust). The average amount of ingested microplastics by individuals is of a magnitude that leads the authors to call for precautionary measures in handling exposure [18]. This is in accordance with the study by Soltani et al. [11], who urge the need for further assessment studies while stressing that the microplastic exposure appears concerning, especially for infants ($\leq$0.5 years of age). Vianello et al. [19] illustrated the potential direct human exposure from microplastics in indoor air via a Breathing Thermal Manikin and found that airborne microplastics are ubiquitous, which is lately supported by Chen et al. [20]. Dietary exposure of microplastic through the food chain is an emerging research area for which fish and shellfish may be prominent direct sources; however, plastic is also detected in honey, beer, sugar and salt [12,21]. This year, Ragusa et al. [22] were the first to detect microplastics to be present in the human placenta. The study suggests absorption through the respiratory system and the gastrointestinal tract. The World Health Organization has called for future studies on microplastic and human health after the release of a report on current research on microplastic in drinking water [23]. In the same way, two recent literature reviews found very few papers concerning microplastic in drinking water (tap water and bottled water) with 7 and 12 papers, respectively [24,25]. Both reviews stress the need for harmonized methods to achieve high-quality data and a better understanding of exposure and human health risk assessment.

For both air, food and drinking water it applies that (i) knowledge of nanoplastic exposure and effects is very scarce and (ii) the level of exposure may be heavily determined by geographical, demographical, and cultural factors that ought to be accounted for in the research design [9,10,18].

Assessment of human exposure to plastic particles using citizen science

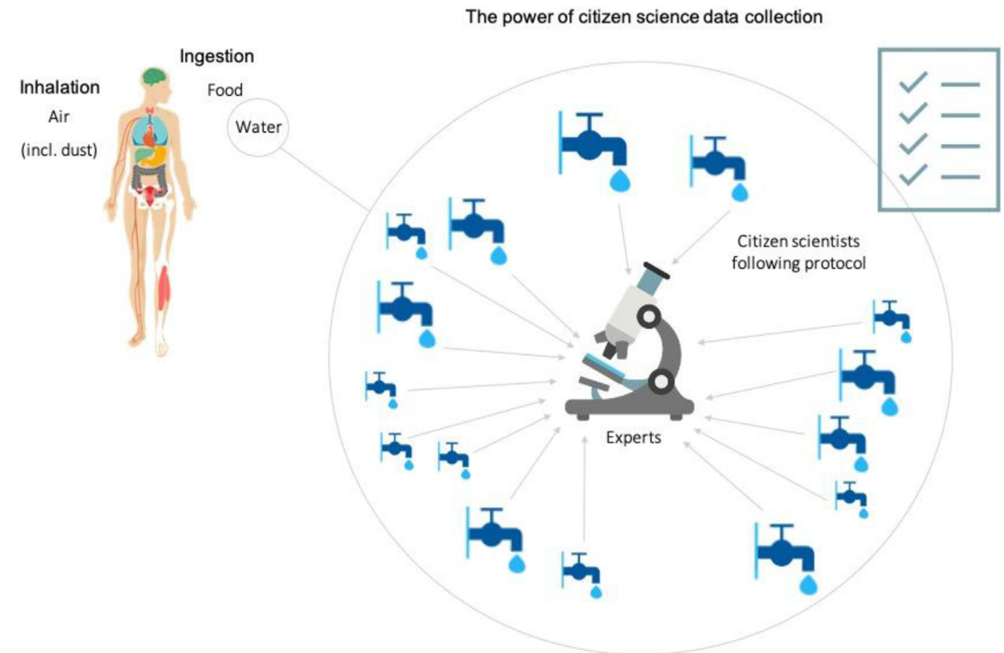
In several ways, CS can contribute to closing knowledge gaps uncovered in this analysis. Some of the highlighted strengths of CS are the ability to encompass low-cost, large-scale, and longitudinal monitoring (see Syberg et al. [8] and Ballatore et al. [26]). When using public participation in data gathering for research purposes, questions about data variation, and general quality arise. In recent years, strong arguments for the validity of CS generated data have been cemented by adopting quality assurance measurements that ensure the quality of CS collected data, including protocols and training programs [27,28].

Another essential aspect of CS projects is to ensure measures that guarantee the health and well-being of participants [29]. Plastic is known to function as a vector for harmful chemical compounds, microorganisms and pathogens, so CS project managers must consider the risk of increased exposure to the very substances which are studied [30]. Rasool et al. [31] revealed that plastic debris collected at Zanzibar was associated with various bacteria, including human pathogens. This risk may be most prominent in studies where participants have direct contact with plastic particles or pieces, for instance, in classic clean-up interventions. Once again, training and thorough protocols can prevent unwanted sample interference including further exposure, as well as sample contamination.

As mentioned by Soltani et al. [11], provided the only example from the past two years with an applied CS approach to data collection of human exposure to microplastic. In this study, atmospheric dust samples from private homes were passively collected in petri dishes provided by the research laboratory, distributed, and collected by mail. Beforehand, the participating citizens completed an online questionnaire about the home environment and were instructed on how to set up and avoid contamination of the samples [11]. The authors noted no uncertainties related to having citizen scientists collect the research data apart from the obvious fact that there was no direct oversight of the collection of samples or completion of the questionnaire. They acknowledged the risk of input errors and incorrect information but highlighted explicit instructions and training to account for this. We have previously mentioned Liboiron et al. (2016), who conducted a CS study collecting gastrointestinal tracts from Atlantic cod (*G. morhua*), as an example of assessing plastic exposure in food sources. As similar studies are needed, low-hanging fruits could be upscaling of already published study set-ups where CS approaches are deemed appropriate, such as [21] examining microplastic contamination of table salts. Laboratory analyses of plastic contamination combined with surveys unfolding metadata on consumption behavior, and so on, could further unveil critical data on human exposure patterns. For plastic pollution exposure through drinking water, CS remains unexploited territory. Monitoring tap water with the use of public participation could be conducted with modified scientific methods such as with simplified steel sampling columns for attachment to water taps as conducted by Strand et al. (2018). An example of a large-scale CS approach applied to risk assessment of drinking water is presented in Figure 2. The citizens in this example will sign up for the project and before the project receive online training while filling out an online questionnaire retrieving personal information and details of the home environment. At project start, the participants receive sampling equipment (filters, transport containers, and cotton attire) and a test guidance protocol by mail. At test termination, the collected samples are returned in the provided transport containers to the experts, which will do the laboratory analysis. In the following period, the participants will be updated on the scientific process and receive the results whenever available.

Future applications hold high promises as CS constitutes a unique instrument to bring together society, science, and policy. With CS, the current evidence base can be strengthened and elevated by the engaged participants as community members and knowledge can be distributed more democratically combined with open science practices, which would ultimately support informed policy decisions [32,33]. A natural way toward incorporating CS in the assessment of human health

Figure 2



Example of a large-scale citizen science approach applied to risk assessment of drinking water — one out of three identified knowledge gaps for human exposure.

risks of plastic pollution would be to build on the already established networks and platforms for CS generated data concerning the environment developed by NGOs. For instance, Earth Day Network, the Wilson center together with the U.S. Department of State launched the 'Earth Challenge 2020', which is a global platform coordinating CS data on plastic pollution and making it accessible and interoperable for the public [34]. Other NGOs are successfully tracking plastic pollution in the environment using CS, including The Ocean Conservancy's underwater debris collection program 'Dive Against Debris' and the 'Marine Debris Tracker' app developed by the National Oceanic and Atmospheric Administration Marine Debris Program and the College of Engineering at the University of Georgia [35,36].

Conclusion

The scarcity of studies on human exposure to plastic pollution using CS methods constitutes an opening for obtaining much-needed knowledge by designing future studies with assistance from the public. Much is known on how to include and benefit from public participation in environmental sciences as seen for monitoring and mapping of plastic pollution. Some are known about the impacts on human health from plastic pollution, including sources of exposure, effects of harmful additives or substances adhered to the plastic particles and the significance of size. Yet very little is published on the same matters with CS approaches applied even though the existing literature calls for large-scale studies — which is a significant prospect of CS. We examined how CS is and can be applied to three specific exposure routes, ingestion through food and drinking water, as well as through respiration and find that including CS methods are an opportune next step for the research field. We emphasize that the benefits of using citizens in such studies are plentiful and can unveil the many contributing factors to everyday exposure. However, it is vital that appropriate methodical provisions and guidance is documented to ensure quality data provided by citizen scientists can help uncover the state of human exposure.

CRediT author statement

Nikoline G. Oturai: Conceptualization, methodology, data curation, investigation, writing – original draft, visualization. **Maria Bille Nielsen:** Data curation, investigation, writing – review & editing. **Lauge Peter Westergaard Clausen:** Data curation, investigation, writing – review & editing. **Steffen Foss Hansen:** Data curation, investigation, writing – review & editing. **Kristian Syberg:** Conceptualization, methodology, data curation, investigation, writing – review & editing, supervision, funding acquisition.

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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.

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