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Assessing the impact of hazardous waste on children's health: The exposome paradigm

D.A. Sarigiannis[a,b,c,*]

[a] Aristotle University of Thessaloniki, Department of Chemical Engineering, Environmental Engineering Laboratory, University Campus, Bldg. D, Rm 201, Thessaloniki 54124, Greece

[b] HERACLES Research Center on the Exposome and Health, Center for Interdisciplinary Research and Innovation, Balkan Center, Bldg. B, 10th km Thessaloniki-Thermi Road, 57001 Greece

[c] School for Advanced Study (IUSS), Piazza della Vittoria 15, Pavia 27100, Italy

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ABSTRACT

Assessment of the health impacts related to hazardous waste is a major scientific challenge with multiple societal implications. Most studies related to associations between hazardous waste and public health do not provide established of mechanistic links between environmental exposure and disease burden, resulting in ineffective waste management options. The exposome concept comes to overhaul the nature vs. nurture paradigm and embraces a world of dynamic interactions between environmental exposures, endogenous exposures and genetic expression in humans. In this context, the exposome paradigm provides a novel tool for holistic hazardous waste management. Waste streams and the related contamination of environmental media are not viewed in isolation, but rather as components of the expotype, the vector of exposures an individual is exposed to over time. Thus, a multi-route and multi-pathway exposure estimation can be performed setting a realistic basis for integrated health risk assessment. Waste management practices are thus assessed not only regarding their technological edge and efficacy but also their effects on human health at the individual and community level, considering intra-subject variability in the affected population. The effectiveness of the exposome approach is demonstrated in the case of Athens, the capital of Greece, where the health effects associated to long term and short term exposure to two major waste management facilities (landfill and plastic recycling) are presented. Using the exposome analysis tools, we confirmed that proximity to a landfill is critical for children neurodevelopment. However, this effect is significantly modified by parameters such as parental education level, socioeconomic status and nutrition. Proximity to a plastics recycling plant does not pose significant threats under normal operating conditions; yet, in the case of an accidental fire, release of persistent carcinogenic compounds (dioxins and furans) even for a short period results in increased lifelong risk, especially for breast feeding neonates.

1. Introduction

Assessment of the health impacts related to hazardous waste is a major scientific challenge with multiple societal implications. Health impacts related to the operation of various waste management options have been investigated up to now only using associations of exposure proxies with specific health endpoints. Characteristic examples are the associations observed between cancer prevalence and the presence of incinerators (Forastiere et al., 2011) or the link between residence proximity to landfills and adverse birth outcomes (Elliott et al., 2001). In addition, several review studies have been made available in the last ten years (Giusti, 2009; Hossain et al., 2011; Porta et al., 2009). The conclusion of these reviews is not definitive, with some difficulties in interpreting data from primary studies due to non-homogeneous design, and lack of accurate exposure information and control of potential confounders.

Although these studies provide some rough evidence of the association between adverse health outcomes and proximity of the population to hazardous waste, they do not provide established mechanistic links between environmental exposure and disease burden. Causality is very difficult to establish in these associations, thus prohibiting decision-makers from exploring cost-effective waste management options with the certainty that their choices will bear the expected improvement in terms of protecting the health of man and the environment. The same occurs for other types of hazardous waste, like the ones disposed of in various environmental media (e.g. air, soil, surface waters) from

* Correspondence address: Aristotle University of Thessaloniki, Department of Chemical Engineering, Environmental Engineering Laboratory, University Campus, Bldg. D, Rm 201, Thessaloniki 54124, Greece.
E-mail address: denis@eng.auth.gr.

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industrial activities resulting in contamination of such media with hexavalent chromium, mercury or PCBs. It is critical to evaluate and, if possible, quantify what is the actual burden on overall morbidity and mortality in the relevant population from exposure to hazardous waste. This would support targeted policy interventions for protecting public health and at the same time help develop the optimal technological options that minimize the cost:benefit ratio.

Given that waste management options are reflected in the type of compounds emitted and the respective health effects, it is important to keep in mind the share of the various waste management options employed across Europe. In the 28 Member States, 28% of municipal waste was recycled, 15% was composted (through aerobic and anaerobic processes), while 26% and 31% were, respectively, incinerated and disposed of in landfill. However, there is a large variability in approaching waste management across the EU; in Greece, landfilling accounts for 80.7%, composting only for 3.7% and recycling for 15.5%, while countries which recently joined the EU are characterized by similar figures. In addition, informal activities around waste collection, sorting, treatment and disposal, and illegal flows and trafficking of hazardous waste represent a serious challenge. While the extent of the problem is largely unknown, some data and anecdotal evidence suggest that such activities are not uncommon. Informal waste management activities can provide income and support the livelihoods of families and local communities. Yet, the price in terms of direct health impact for those involved is likely to be very high. Severe questions of health inequality and environmental justice arise, as the people engaged in informal waste management are socially disadvantaged in other respects. A characteristic example in Europe is the Roma population, who have been repeatedly reported to be involved in informal waste handling in order to recover high-added value metals such as copper (WHO, 2016).

The complexity of assessing the health impact of hazardous waste is compounded by the variety of waste types, roughly categorized as (a) municipal, (b) agricultural, (c) e-waste, (d) hospital and (e) industrial, which in turn are associated with a broad range of contaminants, such as dioxins (PCDDs) and furans (PCDFs), toxic metals (Cd, As, Cr(VI), Hg), volatile and semi-volatile organic compounds (VOCs and SVOCs), polyaromatic hydrocarbons (PAHs), hydrogen sulphide (H_2S), particulate matter, methane (CH_4), pesticides, phthalates, and PCBs. Exposure to these compounds is highly variable and the waste management option selection is critical. For example, plastic waste management and the associated risks to human and ecosystem health are recognized as key issues in sustainable waste and resource management worldwide. The plastic crisis, has induced many jurisdictions to pose bans on use of plastic bags and enhance plastic recycling in the respective municipal waste management systems. Still to date, however, landfilling remains the most common waste management practice in countries like Greece, despite enforced regulations aimed at increasing recycling, pre-selection of waste and energy and material recovery. Regarding plastic waste, a lot of studies have exemplified the adverse effects of low-biodegradability plastic material on the health and sustainability of natural ecosystems, disrupting the food web and inducing endocrine disruption and eventually gender alteration (feminization) in sensitive species such as fish. This effect in turn endangers biodiversity and ecosystem sustainability. Yet, there is a much more limited number of studies focusing on the adverse human health effects of plastic products and waste, the ubiquitous nature of plastic material notwithstanding. On the other hand, waste recycling is one of the main cornerstones of the EU waste management strategy (Farmer et al., 2015). It offers many advantages contributing to the circular economy and the sustainable and efficient use of natural and man-made resources. However, waste recycling facilities may be associated to adverse health outcomes in the aftermath of industrial accidents involving the inadvertent generation of toxic chemicals and their release into the environment. One of the major concerns associated with accidents in plastic recycling plants are emissions of dioxins and furans (PCDDs/PCDFs). These compounds are characterized by a high carcinogenic potency (Cole et al., 2003). Because PCDDs/PCDFs appears to be acting like a potent and persistent hormone agonist, it appears reasonable to incorporate mechanistic information on receptor-mediated events in risk assessments for TCDD. This information may be obtained from steroid receptor action and from molecular data on the Ah receptor (Lucier et al., 1993). This receptor based toxicity, results in sex-dependent sensitivities, due to a set of sex-specific PCDDs/PCDFs -responsive genes. However, the estimation of the additional probability of cancer due to the additional exposure burden is quite difficult (Dong et al., 2016). A major obstacle is that an elevated short term external exposure associated to the accidental event, must be translated into long term risk estimates. Considering the significant persistency and bioaccumulation of PCDDs/PCDFs in human body, the use of biokinetic models for assessing the actual internal dosimetry of this complex mixture is of importance. TCDD pharmacokinetics is relatively well understood in adult humans (Kerger et al., 2006; Michalek and Tripathi, 1999; Milbrath et al., 2009). However, the impact of pregnancy and lactation on the elimination of TCDD and other dioxins is not clear (Emond et al., 2016). Accidental fires in plastic industry comprise one of the major events resulting in contamination of various environmental media to PCDDs/PCDFs of the surrounding area; air samples collected in the 5th day of the event were found to contain over 1000 pg/m^3 TEQ (toxic equivalent quantity) of dioxin, exceeding background levels by 2500 – 25,000 fold (Fernando et al., 2014).

Overall, the importance of health effects of waste management and disposal activities has also been extensively recognized by the World Health Organization (WHO), where the need for multisite cohort studies and refined current risk estimates has been highlighted (WHO, 2016). Based on all the above and accounting for the methodological difficulties for a comprehensive assessment of wastes on health, the current study describes how the exposome can improve the efficiency of waste management strategies. The ultimate objective is to enable cost-effective prevention strategies that curb hazardous exposures with precision at the individual level and only limited uncertainty at the community level. This is demonstrated in the case of Athens, where the chronic effects of both short and long term exposure to waste management environmental releases is addressed.

2. Methodology

2.1. The exposome approach versus the existing environmental – health impact assessment paradigm

In principle, current environmental – health impact assessment paradigm relies on the quantitative assessment of exposure to waste management site emitted compounds and on the dose response relating these hazards to the exposure vector. In some cases, exposure proxies are used, such as the proximity to waste management site, further associated to the health endpoints of interest (e.g. congenital anomalies close to landfilling sites), without any further clarifications on the type of compounds that are relevant or the actual magnitude of exposure. These methods, although have provided significant evidence on the associations between the proximity to waste management facilities and effects on public health, yet, they do not provide information on the causality of the observed health effects. Key issues that must be addressed pertain to (a) refinement of exposure assessment, i.e. understanding the additional burden of exposure related to waste management facilities and (b) how this exposure burden is translated into biological responses that will eventually result is adverse health outcomes. Based on the above, introduction of the exposome concept in the waste management and human health arena, aims to provide the additional insights that are needed towards this direction (Fig. 1).

The exposome (Wild, 2005) represents the totality of exposures from conception onwards, including the exogenous and endogenous exposures and modifiable risk factors that predispose to and predict