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Environmental Health Inequalities under the Skin

Looking at Human Biomonitoring through an Environmental Justice Lens

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"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail" – Abraham Maslow 1966

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Chapter 1 General introduction

1.1 Preface

Parma, March 11th, 2010. In this North-Italian city – famous for its parmesan cheese and prosciutto, as well as for its poor air quality and industrial density – 53 European governments signed the 'Parma Declaration' at the Fifth Ministerial Conferences on Environment and Health organized by WHO Europe. The Declaration, for the first time, emphasized two of the focal points of my thesis: socioeconomic inequalities are considered one of the key environmental and health challenges of our time, and the potential of human biomonitoring as a tool for assessing environmental health risks is recognized (WHO, 2010). Following the Parma conference, intensive work was undertaken to collect country-specific data on environmental health inequalities and coordinating initiatives on human biomonitoring. The former led to the publication of the first European environment and health inequality assessment report (WHO, 2012), which indicated that inequalities and injustices related to housing, injuries, noise exposure and access to green space exist in all regions, even though countries may have different patterns of exposure and risk. The report was updated with broader empirical data in the second assessment report (WHO, 2019a) in which I co-authored a chapter on social inequalities in chemical exposure. The latter led to the publication of a report summarizing available human biomonitoring data in the European Region and describing the progress to develop detailed protocols to assist interested countries in a human biomonitoring survey (WHO, 2015). This engagement led to large-scale European biomonitoring projects, reflecting the pioneering role of the Flemish human biomonitoring program.

Although the Parma Declaration emphasizes the importance of both environmental justice and human biomonitoring, the two issues were not linked. But as human biomonitoring gains social and political prominence and the need for scaled-up surveillance programs becomes more apparent, there is momentum to connect a sociological analysis of inequality and justice to this highly technical domain of human biomonitoring. My dissertation is an attempt to integrate a social justice and inclusion agenda into human biomonitoring research in Flanders.

It may be less obvious, but human biomonitoring and environmental justice have much in common. First, both concepts originated in the US, before expanding to a global scope. Second, they both are essentially anthropocentric concepts, meaning they are human-centered and not nature-centered. Third, they can both be considered boundary concepts, located at the intersection of science, policy and society. Finally, on a more rhetorical note, both concepts are to a certain extent unveiling. Human biomonitoring measures the invisible chemical environment inside our bodies. It captures low-dose exposures to pollutants that are imperceptible to the naked eye. Similarly, social stratification and inequality are often the result of invisible power structures and discriminatory forces. Environmental justice research is about revealing hidden exposure disparities and giving voice to powerless and vulnerable groups that usually stay undetected in traditional risks assessment.

Yet both concepts developed to a large extend within different disciplinary traditions and cultures of research. Or to use the catchphrase by the Catalan physician and epidemiologist Miquel Porta: *"social class and environmental pollutants seldom talk to each other"* (Porta et al., 2008, p. 371). My research tries to bridge these concepts by investigating mechanisms and patterns of social inequality in human biomonitoring research in a twofold manner. First, I look at human biomonitoring as an empirical data source to detect how social and biological factors interact and "get under the skin" to influence health in an unequal way. Second, I look at human biomonitoring as a research infrastructure and experiment with innovative ways to make research practices more representative, more inclusive and more participatory to diverse social groups.

The introductory chapter of this dissertation is structured as follows: Section 1.2 places my research topic in a broader theoretical approach by bringing together concepts and frameworks from three interrelated fields of science: environmental health, environmental inequalities and health inequalities. Next, section 1.3 introduces the objectives and research questions. Chapter 1.4 provides an overview of the data collection and methods and an outline of the dissertation.

1.2 Theoretical framework

Intuitively, health, environment and social inequality are inextricably linked at both global, local, and personal levels. But scientifically, the synergies and connections between these three concepts have not often been explored in recent decades, due to the division of scientific knowledge into disciplinary silos. For example, some of the most influential books on social inequality, such as Richard Wilkinson and Kate Pickett's 'The Spirit Level' or Thomas Pikkety's 'Capital in the Twenty-First Century', did not include an environmental or ecological dimension. And conversely, pioneering ecological works such as those by Rachel Carson and Naomi Klein did not incorporate equality claims into their discourse.

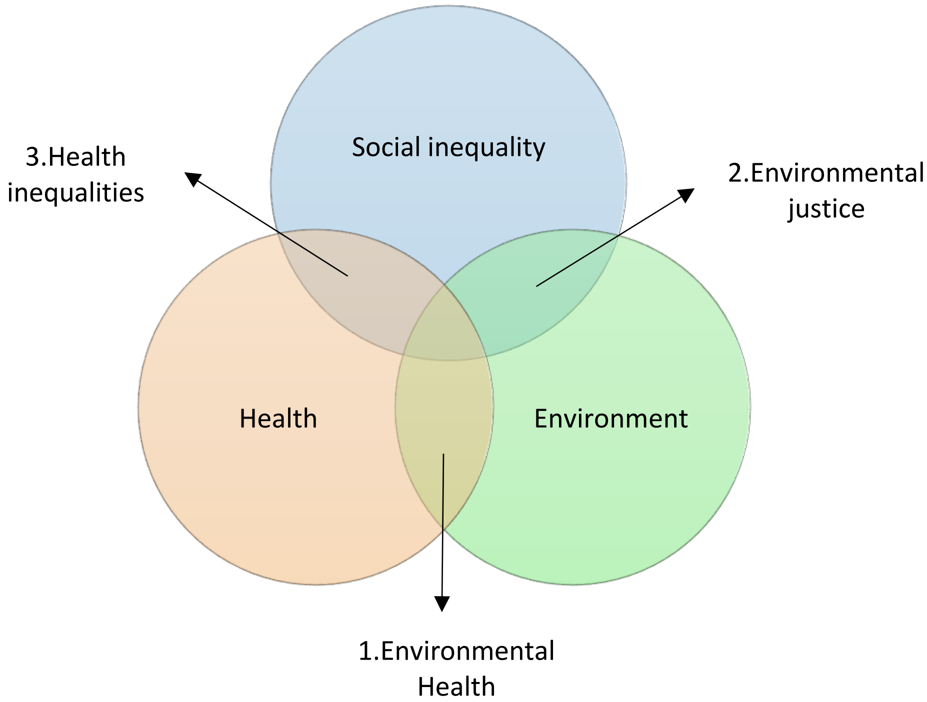
Recently, however, the fields are growing more convergent and the complex relationships between health, inequality and environment are being more thoroughly examined, for example in the emergence of new approaches in literature such as 'ecological public health' (Lang & Rayner, 2012), 'environmental health justice' (Masuda et al., 2010) or 'just sustainability' (Agyeman & Evans, 2004). Notable, also the above-mentioned authors have recently explored these synergies further: Pikkety extended his analysis to the global inequality of carbon emissions in 'Carbon and inequality: from Kyoto to Paris', and Naomi Klein in one of her latest books 'On Fire: The (Burning) Case for a Green New Deal' (2019), positioned the climate crisis more in relation to the unequal distribution of wealth. And where 'The Spirit Level' focused on the macro effects of inequality on the wellbeing of societies, the successor of Wilkinson and Pickett is called 'The Inner level' and focused on the micro effects of inequality on individuals in terms of biophysical mechanisms such as stress.

My dissertation is located at the intersection of these three areas of scholarly inquiry. Therefore, it is useful and necessary to first explore each of these areas.

- Environmental health; within the field of biomedicine and exposure science.
- Environmental justice; within the field of social geography and environmental sociology.
- Health inequalities; within the field of social epidemiology and public health.

For each area of research, I introduce some central concepts to better situate my research and construct the framework of my dissertation. I explain the concepts through a brief overview of their history and some notable features. To structure the section, I use the figure below.

Figure 1: Situating my research topic within three interrelated scientific perspectives



This theoretical section can be read as three separate narratives, each looking at the complex matter of unequal exposure to chemicals from a different scientific perspective. I start with the emerging field of environmental health (section 1.2.1) to introduce the concept of human biomonitoring. In Section 1.2.2, I elaborate on environmental inequalities and situate biomedical research on internal exposure to chemicals within the expanding scope of the environmental justice discourse. Section 1.2.3 addresses the issue of health inequalities. Here, I discuss the recent biosocial approach that places environmental and biological factors within a health inequality frame.

1.2.1 Environmental health

As early as the fifth century BC, Hippocrates made the connection between environment and health by stating: *"If you want to learn about the health of a population, look at the air they breathe, the water they drink, and the places where they live".* Environmental health is broadly defined by the World Health Organization as "those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social, and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations" (WHO, 1992). The first part of the definition refers to the different components of environmental health. This is briefly reviewed in section 1.2.1.1 from different scales and with special emphasis on the link between chemical pollution and inequalities. The second part of the definition refers to the environmental health science and policy through monitoring and control activities. These practices are addressed in section 1.2.2.1 as part of the environmental health paradigm, with a focus on human biomonitoring. Both sections mainly aim to better delineate the scope of the dissertation.

1.2.1.1 *Scaling down pollution inequalities: from countries to cells*

According to the Lancet Commission on pollution and health, pollution is the largest environmental cause of disease and premature death in the world today, responsible for 16% of all deaths worldwide, three times more than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence (Landrigan et al., 2018). Airborne particulate pollution and greenhouse gasses from fossil fuel combustion are major forms of global environmental pollution, with well documented health effects and strong relationships with climate change. In 2016 air pollution was the second largest risk factor causing non-communicable diseases like cardiovascular diseases, cancers and chronic respiratory diseases globally, just after tobacco smoking (Pruss-Ustun et al., 2019). Water and soil contamination from littering and waste are another major pollution source, leading to severe environmental degradation and human health risks.

The Lancet Commission signals that more than 90% of pollution-related deaths occur in low- and middle-income countries, indicating that environmental pollution is distributed unequally across the world and disproportionally affects the global south compared to the global north. These inequalities are presumably manifestations of what political economists and activists call 'ecological distribution conflicts' (Martinez-Alier et al., 2016) or 'ecologically unequal exchanges' (Givens et al., 2019): wealthier and more powerful global north countries experience benefits of environmental resources while displacing and outsourcing the environmental costs and burdens to global south countries. Inequitable production and consumption patterns produce environmental degradation and human health risks elsewhere (Gupta et al., 2019). This is what I call the first scale of environmental health inequity, the unequal and unfair distribution of environmental goods and bads between countries on a global scale, also called global environmental injustice. Studying these forms of inequality requires a geopolitical and economic focus and is beyond the scope of my thesis.

In the European region in general, and in Flanders in particular, the overall quality of the environment has improved considerably over the past decade but pressing environmental health challenges remain and even increase in recent years (EEA, 2013, 2019; VMM, 2012). These problems include the high concentrations of particulate matter caused by the transport and energy sector, pollution of surface water with nitrate, phosphate, and persistent pollutants such as PCBs, and the acidification of soils due to intensive agriculture. Also, there are new emerging environmental issues like noise and light pollution whose harmful effects are increasingly been recognized. The 'Environmental Burden of Disease in European countries project' (Hänninen et al., 2014) calculated that about 3 to 7% of the annual burden of disease in six European countries (including Belgium) is associated with nine selected environmental risk factors, such as particulate matter, secondhand smoke, traffic noise and radon.

It is also increasingly understood that 'overall' indicators of improved environmental quality are not sufficient to assess exposure and potential health impacts across the population (EEA, 2013, p. 14), because also within countries exposure and disease caused by these forms of pollution are most prevalent among minorities and the marginalized (Landrigan et al., 2018). The socio-spatial distribution of environmental and health indicators in various urban and industrial regions in Europe revealed disproportionate exposure risks in those neighborhoods and communities that also face higher social risks from poverty, unemployment, crime, and racial segregation (EEA, 2018; WHO, 2019a). So, in addition to the global inequality faced between countries, there is a second scale of environmental health inequality within countries: the unequal distribution of environmental quality and proximity to pollution sources at the local level. Studying these forms of inequity requires a socio-geographic analysis and this is likewise not within the scope of my thesis.

A specific form of environmental pollution that is a major challenge – and the focus of my dissertation – is chemical pollution: the (diffuse) releasing of synthetic chemicals into the living environment. The Lancet Commission describes chemical pollution as a great and growing problem because the production volume of synthetic chemicals is still increasing and the effects on human health are poorly defined and almost certainly underestimated (Landrigan et al., 2018). A recent comprehensive inventory of chemicals on the global market revealed over 350.000 chemicals and mixtures of chemicals in use, up to three times as many as previously estimated and with substantial differences across countries and regions (Wang et al., 2020). In Europe alone, thousands of these new chemicals enter the market each year as flame retardants for building material or to manufacture plastics products, as additives for the food and pharmaceutical sector, pesticides and fertilizers for the agriculture, or as components of personal care products and consumer articles[1]. These new chemicals come on top of the 'legacy chemicals', pollutants thar are being banned or phased out (sometimes decades ago) but persist in the environment and the food chains and can continue to cause problems for many decades or even centuries (EEA, 2019, p. 236). Recently it was

[1] See for example: https://chemicalsinourlife.echa.europa.eu

found that this mixture of legacy chemicals, such as cadmium and pesticides, as well as new chemicals, such as plastic components, can be found in the bodies of European citizens (Lamkarkach et al., 2021; Lange et al., 2021).

Rachel Carson's Silent Spring first documented the pervasive and widespread use of chemicals and the impact on human health and wildlife as early as 1962, stating that "every human being is now subjected to contact with dangerous chemicals, from the moment of conception until death" (Carson, 1962, p. 15). Carson focused on the use of the synthetic pesticide dichlorodiphenyltrichloroethane (DDT) and the damage it caused on births and animal life. Other historical examples of industrially produced chemicals with (later discovered) health impacts include asbestos, polychlorinated biphenyls (PCBs), and diethylstilbestrol (DES). More contemporary examples are endocrine disruption chemicals (EDCs) like phthalates and perfluoroalkyl chemicals (PFAS) in consumer products.

The public has become increasingly aware of the presence of these harmful chemicals in the everyday environment. Research on risk perception shows the health effects of chemicals to be a source of concern for European citizens (European Commission, 2017).

Chemicals - in concentrations to which the general population is exposed - should (in most cases) not be viewed as rapid poisons with acute health consequences, but rather as long-term risk factors for a range of diseases (Pearce, 2018). For example, it is known that chemical exposure can have a lifelong impact on several disease patterns and health effects through very subtle neurological, endocrine, immunological and genetic influences, even at extremely low doses of exposure. Also, the importance of exposure timing has been recognized. During specific vulnerable life stages, called 'critical windows of exposure' (Selevan et al., 2000), the human body is more sensitive to chemicals than average. The best-known example of such a sensitive phase is the prenatal period (Grandjean et al., 2008; Wang et al., 2016), but recently also the puberal and adolescent age is given attention as a critical life stage due the changes in the endocrine system.

In addition to biologically sensitive populations, there are also socially vulnerable groups that are more exposed or more vulnerable to adverse health effects of chemicals. Toxicological and biomedical studies have identified exposure patterns that vary widely by socioeconomic position and ethnic background, for example, with respect to toxic metals, pesticides, or chemicals found in personal care products (Belova et al., 2013; Nelson et al., 2012; Nguyen et al., 2020; Tyrrell et al., 2013). Other studies have shown how these disparate chemical exposures are linked to early health effects and can become drivers of health inequalities, for example in the case of the impact of lead exposure on neurodevelopment in small children (Bellinger, 2008), or the contribution of endocrine disrupting chemicals to metabolic disease inequalities (Ruiz et al., 2018). This is the third scale of environmental health inequality, the unequal internal concentration of chemical exposure and biological effects at the individual level. This constitutes the subject of my doctoral thesis.

Table 1: Three scales of inequality in environmental health (EH)

	Level of analysis	Main discipline	Research topics
First scale of EH inequality	Global: between countries	Political economy	Climate change, waste recycling
Second scale of EH inequality	Local: between regions and neighborhoods	Social geography	Traffic pollution, water quality, industrial pollution
Third scale of EH inequality	Personal: between groups of individuals	Toxicology, biomedicine	Indoor pollution, chemical exposure

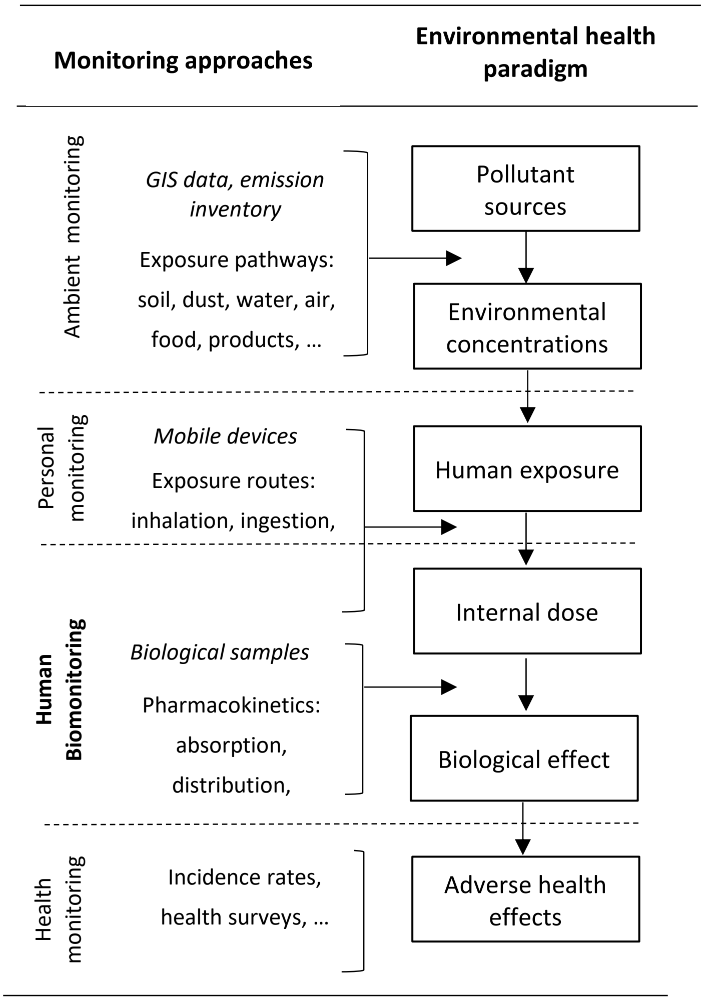
1.2.1.2 *Monitoring environmental health risks*

The essential model to study and assess environmental health risks at the local and personal level is called the 'environmental health paradigm' (K. Sexton, 1997) or the 'Source–Exposure–Outcome model' (Guidotti, 2018). It is presented in a simplified manner in Figure 2. To the left, the different monitoring approaches are given for each step of the model.

Pollutant sources include local point sources with a distinct spatial pattern, such as incinerators and factory plants, as well as diffuse sources from many places (e.g. pesticides from agriculture, NO2 from traffic, …), which release chemical substances in different environmental media such as water, soil, air or food. The substances present in these media are labeled environmental concentrations. Human contact with these substances is quantified in terms of exposure, which is a function of concentration of the specific pollutants and the time when people are subjected to them. Through different exposure routes, humans take up a certain amount of the pollutant, often termed as the internal dose or body burden. Some of that internal dose is excreted by the body, but with long-term or high exposure, some is also absorbed into the organs and into adipose tissue. There it can produce early biological effects such as DNA-damage or hormonal distortion. When these biological effects persist, they can eventually cause adverse health effects such as asthma, cardiovascular disease, and cancer. Different technologies are available to measure and monitor exposures in each step of the model.

However, the traditional cause-and-effect paradigm is increasingly criticized for being too mechanistic and simplistic and overlooking information to place environmental health risks in a broader social, economic, geographic, and cultural context (Briggs, 2008; Guidotti, 2018). One important way of contextualizing this environmental health paradigm, and the focus of my thesis, is to complement it with key elements of the environmental justice framework. But before we explore this in more detail in section 1.2.2, we will first take a closer look at the technique of human biomonitoring and its scientific applications in Belgium and around the world.

Figure 2: The environmental health paradigm



Source: modified from Sexton et al. 1997 and Angerer et al. 2007

1.2.1.3 *Human biomonitoring*

Human biomonitoring (HBM), a contraction for biological monitoring in humans, is a scientific technique for assessing internal exposures to environmental chemicals. It is based on the use of biomarkers, measurable indicators of the concentration of chemical substances, their metabolites or reaction products in human tissues or specimens, such as blood and urine (Needham et al., 2007). HBM provides a direct and integral measurement of exposure and disposition from all exposure routes (Angerer et al., 2007; Needham et al., 2007). Blood and breast milk are usually used for the analyses of persistent and long-termed chemicals, such as organochlorine pesticides, PCBs, dioxins, brominated flame retardants, and metals, that stay in the body for a very long period and can accumulate in blood or fat tissue. Urine, on the other hand is usually used for analyses of non-persistent chemicals such as bisphenol A (BPA), parabens, phthalates, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs), that reflect more temporal and short-termed exposures. Hair, teeth, nails and salvia are also used in HBM research because of the non-invasive nature, but to a lesser extend due to the lack of standard quality assessment tools.

Although human biomonitoring is a contemporary method which emerged out of recent developments in chemistry and biomedicine, scientists have been measuring chemicals in human bodies since the late 19th century (Creager, 2018). It was first applied about 140 years ago as a diagnostic method in clinical chemistry to monitor the urine of rheumatic patients being treated with large doses of salicylic acid, the precursor of aspirin (Sexton et al., 2004). In the 1920s and 1930s, techniques were further developed within occupational medicine in the US to measure the uptake of chemicals in human fluids and tissues of industrial workers. The determination of lead and benzene metabolites in blood and urine are early examples of human biomonitoring of workplace exposures (Angerer et al., 2007). These monitoring efforts were increasingly set up in factories to control hazards and poisoning in the workplace, or to maintain what has been called 'industrial hygiene' (Sellers, 1997). Because this new scientific practice developed in parallel with the germ theory, it adopted what Linda Nash (2008) called 'a bacteriological model of bodies'. Chemicals were understood to be related to microbes, meaning that only certain agents were capable of causing a specific disease once they entered the body with a certain threshold (Nash 2008: 654). So not the broader environmental context was the initial focus, only a specific chemical exposure at a measurable level.

After the Second World War, human biomonitoring extended from occupational medicine and industrial toxicology to public health and was used in targeted programs to assess population-wide chemical exposure, due to mounting concerns about the health risks of lead in urban residents and pesticides (including DDT) in rural residents (Washburn, 2013). Powerful analytical techniques began to enter the laboratories in the 1960s and 1670s, providing the possibility to determine low concentrations of a larger number of chemicals in human tissues. This is important since research found that – contrary to industrial hygienist's beliefs in biological thresholds below which the body can absorb and adjust to exposure – even at very low concentrations, chemicals can trigger biological effects potentially leading to latter diseases. This paved the way for a growing number of HBM studies in a variety of settings, ranging from clinical trial experiments to sustained national and international monitoring programs. Hendrick and Farquhar (2010, p. 4) identified three broad models for biomonitoring:

I. a laboratory-initiated model that initiates biomonitoring projects in a clinical context to answer specific research hypotheses with human specimens;
II. a community-response model where biomonitoring is reactively used to respond to local concerns about exposure or emergencies with chemicals;
III. a surveillance-based biomonitoring model to estimate nationwide reference values for certain chemicals or to track trends in population exposure.

Some authors supplement a fourth model, based on political advocacy, that uses biomonitoring to mobilise public attention and influence agenda-setting around environmental health risks, often in the context of environmental justice (Daemmrich, 2008; Washburn, 2014).

This classification is important because it shows the exceptional positioning of my research area: I analyze elements of environmental justice and inequality in a government-driven surveillance HBM study in Flanders, rather than in a – more common - advocacy model of HBM.

The first surveillance biomonitoring programs commissioned by governmental agencies in the 1980s and 1990s, both in the US and Europe. The most comprehensive HBM program is the US National Health and Nutrition Examination Survey (NHANES), collecting biomonitoring data from nationally representative samples of around 5.000 to 6.000 people in two-year cycles since 1999. In NHANES, questionnaires are conducted through face-to-face interviews in respondents' homes. Human samples and health measurements are performed in specially designed and equipped mobile centers.

HBM initiatives have been started in several European countries from the 1980s onwards. The German Environmental Survey (GerES) is the longest running program in Europe and has been periodically conducted in Germany since the mid-1980s by the German Federal Environment Agency (UBA). Biological samples are supplemented with monitoring of the participant's environment (e.g., analyses of tap water, house dust, and indoor air). To document background information about exposure pathways and determinants, standardized interview-based questionnaires are conducted (Becker et al., 2007; Schulz et al., 2007). In addition to Germany, biomonitoring programs have been started in Scandinavian countries, France, Spain, the Czech Republic and also in Belgium (Flanders). The Flemish biomonitoring program started in 2002 and is still ongoing. I describe this in more detail in the data and methods section (section 1.4).

Since the beginning of the 21st century, human biomonitoring is called the 'golden standard' for risk assessment of environmental pollution (Sexton et al., 2004). Best known example of the policy impact of large-scale biomonitoring programs is the phasing out and final ban of leaded gasoline after documenting decreasing blood lead levels in the general US population (Creager, 2018). In Europe, HBM data helped frame the early public debate around the REACH regulation for chemicals (Kolossa-Gehring, 2012) and more recently, HBM data were used to strengthen risk assessment of EU restriction regulation for phthalates and bisphenol A as plasticizers in consumer products (Louro et al., 2019).

During the last decade, highly advanced HBM techniques emerged at the crossing of affiliated scientific fields, such as neuropsychiatry and molecular biology, to measure and quantify the totality of environmental exposures from the prenatal period throughout the life course. This is sometimes called the 'exposome' and the related tools are called 'omics biomarkers', for instance DNA profiling and gene expression (Siroux et al., 2016). A technological development associated with these advancements, is the rise of biospecimen banks (or biobanks) where biological samples can be stored for later analyses. Although the scientific opportunities seem endless (Time Magazine termed biobanks one of the ten ideas that are changing the world today), there is considerable debate around the ethical consequences, for example with respect to informed consent or report back protocols (Caulfield & Murdoch, 2017).

With the shift in focus towards life course exposure to chemical mixtures also came the proposal of a new concept called 'environmental hygiene' (Bourguignon et al., 2018). In response to the twentieth century implementation of industrial and anti-microbial hygiene, a more global and holistic strategy of physical-chemical hygiene is needed to protect against lifelong consequences of environmental hazards. Central in the environmental hygiene strategy is preventive intervention against different hazardous factors and exposures as a whole and recognition that specific lifestyle, behaviors and environmental settings may lead to higher risks in vulnerable groups such as the unborn, children or socio-economic deprived subpopulations (Bourguignon et al., 2018, p. 5).

1.2.1.4 *Pollution gets personal*

The popularity of HBM within risk assessment also attracted the attention of social scientists, resulting in a growing body of literature on the social impact of human biomonitoring. In particular, the communication of results to participants and the public became a (controversial) topic of research. Unlike environmental or epidemiological research (which only generate group-level data), HBM research also provides data on participants' personal results. HBM thus has the ability to make pollution personal. The controversy among scientists is whether this should be considered a downside or a benefit. Morello-Frosch et al. (2009) identified three frameworks for reporting-back individual biomonitoring results: (1) a clinical ethics framework, which is expert-driven and only report-back to participants when results exceed clinical action levels. The argument is that communicating scientific uncertainty would lead to unnecessary fear and anxiety and might lead individuals to engage in harmful or ineffective prevention actions, such as ceasing breastfeeding after learning about chemicals present in their breastmilk (LaKind et al., 2008). (2) a community-based participatory framework in which decisions about communicating results are collaborative taken by scientist and community members. The idea is that by learning about their exposure, HBM results can empower participants and communities. From an ethical point, all results should be communicated to the community (right-to-know principle). (3) a citizen-science data-judo framework in which communication is shaped primarily by policy goals to increase public awareness and improve chemical regulation.

A separate research question for social scientists is how individuals understand and cope with their results. Several qualitative studies showed how entering in a human biomonitoring study has a significant impact on participants' perception (Altman et al., 2008; Larrea-Killinger et al., 2017; Lind et al., 2007; Washburn, 2014). For example, because it recasts everyday objects (such as cosmetics) or life-sustaining activities (such as breathing and eating), and not just working or living in high polluted areas, as sources of chemical exposure and control (Washburn, 2014, p. 341). This is what Altman et al. (2008) called the 'exposure experience', the personal, ambiguous experience of living with chronic pollutant exposures. This experience is science-mediated because it depends on the lay understanding of scientific data and not the direct experience of an environmental problem, as opposed to the illness-experience' (Altman et al., 2008).

1.2.1.5 *Risk society and environmental health*

If we want to consider the above-mentioned environmental health risks from a broader sociological framework, we inevitable come across Beck's theory of the risk society. Without going into detail about the different aspects of this theory, it seems interesting to briefly zoom in on the class analysis because this seems to contradict the hypothesis of the environmental justice discourse.

According to Ulrich Beck (1992, 2006; Ekberg, 2007) we are now living in a second, reflexive age of modernity, characterized by an omnipresence of risks such as climate change, air pollution, terrorism and nuclear waste. These risks should no longer be considered externalities or side-effects but are an inherent and uncontrollable part of our technoscientific way of life. Beck makes a distinction between the class-based distribution of wealth and goods in the first modernity and the egalitarian basis of the distribution of risks and bads in the second modernity or risk society. He refers to the 'boomerang effect', to stipulate that even the wealthiest, who have benefited most from the production of risks, are unable to escape these risks. Risks therefore have a democratizing and equalizing effect, captured in the famous phrase that *"hunger is hierarchical, smog is democratic"* (Beck, 1992, p. 36).

Several critiques argue for a rejection of his analysis of the role of class in society because it is not based on empirical data or because it is not theoretically convincing (Atkinson, 2007; Mythen, 2005). Others, such as Dean Curran (2013; 2018b), provided a reconstructed theory with a redressing of three elements that Beck underemphasized in his analysis and that are critical to environmental justice: the gradation of risks, the calculability of risks and the unevenness of impact of risks. First, Beck makes little distinction in gradations of particular risks and captures all under the account of catastrophic potential. But according to Curran, there is no reason to believe that the effects of these risks will be realized in a uniformly (catastrophic) manner. This uniformity precludes to possibility of stratified forms of risk within a given region across social and racial fault lines, as has been shown by environmental justice research. Moreover, chemical exposure in particular often involves subtle, gradual and unspectacular forms of risk that only lead to health damage over time and for certain vulnerable groups. Nixon (2011) refers to this in the context of environmental justice as 'slow violence'. Second, Beck argues that risks are incalculable and therefore surrounded by radical uncertainty. But, as with the previous point, this applies only to the long-term uncertainty associated with risk assessment of an entire society and does not necessarily apply to specific individuals who can make short-term decisions to better protect themselves against risk. Curran stated that *"overall uncertainty should not be equated to radical uncertainty for each individual, especially for the wealthy who always have the power to modify their situation so as to occupy social-material positions that minimize hazards as these unfold"* (D. Curran, 2013, p. 50). Third, for Beck injustice in the risk society is a product of the fact that the production of risk and being subject to risk are spatially and temporally decoupled (Beck, 2010, p. 173). According to Dean (2013, p. 51), this sole focus on regions and international imbalances neglects intra-regional differentiation in risk vulnerability as it implies a merely physical geography of vulnerability, rather than a social geography of vulnerability.

In summary, the criticism seems to point to the fact that risk society is primarily a theory that can elaborate on macro-level trends, such as the statement observation that no one, (regardless of their social position), can escape systemic risks, but is unable to explain the persistence of more local and personal situations of unequal distribution and recovery of risks by social class.

Against Beck's apparent rejection of the importance of social class, Curran places his reconstructed theory of 'risk-classes' in which risk does not replace pre-existing class inequalities associated with 'goods' but is considered an additional site of structuration of class inequalities (Curran, 2018a, 2018b). By emphasizing the positional and relational nature of risk distribution, Curran puts forward the concept of 'risk-classes', defined as *"[…] groups that differ based on their risk positions in terms of differentials in the distribution of risks and in the benefits emerging from the processes that systematically produce risks"* (Curran, 2018b, p. 303). According to Curran, risk positions interact with class positions to increase and intensify social inequalities, but they are not always equivalent to each other and thus may follow different processes and patterns. This is an important hypothesis that is further discussed in the literature around environmental justice in the next section.

1.2.2 Environmental justice

In this section, we again examine the relationship between chemical exposure and social inequality, but now with an emphasis on how this relationship is situated within the growing scope of the environmental justice discourse.

1.2.2.1 *A brief history of the environmental justice movement*

Although we can go back to the human ecology approach of the Chicago school in the 1920s and the pioneering research of British sociologist Charles Booth to explore the interactions between poor social and environmental conditions, the first systematic concerns for inequity in environmental burdens is traced back to the environmental justice movement. The acclaimed birthplace of this movement is Warren County, North Carolina, where in 1982 hundreds of civil rights leaders and community activists protested against plans for a PCB landfill in the majority African-American community. Although the protests didn't prevent the waste dumping, it triggered grassroot activism of agricultural workers, non-governmental organizations, religious workers, trades unions and other civil society groups (Bell, 2014; Taylor, 2000). The Warren County protests were taken up by the scientific community as well, leading to empirical investigations about similar situations nation-wide. In 1987, the groundbreaking study entitled 'Toxic Waste and Race in the United States' (UCC, 1987) was the first to document on a U.S. national scale the links between racial characteristics of communities and their proximity to waste sites. The report found race to be the most important factor in predicting where commercial hazardous waste facilities were located in the US. Since then, hundreds of studies and reports documented that communities of color and working class neighborhoods disproportionately affected by harmful infrastructures, such as landfills, mines, incinerators and polluting factories (Ringquist, 2005). An important contribution in this growing scientific field was sociologist Robert Bullard's publication Dumping in Dixie: Race, Class and Environmental Quality (Bullard, 1990). Under pressure of these empiric results, the EJ movement became increasingly institutionalized in the US. Most significant in policy terms was the creation of an Office of Environmental Justice within the Environmental Protection Agency (EPA) and the signing of Executive Order 12898 by President Clinton in 1992, which requires all federal agencies to work toward environmental justice.

By bringing issues of race and class and into the realm of environmentalism, environmental justice activists challenge the focus of the mainstream environmental movement on resource conservation, wilderness preservation or population growth (Holifield 2001:79). Instead of an abstracted idea of environment that is separate for humans, called 'bounded environmentalism' (Di Chiro, 2008; Gottlieb, 2002), environmental justice advocates insisted on bringing attention to the environmental conditions that people face in their daily lives, called 'environmentalism of everyday life', a recognition of the much more broadly defined conception of environment as the places 'where we live, work, and play' (Novotny, 2000).

Since the year 2000, environmental justice concerns have been taken up in other parts of the world. Within Europe, it is most established in the United Kingdom (UK) (Agyeman & Evans, 2004; Walker, 2012) and Germany (Elvers et al., 2008), although recently, EJ is also gaining attention in European Union institutions (Laurent, 2011). The European approach, however, is quite distinct from the American approach in two ways. First, in contrast to the bottom-up emergence of environmental justice by grassroots civil right movements in the US, the European approach is characterized by a more top-down approach by 'elites' form academia, environmental groups, civil society and government agencies (Walker, 2012, p. 28). For example, it was the mainstream and established environmental group 'Friends of the Earth' (FOE) that first gave attention to the issue of environmental justice in the UK by revealing that 66% of all carcinogen emissions are emitted in the most deprived 10% of wards of Great Britain (FOE, 2001). In the case of Germany, environmental justice issues emerged as a research topic, initially in health sciences, with scientific reports on exposure to air pollution and environmental diseases (Heinrich et al., 2000), and later also in urban planning (Kabisch & Haase, 2014). In 2008, a special issue 'Environmental justice – environment, health and social status' was published as part of the German Action Programme Environment and Health, providing for the first time an overview of research projects and activities in Germany the topic of environmental justice (or its German counterpart 'Umweltgerechtigkeit')[2]. The number of academic and ministerial conferences, often organized by the Federal Environment Agency (UBA), has been growing steadily since (Elvers et al., 2008).

[2] https://www.umweltbundesamt.de/themen/gesundheit/umwelteinfluesse-auf-den-menschen/umweltgerechtigkeit-umwelt-gesundheit-soziale-lage

Second, instead of a dominant focus on racial discrimination and segregation in the US, the European approach addressed broader issues of social deprivation, literacy, age and gender. According to Laurent (2011), this is related to underlying philosophies of public policy: *"the US approach traditionally recognizes the universality of natural rights granted to individuals and aims at curbing discriminations faced by them in exercising those rights, while continental European countries usually focus on correcting the social processes that produce situations of inequalities"* (Laurent, 2011, p. 1849). As a result, there is a more pronounced heterogeneity of topics and patterns in the European approach (Elvers et al., 2008), as well as a less normative and political labelling of 'environmental inequalities' instead of 'environmental injustices' (Walker, 2012).

1.2.2.2 *The environmental justice framework*

As the above historical situation illustrates, environmental justice can be viewed as a field positioned on the crossroads of social movements, scholarship and public policy (Sze & London, 2008). In this dissertation the focus is on environmental justice as an analytic research approach, meaning I will not go into much detail on the activist and governance aspects of environmental justice.

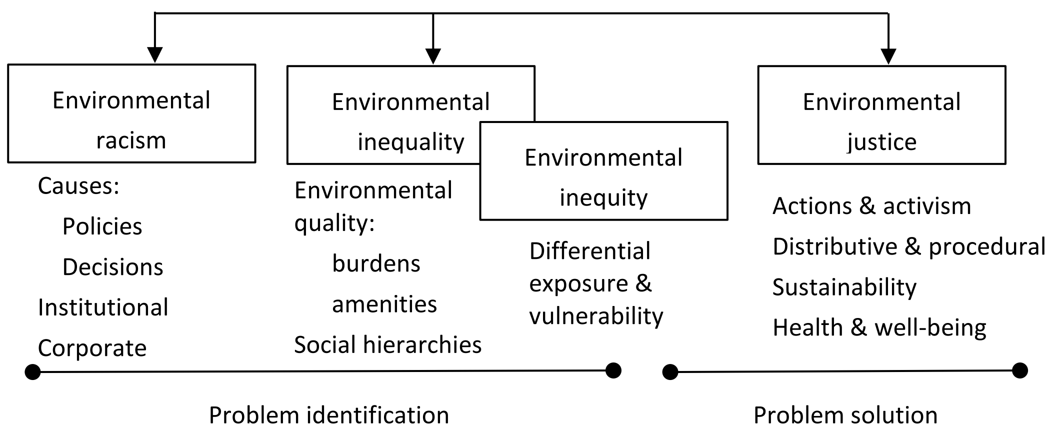
In essence, environmental justice is an interpretive frame for making claims about the intertwining of social and environmental problems (Walker, 2012). Broadly defined, the frame includes the concepts of environmental inequality, inequity and racism (Jerrett et al., 2001). Because there are such diverse notions and contexts around environmental justice, many authors have stated that it is neither possible nor desirable to absolutely define environmental justice (Bell, 2014; Holifield, 2001). Most studies also use the terms 'environmental inequality', 'environmental justice' and 'environmental racism' interchangeable. It is however useful to define and operationalize these distinct terms in a broader framework, as done by theorists like David Pellow (2000) and David Schlosberg (2013).

'Environmental racism' is the term first coined by Benjamin Chavis in 1982 to criticize the disproportionate siting of polluting facilities in racial minority communities. It was the preferred term in much of the early US literature on environmental justice and was defined by Bryant (1995, p. 589) as: *"[…] those institutional rules, regulations, and policies of government or corporate decisions that deliberately target certain communities for least desirable land uses, resulting in the disproportionate exposure of toxic and hazardous waste on communities based upon prescribed biological characteristics"*.

'Environmental inequality' has emerged more recently as a term that focuses on broader dimensions of the intersection between environmental quality and social hierarchies (Pellow, 2000), such as social class, gender and migrant status, as well as the interconnections between these dimensions (Sze & London, 2008). Environmental inequality is a more descriptive term to measure and quantify conditions of differences or unevenness between different groups of people (Walker, 2012, p. 12). When such conditions are not simply interpreted as unequal, but also as unjust, unfair and avoidable, the more normative term 'environmental inequity' is used. This occurs mainly when a public health frame is applied to expand attention from maldistribution of environmental exposures the reasons for increased susceptibility and vulnerability to hazards among certain groups (Northridge et al., 2003; Wakefield & Baxter, 2010).

'Environmental justice' is the term used by social movements and scholars to address and tackle these inequalities and forms of racism. So where environmental racism and environmental inequalities are part of the problem identification (where people are fighting against), 'environmental justice' is part of the problem solution (where people are fighting for) (Pellow, 2000). Environmental inequity holds a middle position between problem identification and solution because it connotes more with a moral objective toward which we are collectively striving (Northridge et al. 2003). Environmental justice is a more politically charged term that connotes some remedial action to correct an injustice posted on a particular group of people (Cutter, 1995). A widely used definition is that by the U.S. Environmental Protection Agency (EPA)[3] which states that environmental justice is: *"The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work."*

Figure 3: The environmental justice framework



Based on Pellow 2000 and Sze and Londen 2008

[3] https://www.epa.gov/environmentaljustice

1.2.2.3 *The expanding scope of environmental justice analysis*

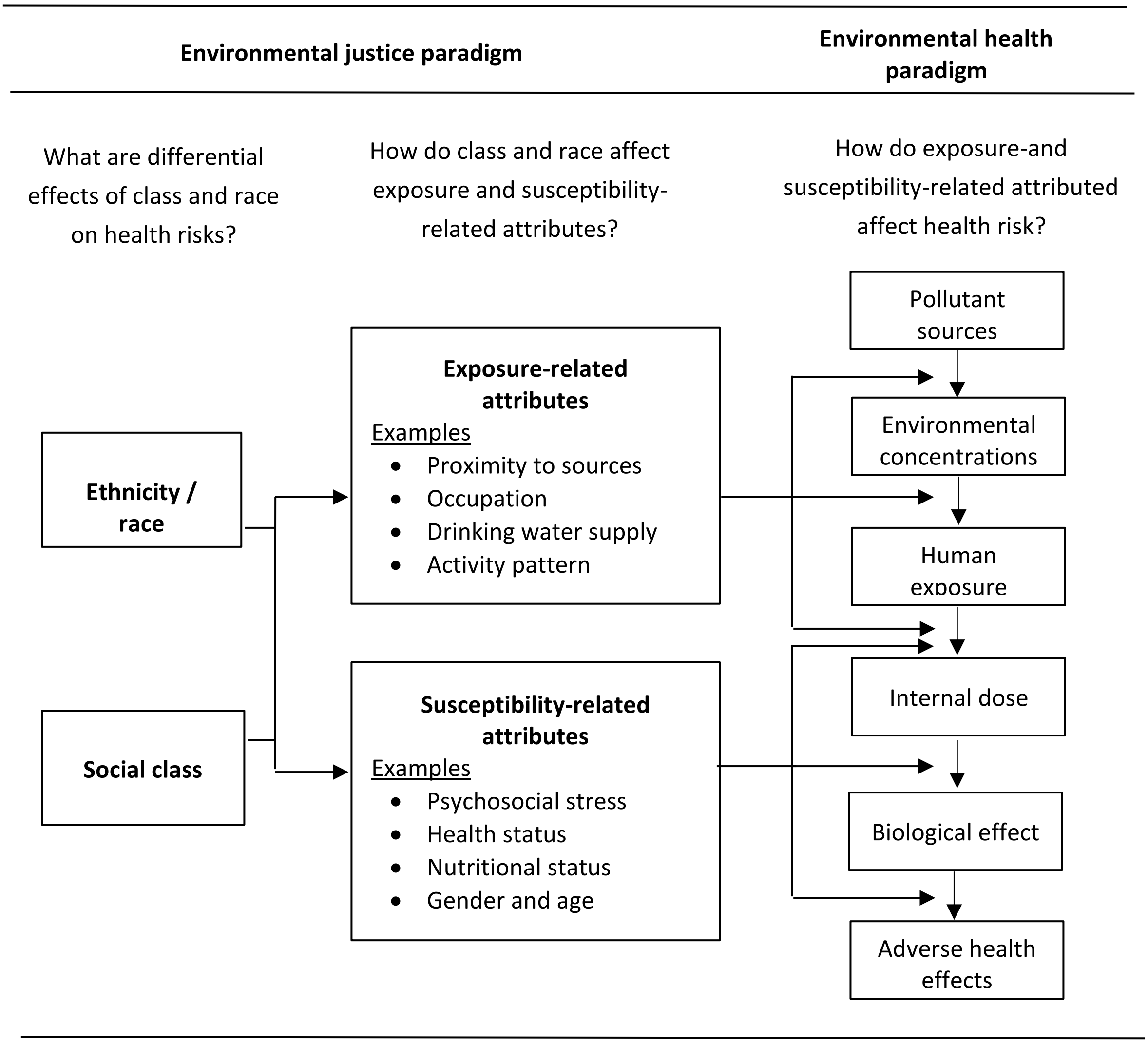
The early environmental justice studies, sometimes referred to as 'first-generation' research (Walker, 2009), were limited in scope and focused primarily on documenting maldistribution of environmental quality through a racial lens. Methodologically, these studies often used rudimentary proximity analysis or emission modeling to correlate aggregate geographic and social data (see: Mitchell, 2011) A 'second-generation' approach tries to overcome these limitations by including a broader range of themes and topics such as transportation, housing, energy justice, food security, green space and environmental health (Chakraborty, 2017; Chakraborty et al., 2016; Nelson & Grubesic, 2018; Sze & London, 2008) and by incorporating a deeper theoretical consideration of the multiple conceptions of justice (Pellow, 2016; Schlosberg, 2007, 2013). I will elaborate on two elements of this extension that are important in positioning my own research and structuring this doctoral thesis: (1) a broadening of the scope from exposure-oriented research to vulnerability-oriented research, captured in the concept of the double jeopardy hypothesis. (2) A broadening of the scope from distributional issues to include other dimensions of justice.

1.2.2.4 *The double jeopardy of exposure and vulnerability*

Although concerns about the health effects of environmental pollution are at the heart of the environmental justice frame, the research on health impacts of environmental risk is much less extensively developed in the empirical literature (Brulle & Pellow, 2006; Evans & Kantrowitz, 2002). Brown (1995) noted that in the early 1990s, EPA declared to have found no data on race and class differences in environmental disease, with the exception of lead poisoning. The EPA therefore refused to make the causal connection between environmental inequality and health effects in their reports. This is in line with a literature review from the 1990s in Germany (Heinrich et al., 2000) concluding that with respect to exposures a clear picture emerges in which people with lower socioeconomic status experience higher concentration of harmful substances in the ambient air as well as indoors, but no such clear picture was visible with respect to environmentally related diseases, such as allergies and malignant tumors.

With the expansion of the research scope during the last two decades, more emphasis is placed on studying the health impact of environmental pollution and on conceptually linking environmental exposures to health inequalities (Kruize et al., 2014; Schulz & Northridge, 2004). The health impact is addressed at the community level, for instance by integrating unequal access to green space into the analysis of environmental justice (Taylor et al., 2007) or by focusing on the role of residential segregation in environmental health disparities (Morello-Frosch & Shenassa, 2006). But also the interplay with the individual level is analysed, in particular with a focus on different factors that can make people more vulnerable to the health effects of pollution, in addition to already being more exposed to pollution. This dual mechanism of inequality is reflected in the concept of 'double jeopardy'.

Figure 4: Conceptual model of the double jeopardy



Source: adapted from Sexton and Adgate 1999

Sexton (1999) placed this concept in relation to the environmental health paradigm (Figure 4), thereby providing a useful complement of the framework in section 1.2.1.1 (Figure 2). In this representation, susceptibility is the overarching term for factors that make some people either biologically more sensitive (intrinsic) or socially more vulnerable (acquired) to the adverse health effects of pollution than others (Sexton, 1997). Gee and Payne-Sturges (2004) and Morello-Frosch and Shenassa (2006) tried to untangle this double jeopardy by focusing on the interplay of psychosocial stressors at the individual and the community level.

My research is situated at the intersection of both mechanisms and uses both exposure-related and susceptibility-related factors to study the social distribution of internal concentrations of environmental pollutants.

1.2.2.5 *The plural conceptions of justice*

A second expansion in recent environmental justice research is more theoretical in nature and is based on the multiple conceptualizations of justice. The EPA definition of environmental justice already stipulate 'fair treatment' and 'meaningful involvement' as two important dimensions of justice that respectively refers to distributional and procedural justice. Distributive justice was the initial and dominant focus of the environmental justice movement and refers to equity in the distribution of environmental harms and goods, as well as economic costs and benefits. Procedural justice contains the political part of justice and refers to the opportunities for participation in decision-making processes about environmental issues. It is often described in formal legislation and policy principles, such as the well-known Aarhus convention[4], which includes access to information, public involvement in decision-making and access to formal systems of justice. Some scholars such as David Schlosberg (2013) have argued that recognition of diverse cultural identities should be considered a third dimension of (environmental) justice. Based on the work of Nancy Fraser and Iris Young, this dimension contains both psychological feelings and structural patterns of disrespect, stereotyping, discrimination towards marginalized groups. Where procedural justice is rooted in processes of deliberative democracy, recognitional justice is more about cultural and relational attributes such as norms, symbols, language and experiences.

Table 2: Overview of the multifaced nature of justice

Type of justice	Guiding questions	Key dimensions
Distributional	What gets distributed, to whom, and how?	Environmental, health, economic
Procedural	Who participates in decision-making, and how?	Political public participation, democratic process
Recognitional	Which groups are granted legitimacy and authority?	Culture-based, experiences and status

Source: adapted from Blue et al. (2021) and based on the work of Schlosberg 2007

My research looks at environmental health research through this multifaced lens of environmental justice. I use the three dimensions of distributional, procedural and recognitional justice and transpose them to respectively the results of human biomonitoring research (distributions and social gradients) and the practices of human biomonitoring research (procedures, experiences, perceptions). This latter focus on environmental justice within the scientific research practice aligns with literature on 'just transformations' and is briefly discussed in the next section.

[4] https://unece.org/environment-policy/public-participation

1.2.2.6 *Just transformations in research practices*

Ottinger and Cohen (2011, 2012) argue that science and technology are dynamic and therefore transformable, rather than static. Transformations in scientific practices can be triggered after large disruptions of social structure, like wars or health epidemics, but can also occur by everyday choices and subtle activities of scientists. Ottinger and Cohen identified the environmental justice movement as an important source of transformative power because it *"highlights the inequities produced by industrial technologies and insists on the importance of laypeople's local and experiential knowledge"* (Ottinger & Cohen, 2012, p. 160). This is encompassed in the concept of 'environmentally just transformations'. Two important manifestations of these just transformations that relate to my own research are: (1) the recognition of cultural diversity. Environmental justice activists have long pushed experts and institutions to tackle the 'white-male bias' in traditional quantitative risk assessments by making assessments more representative and less blind to race and cultural contexts (Ottinger & Cohen, 2012; Powell & Powell, 2011)[5] . (2) The introduction of new methods and best practices to make research practices more inclusive and participatory, by promoting community engagement (Cordner et al., 2019), deliberative democracy (Dodge, 2009) or street science (Corburn, 2005). Important for these just transformations to be effective is that they are incorporated slowly and inconspicuous into technoscientific practices, described by Frickel (2011, p. 34) as 'low-dose' activism, setting quietly transformative change in motion. In Chapters 6 through 8, I attempt to implement these types of transformations in the research practices of the Flemish human biomonitoring program.

1.2.3 Health inequalities

In this final section of the theoretical framework, I introduce the perspective of health inequality to position the research area of my dissertation. I briefly review existing theories and frameworks that attempt to explain health inequality outcomes, with a focus on the recent biosocial approach. In addition, I also look at some theoretical and conceptual frameworks that identify and address inequality within medical research practice itself.

1.2.3.1 *Defining health inequalities*

A large body of research shows how socially vulnerable groups, such as those with lower education, people living in poverty, ethnic minorities or the unemployed, are more likely to have chronic diseases, depression and mental illness, poorer self-reported health status and shorter life expectancy (Alvarez-Galvez et al., 2013; Dalstra et al., 2005; Muntaner et al., 2004; Stringhini et al., 2017). European research has a tradition of making moral claims about this observed health differences, by calling them 'unnecessary and unjust' (Marmot et al. 2012) or even 'the scandal of our time' (Dorling, 2013). In Belgium, Herman Deleeck devoted his last article to social inequality in health and mortality and stated that "the socially unequal life expectancy and health is the most

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[5] The same criticism is noticeable in clinical trial and public health research (see section 1.2.3.4)

striking expression of the Matthew effect" (Deleeck, 2002). Health inequity is the term used, and linguistically most correctly, to define unfair differences where there is an issue of social (in)justice (McCartney et al., 2019). However, in Europe, the term health inequities is used interchangeable with health inequalities. In contrast, health research in the US generally uses the more value-neutral term health disparities instead of health inequities[6] (Fee & Gonzalez, 2017).

Important to labeling health differences as unjust is the explicit recognition that they can occur stepwise as a gradient across the population ranked by social position. This means that health inequalities are not limited to the poorest segment or the most socially disadvantaged but affect an entire society (M. Marmot, 2002; WHO, 2019b, p. 6). One of the most striking examples of this social gradient in health can be found in the Whitehall studies by Marmot et al. (1991). These studies, in which several thousand British civil servants participated, revealed that those with the highest occupational rank had the lowest mortality rate, and that this rate increased incrementally as the individual's position in the occupational hierarchy was lower. Those at the bottom of the ladder were three times more likely to die than those at the top, mainly from cardiovascular disease, even though all participants had stable, white-collar jobs.

1.2.3.2 *Theories on health inequalities*

The consistency with which inequalities are empirically observed and analyzed stands in stark contrast to the lack of consensus on how to explain these inequalities. Three theoretical frameworks that emphasize different social determinants of health are lifestyle theory, psychosocial theory and political economy of health (Krieger, 2001; Mackenbach, 2012).

First, the majority of studies directed at understanding inequalities in health have been focusing on exploring the role of lifestyle factors such as smoking, alcohol consumption, eating habits and physical exercises (Popay et al., 1998). Many of these studies take an individualistic approach to lifestyles, meaning that they narrow down lifestyle to behavioral patterns as personal choices or 'agency', and thus neglect the structural dimensions of lifestyles. A more collective 'health lifestyle theory' (Abel, 2008; Cockerham, 2005, 2013; Frohlich et al., 2001) tries to restore the role of social structure and context by emphasizing how lifestyle factors tend to cluster in certain patterns and practices that reflect distinct differences by social class, ethnicity or gender. This theory is rooted in the work of French sociologist Pierre Bourdieu on class-related capitals and lifestyles (Bourdieu, 1984). According to Bourdieu, each individual occupies a position on the social hierarchy that constitutes membership in a particular social class. This class membership is based on the amount of three forms of capital: economic capital (resources like income, house or car ownership), social capital (a person's social network) and cultural capital (education, values and norms). Within each

[6] Note that with respect to the term environmental inequalities, the opposite has been observed (see section 1.2.1). There, the US research is more normative by using the term environmental justice, in contrast to the European research that uses more the neutral and descriptive term environmental inequalities.

social class is a specific lifestyle that is constituted through the habitus, a set of internalized preferences, perceptions and dispositions. Two important conclusions can be distilled from this theory: i) lifestyle does not only refer to behaviour but also to more culture-based resources such as health values, knowledge and competences. Frohlich and Abel (2014) therefore introduced the concept of health practices, instead of health behaviour. ii) lifestyle is not the product of personal choice but is constructed in the social context and thus dependent on social, economic and political conditions. Frolich (2001) suggested 'collective lifestyle', as a concept to better capture this structural dimension of lifestyle.

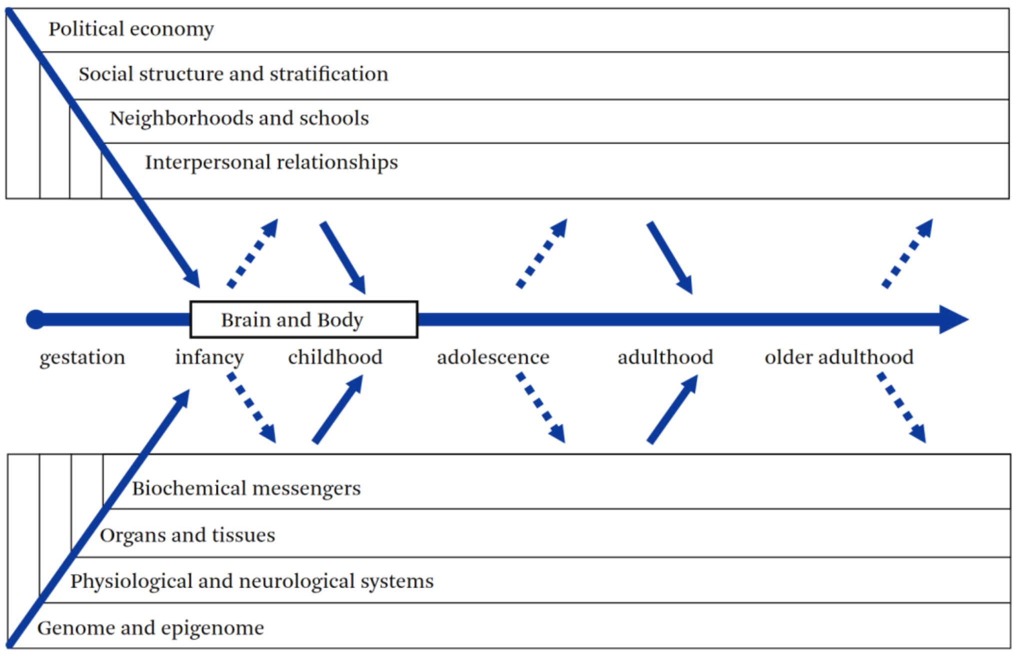
A second approach to explain health inequalities focuses on how psychosocial risk factors influence vulnerability to disease through stress, lack of social support and sense of control (Egan et al., 2008; Siegrist & Marmot, 2004). This psychosocial theory originated from the host-agent-environment' model of John Cassel (1976). Best-known contemporary representatives of this theory are Wilkinson and Pickett (2010), who found that in developed countries, it is not (absolute) income growth, but (relative) income inequality that is most strongly associated with health and life expectancy, implying that income within a society is a measure of status, and not merely a material resource. In unequal societies, income leads to status competition and anxiety, feelings of inferiority and fear of being disrespected. In their research on psychosocial work-related stress, Siegrist and Marmot (2004), especially underline the importance of self-efficacy, the ability to control our lives, within the psychosocial environment. Low grade chronic stress, acting through the brain, mobilises hormones that lead to profound biological changes, which is captured by the concept of allostatic load (McEwen & Stellar, 1993). These effects can be counteracted by the benefits of social support and participating fully in society (Uphoff et al., 2013).

The third framework consists of the 'political economy of health' and the 'neo-material theory'. The hypothesis here is that 'upstream' political and economic factors, such as access to institutions, material resources, welfare regimes and power imbalances are the root or fundamental causes of health inequalities, and not exposure to proximal risk factors like smoking, psychosocial stress or working conditions (Link & Phelan, 1995). According to Lynch (2000), the available evidence on income inequality and health is best explained by a combined lack of resources held by individuals, along with underinvestment in public resources such as schooling, health care and housing. This is in line with the influential work of sociologist Vincente Navarro who studied the role of political traditions and government ideologies in determining health inequalities. He found that in advanced OECD countries, political traditions more committed to redistributive policies (both economic and social), such as the social democratic parties, were generally more successful in improving the health of populations than neo-liberal governments (Navarro & Shi, 2001).

1.2.3.3 *The biosocial approach*

The above theories emphasize the role of various social determinants of health, such as lifestyle, psychosocial stress, economic and political forces. However, a necessary next step in explaining health inequalities is a focus on the intermediate pathways and mechanisms through which these determinants interact and create health effects. A particularly interesting theoretical framework in this regard is the ecosocial (Krieger, 2001) or biosocial approach (Harris & McDade, 2018). Driven by recent developments in neuroscience, biomedicine and environmental epigenetics, this framework is interested in how socioeconomic and biological factors influence human health from the micro to the macro scale[7]. Harris and McDade (2018) define biosocial as *"a broad concept referencing the dynamic, bidirectional interactions between biological phenomena and social relationships and contexts, which constitute processes of human development over the life course"*. These interactions are visually represented in Figure 5, where the upper part of the model represents the different social contexts that influence the body throughout the life course. The lower part similarly shows the different levels of the biological organism that respond to, and are shaped by, the social context.

Figure 5: Conceptual model of the biosocial dynamics across the life course



Source: Harris and McDade 2018

Central in this biosocial approach is Krieger's (2001, p. 672) notion of 'embodiment' that describes how we biologically incorporate the material and social world in which we live, from conception to death. Hertzman and Boyce (2010) refer to the same process as 'biological embedding' which occurs when experience *"gets under the skin and alters human biological processes"*. According to

[7] Apart from the literature on health and inequality, there is also interest in how the biosocial approach permeate the broader field of sociology, anthropology, and political theory, with the elaboration of intriguing concepts such as "embedded bodies" and "local biologies.". See for an overview: Meloni et al. 2016.

Krieger, pathways of embodiment express a cumulative interplay between exposure, susceptibility and resistance, at multiple levels (individual, neighborhood, regional, …) and in multiple domains (home, work, school, …). These pathways connect social experiences with their biological expression and relate to the double jeopardy framework of environmental justice (Morello-Frosch & Shenassa, 2006; Sexton, 1997).

Two recent findings of this embodiment process are biological aging and inflammatory signaling. In both cases, large cohort studies demonstrated the impact of lower socio-economic position (SEP) early in life on biological processes such as telomer length, DNA methylation and chronic inflammation, which in turn can increase chronic diseases such as cardiovascular disease and cancer later in life (McCrory et al., 2019). For example, a meta-analysis with data from more than 16.000 individuals from 12 different countries worldwide showed that people with low SEP were approximately 1 year older epigenetically than those with high SEP (Fiorito et al., 2019). An even larger meta-study of 23.000 participants found a consistent inverse association between SEP and chronic inflammation, with low SEP participants having higher levels of inflammation (Berger et al., 2019). Interestingly, in both studies, education level was most strongly associated with biological markers. Another example that shows how not only SEP affects biological processes but also vice versa is lower birth weight, called small for gestational age (SGA) in biomedical research such as human biomonitoring. Lower educated women are more likely to give birth to SGA babies which in turn has a detrimental effect on the cognitive development and later educational attainment of these babies.

These examples illustrate that social and biological phenomena are equally complex and multidimensional and cannot be studied in isolation from each other. The biosocial approach is therefore inherently an interdisciplinary approach that integrates different scientific backgrounds. Human biomonitoring surveillance programs, especially when they involve biomedical and social science experts as in Flanders, fits well into the biosocial approach.

However, the approach has also been criticized, particularly from an environmental justice perspective (Shostak, 2004). The main argument it that by focusing on biological and molecular aspects, the locus of control for health transforms from the external environment to the internal body. This transformation consequently contributes to a shift in health responsibility from the societal and institutional to the individual level. For example, in the case of environmental pollution this means that attention is redirected from the regulation of a polluting factory to a specific chemical that people living in a polluted neighborhood must avoid ensuring their own health. The social, political and historical factors that determine environmental health – and that are so important for environmental justice activists – are then obscured. This shift in responsibility is part of a broader tendency towards individualization and biomedicalization (Clarke et al., 2003). Individuals are expected to play a central role in managing their own health by adhering to a healthy lifestyle, consuming safe products, and by self-tracking and monitoring their health status (Lupton, 2014). MacKendrick (2014) and Mansfield (2012) additionally introduce a gender dimension to this individualization process by arguing that the shift in responsibility is proportionally weightier for women because it relates to the self-discipline of responsible motherhood.

A second concern from (primarily American) environmental justice research is that technoscientific approaches such as genetic and genomic research will also obscure the meaning of 'race', either by stating that genetic susceptibility is the true and only cause of racial health disparities or by stating that race does not exist because it has no biological basis. In either case, the socio-political reality of racism and discrimination would be minimized (Rondini, 2015; Shostak, 2004).

1.2.3.4 ***Refocusing on research practices***

The above critiques demonstrate the importance of being reflexive of medical and clinical research practice itself and how it can be made more inclusive and equitable. This includes both critical inquiry into existing methodology of (bio)medical practices (e.g. how given categories to define health inequalities can themselves become a form of inequality), as well as engaging in participatory processes to better integrate lay and expert knowledge. I briefly introduce a conceptual approach for each of these two lines of work that is useful for framing and situating my own research more broadly: 'the inclusion-by-difference paradigm' and 'popular epidemiology'.

The sociologist Steve Epstein describes how (bio)medical research and policy in the U.S. since the 1980s has undergone a remarkable evolution from a traditional insensitivity to concepts of race and social class (the one-size-fits-all approach leading to the white male bias) to more equitable research practices and monitoring systems. He encapsulates this evolution under the term 'inclusion-and-difference paradigm' (Epstein, 2007, 2010). The name reflects two different areas of concern for medical research: 1) the inclusion of previously underrepresented groups in clinical and medical studies, in particular, women, racial and ethnic minorities, children, and the elderly, and 2) the measurement, within those studies, of differences across groups with regard to health outcomes, rather than assuming that findings from any one group can be extrapolated to others (Epstein, 2007, p. 6; 2010, p. 65). Building on the work of Michel Foucault, Epstein considers the inclusion-and-difference paradigm an expression of the biopolitical paradigm because it forms a set of ideas, standards and formal procedures which simultaneously shape biomedical and bureaucratic practices.

Referring to the first objective, Epstein puts forward the term 'recruitmentology' to capture the efforts to recruit hard-to-reach groups into clinical studies (Epstein, 2008). An important concept to accomplish more inclusionary research practices is that of 'cultural competence' to understand, through careful, context-sensitive reflection and interaction, the culture of the research population. For the second objective, Epstein suggests an approach termed 'niche standardization'*: "a general way of transforming human populations into standardized objects available for scientific scrutiny […] or other purposes that eschews both universalism and individualism and instead standardizes at the level of the categorical social group — one standard for men, another for women; one standard for blacks, another for whites, another for Asians; one standard for children, another for* *adults; and so on"* (Epstein, 2007, p. 135). This reflects an important intermediate position where medicine is neither generalized nor personalized, but instead is group specific.

A second perspective that has emerged from the critique of dominant practices in epidemiology is that of public participation in the research process. Over the past 20 years, collaboration with citizens and communities has been increasingly recognized as a valuable way to both understand disease distribution in a broader context and recognize the value of experiential knowledge and perceptions (Leung et al., 2004). A well-known example of this perspective, which integrates epidemiology and environmental health is the concept of 'popular epidemiology', developed by sociologist Phil Brown (1987; 2013). According to Brown, popular epidemiology represents two related elements: (1) a participatory process to epidemiological knowledge production by which laypersons gather data and collaborate with experts, and (2) a type of social movement mobilization around the goal of identifying and ameliorating environmental stressors and local illness patterns. Brown developed this approach after his experiences in famous industrial hotspots in the U.S. such as Love Canal and Woburn, where citizens and action groups themselves start linking disease rates and clusters with local pollution.

1.3 Research questions

The thesis has two objectives, divided in five research questions.

Objective 1 is to examine what patterns of inequality emerge from human biomonitoring results in Flanders. Are body concentrations of environmental chemicals (biomarkers of exposure) spread unequally between different population groups? And if so, are these inequalities showing higher exposure levels for people with a lower social position, as suggested by the environmental justice hypothesis and the social health gradient? And what are possible explanations and intermediate factors for these inequalities?

- Research question 1: How are body concentrations of environmental chemicals stratified according to socioeconomic indicators?
- Research question 2: How to explain inequalities in chemical exposure?

Objective 2 is to examine the barriers and opportunities for vulnerable groups to participate in HBM research and in environmental health promotion in Flanders.

- Research question 3: How to tackle the participation bias in HBM research?
- Research question 4: How do participants experience and interpret HBM research results?
- Research question 5: How to reach and empower vulnerable groups with environmental health promotion?

1.4 Data and methods

This doctoral thesis contains results of (1) different research cycles of the Flemish Human Biomonitoring program (FLEHS) and (2) a pilot project on environmental health promoting (EHP). Different types of data are used with different methodologies, each of which is described in the separate publications (chapters 2 to 8). In this section, I give a global overview and structuring of the data and methods used and of the overall research process. First, I will briefly introduce the two research projects.

1.4.1.1 *The Flemish human biomonitoring program*

Since 2002, the Flemish government initiated a human biomonitoring program in Flanders (Belgium) called Flemish Environmental Health Studies (FLEHS). The program is implemented by the Flemish Centre of Expertise for Environment and Health. Within this Centre, researchers from all Flemish universities and two research institutes combined their expertise in medical sciences, toxicology, epidemiology, food sciences, biostatistics, environmental chemistry and social sciences (Schoeters et al., 2012). The program has completed four cycles. More than 4.400 participants participated in FLEHS I (2002-2006). Blood and urine samples were collected from newborn babies, adolescents (14-15 years) and adults (50-65 year) living in eight regions of Flanders with a different environmental pressure. FLEHS I measured a limited set of biomarkers of exposure such as persistent chlorinated compounds, heavy metals, dioxins, and metabolites of PAHs (Schroijen et al., 2008). FLEHS II (2007–2011) included the same three age groups in a smaller sample (250 newborns, 200 adolescents and 200 adults) but on a more representative Flemish scale and for a wider range of biomarkers (more than 40 compounds). This allowed the calculation of reference values for exposure to environmental chemicals of the general Flemish population. In addition, the FLEHS II cycle recruited 400 adolescents living in the proximity of two selected industrial hotspots (in Genk and Menen). FLEHS III (2012-2016) was a continuation of FLEHS III, with the reference biomonitoring of 3 age groups at the Flemish level and the inclusion of a new local hotspot in the Ghent harbor area. Finally, FLEHS IV (2017-2020) monitored 80 biomarkers in 428 adolescents, with an additional focus on three new research topics: eco-behaviour, indoor quality, and green space (Schoeters et al., 2022).

A stratified clustered multi-stage design was used to select participants (Schoeters et al. 2012; 2017). Adolescents were recruited from randomly selected schools in each Flemish province. Mothers giving birth were recruited from maternity hospitals. All participants signed an informed consent form and had the right to withdraw from the study at any time. Study protocols of each FLEHS cycle were approved by the ethical committee of the University of Antwerp. Participants provided information on their health status, dietary habits, living conditions and socio-economic position through extensive, self-completed questionnaires. Body height and weight were measured by study nurses when they donated blood, urine and hair samples. Individual results are reported-back to the participants by post and, if they wish, to their general practitioner as well. In order to support policy translation of HBM results, a phased action plan is designed after each research cycle, with active involvement of various stakeholders and experts (Keune et al., 2009; Reynders et al., 2017).

1.4.1.2 *The pilot project on environmental health promotion*

During 2015 and 2016, a pilot project was carried out by the University of Antwerp (Department of Sociology) and the Flemish Institute for Healthy Living (Vlaams Instituut Gezond Leven) to examine how existing information and awareness about environmental health risks could be made more accessible and have a greater impact on disadvantaged groups. The project was commissioned by the Flemish government's Environment, Nature and Energy Department (LNE). The project was embedded into community working groups (Samenlevingsopbouw) in the Antwerp neighbourhood Kiel and centered around two environmental health themes: indoor environment (health risks associated with poor housing quality) and gardening (health risks associated with locally grown food). The analysis and intervention level of this pilot project was the interpersonal level, an intermediary level between the individual and the community, with a focus on a social network of people with a migrant background within a more or less spatially defined environment. The project was named 'Air your Life' (Lucht in je Leven).

1.4.1.3 *Description of data and methods*

I use FLEHS data from two age groups, adolescents (14-15 years) and mother-newborn pairs, within three consecutive research cycles (FLEHS I, II and III). Chapters 2 to 5 contain quantitative statistical analyses using both biomedical data and survey data to investigate associations between biomarker exposure level and socioeconomic position. Conceptually, these chapters could be framed within the distributive dimension of the environmental justice discourse. Methodologically, they apply a stratification approach as part of the health inequality discourse. The specifications of each analysis are summarized in the Table 3.

Chapter 2 describes the first published stratification analysis conducted on FLEHS data. It contains results of 7 biomarkers, with a focus on historical pollutants to which a general population may be chronically exposed through the environment or diet, such as polychlorinated biphenyls (PCBs) and cadmium. The parental educational attainment of 1.642 adolescents (age 14-15) was examined in relation to two measures of pollutant concertation: the average (geometric mean) and high exposure (odds ratios above P90) concentration for each biomarker, using multiple linear and logistic regression.

In chapter 3, the stratification analysis is repeated on data of two hotspot biomonitoring studies (FLEHS II). The average concentration of 13 chemical substances, related to the present industry, measured in blood, urine and hair samples of about 200 adolescents per hotspot was compared with the concentrations in a Flemish reference group. Social differences were examined for educational level of the parents and school type of the adolescents by means of linear regression methods.

Chapter 4 focuses on exposure to new emerging chemicals in consumer products. The stratification analysis again includes 200 adolescents aged 14-15 (FLEHS III), but this time three indicators of socio-economic position are taken into account: education of the mother, school type of the adolescents and family income.

Finally, chapter 5 is an additional analysis that has not yet been published and contains the results of the newborn study within FLEHS III. Ten biomarkers of exposure, both historical and new emerging substances, are studied in relation to three indicators: maternal education, family income and migration background of the mother.

Table 3: Overview of quantitative chapters of the thesis

	FLEHS I 2002-2006	**FLEHS II 2007-2011**	**FLEHS III 2012-2015**	
	Chapter 2	**Chapter 3**	**Chapter 4**	**Chapter 5**
Target group	Adolescents	Adolescents	Adolescents	Mother-newborns
Sample number	N= 1.642	N= 197; N=199	N=208	N=281
Target area	8 Flemish areas with different pollution pressure	2 industrial hotspots (Genk-Zuid and Menen)	Flanders	Flanders
Data - Exposure measures	7 biomarkers, with focus on historical chemicals	13 biomarkers, related to industrial activity present	3 markers of phthalates, an emerging chemical in plastic	10 biomarkers, both historical and new emerging chemicals
Data - Socioeconomic measures	- Parental educational attainment	- Parental educational attainment - school type of adolescent	- Maternal educational attainment - School type of adolescent - Equivalent family income	- Maternal educational attainment - Equivalent family income - Migrant background
Statistical methods	Multiple linear regression (GM exposure) and logistic regression (high exposure, > P90)	Multiple linear regression models, based on geometric mean exposure	Multiple linear regression models, based on geometric mean exposure	Multiple linear regression models, based on geometric mean exposure
Data analysis	Descriptive	Descriptive	Descriptive	Descriptive

The subsequent chapters 6, 7 and 8 are quantitative and use data from face-to-face interviews, focus groups and stakeholder consultations within FLEHS III and the pilot project on EHP. They could be framed within the procedural and recognitional dimensions of environmental justice. Methodologically, they apply a relational approach of inequality, focusing more on interactions between different groups and stakeholders.

Table 4: Overview of the qualitative chapters of the thesis

	FLEHS III 2012-2015		**Pilot Project EHP 2015-2016**
	Chapter 6	**Chapter 7**	**Chapter 8**
Target group	Mothers of neonates	Mothers of neonates	Migrant women
Target area	2 maternity hospitals (Antwerp and Heusden)	Province of Antwerp	Kiel, Antwerp
Qualitative data	Design, implementation and evaluating of a targeted recruitment strategy to enhance participation of Turkish and Moroccan	First hands experiences and perceptions of former participants about the report-back process of HBM results	Practice-based project to make information on environmental health risks more accessible and meaningful for disadvantaged groups
Methods	- 8 in-dept interviews - 1 focus group - Stakeholder consultation	- 11 in-depth interviews	- Interactive info sessions - Participant observation - Stakeholder consultation - 3 in-depth interviews
Analysis	Prescriptive	Diagnostic	Prescriptive

Chapter 6 contains the design and implementation of a targeted three-track strategy within FLEHS III to better recruit pregnant women with a migrant background in two maternity hospitals (Antwerp and Heusden). First, advice on the ethnic matching of study procedures was collected by conducting eight semi-structured in-depth interviews with organizations and experts in the field of prenatal care, poverty and ethnic cultural minorities, and one focus group with five young mothers from an urban Moroccan and Turkish community. Second, bilateral consultations with local organizations (e.g. community centers, general practitioners) were organized to personally introduce and advertise the study. Third, a personal buddy system for participants was set-up by training and supporting three third-party women with a Turkish and Moroccan background. The targeted strategy is evaluated in a quantitative manner, with reflections from the research team, the buddies and the midwifes, and in a qualitative manner, by comparing the profiles of participants recruited using the targeted strategy and those recruited without this strategy.

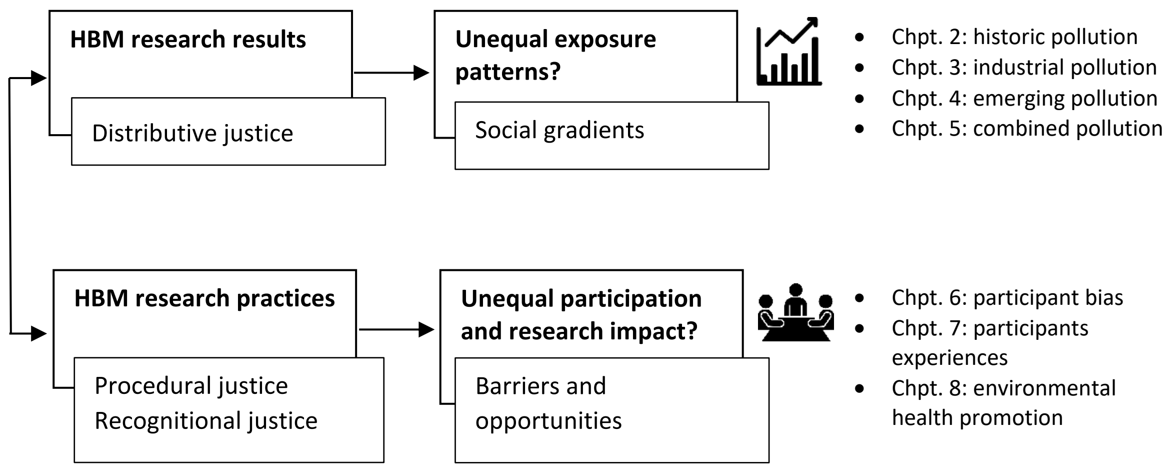
Chapter 7 is a follow-up study based on eleven face-to-face interviews with mothers who participated in FLEHS III to investigate how they experienced and interpreted individual biomonitoring results. The interview protocol used open-ended questions and consisted of three parts: study participation (how did respondents experience the study?), study results (how did they understand their results?) and study impact (how did they respond to their results?). The audio recordings of the interviews were transcribed, and answers were categorized into relevant themes and issues.

Chapter 8 describes the research process of a practice-based pilot project on environmental health promotion in the Kiel district of Antwerp. Barriers and success factors for making information materials more accessible and meaningful for socially vulnerable groups such as people with a migration background are summarized based on consultations with stakeholder organizations, participant observations and interviews with people from the target group.

I use the term environmental inequality when referring to the (more descriptive) social distribution of the research results of human biomonitoring (chapters 2 to 5) and the term environmental (in)justice when referring to the (more prescriptive) procedural barriers and opportunities in the research practice of human biomonitoring (chapters 6 to 8).

Figure 6 summarizes the structure of the PhD schematically with the link to the dimensions of justice, the research approach and the different chapters within each section.

Figure 6: Schematic representation of PhD structure



1.4.1.4 *Research process and position*

Concerning the general research process, it is important to underline that my doctoral trajectory did not follow a traditional linear process with predefined hypotheses and research questions that needed to be answered. Rather, my research followed a more organic and flexible process, starting from a combination of orienting concepts and empirical findings that guided and framed my further research design and incrementally evolved into a collection of published articles.

Because my research is embedded in broader and ongoing interdisciplinary research projects, I conceived my own research position primarily from the perspective of what Derek Layder (2018) describes as 'investigative research', which is *"exploratory in character in the sense of being open to possible outcomes regardless of the amount of previous research on the area, [and] […] to discover new angles on a phenomenon or problem, or from alternative perspectives"* (Layder, 2018, p. 3). This meant that in available biomedical data, I tried to unravel patterns of social inequality that had not yet been revealed. And in established study procedures, I tried to identify and resolve barriers for vulnerable groups that were not yet addressed by other scientists. In this way I used environmental justice as an 'opposing concept'[8] to the already existing human biomonitoring research in Flanders.

However, this did not mean that I conducted my research as an antagonistic outsider. On the contrary, my position in the research was one of 'epistemic empathy', the honest desire to learn from other disciplines and to engage with communities and lay people (Little & Pennell, 2017). Methodologically, this meant that the quantitative analyses were always carried out in cooperation with biostatistics from the Research Centre and that the qualitative projects were always organised with the input of local stakeholders, participants and civil society.

References

Abel, T. (2008). Cultural capital and social inequality in health. *Journal of Epidemiology and Community Health*, 62(7), e13-e13.

Agyeman, J., Evans, B. (2004). 'Just sustainability': the emerging discourse of environmental justice in Britain? *The Geographical Journal*, 170(2), 155-164.

Altman, R.G., Morello-Frosch, R., Brody, J.G., Rudel, R., Brown, P., Averick, M. (2008). Pollution Comes Home and Gets Personal: Women's Experience of Household Chemical Exposure. *Journal of Health and Social Behavior*, 49(4), 417-435.

Alvarez-Galvez, J., Rodero-Cosano, M.L., Motrico, E., Salinas-Perez, J.A., Garcia-Alonso, C., Salvador-Carulla, L. (2013). The Impact of Socio-Economic Status on Self-Rated Health: Study of 29 Countries Using European Social Surveys (2002–2008). *International Journal of Environmental Research and Public Health*, 10(3), 747-761.

Angerer, J., Ewers, U., Wilhelm, M. (2007). Human biomonitoring: State of the art. *International Journal of Hygiene and Environmental Health*, 210(3-4), 201-228.

Atkinson, W. (2007). Beck, individualization and the death of class: a critique. *The British Journal of Sociology*, 58(3), 349-366.

Beck, U. (1992). *Risk society: Towards a new modernity*. London: Sage.

[8] https://environmentaljustice.de/research.php

Beck, U. (2006). Living in the world risk society. *Economy and Society*, 35(3), 329-345.

Beck, U. (2010). Remapping social inequalities in an age of climate change: for a cosmopolitan renewal of sociology. *Global Networks*, 10(2), 165-181.

Becker, K., Conrad, A., Kirsch, N., Kolossa-Gehring, M., Schulz, C., Seiwert, M., Seifert, B. (2007). German Environmental Survey (GerES): Human biomonitoring as a tool to identify exposure pathways. *International Journal of Hygiene and Environmental Health*, 210(3-4), 267-269.

Bell, K. (2014). *Achieving environmental justice: A cross-national analysis.* Bristol: Bristol University Press.

Bellinger, D.C. (2008). Lead neurotoxicity and socioeconomic status: conceptual and analytical issues. *Neurotoxicology*, 29(5), 828-832.

Belova, A., Greco, S.L., Riederer, A.M., Olsho, L.E., Corrales, M.A. (2013). A Method to screen U.S. environmental biomonitoring data for race/ethnicity and income-related disparity. E*nvironmental Health*, 12(114).

Berger, E., Castagné, R., Chadeau-Hyam, M., Bochud, M., d'Errico, A., Gandini, M., et al. (2019). Multi-cohort study identifies social determinants of systemic inflammation over the life course. *Nature Communications*, 10(1), 773.

Blue, G., Bronson, K., Lajoie-O'Malley, A. (2021). Beyond distribution and participation: A scoping review to advance a comprehensive environmental justice framework for impact assessment. *Environmental Impact Assessment Review*, 90, 106607.

Bourdieu, P. (1984). *Distinction: A social critique of the judgement of taste*. Cambridge: Harvard University Press.

Bourguignon, J.P., Parent, A.S., Kleinjans, J.C.S., Nawrot, T.S., Schoeters, G., Van Larebeke, N. (2018). Rationale for Environmental Hygiene towards global protection of fetuses and young children from adverse lifestyle factors. *Environmental Health*, 17(1): 1-11.

Briggs, D.J. (2008). A framework for integrated environmental health impact assessment of systemic risks. *Environmental Health*, 7(1): 1-17.

Brown, P. (1987). Popular Epidemiology: Community Response to Toxic Waste-Induced Disease in Woburn, Massachusetts. *Science, Technology, & Human Values*, 12(3/4), 78-85.

Brown, P. (1995). Race, class, and environmental health. A review and systematization of the literature. *Environmental Research*, 69(1), 15-30.

Brown, P. (2013). Integrating Medical and Environmental Sociology with Environmental Health: Crossing Boundaries and Building Connections through Advocacy. *Journal of Health and Social Behavior*, 54(2), 144-163.

Brulle, R.J., Pellow, D.N. (2006). Environmental justice: Human health and environmental inequalities. *Annual Review of Public Health*, 27, 103-124.

Bryant, B. (1995). Pollution prevention and participatory research as a methodology for environmental justice. *Virginia Environmental Law Journal*, 14(4), 589-613.

Bullard, R. (1990). *Dumping in Dixie: Race, class and environmental quality*. Boulder: Westview Press.

Carson, R. (1962). *Silent spring, fortieth anniversary edition (2002).* Boston, MA: Houghton Mifflin.

Cassel, J. (1976). The contribution of the social environment to host resistance: the Fourth Wade Hampton Frost Lecture. *American Journal of Epidemiology*, 104(2), 107-123.

Caulfield, T., Murdoch, B. (2017). Genes, cells, and biobanks: Yes, there's still a consent problem. *PLoS biology*, 15(7), e2002654.

Chakraborty, J. (2017). Focus on environmental justice: new directions in international research. *Environmental Research Letters*, 12(3).

Chakraborty, J., Collins, T.W., Grineski, S.E. (2016). Environmental Justice Research: Contemporary Issues and Emerging Topics. *International Journal of Environmental Research and Public Health*, 13(11).

Clarke, A.E., Shim, J.K., Mamo, L., Fosket, J.R., Fishman, J.R. (2003). Biomedicalization: Technoscientific Transformations of Health, Illness, and U.S. Biomedicine. *American Sociological Review*, 68(2), 161-194.

Cockerham, W.C. (2005). Health Lifestyle Theory and the Convergence of Agency and Structure. *Journal of Health and Social Behavior*, 46(1), 51-67.

Cockerham, W.C. (2013). Bourdieu and an Update of Health Lifestyle Theory. In W.C. Cockerham (Ed.), *Medical Sociology on the Move: New Directions in Theory* (pp. 127-154). Dordrecht: Springer Netherlands.

Corburn, J. (2005). *Street science: Community knowledge and environmental health justice*. Cambridge, MA: MIT Press, 271 p

Cordner, A., Poudrier, G., DiValli, J., Brown, P. (2019). Combining Social Science and Environmental Health Research for Community Engagement. *International Journal of Environmental Research and Public Health,* 16(18).

Creager, A.N.H. (2018). Human bodies as chemical sensors: A history of biomonitoring for environmental health and regulation. *Studies in History and Philosophy of Science*, 70, 70-81.

Curran, D. (2013). Risk society and the distribution of bads: theorizing class in the risk society. *Br J Sociol*, 64(1), 44-62.

Curran, D. (2018a). Beck's creative challenge to class analysis: from the rejection of class to the discovery of risk-class. *Journal of Risk Research*, 21(1), 29-40.

Curran, D. (2018b). Environmental Justice Meets Risk-Class: The Relational Distribution of Environmental Bads. *Antipode*, 50(2), 298-318.

Cutter, S. L. (1995). Race, class and environmental justice. *Progress in Human Geography*, 19(1), 111-122.

Daemmrich, A. (2008). Risk frameworks and biomonitoring: Distributed regulation of synthetic chemicals in humans. *Environmental History*, 13(4), 684-694.

Dalstra, J., Kunst, A., Borrell, C., Breeze, E., Cambois, E., Costa, G., et al. (2005). Socioeconomic differences in the prevalence of common chronic diseases: an overview of eight European countries. *International Journal of Epidemiology*, 34(2), 316-326.

Deleeck, H. (2002). Dood en verdeling – Over sociale ongelijkheid in ziekte, zorg en dood. *Streven*, 70(1), 20-32.

Di Chiro, G. (2008). Living environmentalisms: coalition politics, social reproduction, and environmental justice. *Environmental Politics,* 17(2), 276-298.

Dodge, J. (2009). Environmental justice and deliberative democracy: How social change organizations respond to power in the deliberative system. *Policy and Society*, 28(3), 225-239.

Dorling, D., (2013). *Unequal health: The scandal of our times*. Bristol: Policy Press.

Friends of the Earth (FOE). (2001). Pollution and Poverty - Breaking the Link. Friends of the Earth, London.

EEA. (2013). *Environment and human health*. European Environment Agency, EEA report No 5/2013.

EEA. (2018). *Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe*. European Environment Agency, EEA report No 22/2018.

EEA. (2019). *The European environment — state and outlook 2020, Knowledge for transition to a sustainable Europe*. European Environment Agency, EEA.

Egan, M., Tannahill, C., Petticrew, M., Thomas, S. (2008). Psychosocial risk factors in home and community settings and their associations with population health and health inequalities: A systematic meta-review. *BMC Public Health*, 8(1), 239.

Ekberg, M. (2007). The Parameters of the Risk Society: A Review and Exploration. *Current Sociology*, 55(3), 343-366.

Elvers, H.D., Gross, M., Heinrichs, H. (2008). The diversity of environmental justice. Towards a European Approach. *European Societies*, 10(5), 835-856.

Epstein, S. (2007). *Inclusion: the politics of difference in medical research*. Chicago: The University of Chicago Press.

Epstein, S. (2008). The Rise of `Recruitmentology': Clinical Research, Racial Knowledge, and the Politics of Inclusion and Difference. *Social Studies of Science*, 38(5), 801-832.

Epstein, S. (2010). Beyond inclusion, beyond difference: The biopolitics of health. In: Whitmarsh I. and Jones D.S. (Eds.), *What's the Use of Race? Modern Governance and the Biology of Difference* (63-87). Cambridge, Massachusetts: The MIT Press.

European Commission. (2017). *Special Eurobarometer 468: Attitudes of European citizens towards the environment*. European Union, Brussels, Belgium.

Evans, G.W., Kantrowitz, E. (2002). Socioeconomic status and health: The potential role of environmental risk exposure. *Annual Review of Public Health*, 23, 303-331.

Fee, E., Gonzalez, A.R. (2017). The history of health equity: concept and vision. *Diversity and Equality in Health and Care*, 14(3), 148-152.

Fiorito, G., McCrory, C., Robinson, O., Carmeli, C., Ochoa-Rosales, C., Zhang, Y., et al. (2019). Socioeconomic position, lifestyle habits and biomarkers of epigenetic aging: a multi-cohort analysis. *Aging*, 11(7), 2045-2070.

Frickel, S. (2011). Who are the experts of environmental health justice. In: Ottinger G. and Cohen B.R. (Eds.), *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement* (21-39). Cambridge, Massachusetts: The MIT Press.

Frohlich, K.L., Abel, T. (2014). Environmental justice and health practices: understanding how health inequities arise at the local level. *Sociology of Health & Illness*, 36(2), 199-212.

Frohlich, K.L., Corin, E., Potvin, L. (2001). A theoretical proposal for the relationship between context and disease. *Sociology of Health & Illness*, 23(6), 776-797.

Gee, G.C., Payne-Sturges, D.C. (2004). Environmental health disparities: A framework integrating psychosocial and environmental concepts. *Environmental Health Perspectives*, 112(17), 1645-1653.

Givens, J.E., Huang, X.R., Jorgenson, A.K. (2019). Ecologically unequal exchange: A theory of global environmental injustice. *Sociology Compass*, 13(5).

Gottlieb, R. (2002). *Environmentalism unbound: Exploring new pathways for change*. Cambridge, Massachusetts: The MIT Press.

Grandjean, P., Bellinger, D., Bergman, A., Cordier, S., Davey-Smith, G., Eskenazi, B., et al. (2008). The Faroes statement: human health effects of developmental exposure to chemicals in our environment. *Basic Clin Pharmacol Toxicol*, 102(2), 73-75.

Guidotti, T.L. (2018). Environmental health needs an expanded paradigm, II. Contextualizing environmental health with environmental studies. *Archives of Environmental & Occupational Health*, 73(6), 331-333.

Gupta, J., Scholtens, J., Perch, L., Dankelman, I., Seager, J., Sánder, F., et al. (2019). Re-imagining the driver–pressure–state–impact–response framework from an equity and inclusive development perspective. *Sustainability Science*, 15(2), 503-520.

Hänninen, O., Knol, A.B., Jantunen, M., Lim, T.-A., Conrad, A., Rappolder, M., et al. (2014). Environmental Burden of Disease in Europe: Assessing Nine Risk Factors in Six Countries. *Environmental Health Perspectives*, 122(5), 439-446.

Harris, K.M., McDade, T.W. (2018). The Biosocial Approach to Human Development, Behavior, and Health Across the Life Course. *RST: The Russell Sage Journal of the Social Sciences*, 4(4), 2-26.

Heinrich, J., Mielck, A., Schäfer, I., Mey, W. (2000). Social inequality and environmentally-related diseases in Germany: review of empirical results. *Sozial-und Präventivmedizin*, 45(3), 106-118.

Hertzman, C., and Boyce, T. (2010). How experience gets under the skin to create gradients in developmental health. *Annu Rev Public Health*, 31, 329-347

Holifield, R. (2001). Defining environmental justice and environmental racism. *Urban Geography*, 22(1), 78-90.

Jerrett, M., Burnett, R.T., Kanaroglou, P., Eyles, J., Finkelstein, N., Giovis, C., Brook, J.R. (2001). A GIS - environmental justice analysis of particulate air pollution in Hamilton, Canada. *Environment and Planning A*, 33(6), 955-973.

Kabisch, N., Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and urban planning*, 122, 129-139.

Keune, H., Morrens, B., Springael, J., Koppen, G., Colles, A., Loots, I., et al. (2009). Policy interpretation of human biomonitoring research results in Belgium: priorities and complexity, politics and science. *Environmental Policy and Governance*, 19(2), 115-129.

Kolossa-Gehring, M. (2012). A meeting report, human biomonitoring: political benefits — scientific challenges. September 26–28, 2010*. International Journal of Hygiene and Environmental Health*, 215, 247-252.

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology*, 30(4), 668-677.

Kruize, H., Droomers, M., van Kamp, I., Ruijsbroek, A. (2014). What Causes Environmental Inequalities and Related Health Effects? *An Analysis of Evolving Concepts. International Journal of Environmental Research and Public Health*, 11(6), 5807-5827.

LaKind, J.S., Aylward, L.L., Brunk, C., DiZio, S., Dourson, M., Goldstein, D.A., (2008). Guidelines for the communication of Biomonitoring Equivalents: Report from the Biomonitoring Equivalents Expert Workshop. *Regulatory Toxicology and Pharmacology*, 51(3, Supplement), S16-S26.

Lamkarkach, F., Ougier, E., Garnier, R., Viau, C., Kolossa-Gehring, M., Lange, R., Apel, P. (2021). Human biomonitoring initiative (HBM4EU): Human biomonitoring guidance values (HBM-GVs) derived for cadmium and its compounds. *Environment International*, 147, 106337.

Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N., et al. (2018). The Lancet Commission on pollution and health. *Lancet*, 391(10119), 462-512.

Lang, T., Rayner, G. (2012). Ecological public health: the 21st century's big idea? An essay by Tim Lang and Geof Rayner. BMJ : *British Medical Journal*, 345, e5466.

Lange, R., Apel, P., Rousselle, C., Charles, S., Sissoko, F., Kolossa-Gehring, M., Ougier, E. (2021). The European Human Biomonitoring Initiative (HBM4EU): Human biomonitoring guidance values for selected phthalates and a substitute plasticizer. *International Journal of Hygiene and Environmental Health*, 234, 113722.

Larrea-Killinger, C., Munoz, A., Mascaro, J., Zafra, E., Porta, M. (2017). Discourses on the Toxic Effects of Internal Chemical Contamination in Catalonia, Spain. *Medical Anthropology*, 36(2), 125-140.

Laurent, E. (2011). Issues in environmental justice within the European Union. *Ecological Economics*, 70(11), 1846-1853.

Layder, D. (2018). *Investigative Research Theory and Practice*. London: Sage.

Leung, M.W., Yen, I.H., Minkler, M. (2004). Community based participatory research: a promising approach for increasing epidemiology's relevance in the 21st century. *International Journal of Epidemiology*, 33(3), 499-506.

Lind, U., Mose, T., Knudsen, L.E. (2007). Participation in environmental health research by placenta donation - a perception study. *Environmental Health*, 6(1), 1-7.

Link, B.G., Phelan, J. (1995). Social Conditions As Fundamental Causes of Disease. *Journal of Health and Social Behavior*, 80-94.

Little, P.C., Pennell, K.G. (2017). Measuring vapor intrusion: from source science politics to a transdisciplinary approach. *Environmental Sociology*, 3(2), 145-154.

Louro, H., Heinala, M., Bessems, J., Buekers, J., Vermeire, T., Woutersen, M., et al. (2019). Human biomonitoring in health risk assessment in Europe: Current practices and recommendations for the future. *International Journal of Hygiene and Environmental Health*, 222(5), 727-737.

Lupton, D. (2014). Critical perspectives on digital health technologies. *Sociology Compass*, 8(12), 1344-1359.

Lynch, J.W., Smith, G.D., Kaplan, G.A., House, J.S. (2000). Income inequality and mortality: importance to health of individual income, psychosocial environment, or material conditions. *BMJ*, 320(7243), 1200-1204.

Mackenbach, J.P. (2012). The persistence of health inequalities in modern welfare states: The explanation of a paradox. *Social Science & Medicine*, 75(4), 761-769.

Mackendrick, N. (2014). More Work for Mother: Chemical Body Burdens as a Maternal Responsibility. *Gender & Society*, 28(5), 705-728.

Mansfield, B. (2012). Gendered Biopolitics of Public Health: Regulation and Discipline in Seafood Consumption Advisories. *Environment and Planning D: Society and Space*, 30(4), 588-602.

Marmot, M. (2002). The Influence Of Income On Health: Views Of An Epidemiologist. *Health Affairs*, 21(2), 31-46.

Marmot, M.G., Stansfeld, S., Patel, C., North, F., Head, J., White, I., et al. (1991). Health inequalities among British civil servants: the Whitehall II study. *The Lancet*, 337(8754), 1387-1393.

Martinez-Alier, J., Temper, L., Del Bene, D., Scheidel, A. (2016). Is there a global environmental justice movement? *Journal of Peasant Studies*, 43(3), 731-755.

Masuda, J.R., Poland, B., Baxter, J. (2010). Reaching for environmental health justice: Canadian experiences for a comprehensive research, policy and advocacy agenda in health promotion. *Health Promotion International*, 25(4), 453-463.

McCartney, G., Popham, F., McMaster, R., Cumbers, A. (2019). Defining health and health inequalities. *Public Health*, 172, 22-30.

McCrory, C., McLoughlin, S., O'Halloran, A.M. (2019). Socio-Economic Position Under the Microscope: Getting 'Under the Skin' and into the Cells. *Current Epidemiology Reports*, 6(4), 403-411.

McEwen, B.S., Stellar, E. (1993). Stress and the Individual: Mechanisms Leading to Disease. *Archives of Internal Medicine*, 153(18), 2093-2101.

Mitchell, G. (2011). Environmental justice: an overview. In: Nriagu, J. (Eds*.), Encyclopedia of Environmental Health*, Elsevier, Amsterdam, London (449-458).

Morello-Frosch, R., Brody, J.G., Brown, P., Altman, R.G., Rudel, R.A., Pérez, C. (2009). Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. *Environmental Health*, 8(1), 6.

Morello-Frosch, R., Shenassa, E.D. (2006). The environmental "Riskscape" and social inequality: Implications for explaining maternal and child health disparities. *Environmental Health Perspectives*, 114(8), 1150-1153.

Muntaner, C., Eaton, W.W., Miech, R., O'Campo, P. (2004). Socioeconomic Position and Major Mental Disorders. *Epidemiologic Reviews*, 26(1), 53-62.

Mythen, G. (2005). From 'Goods' to 'Bads'? Revisiting the Political Economy of Risk. *Sociological Research Online*, 10(3), 191-203.

Navarro, V., Shi, L. (2001). The Political Context of Social Inequalities and Health. *International Journal of Health Services*, 31(1), 1-21.

Needham, L.L., Calafat, A.M., Barr, D.B. (2007). Uses and issues of biomonitoring. *International Journal of Hygiene and Environmental Health*, 210(3-4), 229-238.

Nelson, J.R., Grubesic, T.H. (2018). Environmental Justice: A Panoptic Overview Using Scientometrics. *Sustainability*, 10(4).

Nelson, J.W., Scammell, M.K., Hatch, E.E., Webster, T.F. (2012). Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. *Environmental Health*, 11(1), 1-15.

Nguyen, V.K., Kahana, A., Heidt, J., Polemi, K., Kvasnicka, J., Jolliet, O., Colacino, J.A. (2020). A comprehensive analysis of racial disparities in chemical biomarker concentrations in United States women, 1999–2014. *Environment International*, 137, 105496.

Nixon, R. (2011). *Slow Violence and the Environmentalism of the Poor*. Cambridge, Massachusetts: Harvard University Press.

Northridge, M.E., Stover, G.N., Rosenthal, J.E., Sherard, D. (2003). Environmental equity and health: Understanding complexity and moving forward. *American Journal of Public Health*, 93(2), 209-214.

Novotny, P. (2000). *Where we live, work, and play: the environmental justice movement and the struggle for a new environmentalism*. Westport: Greenwood Publishing Group.

Ottinger, G., Cohen, B. (2011). *Technoscience and Environmental Justice. Expert Cultures in a Grassroots Movement*. Cambridge, Massachusetts: The MIT Press.

Ottinger, G., Cohen, B. (2012). Environmentally just transformations of expert cultures: Toward the theory and practice of a renewed science and engineering. *Environmental Justice*, 5(3), 158-163.

Pearce, J. (2018). *Annual Report of the Chief Medical Officer 2017, Health Impacts of All Pollution - what do we know?* Annual Report of the Chief Medical Officer 2018.

Pellow, D.N. (2000). Environmental inequality formation - Toward a theory of environmental injustice. *American Behavioral Scientist*, 43(4), 581-601.

Pellow, D.N. (2016). Toward a critical environmental justice: Black Lives Matter as an Environmental Justice Challenge. *Du Bois Review-Social Science Research on Race*, 13(2), 221-236.

Popay, J., Williams, G., Thomas, C., Gatrell, T. (1998). Theorising Inequalities in Health: The Place of Lay Knowledge. *Sociology of Health & Illness*, 20(5), 619-644.

Porta, M., de Basea, M.B., Benavides, F.G., Lopez, T., Fernandez, E., Marco, E., et al. (2008). Differences in serum concentrations of organochlorine compounds by occupational social class in pancreatic cancer. *Environmental Research*, 108(3), 370-379.

Powell, M., Powell, J. (2011). Invisible People, Invisible Risks: How Scientific Assessment of Environmental Health Risks Overlook Minorities - and How Community Participation Can Make Them Visible. In: Ottinger G. and Cohen B.R. (Eds.), Te*chnoscience and Environmental Justice: Expert Cultures in a Grassroots Movement* (149-178). Cambridge, Massachusetts: The MIT Press.

Prüss-Ustün, A., van Deventer, E., Mudu, P., Campbell-Lendrum, D., Vickers, C., Ivanov, I., et al. (2019). Environmental risks and non-communicable diseases. *British Medical Journal*, 364, 1265.

Reynders, H., Colles, A., Morrens, B., Mampaey, M., Coertjens, D., Koppen, G., et al. (2017). The added value of a surveillance human biomonitoring program: The case of FLEHS in Flanders (Belgium). *International Journal of Hygiene and Environmental Health*, 220(2), 46-54.

Ringquist, E.J. (2005). Assessing evidence of environmental inequities: A meta-analysis. *Journal of Policy Analysis and Management*, 24(2), 223-247.

Rondini, A.C. (2015). [Mis] Placing race in biomedical clinical context: Racial categories, medical research, and the reproduction of health disparities. *Sociology Compass*, 9(8), 704-717.

Ruiz, D., Becerra, M., Jagai, J.S., Ard, K., Sargis, R.M. (2018). Disparities in Environmental Exposures to Endocrine-Disrupting Chemicals and Diabetes Risk in Vulnerable Populations. *Diabetes care*, 41(1), 193-205.

Schlosberg, D. (2007). *Defining environmental justice: Theories, movements, and nature*. Oxford: Oxford University Press.

Schlosberg, D. (2013). Theorising environmental justice: the expanding sphere of a discourse. *Environmental Politics*, 22(1), 37-55.

Schoeters, G., Den Hond, E., Colles, A., Loots, I., Morrens, B., Keune, H., et al. (2012). Concept of the Flemish human biomonitoring programme. *International Journal of Hygiene and Environmental Health*, 215(2), 102-108.

Schoeters, G., Govarts, E., Bruckers, L., Den Hond, E., Nelen, V., De Henauw, S., et al. (2017). Three cycles of human biomonitoring in Flanders − Time trends observed in the Flemish Environment and Health Study. *International Journal of Hygiene and Environmental Health*, 220(2, Part A), 36-45.

Schoeters, G., Verheyen, V., Colles, A., Remy, S., Martin, L.R., Govarts, E., et al. (2022). Internal exposure of Flemish teenagers to environmental pollutants: Results of the Flemish Environment and Health Study 2016–2020 (FLEHS IV). *International Journal of Hygiene and Environmental Health*, 242, 113972.

Schroijen, C., Baeyens, W., Schoeters, G., Den Hond, E., Koppen, G., Bruckers, L., et al. (2008). Internal exposure to pollutants measured in blood and urine of Flemish adolescents in function of area of residence. *Chemosphere*, 71(7), 1317-1325.

Schulz, A., Northridge, M.E. (2004). Social determinants of health: Implications for environmental health promotion. *Health Education & Behavior*, 31(4), 455-471.

Schulz, C., Conrad, A., Becker, K., Kolossa-Gehring, M., Seiwert, M., Seifert, B. (2007). Twenty years of the German Environmental Survey (GerES): Human biomonitoring - Temporal and spatial (West Germany/East Germany) differences in population exposure. *International Journal of Hygiene and Environmental Health*, 210(3-4), 271-297.

Selevan, S.G., Kimmel, C.A., Mendola, P. (2000). Identifying critical windows of exposure for children's health. *Environmental Health Perspectives*, 108(suppl 3), 451-455.

Sellers, C.C. (1997). *Hazards of the job: from industrial disease to environmental health science*. Chapel Hill and London, University of North Carolina Press.

Sexton, K. (1997). Sociodemographic aspects of human susceptibility to toxic chemicals: Do class and race matter for realistic risk assessment? *Environmental Toxicology and Pharmacology*, 4(3-4), 261-269.

Sexton, K., Adgate, J.L. (1999). Looking at environmental justice from an environmental health perspective. *Journal of exposure analysis and environmental epidemiology*, 9(1), 3-8.

Sexton, K., Needham, L.L., Pirkle, J.L. (2004). Human biomonitoring of environmental chemicals. *American Scientist*, 92(1), 38-45.

Shostak, S. (2004). Environmental justice and genomics: Acting on the futures of environmental health. *Science as Culture*, 13(4), 539-562.

Siegrist, J., Marmot, M. (2004). Health inequalities and the psychosocial environment—two scientific challenges. *Social Science & Medicine*, 58(8), 1463-1473.

Siroux, V., Agier, L., Slama, R. (2016). The exposome concept: a challenge and a potential driver for environmental health research. *European Respiratory Review*, 25(140), 124-129.

Stringhini, S., Carmeli, C., Jokela, M., Avendaño, M., Muennig, P., Guida, F., et al. (2017). Socioeconomic status and the 25 × 25 risk factors as determinants of premature mortality: a multicohort study and meta-analysis of 1·7 million men and women. *The Lancet*, 389(10075), 1229-1237.

Sze, J., London, J.K. (2008). Environmental Justice at the Crossroads. *Sociology Compass*, 2(4), 1331-1354.

Taylor, D.E. (2000). The Rise of the Environmental Justice Paradigm: Injustice Framing and the Social Construction of Environmental Discourses. *American Behavioral Scientist*, 43(4), 508-580.

Taylor, W.C., Floyd, M.F., Whitt-Glover, M.C., Brooks, J. (2007). Environmental justice: a framework for collaboration between the public health and parks and recreation fields to study disparities in physical activity. *Journal of Physical Activity and Health*, 4(s1), S50-S63.

Tyrrell, J., Melzer, D., Henley, W., Galloway, T.S., Osborne, N.J. (2013). Associations between socioeconomic status and environmental toxicant concentrations in adults in the USA: NHANES 2001-2010. *Environment International*, 59, 328-335.

UCC. (1987). *Toxic wastes and race in the United States : a national report on the racial and socio-economic characteristics of communities with hazardous waste sites*. New York: United Church of Christ, Commission for Racial Justice.

Uphoff, E.P., Pickett, K.E., Cabieses, B., Small, N., Wright, J. (2013). A systematic review of the relationships between social capital and socioeconomic inequalities in health: a contribution to understanding the psychosocial pathway of health inequalities. *International journal for equity in health*, 12, 54-54.

VMM. (2012). *MIRA Indicatorenrapport 2012*, Vlaamse Milieumaatschappij.

Wakefield, S.E.L., Baxter, J. (2010). Linking Health Inequality and Environmental Justice: Articulating a Precautionary Framework for Research and Action. *Environmental Justice*, 3(3), 95-102.

Walker, G. (2009). Beyond Distribution and Proximity: Exploring the Multiple Spatialities of Environmental Justice. *Antipode*, 41(4), 614-636.

Walker, G. (2012). *Environmental Justice Concepts, Evidence and Politics*. New York: Routledge.

Wang, A., Padula, A., Sirota, M., Woodruff, T.J. (2016). Environmental influences on reproductive health: the importance of chemical exposures. *Fertility and sterility*, 106(4), 905-929.

Wang, Z., Walker, G.W., Muir, D.C.G., Nagatani-Yoshida, K. (2020). Toward a Global Understanding of Chemical Pollution: A First Comprehensive Analysis of National and Regional Chemical Inventories. *Environmental Science & Technology*, 54(5), 2575-2584.

Washburn, R. (2013). The Social Significance of Human Biomonitoring. *Sociology Compass*, 7(2), 162-179.

Washburn, R. (2014). Measuring Personal Chemical Exposures Through Biomonitoring The Experiences of Research Participants. *Qualitative Health Research*, 24(3), 329-344.

WHO. (1992). *Our planet, our health: report of the WHO Commission on Health and Environment*. World Health Organization.

WHO. (2010). Parma Declaration on Environment and Health, Parma, Italy, 10-12 March 2010 (No. EUR/55934/5.1 Rev. 2). Copenhagen: World Health Organization Regional Office for Europe.

WHO. (2012). Environmental health inequalities in Europe. Assessment report. World Health Organization.

World Health Organization. (2015). Human biomonitoring: facts and figures (No. WHO/EURO: 2015-3209-42967-60040). World Health Organization. Regional Office for Europe.

WHO. (2019a). Environmental health inequalities in Europe. Second assessment report. World Health Organization.

WHO. (2019b). Healthy, prosperous lives for all: the European Health Equity Status Report: executive summary (No. WHO/EURO: 2019-3536-43295-60680). World Health Organization. Regional Office for Europe.

Wilkinson, R., Pickett, K. (2010). The spirit level. Why equality is better for everyone. Penguin UK.

Chapter 2 Social distribution of internal exposure to environmental pollution in Flemish adolescents

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Abstract

Background: Environmental justice research suggests that inequalities in the distribution of environmental exposure to chemical pollution systematically disadvantage the lower social strata of society. The effects of these inequalities on the human exposure to pollution are however to a large extend unknown. The purpose of this study is to assess social gradients in human biomonitoring results of a representative sample of Flemish adolescents.

Methods: We investigate the associations between individual socioeconomic status (SES), measured by parental educational attainments, and internal body concentration of seven chemical compounds in biological samples of 1642 adolescents aged 14-15 in Flanders (Belgium): PCBs, HCB, DDE, lead, cadmium, benzene and PAHs. Social gradients in average and high exposure to these biomarkers were examined with geometric means and odds ratios (with 95% confidence intervals), using multiple regression models, controlling for covariates and confounders.

Results: Depending on the (type of) pollutant, adolescents with a lower SES either have higher or lower internal concentrations. Chlorinated compounds (PCBs and pesticides HCB and DDE) are positively associated with SES (higher exposures for higher SES), while heavy metals (lead and cadmium) are negatively associated (higher exposures for lower SES). For metabolites of organic compounds (benzene and PAHs) we find no association with SES. Socially constructed factors, such as dietary and lifestyle habits, play an important role in these relations.

Conclusions: Our study suggests that the association between individual SES and the internal body concentration of exposure to environmental pollutants in Flemish adolescents is more complex than can be assumed on the basis of the environmental justice hypothesis.

Keywords: environmental justice; human biomonitoring; socioeconomic status; adolescents; internal environmental exposure

2.1 Background

Since the last few decades, the field of public health has emphasized environmental and social factors as important, but largely separate, determinants of social health inequalities. Important because they both have proven to have damaging effects on the health status of people, separate because they are perceived as two different influences, needing different scientific and political expertise to monitor, evaluate and tackle them. Studies on the social determinants of health rarely include biological measurements of the chemical environment, and vice versa (Adler & Newman, 2002; O'Neill et al., 2003; Porta et al., 2008). Recently however, the interaction between environmental and social factors in producing health inequalities is becoming more and more visible as issues of poverty and health are increasingly entwined with environmental issues emerging out of technological development, global warming and persistent chemicals (O'Neill et al., 2007). Therefore, social and environmental epidemiologists underline the synergies between the biochemical environment and the social environment and stress the importance of exploring the role of environmental pollution as a contributing factor in health disparities (Evans & Kantrowitz, 2002; Krieger, 2001; O'Neill et al., 2007). This research is rooted in the environmental justice movement, which emerged more than two decades ago out of scientific and societal attention for poor African-American communities in the US (Cole & Foster, 2001). The empirical grounding of this environmental justice movement shows that hazards in the physical and chemical environment disproportionately affect those individuals, households and neighbourhoods that also face hazards in their social environment (Brown, 1995).

Two potential disparities are distinguished, that can work independently or together. Minorities and socially disadvantaged populations can be more exposed to environmental pollution (proximity inequality) and can be more susceptible to its damaging health effects (impact inequality), while having a smaller contribution to environmental pressure. The socio-spatial distribution of environmental quality reveals that poor people and deprived communities may experience an accumulation of exposure to multiple, suboptimal environmental conditions (Evans & Kantrowitz, 2002) like proximity to hazardous waste facilities and busy roads, flood risk and air quality (Hipp & Lakon, 2010; Mitchell & Dorling, 2003; Walker & Burningham, 2011). Given the same exposure, disadvantaged groups may also be more vulnerable to adverse health effects than the general population. Due to several ‘susceptibility factors’ (Sexton, 1997) like predisposed diseases and psychological stress, the health impact of environmental pollution appeared to be greater in the lower social classes (Pope et al., 2002; Wheeler & Ben-Shlomo, 2005).

Children and adolescents living in deprived households and neighbourhoods are identified as a particularly susceptible subgroup because their specific behavioural and dietary habits and their physical and mental development makes them even more vulnerable to adverse influences from the living environment (Bolte & Kohlhuber, 2005; Hornberg & Pauli, 2007).

These two types of inequality can independently affect a person’s health status, yet those who are both more exposed and more susceptible will endure the most health effects. This combined inequality is sometimes referred to as the ‘double jeopardy’ of environmental health disparities (Morello-Frosch & Shenassa, 2006). Although it is clear that the combination of both types of inequality will be concentrated in the most deprived segment of a population, the relationship between SES and environmental health may be not confined to poor people alone. Health status follows a clear social gradient, meaning that adverse health outcomes get worse at every step down the social ladder (Wilkinson & Marmot, 2003).

Although the policy implications of the environmental justice discourse are far-reaching, the empirical grounding of this discourse has recently been criticised for using simplistic methodologies and aggregated data which give only a very partial view of the processes involved in environmental inequalities (Briggs et al., 2008; Walker, 2009). Research outside the US is also rather scarce, which raises questions about the validity of US-based results in other settings. Many environmental justice studies link the spatial distribution of pollution sources or emission concentrations to aggregated socio-demographic characteristics of neighbourhoods or city wards. However, the usefulness of this measurement seems to be rather limited, because analysed group-level associations between social determinants and (potential) external exposure to pollutants may not reflect the individual experience. Little research exists on the social distribution of internal pollutant exposure concentrations, measured by human biomonitoring, and available evidence shows inconsistent results which do not always support the environmental justice hypothesis (Borrell et al., 2004; Porta et al., 2008; Vrijheid et al., 2010).

In this paper we attempt to tackle this research gap by socio-stratifying the results of a human biomonitoring study in Flanders, the northern part of Belgium. Human biomonitoring is a technique for measuring the internal exposure and biological effects of chemical compounds in human tissue. Biomarkers of exposure indicate the amount of pollution actually absorbed and retained within the body. The majority of human biomonitoring studies, however, only use socioeconomic measures as confounding factors that ‘control’ for their potential ‘disturbing’ effects, and seldom analyse the specific relationship between socioeconomic indicators and biomarkers.

We investigate the associations between socioeconomic status (SES) and internal exposure to seven selected pollutants in Flemish adolescents aged 14-15. We explore whether specific social gradients emerge when assessing the internal concentration of pollutants in the human body, and whether these gradients can be explained by specific underlying factors related to both exposure and SES.

2.2 Materials and methods

The Flemish Centre for Environment and Health carried out the first Flemish Environment and health Survey (FLEHS I), a large-scale biomonitoring program on neonates, adolescents and older adults, between 2002 and 2006 in Flanders, the northern part of Belgium. The objectives were to measure and compare internal exposure to pollutants of people living in different geographical areas and to assess whether observed differences were associated with biological and health effects. Detailed results about the geographical distribution of the internal exposure to environmental pollution (and the related health effects) are described elsewhere (Croes et al., 2009; Den Hond et al., 2009; Schroijen et al., 2008). In this article we focus on the social distribution of the internal exposures among adolescents.

2.2.1 Study area and subjects

The human biomonitoring campaign of adolescents was carried out in eight areas of Flanders with a different pollution pressure: the Antwerp agglomeration, the Ghent agglomeration, the aggregated industrial harbour areas of Antwerp and Ghent (mainly petrochemical and metallurgic industries, respectively), the industrial zone around the Albert canal (chemical industry), the industrial zone of Olen (non-ferrous industry), the immediate surroundings of household waste incinerators, a rural area with intensive fruit cultivation, and a rural area (countryside). The total surface of the study site covers 22% of the total surface of Flanders and is inhabited by 20% of the Flemish populations.

The adolescents were enrolled via 50 schools located in the eight selected regions and sampled between October 2003 and July 2004. Inclusion criteria were the following: being born in 1988 or 1989, studying in the third year of secondary education, living for at least five years in the same study area, and giving informed consent (both adolescent and parents). 4386 pupils were invited to participate in the human biomonitoring program by letter. 1670 (38.1%) did not respond, because they did not fulfill the inclusion criteria or because they were not interested. Among the 2716 pupils who did respond, 646 (23.8%) refused to participate and 138 (5.0%) were excluded by the researchers because they did not reside in the area for 5 years or because of incomplete questionnaires or insufficient blood or urine sampled. The recruitment resulted in a total of 1679 adolescents, distributed equally over the eight study areas. All participants signed an informed consent form and had the right to withdraw from the study at any time. The study was approved by the Medical Ethics Committee of the University of Antwerp.

2.2.2 Measures of internal exposure

About 200 ml of urine and 40 ml of blood were sampled from each participant to carry out various chemical analyses and assess the internal concentration of 7 biomarkers of exposure, classified within three types of pollutants: chlorinated persistent compounds, heavy metals and volatile compounds. In the selection of these 7 biomarkers, priority was given to historical pollutants to which a general population may be chronically exposed through the environment or diet. These biomarkers are selected because they have well-known health effects, since levels in the general population are expected to be measurable and validated detection methods are available.

Three chlorinated persistent compounds were measured in serum: concentration of polychlorinated biphenyls (PCBs) (sum of marker PCB 138, 153 and 180) and concentration of the organochlorine pesticides hexachlorobenzene (HCB) and p,p'-dichlorodiphenyldichloroethylene (p,p'-DDE, a metabolite of DDT). PCBs were industrially used since the 1950s as hydraulic or transformer fluids, as plasticisers in paint, and in carbonless copying paper. HCB and DDT were used to control insects and fungus. 2) Two heavy metals were measured in whole blood: lead and cadmium. In the past, they were mainly emitted by the non-ferro industry. Lead can also be found in leaded petrol and paint, cadmium is also present in tobacco smoke and can be emitted by waste incinerators. 3) Two metabolites of volatile compounds – PAHs (1-hydroxypyrene) and benzene (t,t'-muconic acid) – were measured in urine. These compounds are associated with incomplete combustion or by traffic. The toxicological procedures of the blood and urine analyses are described in detail elsewhere (Schroijen et al., 2008).

2.2.3 Measures of socioeconomic status

Additionally, to the collection of blood and urine, participants were asked to fill out questionnaires about personal, social, and lifestyle factors. Complementary, the parents of the adolescents completed a questionnaire comprising data on their education, housing, residence history, household income, and the health history of their participating child. Since our research subjects are 14–15-year-old adolescents, and thus not yet active on the labour market, their SES must be defined by parental or household indicators. We used parental educational attainment, defined as the highest educational level of the father and mother, to quantify the adolescent's SES. The questionnaire contains a standard scale with eight response categories representing the different stages of the Flemish education system. We used the highest educational level of one parent if the other parent's information was not listed. Adolescents living in co-parenting households had the opportunity to led parents fill out the education attainment for two separate households (household A and B), and indicating the time the adolescent spend in each household. We classified parental educational attainment into three categories: primary, secondary and tertiary education, corresponding respectively to adolescents with a low, middle or high SES.

2.2.4 Statistical methodology

For each biomarker, two measures of pollutant concentration were examined in relation to SES: the average and high exposure concentration. Average exposure is quantified by the geometric mean (GM) for each category of SES. An adolescent is defined to have a high internal exposure if its individual exposure is higher than the 90th percentile concentration (P90) of the entire group. Since 90% of all adolescents have a body concentration below this value, the P90 stipulates the peak value of the study sample for each biomarker. So, high exposure is defined as an internal exposure above the sample 90th percentile. When associations or gradients between SES and biomarkers of exposure are 'positive', both variables move in tandem: an increase in SES correlates with an increase in exposure, and vice versa. When associations are 'negative', an increase in one variable goes together with a decrease in the second one.

Our analyses consist of (three) consecutive linear and logistic regression models. The first model investigates social gradients in the unadjusted geometric mean exposure (GM and 95% CI) and in the probability to have high exposure (OR and 95% CI). Model 2 extends model 1 by including confounders to be known from literature to influence internal exposure: sex, age, smoking status and living region. For the chlorinated compounds also body mass index is included in this model.

Correcting for these covariates may explain the initially found relations with SES. A third model additionally includes biomarker specific covariates. All analyses are done at a 5% level of significance with SAS version 9.1 and SPSS version 18.

2.3 Results

Using highest parental education as proxy for socioeconomic status (SES), we included 1642 adolescents in our study (2.2% missing). 15.5% of the adolescents have a low SES (meaning that both parents are primary educated), 34.9% have a SES which we termed ‘middle’ (secondary education as highest attainment of parents), and 49.9% have a high SES (at least one parent with tertiary education).

2.3.1 Social distribution of indicators associated with exposure

Sex, age and BMI are significantly related to the SES of adolescents in our study sample. Age and BMI follow a negative social gradient (higher age and BMI for lower SES category). More boys are present in the lower SES categories (potentially indicating a selection bias). Lifestyle factors such as smoking, alcohol consumption and drug use also follow a significant negative social gradient. Daily tobacco smoking is reported three times more often by low compared to high SES adolescents. Our study sample however reveals no significant social gradients for the consumption of home-grown vegetables or daily fish consumption. The daily consumption of meat however follows a significant negative gradient: lower SES consumes more meat. Being breastfed as baby follows a positive social gradient: adolescents with high SES (tertiary educated parents) were significantly more breastfed than adolescents with lower SES. Adolescents with low SES reported higher exposure to environmental tobacco smoke (mean hours per day in locations where people smoke) but indicate less indoor use of pesticides. They also live more closely to busy traffic roads. In our study sample, adolescents with lower SES more frequently live in industrial areas, adolescents with high SES live more in rural areas. Low SES adolescents significantly report worse health status and more doctor-diagnosed asthma Table 5).

Table 5: Self-reported indicators associated with exposure to environmental pollution, by socioeconomic status

	Total N=1642	Socioeconomic status (SES)			p-value
		Low N=254	Middle N=573	High N=815	
Personal factors					
Sex (% boys)	53.2	57.9	55.7	50.1	0.032
Age (years) (mean)	14.9	15.0	14.9	14.8	<0.001
BMI (mean)	20.6	21.2	21.0	20.1	<0.001
Lifestyle factors					
Daily tobacco smoking (%)	8.0	14.3	10.4	4.3	<0.001
Alcohol consumption (mean/week)	2.0	2.9	2.3	1.6	<0.001
Drug use (%)	8.2	12.9	9.1	6.2	0.002
Nutrition factors					
Consumption home grown vegetables (%)	50.9	49.4	52.9	50.9	0.254
Fish consumption (mean g/day)	18.4	19.2	17.5	18.8	0.348
Meat consumption (mean g/day)	108.6	119.9	111.9	103.1	<0.001
Breastfed as baby (%)	60.5	42.4	50.0	73.5	<0.001
Environmental factors					
Indoor					
ETS[a] (mean hours/day)	1.8	2.9	2.3	1.2	0.000
Indoor pesticide use (%)	49.9	47.4	45.6	53.8	0.009
Outdoor					
Living near busy roads[b] (<100m) (%)	53.0	60.4	54.3	49.7	0.010
Residential area (%)					<0.001
Antwerp (urban)	12.3	15.7	14.8	9.4	
Ghent (urban)	12.3	10.2	5.8	17.5	
Harbour (industry)	13.4	21.7	16.1	9.0	
Olen (industry)	13.3	8.7	13.3	14.7	
Albert canal (industry)	11.7	16.1	16.2	7.1	
Near waste incinerators	12.6	11.0	11.7	13.7	
Rural area	12.3	7.1	10.5	15.2	
Near fruit orchards	12.1	9.4	11.7	13.3	
Health factors					
Bad self-rated health status (%)	19.9	25.8	22.4	16.2	<0.001
Asthma (doctor-diagnosed)	9.5	17.9	8.2	7.8	<0.001

[a] ETS: Environmental tobacco smoke; [b] more than one car per minute

2.3.2 Social distribution of biomarkers of internal exposure

Table 6 shows for each biomarker the concentration of mean. geometric mean and high exposure (P90) for all adolescents (n = 1642), and also gives minimum and maximum concentration. In table 3 model 1 shows the unadjusted geometric mean and the probability of having a high concentration to chlorinated compounds. For PCBs the mean exposure significantly increases with increasing SES. Also, the odds for high exposure (>P90) follows a significant and positive gradient. Sex, age, smoking status and BMI are important determining factors of the internal concentration of PCBs and these factors are significantly associated with SES. However, model 2 shows that controlling for these factors does not diminish the effect of SES. Further correction for breastfeeding in model 3 results in a non-significant social gradient for high exposure. The OR for the low and middle SES category approach 1 (indicating no difference with the highest category) and are no longer statistically significant. The social gradient for the risk of having high PCB exposure levels (>P90) in 14–15-year adolescents, can – at least partly – be explained by the social gradient in nursing with maternal milk when these adolescents were babies. The positive social gradient in average exposure to PCBs however stays significant.

Table 6: Total distribution of internal exposure to biomarkers

	Arithmetic mean	Geometric mean (SD)	90th percentile	Min-Max
Chlorinated compounds in serum				
Sum PCBs (ng/g lipid)[a]	75.95	65.81 (46.88)	124.98	7.68-589.85
p.p'-DDE (ng/g lipid)	168.55	106.46 (282.47)	335.11	3.04-4714.83
HCB (ng/g lipid)	21.75	20.55 (7.62)	31.37	4.49-78.22
Heavy metals in whole blood				
Cadmium (µg/l)	0.55	0.31 (0.52)	1.27	0.05-3.22
Lead (µg/l)	25.54	21.30 (16.31)	45.40	1.00-211.92
Metabolites of organic compounds				
Benzene (µg/g creatinine)[b]	0.14	0.09 (0.32)	0.27	0.001-9.37
PAHs (mg/g creatinine)[c]	0.19	0.07 (0.30)	0.48	0.005-4.45

[a] *sum of PCB 138, 153 and 180;* [b] *t,t'-muconic acid in urine;* [c] *1-hydroxypyrene in urine*

For HCB and DDE, the unadjusted geometric mean concentration in model 1 shows a significant positive gradient with SES, but a non-significant OR for high exposure risk. The positive gradient in geometric mean stays significant after correcting for sex, age, smoking status, and BMI. Further correcting for breastfeeding explains the SES gradient in geometric mean for DDE but not for HCB. Additionally adjusting all chlorinated compounds in model 3 for maternal age and parity (not in table) did not change our findings. No significant interactions with residential area or sex were found, meaning that social gradients in internal exposure to chlorinated compounds did not differ between living areas or between sexes (results not shown).

Table 7: Social distribution of average and high exposure to chlorinated compounds (sum PCBs, DDE and HCB), unadjusted and adjusted regression models

	Sum PCBs (ng/g lipid)		**HCB (ng/g lipid)**		**p,p'-DDE (ng/g lipid)**	
	Geometric mean (95% CI)	OR for high exposure (95% CI)	Geometric mean (95% CI)	OR for high exposure (95% CI)	Geometric mean (95% CI)	OR for high exposure (95% CI)
Model 1[a]						
Low SES	56.94 (53.40; 60.71)	0.36 (0.20; 0.65)	19.47 (18.67; 20.31)	0.74 (0.45; 1.21)	99.86 (90.01; 110.78)	0.86 (0.53; 1.40)
Middle SES	61.36 (58.79; 64.05)	0.54 (0.38; 0.79)	20.06 (19.51; 20.63)	0.72 (0.50; 1.05)	100.83 (94.07; 108.07)	0.91 (0.63-1.30)
High SES	72.82 (70.26; 75.49)	1.00	21.31 (20.81; 21.83)	1.00	113.84 (107.42; 120.65)	1.00
p-value	<0.0001	<0.0001	0.0001	0.1680	0.0118	0.7872
Model 2[b]						
Low SES	52.15 (48.86; 55.66)	0.32 (0.17; 0.61)	18.89 (18.05; 19.77)	0.61 (0.35; 1.04)	93.24 (83.04; 104.71)	0.77 (0.45; 1.31)
Middle SES	57.41 (54.48; 60.51)	0.59 (0.39; 0.88)	19.72 (19.01; 20.44)	0.66 (0.44; 0.99)	93.23 (84.91; 102.36)	0.78 (0.53; 1.15)
High SES	65.31 (61.95; 68.86)	1.00	20.97 (20.22; 21.77)	1.00	108.77 (99.00; 119.51)	1.00
p-value	<0.0001	0.0005	<0.0001	0.0614	0.0008	0.3805
Model 3[c]						
Low SES	53.83 (50.53; 57.34)	0.49 (0.26; 0.95)	19.00 (18.16; 19.89)	0.73 (0.41; 1.29)	96.34 (85.97; 107.97)	0.85 (0.49; 1.48)
Middle SES	58.28 (55.40; 61.31)	0.75 (0.49; 1.13)	19.83 (19.13; 20.56)	0.77 (0.51; 1.17)	95.33 (87.01; 104.43)	0.86 (0.58; 1.29)
High SES	62.76 (59.62; 66.08)	1.00	20.69 (19.94; 21.46)	1.00	103.25 (94.11; 113.27)	1.00
p-value	<0.0001	0.0756	0.0008	0.3623	0.1705	0.7234

[a] unadjusted mean exposure and OR for high exposure; [b] adjusted for sex, age, smoking status, BMI and residential area; [c] additionally adjusted for breastfeeding; CI: confidently interval; OR: odds ratio

For cadmium, we found a negative social gradient in the distribution of mean and high exposure (Table 8). This is reflected in OR larger than 1 for the adolescents in the lower SES categories (model 1). The odds for high exposure of adolescents with low SES is more than double the odds for adolescents with high SES. The negative gradient in the mean and high exposure is still present after correction for sex, age, smoking status and study area in (model 2) and remains present after additionally correcting for the consumption of home-grown vegetables (model 3). Note that SES is borderline not significant in model 2 for high exposure (p=0.053). For lead we see a modest and non-significant relation between SES and mean exposure, but a stronger and significant relation with high exposure. This effect disappears after correcting for sex, age, smoking status and living region.

Table 8: Social distribution of average and high exposure to heavy metals (cadmium and lead), unadjusted and adjusted regression models

	Cadmium (µg/l)		Lead (µg/l)	
	Geometric mean (95% CI)	OR for high Exposure (95% CI)	Geometric mean (95% CI)	OR for high Exposure (95% CI)
Model 1[a]				
Low SES	0.38 (0.33; 0.43)	2.21 (1.43; 3.41)	22.03 (20.40; 23.79)	1.78 (1.16; 2.72)
Middle SES	0.38 (0.34; 0.41)	1.57 (1.08; 2.27)	21.18 (20.12; 22.30)	1.12 (0.77; 1.62)
High SES	0.30 (0.28; 0.32)	1.00	21.14 (20.24; 22.08)	1.00
p-value	0.0001	0.0011	0.6388	0.0272
Model 2[b]				
Low SES	0.45 (0.39; 0.52)	1.81 (1.12; 2.94)	21.10 (19.38; 22.96)	1.65 (1.04; 2.60)
Middle SES	0.46 (0.41; 0.52)	1.32 (0.88; 1.97)	20.46 (19.15; 21.85)	1.02 (0.69; 1.52)
High SES	0.40 (0.35; 0.44)	1.00	20.77 (19.46; 22.17)	1.00
p-value	0.0228	0.0531	0.7778	0.0729
Model 3[c]				
Low SES	0.45 (0.39; 0.52)	1.95 (1.19; 3.18)	21.03 (19.31; 22.91)	1.63 (1.02; 2.62)
Middle SES	0.47 (0.42; 0.52)	1.28 (0.85; 1.94)	20.45 (19.23; 21.95)	1.07 (0.72; 1.59)
High SES	0.39 (0.35; 0.44)	1.00	20.61 (19.31; 21.99)	1.00
p-value	0.0142	0.0285	0.8665	0.1095

[a] unadjusted mean exposure and OR for high exposure; [b] adjusted for sex, age, smoking status and residential area; [c] additionally adjusted for consumption of home-grown vegetables
CI: confidently interval; OR: odds ratio

Additionally testing our data for possible interaction of (1) SES and living area and (2) SES and gender resulted in a significant interaction effect between SES and living area for cadmium and between SES and sex for lead. The social dispersion in internal cadmium exposure significantly differs between living areas. In all, but one, areas adolescents with a low SES are more exposed than adolescents with a high SES. The difference in mean cadmium exposure, between low and high SES, is largest in the industrial region of Olen and smallest in the rural area. In the urban area of

Ghent there appeared to be a converted social effect: the cadmium concentration of adolescents with a low SES is on average 0.53 times lower than the concentration of adolescents with a high SES. The social distribution of lead exposure significantly interacts with gender. For boys, the average lead concentration in the lowest SES category equals 1.14 times the concentration in the highest SES, whereas for girls the average lead concentration in the lowest SES category equals 0.87 times the concentration in the highest category. This indicates that socioeconomic status has an opposite effect on lead concentration in boys and girls.

For the metabolites of organic compounds, no social gradients were detected; not in terms of the geometric mean and not in high exposure (Table 9). No interactions with residential area or sex were found.

Table 9: Social distribution of average and high exposure to organic compounds (PAHs and benzene), unadjusted regression models

	PAHs (µg/g creatinine)		**Benzene (mg/g creatinine)**	
	Geometric mean (95% CI)	OR for high exposure (95% CI)	Geometric mean (95% CI)	OR for high exposure (95% CI)
Model 1[a]				
Low SES	0.102 (0.088; 0.118)	1.06 (0.67; 1.68)	0.071 (0.060; 0.083)	0.94 (0.58; 1.53)
Middle SES	0.086 (0.078; 0.094)	0.80 (0.55; 1.16)	0.072 (0.065; 0.080)	0.78 (0.53; 1.14)
High SES	0.088 (0.081; 0.096)	1.00	0.072 (0.066; 0.078)	1.00
p-value	0.1676	0.4148	0.9787	0.4244
Model 2[b]				
Low SES	0.113 (0.095; 0.135)	0.97 (0.60; 1.60)	0.074 (0.062; 0.088)	0.88 (0.53; 1.46)
Middle SES	0.099 (0.087; 0.113)	0.76 (0.52; 1.13)	0.076 (0.066; 0.088)	0.75 (0.50; 1.11)
High SES	0.104 (0.091; 0.119)	1.00	0.076 (0.066; 0.087)	1.00
p-value	0.3464	0.3792	0.9498	0.3500

[a] unadjusted mean exposure and OR for high exposure; [b] adjusted for sex, age, smoking status and residential area; CI: confidently interval; OR: odds ratio

2.4 Discussion

In this study, we tested the general environmental justice hypothesis that people of lower socioeconomic strata are more exposed to environmental pollution than people of higher social strata. Our results show that the association between socioeconomic status (SES) and the internal body concentration of exposure to environmental pollutants in Flemish adolescents (aged 14-15) is more complex than can be assumed on the basis of the environmental justice hypothesis. Depending on the (type of) pollutant, adolescents with a lower (SES) have higher or lower internal concentrations. Chlorinated compounds (PCBs and pesticides HCB and DDE) are positively associated with SES, while heavy metals (lead and cadmium) are negatively associated. For metabolites of volatile compounds (benzene and PAHs) we find no association with SES. Further, our results show that socially constructed lifestyle factors and dietary habits play an important role in these relations. The positive relation between SES and PCBs (OR) or DDE (geometric mean) (higher SES have higher exposure) could not be explained by differences in sex, age, smoking, BMI or residential area, but disappeared after additional adjustment for breastfeeding. This indicates that the nursing habit of the mother is a principal factor in the observed social differences in the body concentration of PCBs and DDE among adolescents. The negative relation between SES and cadmium or lead (higher SES have lower exposure) could to a large extend by explained by age, sex, smoking behaviour and residential area of the adolescent.

Mean and high exposure to environmental pollutants were calculated after stratification of the participants by social class. From a toxicological point of view, analyzing high exposures is sometimes more important than modal or mean exposure, since most health risks are expected for persons and groups having the highest exposure. Similar analyses using 75th or 95th percentile concentrations to assess socioeconomic differences in internal exposure were conducted by other authors (Axelrad et al., 2009; Vrijheid et al., 2010). Our study suggests that when looking at the internal exposure of environmental chemicals, a complex and nuanced picture emerges in which social gradients differ in function of the chemicals under study. Our findings support only partly the environmental justice hypothesis, but the results are consistent with other available studies. Positive associations between indicators of SES and chlorinated compounds are also found elsewhere. In pregnant women, increasing income was associated with increasing concentrations of PCBs but not DDE in the US (Borrell et al., 2004), and with PCBs and HCB, but not DDE in Spain (Vrijheid et al., 2010). The PCB and DDE level of 4-year-old children in the Michigan region (US) was positively associated with family SES (Jacobson et al., 1989). In Germany, PCBs, DDE and HCB concentrations were also higher in children aged 3 to 14 with a higher SES (Becker et al., 2008). However, not all studies are consistent with these findings. In a small study population of adults with pancreatic cancer in Spain, serum concentration of seven organochlorine compounds, including PCBs, HCB and DDE, were significantly higher for lower occupational social classes (Porta et al., 2008). In the Czech adult population, PCB concentrations were not significantly associated with individual educational attainment (Cerna et al., 2008). With respect to DDE, some American studies have suggested that there is a racial difference in DDE levels, with the highest levels being among African Americans (Davies et al., 1972). Social differences in the general or age specific populations are however mostly non-significant, suggesting perhaps more cultural and ethnic than socioeconomic mechanisms behind unequal distributions of DDE concentrations.

PCBs, DDE and HCB have hormone-disrupting, immune-disrupting, neurotoxic and carcinogenic properties (Demers et al., 2002; Osius et al., 1999). Significant relations between these health effects and exposure concentrations of chlorinated compounds were found in a general population in Belgium (Den Hond et al., 2002; Staessen et al., 2001; Van den Heuvell et al., 2002; Vermeir et al., 2005). A higher fish and meat consumption and more nursing with maternal milk are identified as main determinants explaining the social differences in serum concentrations of chlorinated compounds. Similar to our findings, the initially found relation between education and PCBs in US children (4 years) disappeared after adjustment for breastfeeding (Jacobson et al., 1989). Pediatric studies in Europe, US, Canada and Australia have shown clear social class differences in the initiation and duration of breastfeeding and indicate that women who initiate and continue to breastfeed are older, married, better educated, and have higher family incomes than women who do not breastfeed (Callen & Pinelli, 2004).

For heavy metals, negative associations were also found between SES (educational attainment and income) and internal concentrations of lead (Elreedy et al., 1999) and cadmium (McKelvey et al., 2007) in adult populations in the US, and between SES and lead, but not cadmium, in German children aged 3 to 14 (Becker et al., 2008; Kolossa-Gehring et al., 2007). Studies assessing dose-response relations of lead stipulate that differences in exposure in childhood are responsible for social inequalities in neurodevelopment and cardiovascular reactivity in adulthood (Bellinger, 2008; Gump et al., 2007). Both lead and cadmium are carcinogenic (Staessen et al., 2001) nephrotoxic (Staessen et al., 1996), neurotoxic (Vermeir et al., 2005) and have been associated with fertility problems.

The strong association between current smoking and blood cadmium in our study sample of Flemish adolescents was also found in an adult population in the US and underlines the importance of preventing smoking initiation and promoting smoking cessation campaigns (McKelvey et al., 2007).

Apart from the studies mentioned earlier, published research on social patterns of internal environmental exposures is rather scarce. Most human biomonitoring studies either do not include social indicators or tend to consider SES data only to control for potential confounding. But rather than claiming to have ‘controlled for SES’, researchers should acknowledge the potentially relevant aspects of SES when interpreting findings of environment and health studies (Braveman et al., 2005; Hu et al., 2007). Using human biomonitoring, our study attempted to address some of the weaknesses in previous environmental justice studies. First, we used individual-level indicators of exposure to environmental pollution and of socioeconomic status. No aggregated data were used, thereby avoiding results prone to the ecological fallacy. Second, we used biomedical indicators of the actual internal body concentrations of different pollutants, rather than the more generally used geographical measures of external exposure that are considered potential proxies from different points in the source-exposure chain. Third, our study size (n=1642) is considerably higher than most – although not all – other research conducted a social stratification of HBM-results and is representative of the general population rather than for specific medical or social groups such as patients with pancreatic cancer (Porta et al., 2008) or pregnant Afro-American woman (Borrell et al., 2004).

Nonetheless, the limitations of the research need to be recognized. In our study, SES was based on a single indicator: the highest education of the adolescents’ parents. SES is however a multifaceted concept that cannot be captured with a single indicator (Braveman et al., 2005; Galobardes et al., 2006). Moreover, it has been shown that the type of SES indicator can determine the possible health outcomes and environmental exposures in children and adolescents (Hanson and Chen, 2007;

Hoffmann et al., 2009). We selected parental education however not on an 'ad-hoc' basis. Besides more pragmatic reasons (not all SES proxies were adequately measured in the questionnaires), we based SES on parental education because education is termed as a particularly consistent and commonly used indicator in environmental health research and epidemiology (Galobardes et al., 2006; O'Neill et al., 2003). Specifically for children's environmental health, parental education is a recommended individual-level measure of children's SES (Bolte et al., 2005; Carozza et al., 2010). Studies have confirmed that the health and welfare of children are linked to the educational level of their parents, with parental education often a stronger predictor of children's health than family income (Zill, 1996). In line with the theory of Hyman (Hyman et al., 1975) which states that education produces large, pervasive, and enduring effects on knowledge and receptivity to knowledge, we believe that parental education is associated with health-related knowledge and behaviour that affects the exposure to environmental pollution of children and adolescents, for example smoking tobacco products, specific dietary choices and awareness of and access to (preventive) health care. It should however be noted that our study, as well as the greater part of health inequality research, only uses objective measurements of SES (based on parents' material characteristics). Recently however, the development of an adolescent-specific measure of subjective social status, based on adolescents' perceptions of their familial placement in the social hierarchy and their personal placement in the school community, have shown interesting associations with (self-rated) health in the US (Goodman et al., 2001) and Europe (Karvonen & Rahkonen, 2011). This subjective measurement can be a meaningful alternative approach to conceptualise the SES of adolescents since it embodies an element of social comparison to the association between SES and health. This social comparison has shown to be an important determinant of health inequalities (Wilkinson & Pickett, 2006).

It should also be noted that the parental educational level of our study sample is higher compared to the general Flemish population, and indicates that participating in environmental health research, especially when it is as invasive as human biomonitoring, follows in itself a positive social gradient. This has also been observed in other studies (Porta et al., 2009; Tjonneland et al., 2007). Although extensive research on the cultural, social and psychological factors of study participation among socially disadvantaged populations is still missing, it is becoming clear that recruitment of this target group benefits from a more personal approach with a face-to-face relation between researchers and study subjects. This approach can enhance mutual trust and understanding which is essential for involving socially vulnerable populations. When those populations are living in high-risk areas facing multiple environmental stressors, for instance around an industrial hotspot, a continuous human biomonitoring through a community-based participatory approach can be a powerful political tool to address local environmental justice issues, since this may not only provide valuable information for cumulative risk assessments, but may also empower the affected community and engender more effective prevention and intervention actions (NEJAC, 2004; O'Fallon & Dearry, 2002). This touches however also on ethical aspects because a more individual or community-based approach to human biomonitoring may not always match the more traditional medical and clinical ethics which focus on the protection of the autonomy and privacy of research participants (Dumez et al., 2007; Merlo et al., 2008).

Although our results do not favour the traditional environmental justice hypothesis, we believe it remains important to consider the chemical environment in relation to the social environment when monitoring environmental health risks. It seems plausible that issues of environmental justice manifest themselves more in countries with a higher level of social inequality than in Belgium. However, environmental injustice has been shown to be happening in many different ways, and not finding consistent negative social gradients in internal exposure does not mean that inequality in later health effects will not arise from it. Given the same exposure, social disadvantaged people may be more vulnerable to adverse health effects than the general population. Looking at our study sample, the higher prevalence of asthma and the lower self-reported health of adolescents with lower SES can for example indicate a higher susceptibility for the adverse health impact of (even the same concentration) of environmental exposure than adolescents with a higher SES.

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References

Adler, N.E., Newman, K., (2002). Socioeconomic Disparities In Health: Pathways And Policies. *Health Affairs* 21(2), 60-76.

Axelrad, D.A., Goodman, S., Woodruff, T.J., (2009). PCB body burdens in US women of childbearing age 2001-2002: An evaluation of alternate summary metrics of NHANES data. *Environmental Research* 109(4), 368-378.

Becker, K., Müssig-Zufika, M., Conrad, A., Lüdecke, A., Schulz, C., Seiwert, M., et al. (2008). *German Environmental Survey for Children 2003/06 - GerES IV - Human Biomonitoring Levels of selected substances in blood and urine of children in Germany*. Berlin: Federal Environment Agency (Umweltbundesamt), Dessau-Roßlau, Robert Koch-Institut.

Bellinger, D.C., (2008). Lead neurotoxicity and socioeconomic status: Conceptual and analytical issues. *Neurotoxicology* 29(5), 828-832.

Bolte, G., Kohlhuber, M. (2005). *PINCHE Project: Final Report WP5 Socioeconomic Factors*. Gelderland Midden: Public Health Services.

Bolte, G., Kohlhuber, M., Weiland, S.K., Zuurbier, M., Stansfeld, S., Heinrich, J., (2005). Socioeconomic factors in EU-funded studies of children's environmental health. European Journal of Epidemiology 20(4), 289-291.

Borrell, L.N., Factor-Litvak, P., Wolff, M.S., Susser, E., Matte, T.D., (2004). Effect of socioeconomic status on exposures to polychlorinated biphenyls (PCBs) and dichlorodiphenyldichloroethylene (DDE) among pregnant African-American women. *Archives of Environmental Health* 59(5), 250-255.

Braveman, P.A., Cubbin, C., Egerter, S., Chideya, S., Marchi, K.S., Metzler, M., et al., (2005). Socioeconomic status in health research - One size does not fit all. *Journal of the American Medical Association* 294(22), 2879-2888.

Briggs, D., Abellan, J.J., Fecht, D., (2008). Environmental inequity in England: Small area associations between socio-economic status and environmental pollution. *Soc. Sci. Med.* 67(10), 1612-1629.

Brown, P., (1995). Race, class, and environmental health. A review and systematization of the literature. *Environmental Research* 69(1), 15-30.

Callen, J., Pinelli, J., (2004). Incidence and duration of breastfeeding for term infants in Canada, United States, Europe, and Australia: A literature review. *Birth-Issues in Perinatal Care* 31(4), 285-292.

Carozza, S.E., Puumala, S.E., Chow, E.J., Fox, E.E., Horel, S., Johnson, K.J., et al., (2010). Parental educational attainment as an indicator of socioeconomic status and risk of childhood cancers. *British Journal of Cancer* 103(1), 136-142.

Cerna, M., Maly, M., Grabic, R., Batariova, A., Smid, J., Benes, B., (2008). Serum concentrations of indicator PCB congeners in the Czech adult population. *Chemosphere* 72(8), 1124-1131.

Cole, L.W., Foster, S.R., (2001). *From the ground up: Environmental racism and the rise of the environmental justice movement*. New York: New York University Press.

Croes, K., Baeyens, W., Bruckers, L., Den Hond, E., Koppen, G., Nelen, V., et al., (2009). Hormone levels and sexual development in Flemish adolescents residing in areas differing in pollution pressure. *Int. J. Hyg. Environ. Health*. 212(6), 612-625.

Davies, J.E., Cassady, J.C., Edmundso, W.f., Morgade, C., Raffonel, A., (1972). Role of social class in human pesticide pollution. *American Journal of Epidemiology* 96(5), 334-341.

Demers, A., Ayotte, P., Brisson, J., Dodin, S., Robert, J., Dewailly, E., (2002). Plasma concentrations of polychlorinated biphenyls and the risk of breast cancer: A congener-specific analysis. *American Journal of Epidemiology* 155(7), 629-635.

Den Hond, E., Govarts, E., Bruckers, L., Schoeters, G., (2009). Determinants of polychlorinated aromatic hydrocarbons in serum in three age classes-Methodological implications for human biomonitoring. *Environmental Research* 109(4), 495-502.

Den Hond, E., Roels, H.A., Hoppenbrouwers, K., Nawrot, T., Thijs, L., Vandermeulen, C., et al., (2002). Sexual maturation in relation to polychlorinated aromatic hydrocarbons: Sharpe and Skakkebaek's hypothesis revisited. *Environ. Health Perspect*. 110(8), 771-776.

Dumez, B., Van Damme, K., Casteleyn, L., (2007). Research on the socio-ethical impact of biomarker use and the communication processes in ECNIS NoE and NewGeneris IP. *Int. J. Hyg. Environ. Health*. 210(3-4), 263-265.

Elreedy, S., Krieger, N., Ryan, P.B., Sparrow, D., Weiss, S.T., Hu, H., (1999). Relations between individual and neighborhood-based measures of socioeconomic position and bone lead concentrations among community-exposed men - The Normative Aging Study. *American Journal of Epidemiology* 150(2), 129-141.

Evans, G.W., Kantrowitz, E., (2002). Socioeconomic status and health: The potential role of environmental risk exposure. *Annual Review of Public Health* 23, 303-331.

Galobardes, B., Shaw, M., Lawlor, D.A., Lynch, J.W., Smith, G.D., (2006). Indicators of socioeconomic position (part 1). *J. Epidemiol. Community Health* 60(1), 7-12.

Goodman, E., Adler, N.E., Kawachi, I., Frazier, A.L., Huang, B., Colditz, G.A., (2001). Adolescents' perceptions of social status: Development and evaluation of a new indicator. *Pediatrics* 108(2).

Gump, B.B., Reihman, J., Stewart, P., Lonky, E., Darvill, T., Matthews, K.A., (2007). Blood lead (Pb) levels: A potential environmental mechanism explaining the relation between socioeconomic status and cardiovascular reactivity in children. *Health Psychology* 26(3), 296-304.

Hanson, M.D., Chen, E., (2007). Socioeconomic status and health behaviors in adolescence: A review of the literature. *J. Behav. Med.* 30(3), 263-285.

Hipp, J.R., Lakon, C.M., (2010). Social disparities in health: Disproportionate toxicity proximity in minority communities over a decade. *Health Place* 16(4), 674-683.

Hoffmann, B., Kolahgar, B., Rauchfuss, K., Eberwein, G., Franzen-Reuter, I., Kraft, M., et al., (2009). Childhood social position and associations between environmental exposures and health outcomes. *Int. J. Hyg. Environ. Health*. 212(2), 146-156.

Hornberg, C., Pauli, A., (2007). Child poverty and environmental justice. *Int. J. Hyg. Environ. Health.* 210(5), 571-580.

Hu, H., Shih, R., Rothenberg, S., Schwartz, B.S., (2007). The epidemiology of lead toxicity in adults: Measuring dose and consideration of other methodologic issues. *Environ. Health Perspect.* 115(3), 455-462.

Hyman, H.H., Wright, C.R., Reed, J.S., (1975). *The enduring effects of education*. Chicago: University of Chicago Press.

Jacobson, J.L., Humphrey, H.E.B., Jacobson, S.W., Schantz, S.L., Mullin, M.D., Welch, R., (1989). Determinants of polychlorinated-biphenyls (PCBS), poltbrominated biphenyls (PBBS), and dichlorodiphenyl trichloroethane (DDT) levels in the sera of young-children. *American Journal of Public Health* 79(10), 1401-1404.

Karvonen, S., Rahkonen, O., (2011). Subjective social status and health in young people. *Sociol. Health Ill.* 33(3), 372-383.

Kolossa-Gehring, M., Becker, K., Conrad, A., Ludecke, A., Riedel, S., Seiwert, M., et al., (2007). German Environmental Survey for children (GerES IV) - First results. *Int. J. Hyg. Environ. Health.* 210(5), 535-540.

Krieger, N., (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology* 30(4), 668-677.

McKelvey, W., Gwynn, R.C., Jeffery, N., Kass, D., Thorpe, L.E., Garg, R.K., et al., (2007). A biomonitoring study of lead, cadmium, and mercury in the blood of New York city adults. *Environ. Health Perspect.* 115(10), 1435-1441.

Merlo, D.F., Vahakangas, K., Knudsen, L.E., (2008). Scientific integrity: critical issues in environmental health research. *Environ. Health* 7, S1-S9.

Mitchell, G., Dorling, D., (2003). An environmental justice analysis of British air quality. Environment and Planning A 35(5), 909-929.

Morello-Frosch, R., Shenassa, E.D., (2006). The environmental "Riskscape" and social inequality: Implications for explaining maternal and child health disparities. *Environ. Health Perspect.* 114(8), 1150-1153.

NEJAC. (2004). *Ensuring risk reduction in communities with multiple stressors: Environmental justice and cumulative risks/impacts*: National Environmmental Justice Advisory Council.

O'Fallon, L.R., Dearry, A., (2002). Community-based participatory research as a tool to advance environmental health sciences. Environ. Health Perspect. 110, 155-159.

O'Neill, M.S., Jerrett, M., Kawachi, L., Levy, J.L., Cohen, A.J., Gouveia, N., et al., (2003). Health, wealth, and air pollution: Advancing theory and methods. *Environ. Health Perspect.* 111(16), 1861-1870.

O'Neill, M.S., McMichael, A.J., Schwartz, J., Wartenberg, D., (2007). Poverty, Environment, and Health The Role of Environmental Epidemiology and Environmental Epidemiologists. *Epidemiology* 18(6), 664-668.

Osius, N., Karmaus, W., Kruse, H., Witten, J., (1999). Exposure to polychlorinated biphenyls and levels of thyroid hormones in children. *Environ. Health Perspect.* 107(10), 843-849.

Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., et al., (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Jama-Journal of the American Medical Association* 287(9), 1132-1141.

Porta, M., de Basea, M.B., Benavides, F.G., Lopez, T., Fernandez, E., Marco, E., et al., (2008). Differences in serum concentrations of organochlorine compounds by occupational social class in pancreatic cancer. *Environmental Research* 108(3), 370-379.

Porta, M., Gasull, M., Puigdomenech, E., Rodriguez-Sanz, M., Pumarega, J., Rebato, C., et al., (2009). Sociodemographic factors influencing participation in the Barcelona Health Survey study on serum concentrations of persistent organic pollutants. *Chemosphere* 76(2), 216-225.

Schroijen, C., Baeyens, W., Schoeters, G., Den Hond, E., Koppen, G., Bruckers, L., et al., (2008). Internal exposure to pollutants measured in blood and urine of Flemish adolescents in function of area of residence. *Chemosphere* 71(7), 1317-1325.

Sexton, K., (1997). Sociodemographic aspects of human susceptibility to toxic chemicals: Do class and race matter for realistic risk assessment? *Environmental Toxicology and Pharmacology* 4(3-4), 261-269.

Staessen, J.A., Buchet, J.P., Ginucchio, G., Lauwerys, R.R., Lijnen, P., Roels, H.A., et al., (1996). Public health implications of environmental exposure to cadmium and lead: an overview of epidemiological studies in Belgium. J Cardiovasc Risk 3, 26-41.

Staessen, J.A., Nawrot, T., Den Hond, E., Thijs, L., Fagard, R., Hoppenbrouwers, K., et al., (2001). Renal function, cytogenetic measurements, and sexual development in adolescents in relation to environmental pollutants: a feasibility study of biomarkers. *Lancet* 357(9269), 1660-1669.

Tjonneland, A., Olsen, A., Boll, K., Stripp, C., Christensen, J., Engholm, G., et al., (2007). Study design, exposure variables, and socioeconomic determinants of participation in diet, cancer and health: A population-based prospective cohort study of 57,053 men and women in Denmark. *Scandinavian Journal of Public Health* 35(4), 432-441.

Van den Heuvell, R.L., Koppen, G., Staessen, J.A., Den Hond, E., Verheyen, G., Nawrot, T.S., et al., (2002). Immunologic biomarkers in relation to exposure markers of PCBs and dioxins in Flemish adolescents (Belgium). *Environ. Health Perspect*. 110(6), 595-600.

Vermeir, G., Viaene, M., Staessen, J., Den Hond, E., Roels, H.A., (2005). Neurobehavioural investigations in adolescents exposed to environmental pollutants. *Environmental Toxicology and Pharmacology* 19(3), 707-713.

Vrijheid, M., Martinez, D., Aguilera, I., Ballester, F., Basterrechea, M., Esplugues, A., et al., (2010). Socioeconomic status and exposure to multiple environmental pollutants during pregnancy: evidence for environmental inequity? *J Epidemiol Community Health* 66(2), 106-113.

Walker, G., (2009). Beyond Distribution and Proximity: Exploring the Multiple Spatialities of Environmental Justice. *Antipode* 41(4), 614-636.

Walker, G., Burningham, K., (2011). Flood risk, vulnerability and environmental justice: Evidence and evaluation of inequality in a UK context. *Crit. Soc. Policy* 31(2), 216-240.

Wheeler, B.W., Ben-Shlomo, Y., (2005). Environmental equity, air quality, socioeconomic status, and respiratory health: a linkage analysis of routine data from the Health Survey for England. *J. Epidemiol. Community Health* 59(11), 948-954.

Wilkinson, R.G., Marmot, M., (2003). *Social Determinants of Health: The Solid Facts.* Copenhagen Denmark: World Health Organization Regional Office for Europe.

Wilkinson, R.G., Pickett, K.E., (2006). Income inequality and population health: A review and explanation of the evidence. *Soc. Sci. Med.* 62(7), 1768-1784.

Zill, N., (1996). Parental schooling and children's health. *Public Health Reports* 111(1), 34-43.

Chapter 3 Hoe milieuongelijkheid op zich ongelijk kan zijn: blootstelling aan milieuvervuilende stoffen bij buurtbewoners van industriezones

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3.1 Inleiding

In het dichtbevolkte en ruimtelijk versnipperde Vlaanderen liggen woonkernen en industrie vaak op een steenworp afstand van elkaar. In de omgeving van grote industriezones worden echter al jaren verhoogde concentraties aan allerhande milieuvervuilende stoffen gemeten. Tegelijk weten we dat in de dichtbevolkte wijken rondom deze industriezones veel sociaal kwetsbare groepen wonen. Die combinatie van verhoogde milieurisico's en sociale risico's doet ongerustheid ontstaan over de mogelijke gezondheidsgevolgen voor de bewoners van deze regio's. Daarom onderzocht het Steunpunt Milieu en Gezondheid via een humane biomonitoringstudie of wonen in de buurt van twee gekende industriezones in Genk en Menen een invloed heeft op de inwendige blootstelling aan schadelijke stoffen en op de gezondheid van in totaal 400 jongeren. Deze bijdrage bekijkt of de resultaten van die studie een voorbeeld zijn van milieuongelijkheid en of de buurtbewoners van de industriegebieden onevenredig getroffen worden door milieuhinder in vergelijking met Vlaamse gemiddelden.

3.2 Context

Vlaanderen is een sterk verstedelijkte en geïndustrialiseerde regio met een grote bevolkingsdichtheid. Dit leidt tot een algemene en wijd verspreide milieudruk, met hoge concentraties aan milieuvervuilende stoffen in lucht, water en bodem. Gekende problematieken in Vlaanderen zijn bijvoorbeeld de verspreiding van fijn stof, zware metalen en pesticiden in de omgeving (zie o.a. MIRA 2012). Ondanks het feit dat nagenoeg niemand ontsnapt aan deze milieudruk zijn er aanwijzingen dat de impact van milieurisico's sociaal-ruimtelijk ongelijk verdeeld zijn. Sociaal kwetsbare groepen en achtergestelde buurten worden vaak onevenredig getroffen door milieuproblemen. Een ongelijke blootstelling aan milieuvervuiling wordt daarom al sinds lange tijd beschouwd als één van de mogelijke – maar empirisch onderbelichte – verklaringen voor ongelijkheden in gezondheid en sterfte, naast levensstijlfactoren en toegang tot gezondheidszorg (Adler & Newman, 2002). Recent onderzoek naar de impact van luchtvervuiling, klimaatverandering en technologische ontwikkelingen tonen echter aan hoezeer milieuvraagstukken verweven zijn met vraagstukken van armoede en ongelijkheid in onze hedendaagse samenleving, en wijzen op het toenemend belang van milieuongelijkheid als verklarende factor in de productie van gezondheidsongelijkheden (O'Neil e.a., 2007).

3.2.1 De dubbele sociale ongelijkheid bij milieuvervuiling

Milieuongelijkheden werden zo'n dertig jaar geleden het eerst zichtbaar in de Verenigde Staten waar stortplaatsen van gevaarlijk afval, verbrandingsovens en zwaar vervuilende industrieën vaker gelokaliseerd werden in gedepriveerde buurten met een hoger percentage etnische minderheden en armen (Brown, 1995). Deze vaststellingen waren aanleiding tot het ontstaan van de zogeheten 'environmental justice movement', die strijd voert tegen de ongelijke verdeling van milieukwaliteit en milieurisico's, een verdeling die in de VS meestal parallel loopt met raciale scheidslijnen (Leroy, 2001).

Milieu en ongelijkheid is in Europa voorlopig nog een minder geagendeerd thema, hoewel dezelfde problematiek ook hier aanwijsbaar is. Bijvoorbeeld in Nederland, waar men vaststelde dat gebieden met een hoger inkomensniveau een betere milieukwaliteit in hun directe omgeving hebben dan gebieden met een lager inkomensniveau, met name met betrekking tot luchtverontreiniging en beschikbaarheid van publiek toegankelijk groen (Kruize, 2007). Ook in Frankrijk concludeerde men dat sociaal kwetsbare groepen disproportioneel meer blootstaan aan luchtvervuiling en geluidsoverlast, aangezien vervuilende en gevaarlijke industrieën (zoals de zogenaamde Seveso-bedrijven) ook daar vaker gelokaliseerd zijn in gebieden met een lager gemiddeld inkomen (Diebolt & Hellias, 2005). Onderzoek in Duitsland vond duidelijke sporen van sociale ongelijkheid in de concentratie schadelijk stoffen, zowel in de buitenlucht als de binnenlucht van woningen (Heinrich e.a., 2000).

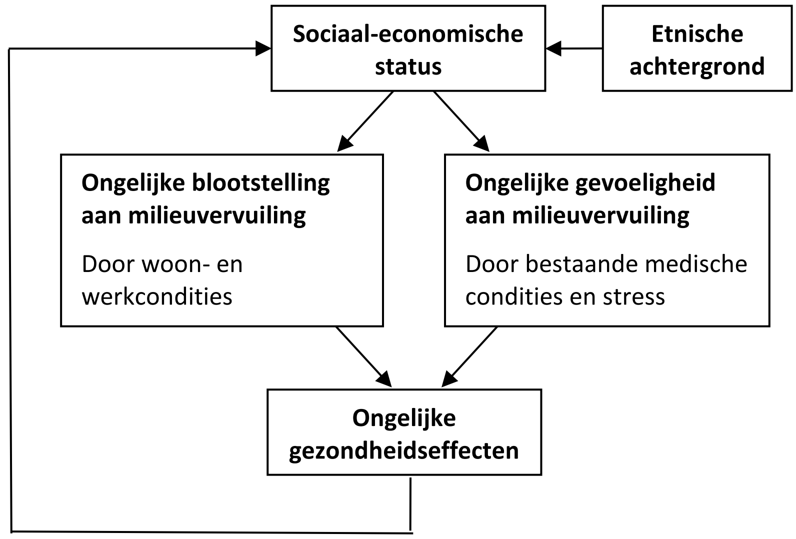
De oorzaken van deze milieuongelijkheden zijn veelzijdig (zie o.a. Coenen & Halfarce, 2000). Zo zullen prijsdalingen van huizen op verontreinigde grond of in de buurt van industrie gezinnen met een laag inkomen aantrekken. Anderzijds zullen overheden en bedrijven makkelijker (uitbreiding van) industrie plannen in gedepriveerde buurten omdat de kans op collectief verzet daar kleiner is. Buurten met middenklassers hebben meer macht en mogelijkheden om hun preferenties door te duwen in NIMBY-situaties (Not In My Backyard).

Ondanks sporadische tegengeluiden die geen of zelfs positieve sociale verschillen in milieublootstelling vinden (voornamelijk in verband met afstand tot drukke verkeerswegen in dichtbebouwde gebieden, bv. Cesaroni e.a., 2010), gaan wetenschappers en beleidsmakers ervan uit dat de beschikbare milieukwaliteit niet gelijk verdeeld is over de verschillende sociale klassen: mensen met een lagere sociale positie wonen en werken vaak dichter bij de bronnen van milieuvervuiling, en hebben hierdoor meer blootstelling dan mensen met een hogere sociale positie. Dit beschouwen we als de eerste vorm van milieuongelijkheid.

Recent komt er echter wel wat kritiek op deze eenzijdige focus die enkel de afstand tot vervuilingsbronnen in rekening brengt. Deze klassieke opvatting van milieuongelijkheid zou te beperkend zijn om ongelijkheden in vaak complexe milieuproblemen te begrijpen (Walker, 2009). Naast blootstelling aan milieuvervuiling is immers ook de impact op de gezondheid van belang. En wat blijkt: mensen, groepen of buurten met een lage sociaal-economische status (SES) zijn niet alleen meer blootgesteld aan vervuiling, ze zijn vaak ook meer vatbaar voor die vervuiling waardoor ze - zelfs bij een gelijke blootstelling - meer of sneller gezondheidseffecten zullen ondervinden dan zij met een hogere SES. Deze tweede vorm van milieuongelijkheid is tot op heden vooral aangetoond bij de gevoeligheid voor de korte- en langetermijneffecten van luchtvervuiling. Door ziekte- en gezondheidsgegevens te vergelijken met luchtkwaliteitsmetingen stelde men vast dat het effect op de gezondheid van eenzelfde concentratie luchtvervuiling veel sterker speelt in de lagere dan in de hogere sociale klassen (Pope e.a., 2002; Wheeler & Ben-Shlomo, 2005). De verhoogde vatbaarheid heeft vooral te maken met een verzwakt immuunsysteem bij sociaal kwetsbare groepen. Zo blijken een heel aantal ziekten die meer voorkomen bij kansarmen en etnische minderheden zoals astma, diabetes en obesitas, het risico op gezondheidsschade door luchtvervuiling te vergroten (Dubowsky e.a., 2006). Ook stress kan tot acute en chronische veranderingen in het immuunsysteem leiden, waardoor de mogelijkheden van het menselijk lichaam om zich te verdedigen tegen milieuvervuiling verzwakken (Gee & Payne-Sturges, 2004).

Er speelt dus een dubbele ongelijkheid bij milieuvervuiling: onderaan de sociale ladder zijn mensen meer blootgesteld en meer gevoelig aan schadelijke stoffen. Door de combinatie van beide mechanismen zijn zij die maatschappelijk het meest kwetsbaar zijn, ook het meest kwetsbaar voor de gezondheidsimpact van milieupollutie. Dit wordt schematisch weergegeven in Figure 7.

Figure 7: De dubbele sociale ongelijkheid bij de gezondheidsimpact van milieuvervuiling



Bron: gebaseerd op O'Neill et al. 2003

3.2.2 Industriële hotspots in Vlaanderen

In Vlaanderen is er tot op heden geen systematisch onderzoek gebeurd naar de sociale verdeling van milieukwaliteit. Er zijn echter wel een aantal industriële zones waar aanwijzingen zijn voor milieuongelijkheid omdat ze – vaak als gevolg van historische planningsprocessen – omringd worden door dichtbevolkte wijken met een sociaal kwetsbare bevolking, bovendien vaak met veel kinderen (die gevoeliger zijn voor milieufactoren omdat hun lichaam nog in ontwikkeling is). Twee gekende voorbeelden zijn het industriegebied van Genk-Zuid en Menen Grensland, waar in de periode 2010-2011 een humaan biomonitoringsonderzoek werd uitgevoerd door het Steunpunt Milieu en Gezondheid.

3.2.2.1 *Het milieuprofiel van de hotspots Genk-Zuid en Menen*

Genk-Zuid is met 1.500 ha veruit het grootste industrieterrein in Limburg en zelfs de vierde grootste industriezone van Vlaanderen. Er is een grote diversiteit aan industriële activiteiten en sectoren aanwezig zoals een metaalverwerkend bedrijf, metaalafvalverwerkingsbedrijven, lijmproductie, spaanplaatindustrie, en een elektriciteitscentrale op steenkool en biomassa. Deze activiteiten zorgen voor heel wat uitstoot van milieuverontreinigende stoffen. De uitstoot van een aantal stoffen en hun concentraties in de lucht en op neervallend stof worden reeds jarenlang opgevolgd door de Vlaamse Milieumaatschappij (VMM), bijvoorbeeld zware metalen, PCB's (polychloorbifenyls) en dioxines (VMM, 2013a). Vooral de waarden van nikkel en chroom in fijn stof liggen hoog in vergelijking met andere Vlaamse meetpunten. De verhoogde metingen hebben hoofdzakelijk met het metaalverwerkend bedrijf te maken. Zowel voor chroom als nikkel bestaat er een verhoogd risico op longkanker bij levenslange blootstelling en is een verband aangetoond met nierschade (ATSDR 2012; 2005). Vermits ook andere polluenten verhoogd voorkomen, is er bezorgdheid over ‘mengseltoxiciteit’ en verhoogde kans op tal van gezondheidseffecten. Het industrieterrein wordt omsloten door een ringweg, waardoor ook de verkeersbelasting groot is. Sommige woonwijken zoals Sledderlo en Kolderbos bevinden zich zeer dicht bij het industriegebied. Een gezondheidsenquête uit 2007 toonde aan dat er onder buurtbewoners een verhoogde ongerustheid is over de gezondheid in relatie tot de industrie, en dat het gebruik van antidepressiva en het voorkomen van luchtwegproblemen hoger was dan in enkele controlewijken (Nelen e.a., 2007). Op basis van de VMM-metingen en de resultaten van de gezondheidsenquête werd een wijkschooltje verplaatst, en kwam er meer media-aandacht voor de milieuproblematiek in Genk-Zuid.

De industriezone ‘Grensland’ situeert zich in Menen in de provincie West-Vlaanderen, aan de grens met Frankrijk. De dichtstbijzijnde woonkernen bevinden zich op enkele honderden meters van de industriezone. In 1982 werd in deze industriezone een huisvuilverbrandingsoven in gebruik genomen die operationeel was tot eind 2005. In 2010 werd op de site een loods gebouwd voor de opslag van klein gevaarlijk afval en elektromateriaal alsook een overdekte overslagruimte voor brandbaar afval afkomstig van KMO’s en gemeenten. De activiteiten van afvalverbrandingsovens gingen vroeger gepaard met een aanzienlijke uitstoot van producten van onvolledige verbranding, zoals dioxines en PAK’s (polycyclische aromatische koolwaterstoffen) en van PCB’s. In 2000 werd een Europese richtlijn ingevoerd die de uitstoot van verbrandingsinstallaties van afval sterk beperkte. In de industriezone ‘Grensland’ bevindt zich sinds 1968 ook een schrootverwerkend bedrijf dat tot de grootste in Europa behoort, met vestigingen aan de Vlaamse en aan de Franse zijde van de landsgrens. De activiteiten van het bedrijf bestaan uit industriële verwerking van afgedankte consumptiegoederen zoals auto’s en fabrieksschroot. Deze activiteiten dragen vooral bij tot de verhoogde PCB-gehalten in de omgeving.

Van 1995 tot 1998 lagen de dioxinegehalten in neervallend stof in Menen ver boven de gezondheidskundige drempelwaarden. Daarna daalden de meetwaarden in de woonzones, maar toch kunnen ook nu nog af en toe hoge waarden voorkomen (VMM, 2012). De PCB-gehalten vertonen sterke schommelingen waardoor ook nu nog de gezondheidskundige drempelwaarden regelmatig overschreden worden (VMM, 2013b). Dit zorgt in Menen al jaren voor heel wat ongerustheid en protest bij omwonenden. Zowel dioxines als PCB’s zijn moeilijk afbreekbare stoffen die zich opstapelen in de bodem, het leefmilieu en het lichaam, en hier een lange tijd aanwezig kunnen blijven. Deze stoffen kunnen het afweersysteem en de hormoonhuishouding in het lichaam verstoren en sommige dioxines en PCB’s worden als kankerverwekkend beschouwd.

3.2.2.2 *Het sociale profiel van de hotspots Genk-Zuid en Menen*

Niet enkel de milieudruk in deze hotspots wijkt af van Vlaamse vergelijkingswaarden, ook het sociaaleconomisch profiel is duidelijk verschillend van Vlaanderen. Cijfers uit de gemeentelijke profielschetsen van de Studiedienst van de Vlaamse regering (SVR) tonen in Genk en Menen een gemiddeld lager inkomen per inwoner, een hogere werkloosheidsgraad en een hoger percentage inwoners met vreemde nationaliteit. Ook twee samengestelde kansarmoede-indicatoren[9] tonen opvallend hogere cijfers voor de hotspots in vergelijking met Vlaamse gemiddelden. Zo werden in 2010 volgens de kansarmoede-index van Kind en Gezin in Genk dubbel zoveel en in Menen bijna drie keer zoveel kinderen in armoede geboren dan gemiddeld in Vlaanderen. Ook het aantal geïnstalleerde budgetmeters voor elektriciteit en aardgas (als proxy voor energiearmoede) is in beide hotspots duidelijk hoger dan gemiddeld.

Table 10 illustreert het sociaaleconomisch profiel van de twee hotspots in vergelijking met Vlaanderen in de periode dat het humaan biomonitoringsonderzoek plaatsvond (2010-2011).

Table 10: Sociaaleconomische parameters voor de bevolking van Genk en Menen in vergelijking met Vlaamse gemiddelden, 2010-2011

	Genk	Menen	Vlaanderen
Totale bevolking (aantal inwoners, 2010)	64.757	32.530	6.251.983
Inwoners met vreemde nationaliteit (%, 2010)	13,0	7,7	6,4
Werkloosheidsgraad (%, 2010)	12,6	8,1	7,2
Gemiddeld jaarlijks inkomen per inwoner (€, 2010)	13.943	14.313	16.599
Onderwijs kansarmoede indicator (cijfer van 0 tot 4, 2010)	1,61	1,0	0,78
Geboorten in kansarme gezinnen (%, 2010)	17,6	22,3	8,6
Budgetmeters elektriciteit (%, 2011)	3,53	3,70	1,64
Budgetmeters aardgas (%, 2011)	2,21	2,71	1,47

Bron: SVR, gemeentelijke profielschetsen 2014

In Genk is de sociale achterstelling voornamelijk gelokaliseerd in twee wijken rondom de industriezone, met name Kolderbos en Nieuw-Sledderlo. Deze buurten kennen een erg hoge bevolkingsdichtheid (resp. 3.765 en 2.823 inwoners per km² ten opzichte van 732 inw./km² gemiddeld in Genk), voornamelijk in sociale woningbouw, een groot aandeel niet-Belgen (voornamelijk Turken en Marokkanen) en een hoge werkloosheidsgraad, vooral werklozen met een niet-Europese etnische achtergrond. In Menen situeert de sociale achterstelling zich meer als gevolg van het zware industriële verleden en de grenscriminaliteit met Frankrijk. In Menen zijn zes

[9] De onderwijs kansarmoede-indicator (OKI) van het Departement Onderwijs is samengesteld uit vier leerlingenkenmerken: (1) laag opleidingsniveau van de moeder; (2) gezinstaal niet Nederlands; (3) buurt met hoge mate van schoolse vertraging; (4) schooltoelage. De OKI wordt berekend als het aantal leerlingenkenmerken waarop de leerling scoort en is bijgevolg een cijfer tussen 0 en 4. Een hoger cijfer wijst op een hogere indicatie van kansarmoede. De kansarmoede-index van Kind & Gezin geeft het percentage geboorten weer in kansarme gezinnen per jaar. Hiervoor toetsen regioteamleden van Kind en Gezin elk gezin met een geboorte aan zes vooropgestelde criteria: (1) beschikbaar maandinkomen; (2) opleiding ouders; (3) arbeidssituatie ouders; (4) laag stimulatieniveau kinderen; (5) huisvesting; (6) gezondheid. Wanneer een gezin aan drie of meer van deze criteria beantwoordt, wordt het als kansarm beschouwd.

wijken gedefinieerd als kansarm volgens een 10 puntenschaal van het Steunpunt Sociale Planning van de Provincie West-Vlaanderen.

Volgens de klassieke opvatting van de milieuongelijkheidsthese zijn er in beide hotspots dus duidelijke indicaties voor milieuongelijkheid: we vinden immers een combinatie van verhoogde milieudruk en sociale risicofactoren. Met de resultaten van de humane biomonitoring kunnen we nu nagaan of we deze sporen van ongelijkheid ook terugvinden in het lichaam van mensen die in deze hotspots wonen.

3.3 Humane biomonitoring in hotspots: meten van (ongelijke?) blootstelling en gezondheidseffecten bij buurtbewoners

Humane biomonitoring (HBM) is een techniek waarbij de aanwezigheid en de effecten van milieuvervuilende stoffen in de mens worden gemeten. Er wordt een onderscheid gemaakt tussen twee soorten biomerkers: blootstellingsmerkers, die een maat zijn voor de blootstelling aan polluenten, en effectmerkers die biologische effecten of vroegtijdige gezondheidseffecten in het lichaam reflecteren. Biomerkers worden in het lichaam van mensen gemeten zoals bijvoorbeeld in het bloed, urine of haar.

De HBM-studies in Genk en Menen werden uitgevoerd door het Steunpunt Milieu en Gezondheid, een interdisciplinair onderzoeksconsortium bestaande uit (bio)medische en sociale wetenschappers dat in opdracht van de Vlaamse overheid in 2002 startte met het opzetten van een humaan biomonitoringsmeetnet[10]. Dit meetnet kadert in het preventiedecreet van de Vlaamse regering dat voorziet om op regelmatige basis de gehaltes van chemische stoffen in de mens te bepalen en trends op te volgen. In de periode 2007-2011 koos het Steunpunt voor twee vormen van biomonitoring: een referentiebiomonitoring bij drie representatieve leeftijdsgroepen: (1) moeders en pasgeborenen, (2) jongeren (14-15 jaar) en (3) jong volwassenen (20-40 jaar) om een beeld te krijgen van de situatie in heel Vlaanderen, en een hotspotbiomonitoring bij één van deze drie leeftijdsgroepen die inzoomt op specifieke probleemgebieden.

De hotspotbiomonitoring werd uitgevoerd in twee meetcampagnes tussen 2010 en 2011 waarbij de gehaltes aan specifieke polluenten en gezondheidsparameters onderzocht werden in een steekproef van buurtbewoners van de industriële hotspots Genk-Zuid en Menen Grensland. De resultaten van de hotspots werden vergeleken met de Vlaamse referentieresultaten van een steekproef die door toeval werd geselecteerd uit de algemene Vlaamse bevolking. Er werd gekozen

[10] Het onderzoek kwam tot stand in opdracht van, en werd gefinancierd door, het Departement Economie, Wetenschap en Innovatie, het Vlaams Agentschap Zorg en Gezondheid, en het Departement Leefmilieu, Natuur en Energie.

om deze hotspotmeetcampagnes uit te voeren bij jongeren (14-15 jaar) omdat zij worden blootgesteld aan lokale leefmilieufactoren maar nog geen beroepsblootstelling kennen.

Omdat het onderzoek plaatsvond in een lokale context, werd veel geïnvesteerd in overleg met plaatselijke actoren. Er werd in elke hotspot bij aanvang van de campagne een lokale adviesgroep opgericht bestaande uit o.a. gemeentelijke diensten, sociaal werkers, milieuverenigingen, industrie, huisartsen en actiegroepen. In beide hotspots was een groep van ongeveer 25 actoren actief. Zij adviseerden het Steunpunt in alle fasen van het onderzoek, van het uittekenen van de studieopzet en de rekrutering van deelnemers tot de communicatie van de resultaten en de beleidsvertaling.

In dit hoofdstuk gaan we op zoek naar antwoorden op volgende drie onderzoeksvragen:

1. Zijn jongeren in de hotspots meer blootgesteld aan vervuilende stoffen dan gemiddeld in Vlaanderen?
2. Zijn er verbanden tussen de concentratie aan vervuilende stoffen en bepaalde gezondheidseffecten? Met andere woorden: ondervinden jongeren met hogere waarden ook meer gezondheidseffecten?
3. Zijn er sociale verschillen in de resultaten merkbaar? Hebben jongeren met een lagere sociaaleconomische status hogere waarden aan vervuilende stoffen?

Om de antwoorden op deze vragen goed te kunnen kaderen, starten we eerst met een korte omschrijving van de gebruikte methode en data. Uitgebreide rapporten over de studies zijn te vinden op de website van het Steunpunt www.milieu-en-gezondheid.be.

3.4 Methode en data

3.4.1 Rekrutering van jongeren

De betrokken stadsbesturen leverden de persoonsgegevens van alle jongeren geboren in 1994 tot en met 1996. Daaruit werden de adressen geselecteerd die binnen het studiegebied vielen. Die jongeren werden aangeschreven op hun thuisadres met de vraag om deel te nemen. Inclusiecriteria waren: ten minste 5 jaar in het studiegebied wonen, toestemming van ouders en jongere (ondertekend toestemmingsformulier) geven om deel te nemen aan alle onderdelen van de studie (zie verder), en een Nederlandstalige vragenlijst kunnen invullen. Voor de jongeren uit sociaal kwetsbare buurten werden huisbezoeken georganiseerd om de studie persoonlijk toe te lichten. Dit gebeurde samen met vrijwilligers en vertrouwenspersonen uit de buurt zoals sociaal werkers. In Genk werd ook speciale aandacht besteed aan de grote Turkse gemeenschap, onder meer door een oproep te lanceren via de moskee met ondersteuning van een Turkse huisarts. Het veldwerk zelf gebeurde meestal op school. Jongeren die niet in de hotspots naar school gingen of die niet aanwezig konden zijn op de geplande onderzoeksdag op school konden deelnemen op onderzoeksdagen in hun buurt, tijdens de schoolvakanties of op een zaterdag. De privacy werd beschermd door het gebruik van anonieme codenummers op de stalen en de vragenlijsten. Jongeren die dat wilden, kregen hun persoonlijke resultaten per post toegestuurd.

3.4.2 Metingen en bevragingen

Op basis van de beschikbare milieumeetgegevens en een inventaris van de aanwezige industrie werden drie typen polluenten geselecteerd die relevant zijn voor de hotspots en waarvoor biomerkers beschikbaar zijn.

- zware metalen zoals cadmium, lood, nikkel, chroom, koper, thallium, antimoon en arseen;
- Persistente Organische Polluenten (POP's) zoals PCB's, dioxines, dioxine-achtigen, en gebromeerde vlamvertragers;
- Vluchtige stoffen zoals PAK's en benzeen.

Daarnaast werden gezondheidseffecten gemeten die in verband gebracht kunnen worden met de blootstelling aan deze stoffen:

- merkers voor DNA-schade;
- hormoonverstoring: meting van schildklierhormonen en geslachtshormonen in bloed; opvolgen van de puberteitsontwikkeling via de dossiers van de schoolartsen;
- nierfunctie: klinische merkers voor het opvolgen van de werking van de nier;
- neurologische functie: computertesten en vragenlijsten om de werking van het zenuwstelsel op te volgen (concentratie, geheugen, reactiesnelheid).

Deze biomerkers werden gemeten in het bloed, de urine en het haar van jongeren uit de hotspots en de Vlaamse referentiegroep, of werden bevraagd via gestandaardiseerde vragenlijsten. De vragenlijsten bevatten ook vragen die nodig zijn voor een kwaliteitsvolle interpretatie van de biomerkermetingen, zoals gegevens over de gezinssamenstelling, de woning, hobby's, de gezondheid van de jongere, voeding en sociaaleconomische parameters zoals opleiding en inkomen.

3.4.3 Statistische analyse

Om gebiedsverschillen in blootstelling aan vervuilende stoffen en gezondheidseffecten tussen de hotspots en de Vlaamse referentiepopulatie te beschrijven werd rekening gehouden met verschillen in samenstelling van deze populatie. Dit gebeurde met behulp van een meervoudig regressiemodel. Hiermee wordt het effect van gebied (dit is de hotspot versus Vlaanderen) op een biomerker of effectmerker berekend, terwijl voor andere variabelen die kunnen verschillen tussen de populaties zoals leeftijd en geslacht gecorrigeerd wordt. We kozen ervoor om enkel te corrigeren voor niet-beïnvloedbare variabelen waarvan geweten is dat ze de biomerkerwaarden kunnen bepalen (leeftijd, geslacht, seizoen, densiteit van het urinestaal, en duur van de urinecollectie). De biomerkers werden volgens de natuurlijke logaritmische functie getransformeerd. De reden hiervoor is dat de oorspronkelijke gegevens niet steeds 'normaal' verdeeld zijn. De resultaten van de hotspots worden voorgesteld als procentuele verschillen ten opzichte van het Vlaamse geometrische gemiddelde[11].

Verschillen in blootstelling naar sociaaleconomische status (SES) werden per hotspot bestudeerd door het geometrisch gemiddelde te berekenen voor twee parameters: (1) hoogste opleidingsniveau van de ouders van de jongeren (in drie klassen: maximaal lager secundair onderwijs, maximaal hoger secundair onderwijs of hoger onderwijs) en (2) onderwijstype van de jongeren (ASO, TSO of BSO). Bijkomend werd in aparte regressiemodellen gekeken naar equivalent maandinkomen van het gezin (in drie klassen: minder dan 1200 euro, tussen 1200 en 1600 euro, of meer dan 1600 euro), en naar de etnische achtergrond van de jongeren, berekend volgens geboorteland van de ouders (in drie klassen: beide ouders België, één ouder niet-België, beide ouders niet-België). De geometrische gemiddelden van elke SES-categorie binnen de hotspot werden vergeleken met het geometrisch gemiddelde van de totale Vlaamse referentiepopulatie; uiteraard weer na correctie voor niet-beïnvloedbare factoren. Ook deze verschillen werden procentueel voorgesteld.

3.5 De resultaten

3.5.1 Beschrijving van de onderzoeksgroep

De totale respons bedroeg 34% voor de hotspot Genk-Zuid en 22,5% voor de hotspot Menen. De steekproef in Genk-Zuid bestond uit 197 jongeren, in Menen uit 199 jongeren. Beide hotspots werden vergeleken met 210 leeftijdsgenoten uit de Vlaamse referentiegroep. De voornaamste sociale en demografische kenmerken van de deelnemers worden weergegeven in Table 11.

[11] Hierbij dient wel opgemerkt dat de mate waarin een biomerker ‘procentueel stijgt’ op zich nog niet veel zegt over de ernst van de afwijking. Zo kan een stijging van 10% statistisch significant zijn maar in absolute waarde te klein zijn om iets te betekenen in functie van gezondheidsernst.

Table 11: Sociale karakteristieken van de 3 HBM-meetcampagnes

Parameter	**Genk-Zuid (n=197)**	**Regio Menen (n=199)**	**Vlaanderen (n=210)**
Geslacht, n (%)			
jongens	89 (45,2%)	114 (57,3%)	121 (57,6%)
meisjes	108 (54,8%)	85 (42,7%)	89 (42,4%)
Opleidingsniveau jongere			
BSO	39 (20,4%)	26 (13,2%)	20 (9,7%)
TSO	43 (22,5%)	63 (32%)	86 (41,5%)
ASO	109 (57,1%)	106 (53,8%)	101 (48,8%)
Hoogste opleidingsniveau in het gezin			
Max. lager secundair	28 (19,7%)	30 (15,3%)	25 (12,1%)
Max. hoger secundair	61 (31,6%)	54 (27,6%)	66 (31,9%)
Hoger onderwijs	94 (48,7%)	112 (57,1%)	116 (56,0%)
Equivalent maandelijks gezinsinkomen			
<1.200 euro	78 (42,9%)	55 (30,1%)	56 (32,9%)
1.200-1.600 euro	55 (30,2%)	60 (32,8%)	46 (27,1%)
>1.600 euro	49 (26,9%)	68 (37,2%)	68 (40,0%)
Etnische achtergrond (geboorteland ouders)			
Beide ouders Belg	128 (67,7%)	172 (87,3%)	189 (90,4%)
Eén van de ouders niet-Belg	22 (11,6%)	18 (9,1%)	15 (7,2%)
Beide ouders niet-Belg	39 (20,6%)	7 (3,6%)	5 (2,4%)

Het sociale profiel van de steekproef in de hotspots is duidelijk verschillend van die van de Vlaamse referentie. In Menen, maar vooral in Genk-Zuid, werden meer jongeren gerekruteerd uit het BSO, met laagopgeleide ouders, met een lager gezinsinkomen en met een andere etnische achtergrond.

3.5.2 Zijn jongeren in de hotspots meer blootgesteld aan vervuilende stoffen dan gemiddeld in Vlaanderen?

3.5.2.1 *Zware metalen*

Zware metalen zijn metalen die schade kunnen toebrengen aan onze gezondheid. Ze komen van nature voor in de bodem, maar door menselijke activiteit (o.a. in de buurt van een industriegebied of door verkeer) komen zware metalen in sommige regio's meer voor in de lucht, de bodem, het water en lokaal gekweekte voeding.

Vergeleken met een gemiddelde blootstelling bij jongeren in Vlaanderen liggen de waarden bij jongeren in Genk-Zuid hoger voor arseen (+33,1%), chroom (+29,3%), cadmium (+13,3%), thallium (+10,7%) en koper (+3,8%) (zie Table 12). De waarden voor lood zijn vergelijkbaar in Genk-Zuid en Vlaanderen, de waarden voor antimoon liggen lager in Genk-Zuid (-21,2%). Bij de jongeren die wonen nabij het industriegebied in Menen werd een significant hogere blootstelling gemeten voor thallium (+26,0%), cadmium (in urine +28%), en koper (+6,6%) (zie Table 13). Er werden in Menen significant lagere waarden gemeten voor lood (-15,0%), antimoon (-31,8%) en arseen (-17,7%).

Indien we de biomonitoringsresultaten in verband brengen met de beschikbare milieumetingen voor zware metalen in de twee hotspots, dan zien we de meest consistente relaties voor chroom in Genk. Al jaren worden hogere concentraties aan chroom in de bodem en lokale groenten gemeten naarmate men dichter bij de industriezone van Genk-Zuid komt. Pollutierozen van luchtmetingen lokaliseerden het metaalverwerkend bedrijf als de bron van deze vervuiling. Dit werd bevestigd in het HBM-onderzoek: we stelden vast dat de waarden van chroom in het lichaam van jongeren verhoogd zijn kort na de dagen dat er ook hogere concentraties van chroom in de buitenlucht gemeten werden. We zien in Genk-Zuid ook een relatie tussen de inwendige blootstelling aan sommige vervuilende stoffen en de afstand tot de meetposten voor luchtkwaliteit opgesteld aan het industrieterrein, bijvoorbeeld hoe dichter we bij het terrein komen, hoe hoger de waarden van lood in bloed. Ook in de hotspot Menen vinden we aanwijzingen in de beschikbare milieumetingen. Zo tonen meetgegevens in sedimenten verhoogde concentraties van thallium en cadmium in de rivier de Leie ter hoogte van Menen in vergelijking met de Bovenschelde en de IJzer.

De biomerkers voor blootstelling aan chroom, koper, thallium en arseen weerspiegelen recente blootstelling. Verhoogde waarden rond een industriegebied kunnen mogelijk wijzen op een lokale bron. Cadmium geeft een maat voor middellange tot levenslange blootstelling en kan dus zowel geaccumuleerde blootstelling uit het verleden als een recente lokale bron weerspiegelen.

3.5.2.2 *Persistent Organische Polluenten (POP's)*

POP's omvatten onder meer PCB's, dioxines, en gebromeerde vlamvertragers. Veel van die stoffen zijn momenteel verboden, maar omdat ze zeer moeilijk worden afgebroken vinden, we ze nog altijd terug in het leefmilieu en in de voeding (onder andere in vette vis en eieren). Deze stoffen kunnen ook nog vrijkomen bij afvalverbranding of bij sommige industriële processen zoals schrootverwerking.

De blootstelling aan alle POP's is zowel in Genk-Zuid als in regio Menen lager dan in Vlaanderen. Mogelijke verklaringen voor deze lagere concentraties kunnen te maken hebben met een tijdsfactor (de concentraties van POP's dalen globaal in het milieu en de metingen in de hotspots werden twee jaar later uitgevoerd dan de referentiemetingen) of met voedingsgewoonten (vetrijke en lokaal geteelde voeding zorgen voor meer opname van POP's en worden minder geconsumeerd in de hotspots, deels door preventieve adviezen die in het verleden door het gemeentebestuur werden verspreid).

3.5.2.3 *Vluchtige stoffen*

PAK's (polyaromatische koolwaterstoffen) ontstaan bij verbranding (door industrie of particulier, bijvoorbeeld het verwarmen van de woning), in het verkeer (uitlaatgassen) en in sigarettenrook, maar kunnen ook aanwezig zijn in de voeding (bijv. gegrilde producten, BBQ). Benzeen is een oplosmiddel dat in sommige industrieën wordt gebruikt, maar dat ook uitgestoten wordt door verkeer.

De waarden voor PAK's zijn verhoogd in het lichaam van jongeren die in de nabijheid van de industriezone Genk-Zuid en Menen wonen (resp. +30,0% en +44,7%). De blootstelling aan benzeen is daarentegen in beide hotspots vergelijkbaar met die van de gemiddelde Vlaamse leeftijdsgenoot. De verhoogde concentraties van PAK's werden ook terug gevonden in verschillende milieumetingen in de hotspots. Zo tonen luchtmetingen in Genk-Zuid verhoogde waarden in de buurt van schrootverwerkende installaties tijdens de periode van de HBM-studie in vergelijking met controlepunten. In Menen werden daarnaast ook op verschillende meetpunten in waterbodems afwijkende tot sterk afwijkende waarden aangetroffen voor PAK's.

Er werden geen significante relaties gevonden tussen blootstelling aan PAK's en het binnen- of buitenshuis verbranden van brandstoffen (gas, hout, steenkool) of afval (bijv. papier, snoeiafval, huishoudafval) (mogelijk omwille van de kleine subgroepen) wat doet vermoeden dat de verhoogde concentraties in vergelijking met Vlaanderen te wijten zijn aan industriële activiteiten en verkeer.

Op basis van twee verschillende statistische technieken, nl. correlatiematrices en regressieboom-analyse[12] kon worden vastgesteld dat voor Genk-Zuid verhoogde waarden van PAK's samen voorkomen met cadmium, koper, thallium en chroom. Zij vormen met andere woorden een cluster van polluenten en hebben dus vermoedelijk dezelfde bron. Arseen daarentegen bleek apart voor te komen en kent dus mogelijk een andere bron.

3.5.3 Hebben jongeren in de hotspots meer gezondheidseffecten dan gemiddeld in Vlaanderen en is er een verband met de blootstelling aan vervuilende stoffen?

Er werden verschillen in enkele vroegtijdige gezondheidseffecten vastgesteld tussen de hotspots en Vlaanderen die gerelateerd zijn aan milieuvervuilende stoffen.

3.5.3.1 *Kankerverwekkende stoffen*

Onze erfelijke informatie zit opgeslagen in DNA-moleculen of DNA-ketens in al onze lichaamscellen. Beschadigingen aan dit DNA, door breuken of chemische veranderingen aan de DNA-bouwstenen ten gevolge van onder andere blootstelling aan schadelijke stoffen, worden door het lichaam in de meeste gevallen hersteld, maar herstel is nooit 100% volledig en correct, zodat mutaties kunnen

[12] Regressieboomanalyse is een statistische techniek die toelaat om gelijkaardige observaties op basis van een set van gemeenschappelijke kenmerken te groeperen en op een visuele manier (onder vorm van een vertakte boomstructuur) weer te geven.

ontstaan. Op groepsniveau is het daarom waarschijnlijk dat een grotere hoeveelheid breuken in DNA gepaard gaat met een groter kankerrisico. DNA-breuken in bloedcellen bleek aanzienlijk hoger te zijn in Genk-Zuid (+38,2%) en in Menen (+62,0%) in vergelijking met de Vlaamse referentiepopulatie. Het verschil blijkt nog groter te zijn (resp. 63,3% en 97,3%) wanneer ook andere vormen van DNA-schade in rekening worden gebracht.

Via statistische blootstelling-effect analyses werd vastgesteld dat er een positief verband bestaat tussen enerzijds DNA-schade en anderzijds de blootstelling aan PAK's en aan de zware metalen chroom, cadmium, thallium en arseen. Bij jongeren met een hogere blootstelling aan deze vervuilende stoffen werd meer DNA-schade gemeten. Dit samengaan van chemische stoffen in de leefomgeving en kankerverwekkende effecten werd ook bevestigd in een apart onderzoeksproject dat in Genk-Zuid in dezelfde periode werd uitgevoerd. Daarbij werd de biologische activiteit van stofstalen uit de omgevingslucht van Genk-Zuid gemeten met in vitro laboratoriumtesten. De stofstalen werden genomen op de dagen dat de bloedstalen bij de jongeren werden afgenomen. In de stofstalen van Genk-Zuid werd een hogere kankerverwekkende activiteit (oxidatieve stress en mutagene activiteit) gemeten in vergelijking met controlestalen uit Koksijde. De hoeveelheid oxidatieve stress en mutagene activiteit van de stofstalen was gerelateerd aan de hoeveelheid zware metalen en/of PAK's op de stofstalen. De waarden van oxidatieve stress van de stofstalen waren geassocieerd met de resultaten van de oxidatieve komeettest bij de jongeren uit de biomonitoringstudie.

3.5.3.2 *Hormoonverstoring en neurologische ontwikkeling*

Er werden regionale verschillen in de werking van de schildklier en de puberteitsontwikkeling vastgesteld. Jongeren uit Genk vertoonden een versnelde seksuele rijping vergeleken met de Vlaamse referentiepopulatie. Tevens werd er een lichte verstoring van het concentratievermogen gemeten in Genk-Zuid, maar niet in Menen. Jongeren uit de regio Menen scoorden wel iets minder goed op enkele testen die verband houden met korte termijn geheugen en motorische vaardigheden dan hun leeftijdsgenoten in de Vlaamse referentiepopulatie. Deze verschillen tussen de hotspots en Vlaanderen zijn deels toe te schrijven aan verschillen in de karakteristieken van de populatie, bijv. leeftijd, etniciteit (bijv. snellere puberteitsontwikkeling), maar ook na correctie voor deze verstorende factoren blijven de verschillen bestaan, wat doet vermoeden dat een lokale milieufactor een rol speelt. Op groepsniveau (Genk, Menen en Vlaanderen samen) werden significante relaties vastgesteld tussen zware metalen, POP's en PAK's enerzijds en puberteitsontwikkeling en hormoonconcentraties anderzijds; tussen zware metalen en nierfunctie; en tussen zware metalen en neurologische ontwikkeling. Een hogere waarde voor blootstelling ging telkens gepaard met een hogere waarde voor gezondheidseffecten.

3.5.4 Zijn er sociale verschillen in de resultaten merkbaar?

In deze paragraaf gaan we op zoek naar sociale verschillen in de inwendige blootstelling aan milieuvervuilende stoffen binnen de twee hotspots. Dit bepalen we door te kijken naar het opleidingsniveau van de ouders van de jongeren en naar het onderwijstype van de jongeren. Table

12 en Table 13 geven de procentuele verschillen van de biomerkers per opleidingsniveau van de ouders en onderwijstype van de jongere ten opzichte van de Vlaamse gemiddelden.

Bij zes van de zeven zware metalen zien we verbanden met het opleidingsniveau, hoewel ze niet altijd consistent zijn in de twee hotspots of voor de twee opleidingsparameters. Voor cadmium, lood, koper, thallium en arseen zijn de verbanden negatief: hoe lager de opleiding, hoe hoger de blootstelling. Voor antimoon is het verband positief: lager opgeleiden hebben een lagere blootstelling.

De sociale verschillen zijn het grootst voor lood. Zowel in Genk-Zuid als in Menen stijgt de concentratie aan lood in het bloed met een lager opleidingsniveau. Dit is opvallend aangezien de loodconcentratie van de totale steekproef in beide hotspots lager ligt dan gemiddeld in Vlaanderen (-1,5% in Genk-Zuid en -15,0% in Menen). Kijken we echter enkel naar de jongeren met laagopgeleide ouders, dan is de loodconcentratie bij hen net hoger dan het Vlaams gemiddelde (+13,5% in Genk-Zuid en +3,0% in Menen). Op basis van de absolute bloedwaarden (niet in tabel) stellen we vast dat de concentratie lood bij jongeren met laagopgeleide ouders in Genk-Zuid en in Menen 28% hoger ligt dan bij jongeren met hoogopgeleide ouders.

Ook voor blootstelling aan cadmium, koper en thallium vinden we dezelfde negatieve trend met het opleidingsniveau, hoewel de verschillen hier minder consistent zijn dan bij lood. Voor cadmium zien we in Genk-Zuid een significant negatief verband met het onderwijsniveau van de deelnemers. Jongeren uit het BSO en TSO hebben hogere cadmiumwaarden dan jongeren uit het ASO. Opnieuw op basis van absolute bloedwaarden van Genk-Zuid is de concentratie cadmium bij BSO en TSO leerlingen 22% hoger dan bij ASO leerlingen. Dezelfde trend zien we bij het opleidingsniveau van de ouders, maar daar is het verband niet significant. In Menen blijken vooral deelnemers uit het BSO opvallend meer blootstelling aan cadmium te kennen dan gemiddeld in Vlaanderen (+23,0%), maar het verband is ook hier niet statistisch significant.

Blootstelling aan koper is in beide hotspots significant negatief geassocieerd met opleiding, maar de trend is niet lineair voor het opleidingsniveau van de ouders. De middelste opleidingscategorie kent de hoogste blootstelling. Voor het onderwijstype van de jongeren in Genk-Zuid zien we wel een lineair negatief verband: de concentratie koper in het bloed van jongeren uit het BSO is 11,6% hoger dan gemiddeld, terwijl dit bij jongeren uit het ASO maar 1,3% hoger dan gemiddeld is.

In tegenstelling tot de zware metalen vinden we voor bijna alle persistente organische stoffen positieve verbanden met opleiding: een hogere opleiding gaat samen met een hogere blootstelling. Dit is het duidelijkst zichtbaar bij de PCB’s. In beide hotspots en voor beide opleidingsparameters zien we een significant positieve associatie. De concentratie aan PCB’s ligt in de totale steekproef van beide hotspots ver onder het Vlaams gemiddelde, maar binnen de groep hoogopgeleiden is de blootstelling wel dubbel zo hoog als binnen de groep laagopgeleiden.

Voor dioxineachtige PCB's en vooral voor de gebromeerde vlamvertrager BDE153 zien we enkel in Genk-Zuid significante positieve verbanden (hoewel de trend ook in Menen zichtbaar is). Jongeren met laagopgeleide ouders hebben een concentratie BDE153 in hun bloed die 42,2% lager ligt dan het Vlaams gemiddelde, terwijl dit bij jongeren met hoogopgeleide ouders maar 5,8% lager ligt.

Voor de vluchtige stoffen zien we opnieuw negatieve verbanden met opleiding. De concentratie PAK's ligt bij de totale groep jongeren in Genk-Zuid 44,7% en in Menen 30% boven het Vlaams gemiddelde, maar binnen de groep jongeren met laagopgeleide ouders is dit respectievelijk 75,4% en 51,1% boven het gemiddelde (hoewel het verband enkel in Menen significant is). Jongeren met hoogopgeleide ouders hebben een PAK's waarde die bijna twee keer lager ligt. Voor benzeen zien we dezelfde trend die vooral in Menen sterk significant is. Hier zien we hetzelfde fenomeen als bij lood: kijken we naar de totale groep jongeren dan is de blootstelling in Menen lager dan gemiddeld in Vlaanderen (-4,3%), kijken we echter naar de verdeling van opleidingsgroepen dan valt op dat dit totale percentage vooral te wijten is aan een lage blootstelling bij hoogopgeleiden (-23,4%) en dat laagopgeleiden een veel hoger dan gemiddelde blootstelling kennen (+19,5%).

Hoe kunnen die gevonden sociale verschillen nu verklaard worden? In aparte multiple regressiemodellen werden de verbanden tussen opleidingsniveau en biomerkers voor de hotspot Genk-Zuid verder in kaart gebracht (zie o.a. Morrens e.a., 2013). Geografische factoren zoals afstand van de woonplaats tot het industrieterrein konden geen verklaring bieden voor de gevonden sociale verschillen. Dit is consistent met de resultaten van eerdere humane biomonitoringsstudies in acht ruimere aandachtsgebieden in Vlaanderen. Ook daar konden sociale gradiënten in blootstelling niet verklaard worden door geografische factoren (Morrens e.a., 2012). Bepaalde levensstijl- en voedingspatronen bleken echter wel in een aantal gevallen de sociale verschillen in blootstelling te verklaren. Het rookgedrag van de jongere kon bijvoorbeeld de sociale gradiënt voor lood verklaren. Jongeren met laagopgeleide ouders en jongeren uit het BSO roken vaker en dit zorgt voor hogere gehalten van lood in hun bloed. Sociale verschillen in blootstelling aan cadmium bleken o.a. bepaald te worden door de ijzerstatus van de jongeren. Een ijzertekort (bijvoorbeeld ten gevolge een onevenwichtig voedingspatroon) zorgt ervoor dat zware metalen makkelijker geabsorbeerd kunnen worden in het lichaam en is in onze steekproef geassocieerd met een lager opleidingsniveau. De sociale verschillen in blootstelling aan vluchtige stoffen konden niet verklaard worden door het rookgedrag van de jongeren of door de tijd dat jongeren doorbrengen in het verkeer. Andere invloedsfactoren liggen dus aan de basis van de gevonden sociale verschillen voor de stoffen. De positieve sociale verschillen in blootstelling aan POP's konden wel verklaard worden door twee specifieke invloedsfactoren: de bodymass index (BMI) van de jongeren en het feit of de jongeren als baby borstvoeding gekregen hebben. POP's zijn persistente stoffen die zeer moeilijk afgebroken worden in het milieu. Ze worden opgenomen door de mens en stapelen zich op in het vetweefsel. Een hogere BMI betekent dat POP's 'verdund' kunnen worden over meer vetweefsel. Omdat jongeren met een hogere BMI meestal een lagere opleiding hebben, verklaart dit een deel van de gevonden sociale verschillen in blootstelling. Ook het krijgen van borstvoeding is een gekende invloedsfactor voor POP's omdat moedermelk een hoog vetgehalte heeft. Jongeren met lageropgeleide ouders kregen minder vaak borstvoeding als baby waardoor ze op de leeftijd van 15 jaar gemiddeld lagere waarden voor POP's hebben dan jongeren met hoogopgeleide ouders.

Wanneer we in aparte regressiemodellen opleiding vervangen door equivalent gezinsinkomen (niet in tabel), dan wordt voor beide hotspots enkel het negatieve verband met koper bevestigd. Voor Genk-Zuid zien we echter ook negatieve verbanden voor lood en PAK's: jongeren met een lager gezinsinkomen hebben een hogere blootstelling. We vinden geen positieve verbanden tussen inkomen en blootstelling aan POP's, met uitzondering van de gebromeerde vlamvertrager BDE153 in Genk-Zuid. Wordt opleiding vervangen door etnische achtergrond (geboorteland van de ouders), dan zien we in Genk-Zuid significante verbanden voor lood en koper: jongeren met een andere etnische achtergrond hebben hogere concentraties. Deze etnische verschillen bleven significant na correctie voor opleiding wat doet vermoeden dat ook bepaalde culturele praktijken een invloed kunnen hebben op blootstelling aan chemische stoffen.

Table 12: Vergelijking van biomerkers van blootstelling tussen Genk-Zuid en Vlaanderen, totale verschillen en verschillen naar SES

Genk-Zuid	**Totaal verschil met Vlaanderen**		**Verschil met Vlaanderen naar opleidingsniveau ouders**				**Verschil met Vlaanderen naar onderwijstype jongeren**			
		p-waarde	**Lager secundair**	**Hoger secundair**	**Hoger onderwijs**	**p-waarde**	**BSO**	**TSO**	**ASO**	**p-waarde**
Zware metalen										
Cadmium	+13,3	0.06	+22,7	+16,3	+7,8	0.47	+29,6	+29,3	+3,0	<0.01
Lood	-1,7	0.67	+13,5	+7,6	-10,0	<0.01	+16,2	+2,5	-8,1	<0.01
Chroom	+29,3	<0.01	+21,9	+35,2	+25,1	0.33	+33,1	+45,8	+22,1	0.27
Koper	+3,8	0.02	+4,5	+8,6	+1,0	0.15	+11,6	+6,4	+1,3	<0.01
Thallium	+10,7	<0.01	+6,6	+15,2	+8,9	0.02	+8,1	+6,7	+12,7	0.16
Arseen	+33,1	<0.01	+52,7	+19,5	+35,8	0.47	+35,2	+36,4	+31,0	0.66
Antimoon	-21,2	<0.01	-29,4	-19,9	-19,2	0.71	-31,1	-25,7	-14,1	0.01
POP's										
PCB's	-31,6	<0.01	-38,7	-38,2	-19,6	<0.01	-39,9	-38,7	-21,2	<0.01
Diox. PCB's	-68,6	<0.01	-70,9	-71,2	-66,3	0.11	-73,4	-71,1	-66,0	0.02
Dioxines en furanen	-59,0	<0.01	-57,2	-59,8	-57,9	0.92	-63,5	-52,4	-59,2	0.17
BDE153	-19,7	<0.01	-42,2	-25,7	-5,8	<0.01	-26,5	-35,6	-12,0	<0.01
Vluchtige stoffen										
PAK's	+30,0	<0.01	+51,1	+41,6	+24,0	0.57	+55,5	+50,7	+17,0	0.09
Benzeen	+15,6	0.19	+75,5	+16,6	+3,7	0.18	+75,4	-6,7	+6,5	0.05

De cijfers geven aan hoeveel procent hoger (+) of lager (-) de waarde in Gent-Zuid ligt t.o.v. Vlaanderen na correctie voor niet-beïnvloedbare verschillen in samenstelling van de groepen (leeftijd, geslacht, seizoen, densiteit urine, duur collectie). Eerst worden de totale verschillen getoond t.o.v. Vlaanderen, vervolgens is er een opdeling per opleidingsniveau van (de ouders van) de deelnemers.

Table 13: Vergelijking van biomerkers van blootstelling tussen regio Menen en Vlaanderen, totale verschillen en verschillen naar SES

Menen	Totaal verschil met Vlaanderen		Verschil met Vlaanderen naar opleidingsniveau ouders				Verschil met Vlaanderen naar onderwijstype jongeren			
		p-waarde	Lager secundair	Hoger secundair	Hoger onderwijs	p-waarde	BSO	TSO	ASO	p-waarde
Zware metalen										
Cadmium	-5,1	0.50	-10,4	-6,0	-7,2	0.98	+23,0	-6,8	-12,4	0.29
Lood	-15,0	<0.01	+3,0	-18,1	-18,9	<0.01	-7,4	-18,8	-15,6	0.72
Koper	+6,6	<0.01	+4,3	+10,9	+4,6	0.01	+5,3	+8,8	+5,3	0.05
Thallium	+26,0	<0.01	+30,7	+29,9	+22,7	0.78	+29,1	+21,2	+23,2	0.05
Arseen	-17,7	0.01	-16,4	-35,6	-16,7	0.66	-34,9	-26,3	-17,1	0.27
Antimoon	-31,8	<0.01	-32,5	-10,1	-38,3	0.01	-22,6	-27,0	-35,1	0.09
POP's										
PCB's	-23,0	<0.01	-34,4	-34,3	-11,4	<0.01	-37,2	-24,9	-15,3	0.01
Diox. PCB's	-20,4	<0.01	-18,7	-22,3	-21,6	0.48	-27,1	-18,8	-20,9	0.79
Dioxines en furanen	-39,6	<0.01	-40,8	-42,8	-39,0	0.87	-45,8	-37,7	-40,5	0.75
BDE153	-1,8	0.82	-11,9	-2,6	+1,7	0.33	-10,2	-0,7	+1,3	0.61
Vluchtige stoffen										
PAK's	+44,7	<0.01	+75,4	+46,7	+29,9	0.03	+30,9	+31,5	+44,4	0.76
Benzeen	-4,3	0.66	+19,5	+41,5	-23,4	<0.01	+81,8	+6,5	-21,8	<0.01

De cijfers geven aan hoeveel procent hoger (+) of lager (-) de waarde in Menen ligt t.o.v. Vlaanderen na correctie voor niet-beïnvloedbare verschillen in samenstelling van de groepen (leeftijd, geslacht, seizoen, densiteit urine, duur collectie). Eerst worden de totale verschillen getoond t.o.v. Vlaanderen, vervolgens is er een opdeling per opleidingsniveau van (de ouders van) de deelnemers.

3.6 Conclusie

Wonen in de buurt van de industriële hotspots in Genk-Zuid en Menen gaat gepaard met een verhoogde milieudruk. Dit vertaalt zich in hogere concentraties van bepaalde vervuilende stoffen en merkbare biologische effecten in het lichaam van jonge buurtbewoners. Ondanks de verschillen in type industrie werden in de buurt van de beide hotspots grotendeels dezelfde verhogingen gemeten, namelijk voor zware metalen en PAK's. Meest ernstig is het feit dat deze verhogingen samengaan met verhoogde DNA-schade in het lichaam wat kan wijzen op een verhoogd kankerrisico voor de regio. Tegelijk met de verhoogde milieudruk worden de buurten rondom deze hotspots ook gekenmerkt door een lager sociaal-economisch profiel. Dat is op zich een duidelijk voorbeeld van milieuongelijkheid volgens de klassieke opvatting van de 'Environmental Justice Movement' die focust op de ongelijke verdeling van externe milieukwaliteit.

Toch vonden we geen duidelijke aanwijzingen dat binnen deze buurten zij met een meer kwetsbare positie ook meer milieudruk kennen. We vinden geen systematische sporen van sociale ongelijkheid in de resultaten van de humane biomonitoringsstudie. We vinden wel sociale verschillen in blootstelling aan bepaalde stoffen, die zowel in positieve als negatieve richting gaan. Blootstelling aan zware metalen en verbrandingsproducten lijken meestal te stijgen met een dalend opleidingsniveau, terwijl voor persistente polluenten het omgekeerde geldt. De verklaring hiervoor wordt niet zozeer gevonden in geografische factoren (afstand tot bronnen), maar eerder specifieke levensstijl- of voedingspatronen of zelfs biologische en metabole mechanismen liggen aan de oorsprong van deze sociale verschillen. De resultaten zijn aldus geen eenduidige bevestiging van de literatuur rond milieuongelijkheden, maar eerder een voorbeeld van de complexiteit van mechanismen tussen externe en interne blootstelling. De resultaten tonen daarbij wel duidelijk aan dat blootstelling aan chemische stoffen in onze leefomgeving niet enkel een milieu-geografisch proces is, bepaald door afstand tot (punt)bronnen, maar ook een sociaal proces, beïnvloed door zeer specifieke factoren die samenhangen met onze sociale positie, levensstijl en voedingsgewoonten.

We stellen ook vast dat de resultaten vaak afhankelijk zijn van de gebruikte SES-indicator. Dit wijst erop dat het onderwijstype van jongeren en het opleidingsniveau van ouders andere invloedfactoren bevatten. Een hypothese kan zijn dat het onderwijstype van jongeren meer verband houdt met persoonlijke blootstelling aan schadelijke stoffen (denk aan contact met uitlaatgassen in technische onderwijsrichtingen), terwijl het opleidingsniveau van de ouders een betere proxy is voor de sociaaleconomische status, en de daaraan gerelateerde levensstijlfactoren en gezondheidbeïnvloedend gedrag en kennis. We vonden ook bepaalde relaties met de etnische achtergrond van jongeren wat doet vermoeden dat ook culturele praktijken een invloed hebben op blootstelling.

Deze bijdrage onderstreept het belang van de deconstructie van sociale indicatoren en de identificatie van achterliggende sociale mechanismen en specifieke blootstellingsroutes voor het bepalen en beheren van milieurisico's. Klassieke risicoanalyse is nog te vaak een probabilistische of deterministische oefening waarbij men aan de hand van centrummaten tracht de gemiddelde blootstelling aan bepaalde stoffen weer te geven. Risicogroepen die een verhoogde blootstelling kunnen hebben, worden daarbij soms over het hoofd gezien, zeker als het gaat over sociale risicogroepen. Sociaaleconomische factoren zoals opleiding, deprivatie of etniciteit worden in de meeste toxicologische studies niet bevraagd of hoogstens beschouwd als 'verstorende factoren' waarvoor gecontroleerd moet worden. Sociale verschillen in blootstelling kunnen hierdoor onderbelicht blijven. Daarom zou aandacht voor sociale ongelijkheid een basisreflex moeten zijn in elk milieu- en gezondheidsonderzoek.

Referenties

Adler, N.E. & Newman, K. (2002), Socioeconomic Disparities In Health: Pathways And Policies, *Health Affairs*, 21 (2), 60-76.

Agency for Toxic Substance and Disease Registry (ATSDR) (2005), *Toxicological profile for nickel*, U.S. Department of Health and Human Services, https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf

Agency for Toxic Substance and Disease Registry (ATSDR) (2012), *Toxicological profile for chromium*, U.S. Department of Health and Human Services, http://www.atsdr.cdc.gov/toxprofiles/tp7.pdf

Brown, P. (1995), Race, class, and environmental health. A review and systematization of the literature, *Environmental Research*, 69 (1), 15-30.

Cesaroni, G., Badaloni, C., Romano, V., Donato, E., Perucci, C.A., Forastiere, F. (2010), Socioeconomic position and health status of people who live near busy roads: the Rome Longitudinal Study (RoLS), *Environmental Health*, 9 (41).

Coenen, F., Halfacre, A. (2000), De verdeling van milieueffecten en milieurisico's over de Nederlandse bevolking als milieuprobleem: 'Environmental injustice' in Nederland, *Beleidswetenschap*, 4 (4), 316-339.

Diebolt, W., Hellias, A. (2005), *Les inégalités écologiques en milieu urbain, Ministère de l'Ecologie et du Développement Durable*, rapport de l'Inspection Générale de l'Environnement, IGE/04/022.

Dubowsky, S.D., Suh, H., Schwartz, J., Coull, B.A., Gold, D.R. (2006), Diabetes, Obesity, and Hypertension May Enhance Associations between Air Pollution and Markers of Systemic Inflammation, *Environmental Health Perspectives,* 114 (7), 992-998.

Gee, G.C., Paye-Strurges, D.C. (2004), Environmental Health Disparities: A Framework Integrating Psychosocial and Environmental Concepts, *Environmental Health Perspectives*, 112 (17), 1645-1653.

Heinrich, J., Mielck, A., Schäfer, I., Mey, W. (2000), Social inequality and environmentally-related diseases in Germany: Review of empirical results, *Sozial- und Präventivmedizin*, 45, 106-118.

Kruize, H. (2007), *On environmental equity. Exploring the distribution of environmental quality among socio-economic categories in the Netherlands*, doctoraal proefschrift, Universiteit Utrecht.

Leroy, P. (2001), Milieubesef als cultuurgoed, *Ons Erfdeel*, 44, 21-30.

Milieurapport Vlaanderen (MIRA) (2012), *Indicatorenrapport 2012*.

Morrens, B., Bruckers, L., Loots, I., Den Hond, E., Nelen, V., Larebeke, N., Sioen, I., Schoeters, G., Baeyens, W. (2013), Environmental justice under our skin? Socio-stratifying human biomonitoring results of adolescents living near an industrial hotspot in Flanders, Belgium, in: Druffel, K. (ed.), *Looking within: finding an environmental justice and global citizenship lens*. Oxford, Inter-Disciplinary Press, 185-199.

Morrens, B., Bruckers, L., Den Hond, E., Nelen, V., Schoeters, G., Baeyens, W., Van Larebeke, N., Keune, H., Bilau, M., Loots, I. (2012), Social distribution of internal exposure to environmental pollution in Flemish adolescents, *International journal of hygiene and environmental health*, 215 (4), 474-481.

Nelen, V., Bruckers, L., Van De Mieroop, E., Thys, G. (2007), *Gezondheidsenquête Genk-Zuid 2007*. Bilzen, Diepenbeek, Genk, Zutendaal, Eindrapport.

O'Neill, M.S., Jerrett, M., Kawachi, L., Levy, J.L., Cohen, A.J., Gouveia, N., et al. (2003), Health, wealth, and air pollution: Advancing theory and methods, *Environmental Health Perspectives*, 111(16), 1861-1870.

O'Neill, M.S., McMichael, A.J., Schwartz, J., Wartenberg, D. (2007), Poverty, Environment, and Health The Role of Environmental Epidemiology and Environmental Epidemiologists, *Epidemiology*, 18(6), 664-668.

Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurnston, G.D. (2002), Lung Cancer, Cardiopulmonary Mortality and Long-Term Exposure to Fine Particulate Air Pollution, *Journal of the American Medical Association*, 287(6), 1132-1141.

VMM (2013a) *Luchtkwaliteit in Vlaanderen. Luchtkwaliteit in Genk – periode 2003-2012*.

VMM (2013b) *Luchtkwaliteit in Vlaanderen. Dioxine- en PCB-depositiemetingen in de periode april 2012-april 2013.*

VMM (2012) *AEROPA: Resultaten grensoverschrijdende luchtkwaliteitstudie in de regio Menen-Wervik/Halluin-Bousbecque*.

Walker, G.,(2009), Beyond Distribution and Proximity: Exploring the Multiple Spatialities of Environmental Justice, *Antipode* 41(4), 614-636.

Wheeler, B.W., Ben-Shlomo, Y. (2005), Environmental equity, air quality, socioeconomic status, and respiratory health: a linkage analysis of routine data from the Health Survey for England, *Journal of Epidemiology and Community Health*, 59, 948-954.

Chapter 4 Blootstelling aan hormoonverstorende stoffen in consumptieproducten. Op zoek naar linken tussen duurzaamheid, gezondheid en sociale ongelijkheid

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4.1 Inleiding

Zonder het goed en wel te beseffen, komen we in ons dagelijkse leven in contact met heel wat synthetische chemische stoffen. Als gevolg van technologische innovaties worden aan allerlei consumptieproducten, waaronder voedingsmiddelen, verzorgingsproducten, speelgoed, elektronica, en bouwmaterialen, talrijke chemicaliën toegevoegd die ervoor zorgen dat deze producten duurzamer, (brand)veiliger en makkelijker bruikbaar zijn. Plastics worden soepel gemaakt, meubilair en elektronica krijgen een vlamvertragende beschermlaag, textiel wordt water- en vuilafstotend, aan cosmetica worden stoffen toegevoegd om kleur en geur langer te behouden, enzovoort. Ondanks de vele technologische en duurzame toepassingen die bijdragen aan onze veiligheid, ons comfort en onze gezondheid, is de keerzijde van deze medaille een toename van chemische stoffen in ons leefmilieu en daardoor ook in het menselijk lichaam. Uit de Global Chemicals Outlook van het VN-Milieuprogramma (UNEP), waarvan in 2019 een tweede editie verscheen, blijkt dat de productie van de chemische industrie wereldwijd verdubbelde sinds 2000. Tegen 2030 wordt opnieuw een verdubbeling verwacht. Dit maakt de chemische industrie vandaag de tweede grootste industrietak ter wereld, met tienduizenden verschillende chemische stoffen in omloop (UNEP, 2019). Hoewel de toename in productie en consumptie zich vooral manifesteert in opkomende economieën zoals China, zien we ook in Europa en in België een groeiende chemische sector.

Het merendeel van de chemicaliën die in omloop zijn, is echter amper onderzocht op hun gevolgen voor de gezondheid, aangezien wetenschappelijk onderzoek en regelgeving traag verlopen. Slechts over 1% van alle stoffen zou momenteel voldoende kennis beschikbaar zijn (Bourguignon e.a., 2018). Bovendien verloopt het onderzoek en de regulering van chemische stoffen nog te veel stof per stof. Terwijl we in de praktijk worden blootgesteld aan een cocktail van chemische stoffen.

Voor vele van deze stoffen is er groeiende bezorgdheid voor de menselijke gezondheid omwille van hun hormoonverstorende werking. Ons lichaam maakt zelf meerdere hormonen aan die de werking van de verschillende lichaamsfuncties sturen en onder controle houden. Hormoonverstorende stoffen zijn lichaamsvreemde stoffen die de werking van onze hormonen verstoren, bijvoorbeeld omdat ze hormonen nabootsen of blokkeren. Hierdoor kunnen de lichaamsfuncties uit evenwicht gebracht worden. Dit kan verschillende veranderingen in het lichaam tot gevolg hebben, die soms kunnen uitgroeien tot gezondheidsklachten of ziekten. Zeker in bepaalde kwetsbare perioden, zoals tijdens de zwangerschap en de ontwikkeling van jonge kinderen, kan hormoonverstoring problematisch zijn en bijdragen tot verschillende welvaartsziektes (Bourguignon e.a., 2018). Vergeleken met volwassenen krijgen kinderen een grotere dosis chemicaliën binnen per kilogram lichaamsgewicht en worden deze stoffen in hun lichaam soms ook anders verwerkt. Dit is onder meer te wijten aan een hogere ademhalingsfrequentie, een grotere lichaamsoppervlakte ten opzichte van hun gewicht, een dunnere huid en een andere stofwisseling bij kinderen dan bij volwassenen. Het hand-mond contact is ook typisch voor kinderen, wat de blootstelling vergemakkelijkt. Bovendien zijn verschillende biologische systemen in het lichaam van kinderen nog volop in ontwikkeling, wat hen gevoeliger maakt aan de schadelijke effecten van deze stoffen. Philippe Grandjean, een autoriteit op dit gebied, waarschuwt zelfs voor een 'chemical braindrain', gezien de invloed van die hormoonverstoorders op onder andere de hersenontwikkeling en het mogelijke verlies aan IQ (Grandjean, 2013). Door de toenemende bewijslast voor dit probleem, werd in 2018 in de Belgische Senaat een uitgebreid informatieverslag opgesteld over hormoonverstoring, na een hele reeks hoorzittingen. Daarin worden verschillende beleidsvoorstellen geformuleerd, met veel aandacht voor samenwerking over de beleidsgrenzen heen (Belgische Senaat, 2018).

Een specifieke stofgroep die in verband met hormoonverstoring veel aandacht krijgt zijn de ftalaten. Ftalaten zijn chemische stoffen die gebruikt worden om plastic en kunststoffen soepel en flexibel te maken. Ze zitten in tal van gebruiksvoorwerpen zoals (plastic) keukengerei, verpakkingen van voedsel, speelgoed, plakband, vinyl- en kunststof vloerbedekkingen, maar ook in bepaalde verzorgingsproducten, schoonmaakmiddelen en verf (om onder andere geur en kleur te fixeren). In België alleen wordt 1.000 tot 10.000 ton aan ftalaten geproduceerd per jaar. Ftalaten zijn echter niet chemisch gebonden aan plastic. Hierdoor kunnen ze uitlogen, migreren of verdampen in de binnenlucht en de atmosfeer, in voedsel of in andere materialen en zijn ze alomtegenwoordig in onze omgeving (Lambrechts e.a., 2018). Blootstelling aan ftalaten wordt onder andere geassocieerd met voorkomen van diabetes, obesitas, astma, vruchtbaarheidsproblemen, tragere ontwikkeling van het ongeboren kind en neurologische stoornissen zoals ADHD (Benjamin e.a., 2017).

De vraag die centraal staat in dit hoofdstuk is of er – ten gevolge de bezorgdheid voor leefmilieu en volksgezondheid – ook een bijkomende bezorgdheid moet zijn voor sociale ongelijkheid bij deze problematiek. Zijn mensen lager op de sociale ladder meer blootgesteld of meer vatbaar voor de (hormoonverstorende) effecten van deze schadelijke stoffen dan mensen hoger op de sociale ladder? Deze vraagstelling kadert in het discours van milieu(on)rechtvaardigheid (environmental justice) dat stelt dat milieurisico's ongelijk verdeeld zijn en onevenredig vaak terecht komen bij minder gegoede en gekleurde bevolkingsgroepen. Hoewel van oorsprong Amerikaans, met wortels in de Afro-Amerikaanse burgerbewegingen van de jaren 1980, krijgt dit discours de laatste jaren ook meer en meer aandacht in Europees beleid en onderzoek (WHO 2012), zij het met meer nadruk op sociaaleconomische dan op etnische ongelijkheden. Zo publiceerde het Europees Milieuagentschap in 2018 een omvangrijk rapport waaruit blijkt dat ook in Europa sociaal zwakkere bevolkingsgroepen, voornamelijk laagopgeleiden, werklozen en mensen met een laag inkomen, vaker wonen en werken in wijken met een lagere milieukwaliteit waardoor ze meer blootgesteld zijn aan luchtvervuiling, geluidsoverlast en hittestress. Daarnaast zijn deze groepen ook meer kwetsbaar voor milieurisico's omdat ze vaak al een slechtere gezondheid hebben, meer stress ervaren en minder in staat zijn de negatieve effecten ervan te vermijden (Kaźmierczak, 2018).

In dit hoofdstuk zullen we nagaan of de hypothese van milieuongelijkheid ook geldt voor de blootstelling aan hormoonverstorende stoffen van een Vlaamse populatie. We gebruiken hiervoor humane biomonitoring data die het Steunpunt Milieu en Gezondheid in 2013-2014 verzamelde bij 200 jongeren in opdracht van de Vlaamse overheid, Departementen Leefmilieu (nu departement Omgeving), Volksgezondheid en Wetenschapsbeleid. Humane biomonitoring (HBM) staat voor het meten van chemische stoffen en hun mogelijke effecten in de mens. De blootstellingsdata weerspiegelen de inwendige dosis aan heel wat milieuvervuilende stoffen in bloed- en urinestalen bij een representatieve Vlaamse steekproef van 14-15 jarige jongeren. Voor dit hoofdstuk focussen we op de data van de ftalaten, waarvan de afbraakproducten gemeten werden in de urine van de deelnemers.

4.2 Data en methode

Deelnemers aan het humane-biomonitoringsonderzoek waren afkomstig uit het derde jaar secundair onderwijs. Per provincie werden willekeurig twee scholengemeenschappen geselecteerd, één in stedelijk gebied (>600 inwoners/km²) en één in niet-stedelijk gebied (≤600 inwoners/km²). In totaal werden 851 jongeren uitgenodigd voor het onderzoek. Hiervan wilden 273 leerlingen deelnemen, wat een positieve respons van 32% opleverde. Uiteindelijk werden 208 deelnemers geselecteerd op basis van drie inclusiecriteria: minimum 10 jaar in Vlaanderen wonen, een Nederlandstalige vragenlijst kunnen invullen en het toestemmingsformulier terugsturen (ondertekend door zowel de ouders als de jongere). Per provincie werd het aantal deelnemers bepaald evenredig met het aantal 14-15 jarige inwoners in elke provincie. De onderzoeken werden gespreid over twee schooljaren en vonden plaats op school. Tijdens het onderzoek werd een bloedstaal en een urinestaal gecollecteerd en werd een vragenlijst ingeleverd die vooraf door de ouders en de jongere werd ingevuld. Deelnemers kregen na afloop een beloning van 20 euro. De studie werd goedgekeurd door de ethische commissie van de Universiteit Antwerpen.

In dit hoofdstuk wordt de sociaaleconomische positie (SEP) van elke deelnemer bepaald aan de hand van drie indicatoren: (i) de onderwijsvorm van de jongere in drie categorieën: algemeen secundair onderwijs (ASO), technisch of kunst secundair onderwijs (TSO/KSO) of beroepssecundair onderwijs (BSO); (ii) het hoogst behaalde opleidingsniveau van de moeder in drie categorieën: lager secundair, hoger secundair of hoger onderwijs; en (iii) het equivalent gezinsinkomen: het gestandaardiseerd netto maandinkomen, gecorrigeerd voor grootte van het gezin, ingedeeld in kwartielen: < 1.250 euro, 1.250-1600 euro, 1.600-2.000 euro, > 2.000 euro.

We beschrijven de verbanden tussen de SEP van jongeren en de inwendige dosis aan drie ftalaten: (i) de som van afbraakproducten van DEHP (di-ethylhexyl ftalaat), (ii) mono-isobutyl ftalaat of MiBP (een afbraakproduct van di-isobutyl ftalaat of DiBP), en (iii) mono-ethyl ftalaat of MEP (een afbraakproduct van di-ethyl ftalaat of DEP). Deze ftalaatmerkers werden gemeten in de urine van jongeren en geven de blootstelling van de voorbije uren en dagen weer (volledige uitscheiding 24 uur na de blootstelling). In de verdere bespreking verwijzen we naar deze ftalaatmerkers als DEHP, MiBP en MEP. In het volledige onderzoek werden meer ftalaatmerkers gemeten, maar we focussen hier op drie metingen omdat ze de diversiteit aan toepassingsgebieden voldoende weergeven. DEHP wordt vooral gebruikt in PVC-producten zoals vinylvloeren, bedrading en kabels, sportuitrusting, textiel, schoeisel, synthetisch leder en medisch materiaal. DiBP en DEP worden, naast toepassingen in PVC, ook gebruikt in geleermiddelen, verf en kleefstoffen. DEP heeft ook toepassingen in cosmeticaproducten en in geneesmiddelen. DEHP en DiBP mogen niet op de Europese markt worden gebracht als de gehalten in de toepassingen groter of gelijk zijn aan 0,1% voor speelgoed en baby-artikelen en 0,3% voor andere producten. DEHP is in de Europese Unie ook verboden in cosmetica. Geïmporteerde producten van buiten de EU, bv. uit Azië of Amerika, vallen echter niet onder deze regels.

Met de statistische techniek van meervoudige lineaire regressie gaan we na of er sociale verschillen merkbaar zijn in de blootstelling aan ftalaten bij jongeren. In een eerste stap bekijken we de rechtstreekse verbanden tussen indicatoren van SEP en de concentratie ftalaatmerkers, na correctie voor geslacht, leeftijd en de verdunningsgraad van de urine. Door die correcties toe te passen, kunnen we uitsluiten dat verschillen in blootstelling te wijten zijn aan biologische processen in het lichaam die verschillen volgens leeftijd en geslacht van de deelnemer, of aan de verdunningsgraad van het urinestaal. In meer verdunde urine (door drinken of door een korte tijd tussen twee plasbeurten) zijn de concentraties aan deze stoffen immers gemiddeld lager dan in sterk geconcentreerde urine. Wanneer in deze modellen de associatie tussen een SEP-indicator en een ftalaatmerker statistisch significant is (p-waarde < 0,05), dan beschouwen we dit als een sociaal verschil in blootstelling. Wanneer dit sociaal verschil trapsgewijs toeneemt of afneemt bij de verschillende SEP categorieën, spreken we van een sociale gradiënt.

In een tweede stap trachten we de gevonden sociale verschillen en gradiënten te verklaren. Dit doen we door aan het eerste regressiemodel verschillende variabelen toe te voegen die zowel een relatie vertonen met de ftalaatmerkers als met SEP. We noemen deze variabelen risicofactoren omdat ze kunnen bijdragen aan een hogere blootstelling aan ftalaten. Indien de oorspronkelijke associatie tussen SEP en de ftalaatmerker daardoor zijn statistische significantie verliest (p-waarde > 0,05), dan is er aanwijzing dat het sociale verschil (deels) bepaald wordt door die risicofactoren. Er kunnen dan nog wel andere factoren een rol spelen die we niet getest hebben. De verbanden die we vinden wijzen ook niet noodzakelijk op een causale of oorzakelijke relatie.

4.3 Resultaten

4.3.1 Sociale gradiënten in blootstelling aan ftalaten

Table 14 toont de procentuele verschillen in gehalten aan drie ftalaatmerkers (DEHP, MiBP en MEP) voor drie indicatoren van SEP (onderwijsvorm jongere, opleidingsniveau moeder en equivalent gezinsinkomen). De hoogste categorie van elke SEP-indicator geldt telkens als referentiegroep waarmee de andere groepen vergeleken worden. Percentages voor de andere categorieën kunnen bijgevolg hoger of lager zijn dan die van de referentiegroep.

We stellen vast dat de gehalten aan DEHP, MiBP en MEP stijgen naarmate de sociaaleconomische positie van jongeren daalt. Hoe lager het gezinsinkomen, het opleidingsniveau van de moeder of de onderwijsvorm van de jongere, hoe hoger de gehalten aan ftalaten. Zeven van de negen associaties zijn statistisch significant (in vet aangeduid in Table 14). We vinden bovendien voor (bijna) alle associaties een duidelijke sociale gradiënt die een hoger gehalte toont bij elke opeenvolgende categorie die verder van de referentiegroep staat. Dit sluit aan bij de literatuur over gezondheidsongelijkheden en bevestigt dat er geen drempelwaarde is tussen hoge en lage SEP, maar dat gezondheidsrisico's daarentegen toenemen bij elke trede lager op de sociale ladder (Marmot, 2004). De sociale gradiënten zijn het grootst voor de MEP-gehalten, die 121% hoger liggen bij jongeren uit de laagste inkomensgroep (< 1.250 euro per maand) dan bij jongeren uit de hoogste inkomensgroep (> 2.000 euro per maand). Bij de twee tussenliggende inkomensgroepen is het gehalte nog respectievelijk 114% en 68% hoger dan bij de referentiegroep (zie Tabel 1). Ook wanneer we kijken naar de onderwijsvorm van de jongere of het opleidingsniveau van de moeder zien we dezelfde significante verschillen voor MEP-gehalten. Voor de twee andere ftalaten zijn de trends gelijklopend, maar liggen de percentages lager en zijn ze niet altijd statistisch significant.

Table 14: Procentuele verschillen in blootstelling aan ftalaten volgens indicatoren van sociaaleconomische positie (SEP)

Indicatoren van SEP	**n (%) Totaal: 208 jongeren**	**Ftalaten in urine van jongeren***		
		DEHP	MiBP	MEP
Onderwijsvorm jongere				
BSO	35 (16,8)	**+49,6%**	+25,8%	**+78,8%**
TSO/KSO	78 (37,5)	**+6,5%**	+13,1%	**+65,0%**
ASO	95 (45,7)	ref.	ref.	ref.
Opleiding moeder				
Lager secundair	31 (16,2)	+31,1%	**+66,7%**	**+58,4%**
Hoger secundair	77 (40,3)	+14,6%	**+25,7%**	**+111,2%**
Hoger onderwijs	83 (43,5)	ref.	ref.	ref.
Equivalent gezinsinkomen				
< 1.250 euro	54 (27,4)	**+37,1%**	**+57,4%**	**+121,4%**
1.250 – 1.600 euro	41 (20,8)	**+49,1%**	**+31,7%**	**+113,9%**
1.600 – 2.000 euro	53 (26,9)	**+14,5%**	**+13,1%**	**+67,8%**
> 2.000 euro	49 (24,9)	ref.	ref.	ref.

**Procentuele verschillen in blootstelling t.o.v. referentiegroep, na correctie voor geslacht, leeftijd en verdunningsgraad van de urine. Percentages in vet zijn statistisch significant ($p<0.05$). ref.= de referentiecategorie.*

Deze resultaten zijn in overeenstemming met verscheidene buitenlandse studies. Bijvoorbeeld, een hogere blootstelling aan een aantal ftalaten werd eveneens gemeten bij deelnemers met een lagere opleiding en een lager inkomen in Nederland (Ye e.a., 2008) en de Verenigde Staten (Kobrosly e.a., 2012), terwijl in andere studies verschillen minder uitgesproken waren (Den Hond e.a., 2015). Sommige studies vermelden dat de richting van de sociale gradiënten mogelijk ook kan verschillen afhankelijk van de bestudeerde ftalaat en de beschouwde tijdsperiode. Amerikaans onderzoek vond naast sociale ook etnische verschillen in blootstelling terug waarbij vooral Afro-Amerikanen en latino's hogere waarden hebben (James-Todd e.a., 2016).

4.3.2 Hoe kunnen sociale gradiënten verklaard worden?

We identificeren in onze data vijf risicofactoren die zowel een relatie vertonen met hogere concentraties aan ftalaatmerkers, als met de indicatoren van SEP. Deze factoren kunnen dus een mogelijke verklaring bieden voor de gevonden sociale gradiënten. In meervoudige regressiemodellen kon de combinatie van deze risicofactoren zes van de zeven sociale verschillen uit Table 14 wegwerken. De geselecteerde risicofactoren zijn in te delen in twee types: enerzijds factoren die te maken hebben met consumptiepatronen en anderzijds met binnenhuiskwaliteit. Table 15 toont in welke mate deze factoren zorgen voor een hogere blootstelling aan ftalaten. Figure 8 toont hoe de factoren samenhangen met de sociaaleconomische positie van jongeren.

Table 15: Procentuele verschillen in gehalten aan ftalaatmerkers volgens risicofactoren

Risicofactoren voor blootstelling	n (%)	Ftalaten in urine van jongeren*		
		DEHP	MiBP	MEP
Consumptiepatronen				
Verzorgingsproducten**				
Hoog gebruik	70 (33,8)	**+26,3%**	+24,2%	**+264,0%**
Matig gebruik	77 (37,2)	**-13,8%**	-9,6%	**+81,0%**
Laag gebruik	60 (29,0)	ref.	ref.	ref.
Alcohol				
Wekelijks	107 (51,9)	**+56,3%**	+30,1%	+70,7%
Maandelijks	55 (26,7)	**+21,0%**	+20,0%	-4,4%
Nooit	44 (21,4)	ref.	ref.	ref.
Kauwgum**				
Ja	97 (47,1)	**+38,0%**	+33,3%	**+66,1%**
Nee	109 (52,9)	ref.	ref.	ref.
Binnenhuisfactoren				
Passief roken thuis				
Dagelijks	146 (71,6)	+11,0%	**+22,5%**	**+107,2%**
Soms	30 (14,7)	+2,3%	**+8,3%**	**+31,4%**
Nooit	28 (13,7)	ref.	ref.	ref.
PVC vloer of behang				
Ja	52 (26,1)	+14,5%	**+31,2%**	+7,7%
Nee	147 (73,9)	ref.	ref.	ref.

**Procentuele verschillen in blootstelling t.o.v. referentiegroep, zonder bijkomende correcties. Percentages in vet zijn statistisch significant (p<0,05). ref. = de referentiecategorie. ** = gebruik van de laatste 3 dagen voor het onderzoek.*

4.3.2.1 *Consumptiepatronen*

Het gebruik van verzorgingsproducten en cosmetica vertoont de grootste verschillen in de gehaltes aan ftalaten, vooral bij MEP. Dat is niet verwonderlijk aangezien DEP (waarvan MEP het afbraakproduct is) – in tegenstelling tot sommige andere ftalaten – in de wetgeving niet gereglementeerd is en dus tot op heden toegelaten blijft in heel wat producten, waaronder cosmetica. We bevroegen jongeren naar het recent gebruik (de drie dagen voor het onderzoek) van 10 soorten producten zoals make-up, haarverzorging, crèmes en parfums of deodoranten. Het gebruik werd ingedeeld in drie groepen: laag gebruik (0 tot 2 producten), matig gebruik (3 tot 5 producten) en hoog gebruik (6 tot 10 producten). Bij de groep jongeren met een hoog gebruik ligt het MEP gehalte 264% hoger dan bij de groep met een laag gebruik. Voor de andere twee ftalaten is er een verschil van ruim 20% (zie Table 15).

Deelnemers uit het BSO en het TSO/KSO hebben opvallend vaker een hoog gebruik van verzorgingsproducten en cosmetica in vergelijking met jongeren uit het ASO (respectievelijk 37 en

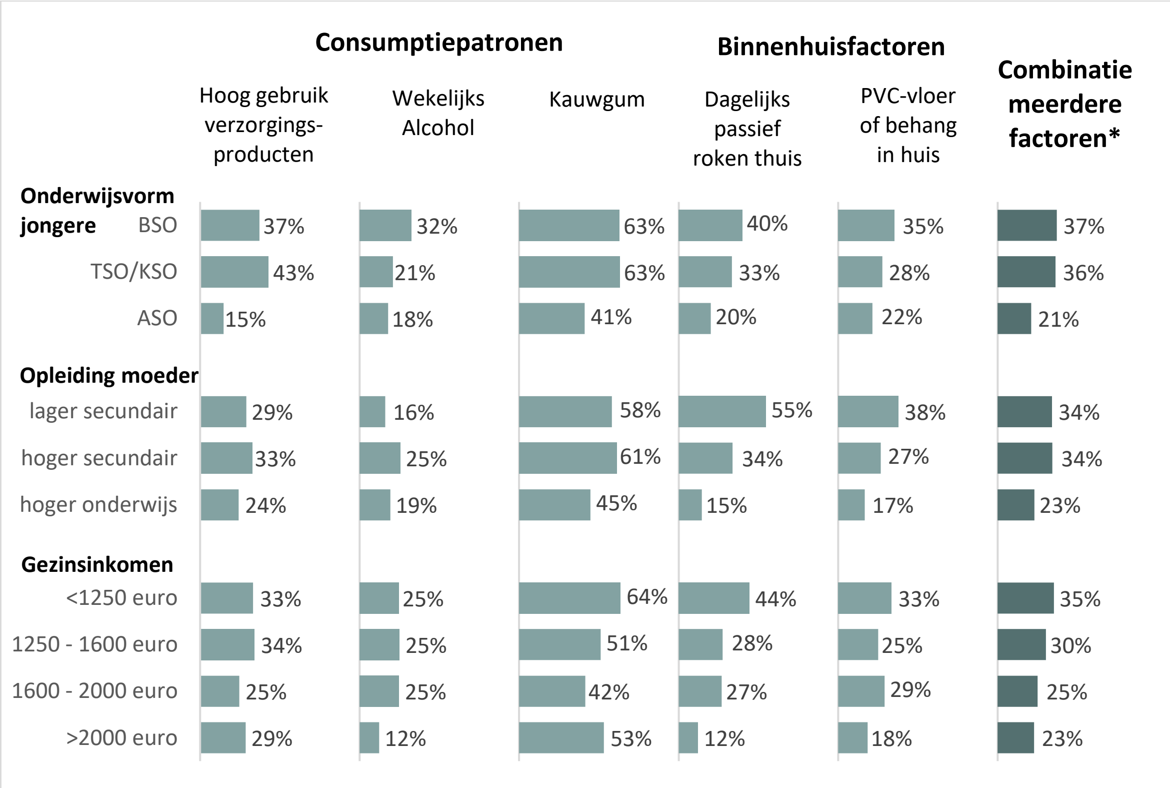
43% t.o.v. 15%, zie figuur 1). Voor de andere SEP indicatoren is de gradiënt minder uitgesproken. In Europese consumptiestudies werd een soortelijke trend vastgesteld waarbij respondenten met een lagere SEP een hoger gebruik hadden van voornamelijk haarproducten, deodorant en make-up (Biesterbos e.a., 2013). Een mogelijke verklaring voor deze sociale verschillen in productgebruik is de invloed van reclame en media (Yoo & Kim, 2010). Mensen in armoede zijn vaak meer blootgesteld aan reclame maar hebben tegelijk een lagere 'reclamewijsheid' waardoor ze commerciële boodschappen vaak moeilijk kunnen onderscheiden en dus meer vatbaar zijn voor de invloed van reclame. Mogelijk heeft onze bevinding ook te maken met verschillen in culturele verwachtingspatronen en zelfwaardegevoel tussen leerlingen uit het BSO en het ASO (Vettenburg e.a. 2009).

Uit buitenlands humane biomonitoringsonderzoek blijkt ook dat niet enkel mensen in armoede, maar ook etnische minderheden hogere concentraties hormoonverstorende chemicaliën in hun lichaam hebben (Bloom e.a., 2019). Onder druk van de dominante, blanke cultuur gaan Afro-Amerikaanse en Aziatische vrouwen vaak erg agressieve producten gebruiken die de uiterlijke kenmerken van hun etnische herkomst moeten maskeren, bijvoorbeeld door de huid te bleken of het haar te stijlen (Zota, 2017). Op die manier krijgt deze thematiek naast een sociaaleconomische ook een duidelijke etnisch culturele dimensie.

Alcoholconsumptie vertoont eveneens een relatie met de gehaltes aan deze ftalaten. In vergelijking met de groep jongeren die nooit alcohol drinken, ligt het gehalte DEHP bij de groep die wekelijks alcohol drinken 56% hoger (zie Table 15). Hoewel dit verband ook in andere studies werd teruggevonden, heerst er voorlopig wetenschappelijke onduidelijkheid over de concrete interpretatie. Aangezien alcoholconsumptie onderdeel vormt van een ongezonde levensstijl zou het in ons onderzoek slechts een proxy kunnen zijn voor andere risicofactoren die bijdragen tot blootstelling aan ftalaten. Zo vond een Australische studie een hoger gehalte aan ftalaten bij volwassen mannen die er een combinatie van een ongezond voedingspatroon (veel gesuikerde dranken, weinig fruit en groenten) en een risicovolle levensstijl (roken en gebrek aan fysieke activiteit) op nahielden (Bai e.a., 2015). Maar er zijn ook aanwijzingen dat alcohol zelf een specifieke bron van ftalaten kan zijn, bijvoorbeeld omdat ze aanwezig zijn in de epoxy coatings van wijnvaten (Chatonnet e.a. 2014). Deelnemers die kauwgum aten in de drie dagen voor het onderzoek hebben ook significant hogere gehaltes aan DEHP en MEP, respectievelijk 38% en 66%. Dit werd reeds in Europees onderzoek vastgesteld (Den Hond e.a., 2015). Er zijn aanwijzingen in patentdocumenten dat ftalaten gebruikt worden tijdens het productieproces van kauwgum. Daarnaast kan kauwgumgebruik in onze data ook verwijzen naar opname van ftalaten via andere voedingsproducten die we niet bevraagd hebben in onze vragenlijst, zoals frisdrank en fast food. Ftalaten worden namelijk ook gebruikt in voedingsverpakkingen en in printinkt en kunnen zo in de voedingsmiddelen terechtkomen.

Alcohol en kauwgum worden in het algemeen vaker geconsumeerd door deelnemers met een lagere SEP (zie Figure 8). De verschillen zijn het grootst bij de onderwijsvorm van de jongeren. Dit ligt in lijn met de studies 'Jongeren en Gezondheid' waaruit blijkt dat het dagelijks drinken van frisdrank en alcoholconsumptie hoger ligt bij jongeren uit het beroeps- en technisch onderwijs in vergelijking met het algemeen onderwijs (De Clercq 2014).

Figure 8: Risicofactoren voor blootstelling aan ftalaten volgens indicatoren van sociaaleconomische positie (SEP), in percentages



** percentage deelnemers met minstens twee van deze risicofactoren*

In buitenlandse studies vinden we aanwijzingen voor twee bijkomende consumptiefactoren die kunnen bijdragen aan sociale gradiënten in ftalaatblootstelling, respectievelijk voor een iets jongere en een iets oudere leeftijdsgroep dan onze studie bij 14-15 jarige jongeren. Het gaat enerzijds over goedkoop plastic speelgoed dat vaak ontsnapt aan Europese wetgeving en controles wanneer het bijvoorbeeld vanuit China op de markt komt (PROSAFE, 2018). Kinderen uit lage inkomensgezinnen kunnen hier vaker mee in contact komen. Anderzijds gaat het om ftalaten die worden toegevoegd aan de plastic omhulsels van medicijnen en voorkomen in heel wat medische apparatuur. Aangezien sociaal kwetsbare groepen en mensen in armoede een hogere medische consumptie kennen, zowel in het gebruik van geneesmiddelen als in ziekenhuisopnames (Drieskens & Gisle 2015), kan ook dit bijdragen tot hogere concentraties ftalaten bij deze groepen.

4.3.2.2 *Binnenhuisfactoren*

Deelnemers die wonen in een huis waar gerookt wordt, hebben hogere ftalaatgehalten in hun urine (zie Table 15). In de groep jongeren die thuis dagelijks wordt blootgesteld aan tabaksrook is het MEP-gehalte gemiddeld 107% hoger dan de referentiegroep waar nooit gerookt wordt. De groep jongeren die soms passief meeroken heeft 31% hogere MEP-gehalten dan de referentiegroep, wat ook hier wijst op een gradiënt. Een gelijkaardige gradiënt wordt waargenomen voor MiBP, maar met kleinere verschillen ten opzichte van de referentiegroep. Ook het gebruik van bepaalde materialen in de woning kan een invloed hebben op blootstelling aan ftalaten. De groep jongeren waarbij PVC (polyvinyl chloride of ‘vinyl’) -vloer of -behang aanwezig is in de woning heeft 31% hogere MiBP-gehalten in de urine dan de groep waarbij deze materialen niet aanwezig zijn. Beide resultaten wijzen op het belang van de woningkwaliteit en in het bijzonder van de binnenluchtkwaliteit voor blootstelling aan ftalaten. Het dagelijks verluchten en ventileren van de woning verbetert de binnenluchtkwaliteit en kan blootstelling aan sommige chemische stoffen verminderen. Dit werd ook in ander Vlaams humane-biomonitoringsonderzoek bevestigd. Zo bleken de gehaltes aan sommige ftalaten in de urine van 300 zwangere vrouwen uit de Kempense gemeenten Dessel, Mol en Retie hoger te liggen indien hun woning onvoldoende verlucht werd en niet over een mechanisch ventilatiesysteem beschikte (Lambrechts e.a., 2018).

Deze risicofactoren zullen vaker spelen bij mensen in een sociaal kwetsbare positie. In onze data volgt het passief roken in huis een opvallende sociale gradiënt (zie Figure 8). In de woning van jongeren met een kort opgeleide moeder en met een beperkt gezinsinkomen wordt 3,6 keer vaker gerookt dan in de woning van jongeren met een hoog opgeleide moeder en een hoog inkomen (55% versus 15% voor opleiding moeder en 44% versus 12% voor gezinsinkomen). Ook de aanwezigheid van PVC vloer of behang in huis volgt een soortgelijke gradiënt. Mensen met een beperkt inkomen zijn vaker genoodzaakt goedkopere materialen te gebruiken, zoals plastic vloerbekleding, of kunnen in het geval van huurwoningen de aanwezige bekleding niet altijd zelf kiezen. Ook het plaatsen van een mechanisch ventilatiesysteem vraagt een financiële investering die mensen in armoede vaak niet kunnen dragen. Het manueel dagelijks verluchten van de woning vergt anderzijds een aandachtspunt waarvan mensen in een kwetsbare positie of met een beperkte scholing misschien moeilijker te overtuigen zijn omdat het samengaat met (een gevoel van) energieverlies. Zo toont de Belgische gezondheidsenquête (Charafeddine & Demarest, 2015) dat hoe lager het opleidingsniveau van de bevraagden, hoe vaker wordt aangegeven dat de woning niet elke dag wordt verlucht.

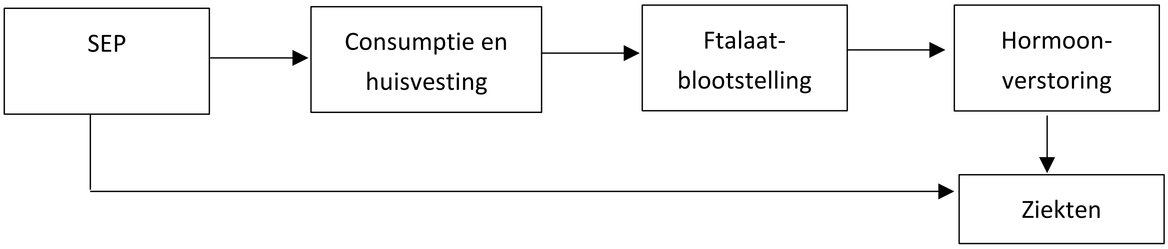
4.3.2.3 *Combinatie van risicofactoren*

Onze data tonen ook dat er een sociale gradiënt aanwezig is in het aantal risicofactoren die voorkomen (zie Figure 8). Het percentage deelnemers waarbij één of meerdere van de vijf risicofactoren samen voorkomt, stijgt bij een lagere sociaaleconomische positie (SEP). In de laagste SEP-categorieën heeft meer dan 1 op 3 jongeren een combinatie van verschillende risicofactoren terwijl dit in de hoogste SEP-categorieën slechts 1 op 5 jongeren is. Dit zijn aanwijzingen voor een accumulatie van ongunstige factoren voor sociaal kwetsbare groepen, wat aansluit bij de literatuur rond blootstelling aan multiple omgevingsrisico's voor lagere sociale klassen (Evans & Kantrowitz, 2002).

4.3.3 Doorwerking naar gezondheidseffecten en ziekten?

In hoeverre deze sociale verschillen in blootstelling aan ftalaten ook zorgen voor verschillen in hormoonverstoring en in latere gezondheidseffecten is momenteel nog moeilijk te kwantificeren. Wanneer we gegevens uit de sociale epidemiologie en toxicologie naast elkaar leggen, lijkt het echter aannemelijk dat de ongelijke blootstelling aan ftalaten kan bijdragen tot bepaalde gezondheidsongelijkheden. Ftalaten kunnen immers al in een lage dosis de normale werking van onze hormonen ontregelen en daardoor een invloed uitoefenen op het ontstaan van heel wat chronische ziekten en stoornissen die hormonaal gestuurd worden zoals obesitas en diabetes, vruchtbaarheidsproblemen, kankers, maar ook astma en luchtwegontstekingen. We weten dat deze gezondheidsklachten sterk sociaal gestratificeerd zijn en vaker voorkomen bij mensen onderaan de sociale ladder, ook in België (Demarest e.a., 2008). We illustreren de mogelijke invloed van hormoonverstoring door ftalaten op deze gezondheidsongelijkheden aan de hand van twee voorbeelden: insuline en stresshormonen. Insuline is een hormoon dat ervoor zorgt dat lichaamscellen koolhydraten en suikers uit het bloed opnemen. Een verstoring van de hormoonbalans kan bijdragen aan insulineresistentie. De cellen worden dan minder gevoelig voor insuline waardoor de alvleesklier of pancreas steeds meer insuline moet produceren om ervoor te zorgen dat cellen suikers en koolhydraten uit het bloed opnemen. Een hoge consumptie van suiker en overgewicht zijn belangrijke oorzaken van insulineresistentie die op termijn kunnen zorgen voor diabetes. Maar ook blootstelling aan ftalaten kan bijdragen aan insulineresistentie (Trasande e.a., 2013). Uit onderzoek blijkt insulineresistentie vaker voor te komen bij jongeren met laag opgeleide ouders en bij jongeren met een andere etnische herkomst (Goodman e.a., 2007). Ook in onze Vlaamse HBM-data vinden we aanwijzingen voor een etnische gradiënt in insulinegehalten. Een onderzoek bij 281 pasgeboren baby's detecteerde hogere insulinewaarden bij moeders met een niet-Europese migratieachtergrond, na correctie voor leeftijd en BMI (Colles e.a., 2015). Dit draagt bij tot het risico op obesitas en diabetes in het latere leven, twee chronische ziekten met een duidelijke sociale kloof. Ook stresshormonen zoals cortisol kunnen verstoord raken door blootstelling aan chemische stoffen, waaronder ftalaten (Kim e.a., 2018). Biomedische studies hebben hogere cortisolwaarden gemeten bij kinderen en volwassenen met een lagere sociaaleconomische status, vermoedelijk omwille van chronische stress ten gevolge hun achtergestelde positie en kwetsbare thuisomgeving (Vliegenthart e.a., 2016). Maar dus ook blootstelling aan ftalaten kan een gedeeltelijke verklaring bieden voor de hogere gehalten stresshormonen en daardoor bijdragen aan de verhoogde incidentie van verschillende ziekten. Deze voorbeelden worden schematisch weergegeven in onderstaande figuur.

Figure 9: Schematische voorstelling van de invloed van sociaaleconomische positie (SEP) op blootstelling aan ftalaten en gezondheidseffecten



4.4 Uitleiding

De grote hoeveelheid chemische stoffen in dagdagelijkse consumptieproducten zoals kledij, cosmetica en voeding vormt een maatschappelijk probleem in de strijd voor een meer duurzaam leefmilieu. Tegelijk groeit de aandacht voor de mogelijke gezondheidsrisico's hiervan. Bepaalde chemische stoffen blijken immers de werking van hormonen in ons lichaam in de war te sturen, wat kan bijdragen tot de ontwikkeling van heel wat gezondheidsproblemen. We stelden ons in dit hoofdstuk de vraag of blootstelling aan hormoonverstorende stoffen ook een voorwerp van sociale ongelijkheid vormt en keken hiervoor naar blootstelling aan ftalaten, chemicaliën die onder andere plastic flexibel maken, gemeten in de urine van 200 jongeren in Vlaanderen. De resultaten voor deze drie ftalaten tonen duidelijke sociale gradiënten in de lichaamsconcentraties: hoe lager de sociaaleconomische positie, hoe hoger de gehalten aan deze stoffen in het lichaam. De sociale gradiënten dragen vermoedelijk via mechanismen van hormoonverstoring bij aan de sociale gezondheidskloof. We identificeerden een combinatie van risicofactoren gerelateerd aan consumptiepatronen en huisvesting die de sociale gradiënten kunnen verklaren.

Dit type onderzoek naar sociale verschillen en gradiënten bij inwendige milieublootstelling toont hoe sociale ongelijkheid letterlijk onder de huid kan kruipen en hoe het sociale en het biologische zich tot elkaar verhouden. Het identificeert sociaal kwetsbare bevolkingsgroepen als gevoelige groepen voor specifieke vormen van milieuvervuiling. Dat heeft een belangrijke beleidsimplicatie, omdat het de verstrekkende gevolgen van armoede en uitsluiting zichtbaar kan maken. Er schuilt echter ook een valkuil, wanneer complexe sociale fenomenen daardoor gereduceerd zouden worden tot louter biologische processen. Dit reductionisme beperkt de mogelijkheden voor collectieve actie omdat het de aandacht verplaatst van een maatschappelijke naar een meer individuele verantwoordelijkheid. De analyse van persoonlijke blootstelling via HBM onderzoek draagt op die manier bij tot de bredere tendens van biomedicalisering en individualisering van risico's (Clarke e.a., 2003). Kennis over persoonlijke meetgegevens en mogelijke risicofactoren moet het individu ertoe brengen te handelen als coproducent van zijn of haar eigen gezondheid door bewuste en geïnformeerde gedragskeuzes te maken. Dit vereist echter een grote mate van controle en regie over de eigen situatie en is net daardoor problematisch voor mensen in armoede. Mensen in armoede hebben immers sterk het gevoel geen greep (meer) te hebben op hun leefsituatie en hebben de ervaring dat zij het leven moeten 'ondergaan' (Driesens & Van

Regenmortel, 2006). Bewust en duurzaam consumeren wordt daardoor een luxe die ze zich vaak niet kunnen veroorloven.

Het is daarom vanuit een armoedeperspectief belangrijk de risicofactoren van blootstelling aan chemische stoffen niet eenzijdig als individuele of bewuste keuzes te beschouwen, maar eerder als onderdeel van wat men in de literatuur ‘gedragspraktijken’ noemt (Spaargaren e.a., 2002): meer of minder geroutineerde handelingen die individuen met anderen gemeenschappelijk hebben. Deze gedragspraktijken stellen de sociale context centraal en staan daardoor tussen actoren enerzijds en structuren anderzijds. Het gaat dan bijvoorbeeld over de manier waarop mensen zich kleden, verplaatsen of voeden. De nadruk op gedragspraktijken helpt ook de dichotomie in beleidsopties te overstijgen tussen een structurele aanpak via regulering enerzijds en een individuele aanpak via gedragsverandering anderzijds. Er zijn namelijk ook beloftevolle netwerk- en buurtgerichte initiatieven die op maat van sociaal kwetsbare doelgroepen kunnen werken rond dit thema en waarbij gedragssturing niet top-down wordt opgedrongen maar bottom-up kan groeien door hefbomen uit de sociale omgeving in groep op te bouwen en te ondersteunen (zie Morrens e.a., 2018).

Een tweede argument om risicofactoren van milieublootstelling niet te individueel te benaderen is de link met (secundaire) beroepsblootstelling. De alomtegenwoordigheid van vervuilende stoffen in consumptieproducten maakt dat milieurisico’s ook in een veel bredere groep van beroepssectoren een impact kunnen hebben. Het gaat daarbij bovendien vaak om specifiek vrouwelijke en meer kortgeschoolde beroepsgroepen zoals kappers en nagelstylisten, kassiersters en schoonmaaksters, die vaak minder kunnen mobiliseren en sensibiliseren rond deze risico’s dan de klassieke (en grotendeels mannelijke) industriële beroepssectoren. Zo is in Amerikaans onderzoek al aan het licht gekomen dat kassiersters een risico lopen op verhoogde blootstelling aan bisfenol A (BPA), tevens een hormoonverstoorder, dat aanwezig is in het thermisch papier waarvan kassabons gemaakt zijn (Braun e.a., 2011). Dit thermisch papier is niet recycleerbaar en daardoor dus niet duurzaam, maar omwille van de toevoegingen van BPA vormt het een bijkomend gezondheidsrisico voor de voornamelijk kortgeschoolde en laag betaalde kassamedewerkers die er continu mee in aanraking komen. Vanaf 2020 gaat daarom een Europees verbod op bisfenol A in thermisch papier van kracht (EU verordening 2016/2235).

Referenties

Bai, P.Y., Wittert, G.A., Taylor, A.W., Martin, S.A., Milne, R.W., Shi, Z. (2015), The Association of Socio-DemographicStatus, Lifestyle Factors and Dietary Patterns with Total Urinary Phthalates in Australian Men, *PLoS ONE*, 10 (4): e0122140.

Belgische Senaat (2018), *Informatieverslag betreffende de noodzakelijke samenwerking tussen de federale overheid, de Gemeenschappen en de Gewesten inzake de preventie en de eliminatie van hormoonverstorende stoffen in de consumptie, met het oog op de bevordering van de volksgezondheid, Verslag namens de commissie institutionele aangelegenheden*, 6-303/2.

Benjamin, S., Masai, E., Kamimura, N., Takahashi, K., Anderson, R.C., Faisal, P.A. (2017), Phthalates impact human health: Epidemiological evidences and plausible mechanism of action*, Journal of Hazardous Materials*, 340: 360-383.

Biesterbos, J.W.H., Dudzina, T., Delmaar, C.J.E., Bakker, M.I., Russel, F.G.M., von Goetz, N., Scheepers, P.T.J., Roeleveld, N. (2013), Usage patterns of personal care products: Important factors for exposure assessment, *Food and Chemical Toxicology*, 55: 8–17.

Bloom, M.S., Wenzel, A.G., Brock, J.W., Kucklick, J.R., Wineland, R.J., Cruze, L., Unal, E.R., Yucel, R.M., Jiyessova, A., Newman, R.B. (2019), Racial disparity in maternal phthalates exposure; Association with racial disparity in fetal growth and birth outcomes, *Environment International*, 127: 473-486.

Bourguignon, J., Parent, A., Kleinjans, J.C.S., Nawrot, T.S., Schoeters, G., Van Larebeke, N. (2018), Rationale for Environmental Hygiene towards global protection of fetuses and young children from adverse lifestyle factors, *Environmental Health*, 17:42.

Braun, J.M., Kalkbrenner, A.E., Calafat, A.M., Bernert, J.T., Ye, X., Silva, M.J., Boyd Barr, D., Sathyanarayana, S., Lanphear, B.P. (2011), Variability and Predictors of Urinary Bisphenol a Concentrations During Pregnancy, *Environmental Health Perspectives*, 119, 1: 131-37.

Charafeddine, R., Demarest, S. (ed.) (2015), *Gezondheidsenquête 2013, rapport 4: Fysieke en sociale omgeving*, WIV-ISP, Brussel.

Clarke, A.E., Shim, J.K., Mamo, L., Fosket, J.R., Fishman, J.R. (2003), Biomedicalization: Technoscientific Transformations of Health, Illness, and U.S. Biomedicine, *American Sociological Review*, 68 (2): 161-194.

Colles, A., Morrens, B., Bruckers, L., Schoeters, G., Loots, I. (2015), *Vlaams Humaan Biomonitoringsprogramma 2012-2012, Analyses invloed sociaaleconomische status en etnische herkomst – rapport pasgeborenen*, Brussel, Steunpunt Milieu en Gezondheid.

Chatonnet, P., Boutou, S., Plana, A. (2014), Contamination of wines and spirits by phthalates: types of contaminants present, contamination sources and means of prevention, *Food Additives & Contaminants: Part A,* 31(9): 1605-15.

De Clercq, B. (2014), *Jongeren en Gezondheid 2014, Factsheets Vlaanderen*.

Demarest, S., Drieskens, S., Gisle, L., Van der Heyden, J., Tafforeau, J. *Gezondheidsenquête België, 2008. Rapport V – Sociaal-Economische Ongelijkheden in Gezondheid*, Brussel, Wetenschappelijk Instituut Volksgezondheid.

Den Hond, E., Govarts, E., Willems, H., Smolders, R., e.a. (2015), First steps toward harmonized human biomonitoring in Europe: Demonstration project to perform human biomonitoring on a European scale, *Environmental Health Perspectives*, 123: 255–263.

Driesens, K., Van Regenmortel, T. (2006), Bind-Kracht in armoede, Leuven: Lannoo.

Drieskens, S., Gisle, L. (ed.) (2015), *Gezondheidsenquête 2013, Rapport 3: Gebruik van gezondheids- en welzijnsdiensten*, WIV-ISP, Brussel.

Evans, G.W., Kantrowitz, E. (2002), Socioeconomic status and health: The Potential Role of Environmental Risk Exposure, *Annual Review of Public Health*, 23: 303–31.

Goodman, E., Daniels, S.R., Dolan, L.M. (2006), Socioeconomic disparities in insulin resistance: results from the Princeton School District Study, *Psychosomatic Medicine*, 69 (1): 61-7.

Grandjean, P. (2013), *Only One Chance, How Environmental Pollution Impairs Brain Development - and How to Protect the Brains of the Next Generation*, New York/Oxford: University Press.

James-Todd, T.M., Chiu, Y., Zota, A.R. (2016), Racial/Ethnic Disparities in Environmental Endocrine Disrupting Chemicals and Women's Reproductive Health Outcomes: Epidemiological Examples Across the Life Course, *Current Epidemiology Reports*, 3: 161–180.

Kaźmierczak, A. (eds.) (2018), *Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe*, European Environmental Agency, Kopenhagen.

Kim, J.H., Lee, J., Moon, H., Park, J., Choi, K., Kim, S.K., Kim, S. (2018), Association of phthalate exposures with urinary free cortisol and 8-hydroxy-2′-deoxyguanosine in early childhood, *Science of the Total Environment*, 627: 506–513.

Kobrosly, R.W., Parlett, L.E., Stahlhut, R.W., Barrett, E.S., Swan, S.H. (2012), Socioeconomic factors and phthalate metabolite concentrations among United States women of reproductive age, *Environmental Research*, 115: 11–17.

Lambrecht, N., De Soomer, M., Den Hond, E., Morrens, B., Stappers, D., De Decker, A., Franken, C., Nelen, V., Loots, I., Schoeters, G. (2018), *Humane biomonitoring in Dessel, Mol en Retie, Hormoonverstoorders: ftalaten, 3xG rapport*.

Marmot, M. (2004), *Status Syndrome: How Your Social Standing Directly Affects Your Health*. London, UK: Bloomsbury Publishing.

Morrens, B., Loots, I., Vandermoere, F., Buytaert, B., Verdeyen, A., Van Oyen, L., Verlaek, M., Van Campenhout, K., (2018), Lucht in je leven : een pilootproject rond milieu en gezondheid bij sociaal kwetsbare doelgroepen, *Vlaams tijdschrift voor overheidsmanagement*, 4: 69-77.

PROSAFE (2018), *Chemical risks in plasticized toys, final technical report, Joint Market Surveillance Action on GPSD Products*.

Spaargaren, G., Beckers, T.A.M., Martens, S., Bargeman, B., van Es, T. (2002), Gedragspraktijken in transitie. De gedragspraktijkenbenadering getoetst in twee gevallen: Duurzaam wonen en Duurzame toeristische mobiliteit, *Milieustrategie 2002*; Nr. 1, 's Gravenhage: Ministerie van VROM.

Trasande, L., Spanier, A.J., Sathyanarayana, S., Attina, T.M., Blustein, J. (2013), Urinary phthalates and increased insulin resistance in adolescents, *Pediatrics*, 132(3): 646-55.

UNEP (2019), *Global Chemicals Outlook II, From Legacies to Innovative Solutions: Implementing the 2030, Agenda for Sustainable Development*.

Vettenburg, N., Deklerck, J.,Siongers, J. (red.) (2009), *Jongeren binnenstebuiten - Thema's uit het jongerenleven onderzocht*, Leuven/Den Haag: Acco.

Vliegenthart, J., Noppe, G., van Rossum, E.F., Koper, J.W., Raat, H., van den Akker, E.L. (2016), Socioeconomic status in children is associated with hair cortisol levels as a biological measure of chronic stress, *Psychoneuroendocrinology*, 65: 9-14.

World Health Organization (2012), *Environmental health inequalities in Europe. Assessment report*, WHO European Centre for Environment and Health, Bonn Office.

Ye, X., Pierik, F.H., Hauser, R., Duty, S., Angerer, J., Park, M.M., Burdorf, A., Hofman, A., Jaddoe, V.W.V, Mackenbach, J.P., Steegers, E.A.P., Tiemeier, H., Longnecker, M.P. (2008), Urinary metabolite concentrations of organophosphorous pesticides, bisphenol A, and phthalates among pregnant women in Rotterdam, the Netherlands: the Generation R study, *Environmental Research*, 108: 260–267.

Yoo, J., Kim, H. (2010), Use of Beauty Products among U.S. Adolescents: An Exploration of Media Influence, *Journal of Global Fashion Marketing*, 1(3): 172-181.

Zota, A.R., Shamasunder B. (2017), The environmental injustice of beauty: framing chemical exposures from beauty products as a health disparities concern, *American Journal of Obstetrics & Gynecology*, 217(4): 418.

Chapter 5 Assessing environmental health inequalities in early life: social stratification of maternal and neonatal biomonitoring results in Belgium

Data based on scientific report

Colles A., Morrens B., Bruckers L., Loots I. (2015), Vlaams Humaanbiomonitoringsprogramma 2012-2015, Analyses invloed sociaal-economische status en etnische achtergrond – Rapport Pasgeborenen, Steunpunt Milieu en Gezondheid.

Abstract

Background: human biomonitoring measures environmental chemicals in the human body and produces valuable, yet underexplored, data to test the environmental justice hypothesis, which states that ethnic minorities and people with low socioeconomic position (SEP) are disproportionately exposed to environmental health risks.

Methods: we conducted multiple regression analyses to determine whether and how exposure to 10 chemicals (metals, POPs and PFAS), measured in cord blood from 281 women in Belgium, is associated with three indicators of socioeconomic and ethnic position (education, income, and migrant background). In addition, we analyzed our data for mediating exposure determinants.

Results: exposure to metals and banned pesticides was mainly related to migrant background. Women with a non-Western migrant background, especially of Turkish and Maghreb origin, had higher concentrations compared to native-born women. In contrast, exposure levels of PCBs and PFAS were more associated with socioeconomic position, but in the inverse direction: higher income and education were associated with higher concentrations. Exposure determinants that could explain these associations relate to healthy behavior, ethnocultural context, as well as reproductive mechanisms.

Conclusions: maternal socioeconomic position and migration background influence the infant's environmental exposure early in life, but the patterns of inequality are more complex and nuanced, depending on the type of chemical, and different according to socioeconomic and ethnic indicator.

5.1 Introduction

The increasing use of new synthetic chemicals in consumer products, combined with the persistent nature of long-banned chemicals from industry and agriculture, is creating universal and widespread exposure among people in all parts of the world (EEA, 2019; Wang et al., 2020). Human biomonitoring studies have shown that pregnancy is a particular vulnerable period, as many of these chemicals are known to be transferred from the mother to the fetus in utero (Grandjean et al., 2008). Prenatal exposures, measured in the mother's umbilical cord blood and placenta, can contribute from there to many health effects in the child's later life, ranging from neurodevelopment to cardiovascular diseases (Bellinger, 2013; Vrijheid et al., 2016).

Environmental justice studies, on the other side, have identified racial and socioeconomic inequalities as important determinants of exposure and vulnerability to environmental substances (Mohai et al., 2009; Walker, 2012). People and groups with lower socio-economic position or belonging to an ethnic minority often have a disproportionally higher exposure to environmental pollution because they live and work in neighborhoods with lower environmental quality (Cushing et al., 2015). In addition, they can be more vulnerable to environmental pollution because psychosocial stress and pre-existing diseases can cause larger health impact (Bateson & Schwartz, 2004).

Pregnant women from socially disadvantaged backgrounds may thus find themselves in a doubly disadvantaged position, which should make this group a priority for preventive policy and environmental health research. The combined effect of biological and social vulnerability has been conceptually integrated into eco-social theory (Krieger, 2001) and cumulative impact framework (Morello-Frosch et al., 2011), but the empirical basis however is still small. Human biomonitoring data are not commonly used by the environmental justice research community to identify social inequalities, in part because the highly technical aspects of this type of data require extensive interdisciplinary collaboration between the natural and social sciences (Brown, 2013; Cordner et al., 2019). Our analysis contributes to filling this gap by stratifying exposure biomarker concentrations in a representative sample of pregnant women in Flanders according to different indicators of socioeconomic and ethnic position.

5.2 Methods

In Flanders, the northern part of Belgium, a human biomonitoring program called 'Flemish Environmental Health Study' (FLEHS) is established since 2002, commissioned by the Flemish government (Schoeters et al., 2012). In the third cycle of the program (FLEHS III, 2012-2015), mother-newborn pairs were recruited from all five Flemish provinces, with the number of participants from each province proportional to the number of its inhabitants, to obtain reference values of internal exposure to environmental chemicals for Flanders. A stratified, clustered multi-stage design was used to recruit mothers giving birth in randomly selected maternity hospitals as primary sampling units (PSU). The selected PSUs were located at least 20 km from each other. To account for seasonal variation, recruitment was spread across one full year (November 2013 to November 2014). A targeted recruitment strategy was implemented to increase the participation rate of socially disadvantaged pregnant women (Morrens et al., 2017).

The inclusion criteria of the FLEHS III biomonitoring study were: (1) residing for at least 5 years in Flanders; (2) giving written informed consent, and (3) being able to fill out an extensive Dutch questionnaire (potentially with the assistance of a family member or an interpreter). All participants donated cord blood and consented to a biopsy from the placenta after the birth of their baby. Optionally, they agreed to donate a hair and/or nail sample. In the week after the delivery, the mothers completed an extensive questionnaire (self-administered) providing information on lifestyle, health status, food consumption, use of tobacco and alcohol, residence history, education, etc. The study protocol was approved by the ethical committee of the University Hospital of Antwerp.

In this paper we discuss results of ten biomarkers of exposure measured in cord blood, classified into three chemical groups: 1) metals: lead (Pb), cadmium (Cd), manganese (Mn) and arsenic (As), 2) chlorinated persistent compounds: polychlorinated biphenyls (PCBs) (sum of marker PCB 138, 153 and 180), oxychlordane (Oxy), dichlorodiphenyldichloroethylene (p,p’-DDE, a metabolite of DDT), and lindane (B-HCH), 3) per- and polyfluorinated alkyl substances (PFAS): perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). These 10 biomarkers were selected from a broader set of 17 measured substances in the FLEHS III study, in order to obtain a good overview of detectable chemicals within the three groups (Schoeters et al., 2017).

We based the socioeconomic position (SEP) of the mother (as study participant) on two indicators: educational attainment and equivalent household income. Additionally, migrant background status was defined based on the birth country of the mother and her parents. Educational level was defined as the highest educational attainment of the mother (in terms of obtained diploma). The self-administered questionnaire contained a standard scale with nine response categories representing the different stages of the Flemish education system. We classified the data into three categories: primary, secondary or tertiary education, corresponding respectively to respondents without high school diploma, with a high school diploma, or with a degree in college or university. We used equivalent monthly household income as this is a standardized and comparable measure, taking into account household size. Respondents reported their monthly disposable household income in a categorical question containing sixteen answer categories, ranking from less than 500 euro to more than 5000 euro. Household composition was reported by the number of household members younger than 18 years and older than 18 years. Equivalent income was then calculated by dividing the middle of income category by the sum of household members using the following weigh units: 1 for the reference person, 0.5 for each member older than 18, and 0.3 for each member younger than 18. For example, a total income of 2.500 euro for a household of two parents and two young children is equivalent to 1.119 euro (2.500/(1+0.5+0.3+0.3)). For the analysis we categorized equivalent income in quartiles: ≤ 1.250 euro, 1.250-1.600 euro, 1.600-2000 euro, > 2.000 euro.

Migrant background was based on the country of birth of the participants and their parents. For the categorization of countries, we used a procedure of the World Health Organization to divide the world into sub-regions (A-B-C-D) based on reported mortality rates that serve as a proxy for the welfare level in the respective sub-regions (WHO, 2001). We distinguished three categories: 1) native born (participating mother and both her parents born in Belgium), 2) WHO A region (participant and/or at least one parent born in a WHO A country in Western Europe or Northern America, other than Belgium), and 3) WHO B-C-D region (participant and/or at least one parent born in a WHO B-C-D country with a lower welfare level). WHO A countries reported in our study samples were France, Germany, The Netherlands, Italy, Spain, Portugal and Canada. WHO B-C-D countries reported were Poland, Turkey, Armenia, Belarus, Russia, Congo, Angola, Morocco, Tunisia, Haiti, The Philippines and Indonesia.

We used univariate and multiple linear regression models to examine the relationships between exposure and SEP/migrant background in four sequential steps. First some descriptive statistics were used to examine the correlation between each biomarker of exposure and the various SEP indicators separately. Second, we build multiple regression models, consisting of several fixed covariates and one of the SEP/migrant background indicators, allowing us to study the relationships in more detail. The continuous exposure biomarkers were transformed according to the natural logarithmic function and used as dependent variables in the regression models. Education, income, and migration background constituted the independent, categorical variable in separate regression models. Age was included as a fixed covariate in all multiple models. In the models with PFAS, BMI was also included as a fixed covariate. In the models with the lipid soluble organic pollutants, blood fat was additionally included. Third, we searched for possible explanatory factors to explain the associations between exposure and SEP/migrant background. This was done with descriptive statistics (Spearman correlations and one-way ANOVA) because the small sample size made it difficult to construct comprehensive multiple models with different covariates. Fourthly and lastly, we briefly focused on the specific relationship between certain migrant backgrounds (birth countries) and exposure to two legacy pesticides and two metals. We grouped the exposure level of these four chemicals into quartiles and visualized the distribution for each respondent with a self-constructed heatmap.

5.3 Results

Our sample consisted of 281 women. The distribution across different SEP and migrant background categories is displayed in Table 16, together with age and BMI distribution (both fixed covariates in the regression models).

Table 16: Characteristics of the study sample, FLEHS III (n=281))

	N	%
Education mother		
Primary	26	9,3
Secondary	88	31,3
Tertiary	166	59,1
Missing	1	0,4
Household income		
≤ 1.250 euro	59	21,0
1.250-1.600 euro	61	21,7
1.600-2.000 euro	56	19,9
> 2.000 euro	65	23,1
Missing	40	14,2
Migrant background		
WHO B-C-D	39	13,9
WHO A	18	6,4
Native (Belgium)	220	78,3
Missing	4	1,4
Age		
≤ 25 year	30	10,7
25-30 year	111	39,5
30-35 year	101	35,9
> 35 year	39	13,9
BMI		
< 18,5	7	2,5
18,5-25	188	66,9
25-30	60	21,4
> 30	26	9,3

Table 17 presents the Spearman's rank correlation between the biomarker concentrations of the 10 chemicals in cord blood and the SEP/migrant background indicators. Education and income were ranked from low to high. Migration background was classified from non-Western origin (WHO B-C-D) to native-born. In this way, negative correlation coefficients can be interpreted as higher exposure in participants with lower SEP or non-Western migration background, and a positive correlation coefficient as higher exposure in participants with higher SEP or without migration background.

A mixed picture emerged: each of the three indicators of SEP/migrant background was significantly associated with different biomarkers: maternal education was associated with lead, arsenic, PCBs, oxychlordane, PFOS and PFOA. Household income was associated with lead, cadmium, PCBs, oxchlordane, PFOS and PFOA. And migrant background correlated with the biomarker concentrations of lead, manganese, DDE, lindane, PFOS and PFOA. Also, the direction of the correlations differed: SEP and migrant background are inversely correlated with lead, cadmium, manganese, DDE and lindane, indicating a higher mean concentration in cord blood with lower education, lower income or migration from a WHO B-C-D region. In contrast, correlations are positive for arsenic, PCBs, oxychlordane, PFOS and PFOA, indicating a higher mean concentration in cord blood with higher education, higher income or native background. The strongest correlations are found between income and PFAS (0.340 and 0.263), followed by income and cadmium (-0.243).

Table 17: Spearman correlations between biomarker concentrations and SEP/migrant background indicators, FLEHS III (n=281)

Spearman correlation	**Education**	**Income**	**Migrant background**
Metals			
Pb	-0.124*	-0.123	-0.216**
Cd	-0.092	-0.243**	-0.144*
Mn	-0.081	0.031	-0.153*
As	0.159**	0.142*	0.038
POPs			
PCBs	0.179**	0.170**	-0.002
Oxy	0.161**	0.168**	0.106
DDE	0.031	0.053	-0.185**
B-HCH	0.011	0.101	-0.163**
PFAS			
PFOA	0.122*	0.340**	0.136*
PFOS	0.218**	0.263**	0.167**

Table 18 to Table 20 contain the results of the multiple regression analysis, adjusted for fixed covariates. They are formatted as percentage differences in biomarkers concentrations for the three indicators of SEP and migration background. The highest category of education and income and the category of native-born serve as the reference group to which the other categories are compared. For metals (Table 18), percentage differences were largest (and most significant) for migrant background. Women with a (non-Western) migrant background from a WHO B-C-D country had on average a lead concentration 30% higher, a cadmium concentration 16% higher and a manganese concentration 24% higher compared to women who were native born in Belgium. For cadmium, we also see a significant negative trend with income. For lead, there is a borderline significant negative association with income (p=0.052) and education (p=0.072). Women attaining primary education have an average lead concentration 25% higher compared to women with tertiary education. In contrast, arsenic concentrations were lower for women with lower education. Especially women with secondary education had lower arsenic concentrations (-32%) compared to women with tertiary education.

Table 18: Percentage difference in exposure levels of metals in cord blood, according to indicators of socioeconomic position (SEP) and migrant background

Metals	**Pb**		**Cd**		**Mn**		**As**	
	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]
Education mother		0.072		0.446		0.215		0.012
Primary	**24.8 (3.3, 50.7)**		12.2 (-6.9, 35.1)		5.7 (-9.0, 22.9)		-5.7 (-38.1, 43.6)	
Secondary	2.5 (-8.7, 15.2)		4.3 (-7.0, 17.0)		8.6 (-1.0, 19.1)		**-32.3 (-47.8, -12.2)**	
Tertiary	*Reference*.		*Reference*.		*Reference*.		*Reference*.	
Income		0.052		0.003		0.587		0.119
Quartile 1	8.4 (-6.7, 26.1)		**28.0 (10.8, 47.8)**		-5.5 (-16.3, 6.7)		-33.7 (-53.1, -6.3)	
Quartile 2	-4.7 (-17.9, 10.6)		**17.3 (1.8, 35.3)**		1.2 (-10.2, 14.1)		-25.8 (-47.3, 4.5)	
Quartile 3	-12.9 (-25.1, 1.4)		2.4 (-11.4, 18.3)		-5.1 (-16.0, 7.2)		-17.5 (-41.8, 16.8)	
Quartile 4	*Reference*.		*Reference*.		*Reference*.		*Reference*.	
Migrant background		0.003		0.125		0.002		0.208
WHO B-C-D	**29.6 (11.6, 50.4)**		**15.8 (0.1, 34.0)**		**23.5 (9.9, 38.8)**		2.8 (-26.7, 44.2)	
WHO A	7.9 (-12.6, 33.2)		8.3 (-11.8, 33.0)		0.0 (-15.2, 17.8)		-34.5 (-59.4, 5.5)	
Native-born	*Reference*.		*Reference*.		*Reference*.		*Reference*.	

[a] *Adjusted for age; Statistically significant results (p<0.05) in bold*
[b] *Overall p-value*
CI: confidence interval

Table 19: Percentage difference in exposure levels of POPs in cord blood, according to indicators of SEP and migrant background

POPs	PCBs		Oxychlordane		DDE		Lindane	
	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]
Education mother		0.033		0.025		0,386		0.060
Primary	-5.7 (-23.4, 16.1)		-9.6 (-30.0, 16.7)		17.1 (-15.3, 61.9)		**35.0 (2.9, 77.1)**	
Secondary	**-16.1 (-26.5, -4.3)**		**-20.2 (-32.1, -6.2)**		-6.6 (-24.0, 14.6)		-2.4 (-17.8, 15.9)	
Tertiary	*Reference*.		*Reference*.		*Reference*.		*Reference*.	
Income		0.050		0.123		0,098		0.026
Quartile 1	**-15.7 (-28.5, -0.6)**		-12.9 (-29.2, 7.1)		7.4 (-17.2, 39.4)		-8.4 (-26.9, 14.8)	
Quartile 2	**-19.4 (-31.4, -5.3)**		**-21.9 (-36.2, -4.5)**		-20.5 (-38.3, 2.5)		**-26.0 (-40.6, -7.8)**	
Quartile 3	-8.5 (-22.5, 7.9)		-10.5 (-27.3, 10.1)		-14.6 (-34.3, 10.9)		**-23.2 (-38.7, -3.7)**	
Quartile 4	*Reference*.		*Reference*.		*Reference*.		*Reference*.	
Migrant background		0.945		0.195		0.001		0.000
WHO B-C-D	2.7 (-13.0, 21.4)		-17.2 (-32.5, 1.6)		**61.3 (25.4, 107.3)**		**56.6 (26.9, 93.3)**	
WHO A	-0.9 (-21.4, 25.1)		-2.1 (-26.4, 30.3)		18.0 (-16.9, 67.5)		5.1 (-21.7, 41.0)	
Native-born	*Reference*.		*Reference*.		*Reference*.		*Reference*.	

[a] *Adjusted for age, blood fat and BMI; Statistically significant results (p<0.05) in bold*

[b] *Overall p-value*

CI: confidence interval

For the organochlorine compounds (Table 19), a twofold pattern is seen. Concentrations of PCBs and oxychlordane in cord blood are positively associated with education and income but not with migrant background, meaning that women with a lower educational level or a lower household income had on average lower concentrations compared to the reference group. However, these patterns do not show a clear gradient. On the other hand, concentrations of DDE and lindane (B-HCH) are negatively associated with migrant background, but not (or almost not) with education or income. The percentage differences in exposure are large: women with a migrant background from a WHO B-C-D country had on average a concentration 62% and 57% higher for DDE and linande compared to women who are native-born in Belgium.

Among the per- and polyfluoroalkyl substances (PFAS) (Table 20), we clearly observed significant differences, according to education, as well as income and migration background. The differences are largest and follow a gradient most clearly for income: lower income is associated with a lower concentration of PFAS in cord blood.

Table 20: Percentage difference in exposure levels of PFAS in cord blood, according to indicators of SEP and migrant background

PFAS	**PFOA**		**PFOS**	
	% change (95% CI)[a]	P[b]	% change (95% CI)[a]	P[b]
Education mother		0.013		0.015
Primary	4.7 (-15.9, 30.4)		-17.5 (-37.6, 8.9)	
Secondary	**-17.1 (-27.7, -4.8)**		**-22.5 (-35.0, -7.8)**	
Tertiary	*Reference*.		*Reference*.	
Income		0.000		0.002
Quartile 1	**-32.2 (-42.5, -20.0)**		**-29.9 (-43.8, -12.5)**	
Quartile 2	**-29.2 (-39.8, -16.8)**		**-29.9 (-43.6, -12.9)**	
Quartile 3	-14.3 (-27.4, 1.3)		-11.8 (-29.4, 10.3)	
Quartile 4	*Reference*.		*Reference*.	
Migrant background		0.052		0.007
WHO B-C-D	-13.8 (-27.6, 2.5)		**-28.7 (-42.6, -11.4)**	
WHO A	-21.4 (-38.2, 0.1)		-16.8 (-38.5, 12.6)	
Native-born	*Reference*.		*Reference*.	

The questionnaire data provided indications of possible explanatory factors that could help explain the observed social and ethnic disparities in internal chemical exposure levels. We used an exploratory and hypothesis-driven approach to identify these factors, rather than a data-driven approach.

We identified seven factors that could mediate some associations between SEP/migrant background and biomarker concentrations (Table 21). Smoking during pregnancy was significantly and inversely correlated with maternal education (27% of primary educated women smoked versus

4% of tertiary educated women, p<0.000), but not with income or migrant background. Women who smoked during pregnancy had higher geometric mean exposure levels of lead and cadmium in cord blood than women who did not smoke during pregnancy. Women with a migrant background, with a lower income level and with a lower educational attainment reported more frequent consumption of organ meat (e.g. liver or kidneys). Correlations were strongest for migrant background: 34% of women with a non-Western background consume organ meat at least one's a month, compared to 2% of women native born in Belgium. Additionally, consumption of legumes (e.g. lentils or red beans) followed the same trend for migrant background, but not for education or income. Consumption of organ meat and legumes was associated with lead and manganese exposure, respectively.

Table 21: Factors that are associated with socioeconomic/ethnic position and exposure outcomes

Explanatory factors	**Spearman correlation with SEP and ethnic indicators**			**Exposure outcome [a]**
	Education mother	**Income**	**Migrant backgr.**	
Smoking during pregnancy	-0.306**	-0.098	-0.007	↑ Lead and cadmium
Organ meat consumption	-,210**	-,229**	-,397**	↑ Lead
Legume consumption	-,076	-,125	-,400**	↑ Manganese
Alcohol consumption during pregnancy	,134*	,131*	,163**	↑ PCBs, Oxy, PFOA
Dairy consumption	,154*	,092	,103	↑ PCBs, Oxy
Shellfish and crustaceans consumption	,113	,133*	,067	↑ PCBs, As, PFOS
Parity	,065	-,379**	-,172**	↓ PFOS, PFOA

** Correlation significant at the 0.05 level   **Correlation significant at the 0.01 level*
[a] Based on one-way ANOVA

Alcohol consumption during pregnancy, dairy product consumption, and shellfish consumption were all more frequently reported by mothers with higher education, higher income, and without a migrant background. These factors probably all contributed to the observed positive social differences in exposure to PCBs, oxychlorodane (Oxy), arsenic (As), and/or PFOS/PFOA.

In addition to these lifestyle and dietary factors that influence exposure, we have identified a reproductive factor that is more closely related to chemical elimination: parity (the number of births). It is a known mechanism that women reduce their body burden of PFAS by giving birth, as

PFAS accumulate in the placenta (Brantsæter et al. 2013). In our data, higher parity correlated with lower income and migrant background, making it plausible that this contributed to the positive gradient in PFOS concentration according to income and migrant background.

For DDE and lindane, we could not identify factors from our dataset that could mediate the effect of SEP/migrant background on internal exposure levels.

In a final step in our analysis, we elaborate on the role of migrant background. We observed a significant association between migrant background and exposure concentrations of four chemicals: lead, manganese, DDE and lindane. Table 18 and Table 19 showed that particularly mothers with a (non-Western) migrant background from a WHO B-C-D country had higher exposure concentrations. We tried to explore these associations further by dividing these participants (n=39) into more detailed geographic groups according to birth country. The two largest groups consisted of mothers with Turkish origin (n=17): 5 as migrants (born in Turkey) and 12 as descendants (born in Belgium but one of the parents born in Turkey) and with Maghreb origin (n=11), 5 as migrant and 6 as descendant. 4 mothers have roots in Africa and 3 mothers migrated from a former Soviet Union state.

We grouped the biomonitoring level of these four chemicals into quartiles and visualised the distribution for each respondent belonging to these four groups of non-Western migrant backgrounds (Figure 10). Among respondents of Turkish origin, we see a cluster of higher cord blood levels of manganese and lindane (B-HCH). Respondents of Maghreb origin have a remarkably high exposure to lead (9 out of 11 women had a value above the P75 and 6 of them even above the P90). Among respondents with African roots, we observe high exposure to DDE (2 out of 4 women above P90). And among respondents with a migration background from a former Soviet Union state, we see a cluster of high exposure to the banned pesticides DDE and lindane (in both cases above P90).

Figure 10: Exposure to 4 chemicals, classified into color-code quartiles, among mothers of Turkish, Magreb, African and Former Soviet Union origin

Turkey		Pb	Mn	DDE	B-HCH
1	M			!	!
2	M				!
3	M				!
4	M				
5	M		!		
6	D				!
7	D		!		!
8	D	!			
9	D				
10	D		!		
11	D		!		
12	D	!	!		
13	D		!		
14	D				
15	D				
16	D				
17	D				
Magreb		**Pb**	**Mn**	**DDE**	**B-HCH**
1	M	!	!	!	
2	M	!	!		
3	M	!			
4	M			!	!
5	M				
6	D	!	!		
7	D	!			!
8	D	!			
9	D				
10	D				
11	D				
Africa		**Pb**	**Mn**	**DDE**	**B-HCH**
1	M				!
2	D				
3	D		!	!	
4	D	!		!	
Former Soviet Union state		**Pb**	**Mn**	**DDE**	**B-HCH**
1	M			!	!
2	M			!	!
3	M			!	!

Q1 (P1-P25); Q2 (P26-P50); Q3 (P51-P75); Q4 (P76-P100); ! (>P90)

M= migrants; D= descendants

5.4 Discussion

We stratified the internal exposure concentrations of 10 environmental chemicals, measured in cord blood of 281 women giving birth in Flanders, according to three indicators of socioeconomic and ethnic position (education, income, and migrant background). Our results show that maternal socioeconomic and ethnic position influence the infant's chemical exposure early in life, but that the patterns of inequality are more complex and nuanced than the environmental justice hypothesis suggests, in three distinct ways.

Firstly, the direction of the associations goes in both directions, depending on the type of chemical: mothers with a lower education and income or a migrant background generally had a higher level of exposure to the toxic metals lead and cadmium, but lower levels of the persistent organic pollutants PCBs, oxychlordane and the PFAS. Montazeri and colleagues (2019), using data from 1.300 mother-child pairs from six European birth cohorts, found the same mixed pattern in which lower socioeconomic position (SEP) during pregnancy was associated with higher concentrations, including cadmium and lead, but conversely with lower exposure to arsenic and PFAS. A Spanish population-based birth cohort study containing over 2.000 pregnant women found concentrations of PCBs, HCB and mercury were higher in higher social classes (based on occupational class) but found no significant associations with DDE or β-HCH. A more recent, but smaller-sized biomonitoring study of pregnant women in Spain concluded that higher educated and more affluent mothers had higher PCB and DDE concentrations (Junqué et al., 2020). Similar to our results, lead exposure levels were negatively associated with indicators of SEP in Japan (Ishitsuka et al., 2020), Spain (Llop et al., 2011) and Mexico (Bakhireva et al., 2013).

Secondly, for some (persistent and long-banned) chemicals, stratification according to migrant background is more pronounced than according to socioeconomic position, and we found indications that specific migration trajectories contribute to specific exposure: concentrations of legacy pesticides like DDE and lindane tend to be higher in mothers with Turkish and former Soviet Union origin, whereas concentrations of lead are especially high in mothers with Maghreb roots. Although these results should be interpreted with caution due to small numbers, they point to the importance of birth country, and corresponding consumption and lifestyle factors, as determinants of chemical exposure. The results are supported by those observed in previous studies. Higher concentrations of DDE and lindane were reported in mothers who were not native-born in a Swedish biomonitoring study (Glynn et al., 2007) and a study in Canada (Lewin et al., 2017). Some authors reported elevated values of lindane and DDE in Eastern Europe and Russia and mention excessive and illegal use of pesticides in the former Soviet Union as a possible cause. A recent study in France found lead concentration 37% higher in cord blood of French mothers born in a country with high levels of lead use, including Morocco and Turkey (Saoudi et al., 2018). An earlier study in the UK found pregnant women with an Asian migrant background to have significant higher lead concentrations, independent of educational attainment or social class (Taylor et al., 2013). Another finding of our analysis that also related to ethnicity, but in the opposite direction, is PFAS exposure. Here we observed higher concentrations in mothers who are native-born compared to women with a migrant background. This pattern was also observed in the U.S. (Muennig et al., 2011), presumably because PFAS are primarily manufactured in developed and industrialized countries.

Thirdly, rather than one specific explanation for social differences in chemical exposure, several risk factors are involved that may reinforce or counteract each other. The exposure determinants identified in our analysis can be more broadly classified into three groups. First, factors related to a general health damaging as well as a health promoting lifestyle. The best-known example is tobacco smoke as a source of lead and cadmium exposure affecting the general population. Smoking during pregnancy has been shown to increase the concentration of lead and cadmium in the mother's blood (Bocca et al., 2019; Chelchowska et al., 2013). Another known example in the opposite direction is the consumption of fish and dairy products, which is associated with a healthy diet and higher SEP but causes higher exposure to POPs and PFAS (Eick et al., 2021; Ibarluzea et al., 2011). The role of alcohol as a determinant is less clear, both because less is known about its relationship with exposure (does alcohol by itself cause more exposure, does it cause faster absorption or excretion of chemicals, or is it more likely to be a proxy for other determinants?) and its relationship with SEP (average alcohol consumption tends to be more common at higher SEP, but heavy drinking is in turn more common at lower SEP). A second set of exposure determinants are more embedded in the ethnocultural context and involves specific food patterns, imported consumer products and cultural habits. Dietary patterns are usually quite robust, even among ethnic minorities, and are thus less subject to acculturation when these groups integrate into another society (Sturkenboom et al., 2016). Research in several countries shows that ethnic groups often maintain the cultural dietary preferences of their country of origin (Dekker et al., 2015; Sharma & Cruickshank, 2001), for example by shopping in traditional food stores (Goldman & Hino, 2005). In our analysis, the consumption of organ meats and legumes, which are often consumed in traditional Turkish diet (Gilbert & Khokhar, 2008), was related to higher concentrations of lead and manganese, an association also confirmed in other research (Filippini et al., 2017; Zeinali et al., 2019). Imported consumer products and cultural-related practices may also be a source of exposure to toxic metals. Well-known examples are traditional lead glazed pottery from Asia (Bakhireva et al., 2013), metallic teapots from Morocco (Bolle et al., 2011), the application of henna on hair and hands (Al-Saleh et al., 2011), and the use of alternative medicines or herbal remedies (Gochfeld & Burger, 2011). A third set of determinants are reproductive and metabolic mechanisms that relate more to the absorption and excretion of chemicals than to exposure. Parity (the number of births) and breastfeeding are two factors that allow mothers to reduce their exposure levels because fractions of the body burden are passed on to the child. Also, the absorption of metals is enhanced under nutrient deficiencies, such as calcium and iron, and vitamin deficiencies. It has been shown that higher calcium and vitamin D intake during pregnancy lowered lead in cord blood (Arbuckle et al., 2016). And a biomonitoring study in Spain reported higher excretion of cadmium in mothers who took multivitamins supplements (Bocca et al., 2019). Moreover, the social gradient in diet quality is also known, with people of lower socioeconomic position consuming more high-energy but nutrient-poor diets (Darmon & Drewnowski, 2008).

References

Al-Saleh, I., Shinwari, N., Mashhour, A., Mohamed, G.E.D., Rabah, A. (2011). Heavy metals (lead, cadmium and mercury) in maternal, cord blood and placenta of healthy women. *International Journal of Hygiene and Environmental Health*, 214(2), 79-101.

Arbuckle, T.E., Liang, C.L., Morisset, A.-S., Fisher, M., Weiler, H., Cirtiu, C.M., et al. (2016). Maternal and fetal exposure to cadmium, lead, manganese and mercury: The MIREC study. *Chemosphere*, 163, 270-282.

Bakhireva, L.N., Rowland, A.S., Young, B.N., Cano, S., Phelan, S. T., Artyushkova, K., et al. (2013). Sources of Potential Lead Exposure Among Pregnant Women in New Mexico. *Maternal and Child Health Journal*, 17(1), 172-179.

Bateson, T.F., Schwartz, J. (2004). Who is sensitive to the effects of particulate air pollution on mortality? A case-crossover analysis of effect modifiers. *Epidemiology*, 143-149.

Bellinger, D.C. (2013). Prenatal Exposures to Environmental Chemicals and Children's Neurodevelopment: An Update. *Saf Health Work*, 4(1), 1-11.

Bocca, B., Ruggieri, F., Pino, A., Rovira, J., Calamandrei, G., Martínez, M. Á., et al. (2019). Human biomonitoring to evaluate exposure to toxic and essential trace elements during pregnancy. Part A. concentrations in maternal blood, urine and cord blood. *Environmental Research*, 177, 108599.

Bolle, F., Brian, W., Petit, D., Boutakhrit, K., Feraille, G., Van Loco, J. (2011). Tea brewed in traditional metallic teapots as a significant source of lead, nickel and other chemical elements. *Food Additives and Contaminants Part a-Chemistry Analysis Control Exposure & Risk Assessment*, 28(9), 1287-1293.

Brown, P. (2013). Integrating Medical and Environmental Sociology with Environmental Health: Crossing Boundaries and Building Connections through Advocacy. *Journal of Health and Social Behavior*, 54(2), 144-163.

Chelchowska, M., Ambroszkiewicz, J., Jablonka-Salach, K., Gajewska, J., Maciejewski, T. M., Bulska, E., et al. (2013). Tobacco Smoke Exposure During Pregnancy Increases Maternal Blood Lead Levels Affecting Neonate Birth Weight. *Biological Trace Element Research*, 155(2), 169-175.

Cordner, A., Poudrier, G., DiValli, J., Brown, P. (2019). Combining Social Science and Environmental Health Research for Community Engagement. *International Journal of Environmental Research and Public Health*, 16(18).

Cushing, L., Morello-Frosch, R., Wander, M., Pastor, M. (2015). The Haves, the Have-Nots, and the Health of Everyone: The Relationship Between Social Inequality and Environmental Quality. *Annual Review of Public Health*, 36(1), 193-209.

Darmon, N., Drewnowski, A. (2008). Does social class predict diet quality? *The American Journal of Clinical Nutrition*, 87(5), 1107-1117.

Dekker, L.H., Nicolaou, M., van Dam, R.M., de Vries, J.H., de Boer, E.J., Brants, H.A., et al. (2015). Socio-economic status and ethnicity are independently associated with dietary patterns: the HELIUS-Dietary Patterns study. *Food Nutr Res*, 59, 26317.

EEA. (2019). *The European environment — state and outlook 2020, Knowledge for transition to a sustainable Europe*. European Environmental Agency.

Eick, S.M., Goin, D.E., Trowbridge, J., Cushing, L., Smith, S.C., Park, J.-S., et al. (2021). Dietary predictors of prenatal per- and poly-fluoroalkyl substances exposure. *Journal of Exposure Science & Environmental Epidemiology*, 1-8.

Filippini, T., Michalke, B., Grill, P., Malagoli, C., Malavolti, M., Vescovi, L., et al. (2017). Determinants of serum manganese levels in an Italian population. *Mol Med Rep*, 15(5), 3340-3349.

Gilbert, P.A., Khokhar, S. (2008). Changing dietary habits of ethnic groups in Europe and implications for health. *Nutr Rev*, 66(4), 203-215.

Glynn, A., Aune, M., Darnerud, P.O., Cnattingius, S., Bjerselius, R., Becker, W., Lignell, S. (2007). Determinants of serum concentrations of organochlorine compounds in Swedish pregnant women: a cross-sectional study. *Environ Health*, 6, 2.

Gochfeld, M., Burger, J. (2011). Disproportionate exposures in environmental justice and other populations: the importance of outliers. *American Journal of Public Health*, 101 Suppl 1(Suppl 1), S53-S63.

Goldman, A., Hino, H. (2005). Supermarkets vs. traditional retail stores: diagnosing the barriers to supermarkets' market share growth in an ethnic minority community. *Journal of Retailing and Consumer Services*, 12(4), 273-284.

Grandjean, P., Bellinger, D., Bergman, A., Cordier, S., Davey-Smith, G., Eskenazi, B., et al. (2008). The faroes statement: human health effects of developmental exposure to chemicals in our environment. *Basic Clin Pharmacol Toxicol*, 102(2), 73-75.

Ibarluzea, J., Alvarez-Pedrerol, M., Guxens, M., Santa Marina, L., Basterrechea, M., Lertxundi, A., et al. (2011). Sociodemographic, reproductive and dietary predictors of organochlorine compounds levels in pregnant women in Spain. *Chemosphere*, 82(1), 114-120.

Ishitsuka, K., Yamamoto-Hanada, K., Yang, L., Mezawa, H., Konishi, M., Saito-Abe, M., et al. (2020). Association between blood lead exposure and mental health in pregnant women: Results from the Japan environment and children's study. *Neurotoxicology*, 79, 191-199.

Junqué, E., Garcia, S., Martínez, M.Á., Rovira, J., Schuhmacher, M., Grimalt, J.O. (2020). Changes of organochlorine compound concentrations in maternal serum during pregnancy and comparison to serum cord blood composition. *Environmental Research*, 182, 108994.

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology*, 30(4), 668-677.

Lewin, A., Arbuckle, T.E., Fisher, M., Liang, C.L., Marro, L., Davis, K., et al. (2017). Univariate predictors of maternal concentrations of environmental chemicals: The MIREC study. *Int J Hyg Environ Health*, 220(2 Pt A), 77-85.

Llop, S., Aguinagalde, X., Vioque, J., Ibarluzea, J., Guxens, M., Casas, M., et al. (2011). Prenatal exposure to lead in Spain: Cord blood levels and associated factors. *Science of the Total Environment*, 409(11), 2298-2305.

Mohai, P., Pellow, D., Roberts, J.T. (2009). Environmental Justice. *Annual Review of Environment and Resources*, 34, 405-430.

Montazeri, P., Thomsen, C., Casas, M., de Bont, J., Haug, L.S., Maitre, L., et al. (2019). Socioeconomic position and exposure to multiple environmental chemical contaminants in six European mother-child cohorts. *International Journal of Hygiene and Environmental Health*, 222(5), 864-872.

Morello-Frosch, R., Zuk, M., Jerrett, M., Shamasunder, B., Kyle, A.D. (2011). Understanding The Cumulative Impacts Of Inequalities In Environmental Health: Implications For Policy. *Health Affairs*, 30(5), 879-887.

Morrens, B., Den Hond, E., Schoeters, G., Coertjens, D., Colles, A., Nawrot, T.S., et al. (2017). Human biomonitoring from an environmental justice perspective: supporting study participation of women of Turkish and Moroccan descent. *Environmental Health*, 16(1), 48.

Muennig, P., Song, X., Payne-Sturges, D.C., Gee, G.C. (2011). Blood and urine levels of long half-life toxicants by nativity among immigrants to the United States. *Science of the Total Environment*, 412, 109-113.

Saoudi, A., Dereumeaux, C., Goria, S., Berat, B., Brunel, S., Pecheux, M., et al. (2018). Prenatal exposure to lead in France: Cord-blood levels and associated factors: Results from the perinatal component of the French Longitudinal Study since Childhood (Elfe). *Int J Hyg Environ Health*, 221(3), 441-450.

Schoeters, G., Den Hond, E., Colles, A., Loots, I., Morrens, B., Keune, H., et al. (2012). Concept of the Flemish human biomonitoring programme. *International Journal of Hygiene and Environmental Health*, 215(2), 102-108.

Schoeters, G., Govarts, E., Bruckers, L., Den Hond, E., Nelen, V., De Henauw, S., et al. (2017). Three cycles of human biomonitoring in Flanders − Time trends observed in the Flemish Environment and Health Study. *International Journal of Hygiene and Environmental Health*, 220(2, Part A), 36-45.

Sharma, S., Cruickshank, J.K. (2001). Cultural differences in assessing dietary intake and providing relevant dietary information to British African-Caribbean populations. *J Hum Nutr Diet*, 14(6), 449-456.

Sturkenboom, S.M., Dekker, L.H., Lamkaddem, M., Schaap, L.A., De Vries, J.H., Stronks, K., Nicolaou, M. (2016). Acculturation and dietary patterns among residents of Surinamese origin in the Netherlands: the HELIUS dietary pattern study. *Public health nutrition*, 19(4), 682-692.

Taylor, C.M., Golding, J., Hibbeln, J., Emond, A.M. (2013). Environmental factors predicting blood lead levels in pregnant women in the UK: the ALSPAC study. *PLoS One*, 8(9), e72371.

Vrijheid, M., Casas, M., Gascon, M., Valvi, D., Nieuwenhuijsen, M. (2016). Environmental pollutants and child health-A review of recent concerns. *Int J Hyg Environ Health*, 219(4-5), 331-342.

Walker, G. (2012). *Environmental Justice Concepts, Evidence and Politics*. New York: Routledge.

Wang, Z., Walker, G.W., Muir, D.C.G., Nagatani-Yoshida, K. (2020). Toward a Global Understanding of Chemical Pollution: A First Comprehensive Analysis of National and Regional Chemical Inventories. *Environmental Science & Technology*, 54(5), 2575-2584.

WHO (2001), *The Global Burden of Disease 2000 project: aims, methods and data sources*. Geneva: World Health Organization, 36, 1-57.

Zeinali, T., Salmani, F., Naseri, K. (2019). Dietary Intake of Cadmium, Chromium, Copper, Nickel, and Lead through the Consumption of Meat, Liver, and Kidney and Assessment of Human Health Risk in Birjand, Southeast of Iran. *Biological Trace Element Research*, 191(2), 338-347.

Chapter 6 Human biomonitoring from an environmental justice perspective: supporting study participation of women of Turkish and Moroccan decent

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Abstract

Background: Environmental justice research shows how socially disadvantaged groups are more exposed and more vulnerable to environmental pollution. At the same time, these groups are less represented and, thus, less visible in biomedical studies. This socioeconomic participation bias is a form of environmental injustice within research practice itself.

Methods: We designed, implemented and evaluated a targeted recruitment strategy to enhance the participation of socially disadvantaged pregnant women in a human biomonitoring study in Belgium. We focused on women of Turkish and Moroccan descent and developed a setup using personal buddies that enabled information transfer about study conditions in the pre-parturition period as well as support and follow-up with questionnaires in the post-parturition period.

Results: We identified four barriers to the participation of women with a vulnerable social and ethnic background which were related to psychosocial and situational factors. Lack of trust in researchers and no perceived study benefits were important personal barriers; the complex study design and difficult self-administered questionnaires were equally significant barriers.

Conclusion: By investing in direct, person-to-person contact with trusted buddies and supported by practical advice about cultural and linguistic sensitivity, it was possible to increase study participation of socially disadvantaged people. Above all, this required openness and flexibility in the mind-set of researchers so that study design and procedures could be better grounded in the experiences and circumstances of underprivileged groups.

Keywords: Human biomonitoring, recruitment, participation, barriers, socially disadvantaged groups, ethnic minorities, environmental justice, study design

6.1 Background

Environmental justice research describes the disproportionate effects of environmental pollution on socially disadvantaged populations (Brulle & Pellow, 2006; Morello-Frosch et al., 2011). People living in poverty, having a low socioeconomic status (SES) or belonging to an ethnic minority often live and work in less favourable environmental conditions, which may result in higher exposure to air, water or soil pollution (Hipp & Lakon, 2010; Mitchell & Dorling, 2003). Due to lower levels of access to health care, and higher levels of psychological stress and predisposition to diseases, people with a low SES may also be more vulnerable to the adverse health effects of environmental pollution (Gee & Payne-Sturges, 2004; Wheeler & Ben-Shlomo, 2005). At the same time, socially disadvantaged groups are systematically underrepresented in biomedical and epidemiological studies that aim to assess the health risks of environmental pollution. This paradox challenges both science and policy. Scientifically, the lower levels of participation of vulnerable social groups introduces a selection bias which undermines the external validity of scientific data. It also hinders subgroup-specific analysis of environmental risk exposure, stratified by income, ethnicity or education, which is one of the major weaknesses in research on environmental health inequalities in the European region according to World Health Organization (WHO, 2012). This also has consequences for policymaking and society, because by monitoring only middle and higher social classes, specific risk groups remain hidden, impeding targeted policy action and maintaining existing patterns of social exclusion.

The most commonly encountered participation barriers for socially disadvantaged people can be classified into four groups (Bonevski et al., 2014; Schmotzer, 2012; Spears et al., 2011). Firstly, there may be psychological or emotional barriers (*feelings*), such as mistrust in science and fear of data abuse and violations of privacy, often the result of social stigma or mistreatment of historically disadvantaged communities. A second group of barriers are more socioeconomic and cognitive in nature (*resources*), such as limited health literacy, which makes the benefits of preventive screening and research of less evident value to those with lower levels of education. A third group comprises cultural barriers (*habits*), which may arise when research designs ignore culturally specific beliefs about illness and health or gender roles. Fourthly, logistical and practical barriers (*obstacles*) may also hinder access to research programmes. These might be rigid exclusion criteria or non-flexible sampling methods.

The challenge of assessing a more diverse study population seems to be particularly difficult in research using human biomonitoring (HBM), a technique used to measure the internal exposure and biological effects of chemical compounds in human tissue or specimens, such as blood, urine or breast milk (Angerer et al., 2007). Studies comparing the characteristics of participants and nonparticipants in population-based research involving blood donation reveal that socioeconomic factors strongly affect participation (Porta et al., 2009; Tjonneland et al., 2007). For example, in Spain, individuals with a university education were almost four times more likely to participate in a human biomonitoring study than people with lower levels of education (Porta et al., 2009). This may be problematic, since HBM studies in the US (Nelson et al., 2012; Tyrrell et al., 2013), Germany

(Kolossa-Gehring et al., 2007), Belgium (Morrens et al., 2012) and Spain (Gasull et al., 2013; Vrijheid et al., 2012) have shown that socioeconomic factors also influence internal exposure to pollutants. However, these results are not always in line with the traditional environmental justice hypothesis, because social differences have an effect in both directions. Exposure to lead, cadmium, bisphenol A and brominated flame retardants is usually associated with lower SES (measured by educational attainment, income or occupational social class), while body concentrations of mercury, arsenic, and chlorinated compounds such as polychlorinated biphenyls (PCBs) and dichlorodiphenylethylene (DDE) are mostly higher among people with higher SES (Gasull et al., 2013; Kolossa-Gehring et al., 2007; Morrens et al., 2012; Nelson et al., 2012; Tyrrell et al., 2013; Vrijheid et al., 2012). Besides these larger population-based surveillance studies, HBM data have also been used in (smaller) community-based and advocacy projects that aim to support and empower the voices of specific polluted communities (Washburn, 2013). These projects also emphasise the need for adapted strategies to recruit and retain economically disadvantaged and ethnically diverse participants (Sexton et al., 2003), the challenges of obtaining Institutional Review Board coverage (Brown et al., 2010), and the need to consider reporting-back protocols in populations with varying levels of literacy (Morello-Frosch et al., 2009).

The Flemish Environment and Health Study (FLEHS), a human biomonitoring programme involving newborns, adolescents and adults in Flanders (the northern part of Belgium) (Schoeters et al., 2012), faces the same challenges. Participants with lower SES, defined in terms of educational attainment, household income or ethnic background, are systematically underrepresented in the study samples. For example, of the respondents in the combined samples of the FLEHS II studies of mothers and adults (20-40 years of age) in 2008 (n = 459), 5.1% were in the low educational attainment group (had not completed secondary education), compared to 14.7% in the general Flemish population (25-34 years of age). 3.9% of respondents had a foreign origin (a parent not born in Belgium), compared to 15% of the general Flemish population. Social scientists from the FLEHS research team have begun to explore this participation bias. To address the issue of social inclusion in the study, we designed, implemented and evaluated a targeted recruitment strategy nested in the FLEHS III mother-newborn study of 2014. This article describes the process and the outcome of this targeted approach, which aimed to increase the participation rate of socially disadvantaged pregnant women and obtain a study sample that was more representative of the social and ethnic diversity of the Flemish population.

6.2 Methods

The aim of the Flemish Environment and Health Study was to provide information on the distribution of internal exposure to environmentally hazardous chemicals in the Flemish population. Flanders is an industrialized region in the north of Belgium with 6 million inhabitants. This region is densely populated and has a dense traffic network. In FLEHS III (2012-2015), participants were recruited from all five Flemish provinces, with the number of participants from each province proportional to the number of inhabitants. A stratified, clustered multi-stage design was used to recruit mothers giving birth in randomly selected maternity hospitals as primary sampling units (PSU). The selected PSUs were located at least 20 km from each other. The standard recruitment strategy within each PSU was to ask midwives to inform pregnant mothers about the study and invite them to participate. Study nurses provided potential participants with detailed information about the study protocol and asked mothers to sign the informed consent form. To account for seasonal variation, recruitment was spread across one full year (November 2013 to November 2014). The inclusion criteria were: (1) residing for at least 5 years in Flanders; (2) giving written informed consent, and (3) being able to fill out an extensive Dutch questionnaire (potentially with the assistance of a family member or an interpreter). All participants donated cord blood and consented to a biopsy from the placenta after the birth of their baby. Optionally, they agreed to donate a hair and/or nail sample. In the week after the delivery, the mothers completed an extensive questionnaire (self-administered) providing information on lifestyle, health status, food consumption, use of tobacco and alcohol, residence history, education and occupation. The study protocol was approved by the ethical committee of the University of Antwerp.

The study goal was to recruit 250 pregnant women. We also aimed to recruit an additional 80 women with a socially more vulnerable position from two of the selected maternity hospitals, one situated in the city of Antwerp (urban region) and one in Heusden-Zolder (rural area in a former coal-mining region). Selection for oversampling was based on three criteria: low educational attainment (mother did not complete secondary education), ethnic background (mother having at least one parent not born in Belgium), and at risk of poverty (having a household income below the national poverty line). In defining ethnic background, we focused on people with Moroccan and Turkish roots, as they constitute the largest ethnic minorities in Belgium (Phalet et al., 2007).

To recruit these hard-to-reach volunteers, we designed a three-track strategy that was implemented in the two maternity hospitals during the entire recruitment period of 13 months.

(I) Modify study procedures – the first step in our strategy was to obtain advice on the ethnic matching and suitability of the vocabulary in the information materials and study procedures. To this end, we conducted eight semi-structured in-depth interviews with organizations and experts in the field of prenatal care, poverty and ethnic cultural minorities. The question guideline for the interviews included four categories: (i) environmental health risk perceptions (how do socially vulnerable pregnant women experience environmental health risks? What are their major environmental concerns?), (ii) habits and beliefs concerning pregnancy and delivery (are there specific cultural habits to be aware of when working with ethnic minority women?), (iii) participation barriers for HBM research (which study procedures may cause barriers for socially vulnerable women?), (iv) opportunities to increase participation (how can we motivate pregnant women? Which elements or messages should be emphasized?). We also organized a focus group with five young mothers from an urban Moroccan and Turkish community. The aim was to test the standard introductory talk about the study protocol and informed consent with the mothers and ask for their feedback. All interviews and focus group were audiotaped in order to extract relevant advice, which was then summarized in separate reports. Finally, we outsourced a thorough screening of our standard information and communication material to a non-profit anti-poverty organization.

(II) Network with community organizations and local professionals – the second step in our strategy was to achieve broader publicity and endorsement of the study and to stimulate word-of-mouth promotion within communities in the catchment areas. To this end, we invested in bilateral consultations with local organizations (e.g. community centres, general practitioners) to personally introduce and advertise the study. We also attempted to encourage and support the midwives in the two selected hospitals in advertising the study to pregnant women with an ethnic background during prenatal consultations.

(III) Implement a personal buddy system for participants – the third and central step in our strategy was to build trust and personal relationships with potential participants by offering them individual support throughout the study process. This was done by buddies – third-party women with the same ethnic background as our target group. We employed three Turkish and Moroccan buddies with a strong social network in the catchment areas close to the collaborating hospital. The buddies were instructed and trained in three consecutive meetings with the research team. They were asked to identify pregnant women eligible for the study, inform them of its aims and encourage them to participate. A brochure summarizing the main messages and expectations was created using culturally appropriate and simply formulated language. This brochure was translated into Arabic, Turkish and French, and included a toll-free phone number for further questions. Buddies gave their personal mobile phone number and e-mail address to interested women to contact them after delivery to arrange a visit in the maternity facility, or at home to assist with filling out or translating the questionnaire. Buddies kept a logbook to document their experiences and record the reactions of potential participants. Halfway through and at the end of the recruitment period, we organized a joint evaluation meeting with the buddies and the research team. We discussed the advantages and disadvantages of the recruitment efforts, the barriers observed, and reasons given for study refusal, and the factors associated with willingness to participate.

The results of our targeted recruitment strategy are described in both qualitative and quantitative terms. The qualitative section contains reflections and more formative evaluations of the research team, the buddies and the midwives. Additional input was gathered from a focus group with young mothers of Moroccan and Turkish background, and from consultations with field organizations and poverty experts. The results are structured around the four participation barriers identified. The quantitative results address the summative evaluation and compare the socioeconomic profiles of participants recruited using the targeted strategy and those recruited without this strategy.

6.3 Results

During the design and the implementation of the targeted recruitment strategy, we identified at least four barriers to the participation of disadvantaged people who are at risk of social exclusion from human biomonitoring research.

First barrier: overcoming an intuitive ‘no’. The focus group with Turkish and Moroccan mothers revealed an initial emotional, almost intuitive, barrier to participation in the HBM study. This is related to both the nature of the study (what we ask of participants) and the timing of the study (when we ask for their participation). The biological samples, particularly the placenta sample, was initially a frightening idea and was perceived to involve giving away personal property. The timing for consent (on the day of delivery) was also concerning because they considered that they would be in ‘an emotional danger zone’. It was suggested that this first psychological barrier might be overcome by the provision of more tangible information about the study and giving candidates more time to decide about participation. If information was provided earlier in the pregnancy, there would be more time to reflect and to consult others in their social environment about study participation and thus prevent people being overcome by this sense of fear when consent is asked for immediately after delivery.

Thus, the primal focus of our recruitment strategy was to invest in information transfer to eligible candidates about the study process in the pre-parturition period. Buddies were employed to inform pregnant women in advance and maintain contact to assist with filling in the questionnaire after delivery. In the first instance, the buddies were asked to contact pregnant women wherever they thought appropriate. However, we soon realized that pregnant women perceived the HBM study as a genuine medical study (as opposed to a health survey). A personal introductory talk was therefore most appropriate and most effective in a medical setting, that is, the maternity department of the collaborating hospitals. Recruiting pregnant women in public places or at community organization activities was also tried but proved to be less effective because potential candidates could not always be identified (pregnancy not discernible), and the nature of the research was perceived to be too sensitive and personal to address women in a group or in public settings. As an alternative, the buddies were granted access (by the cooperative hospital management) to the prenatal consultation waiting rooms and could approach pregnant Turkish and Moroccan women who they identified as potential candidates. The introductory talk centred on information about the non-invasive and risk-free nature of the biological sampling.

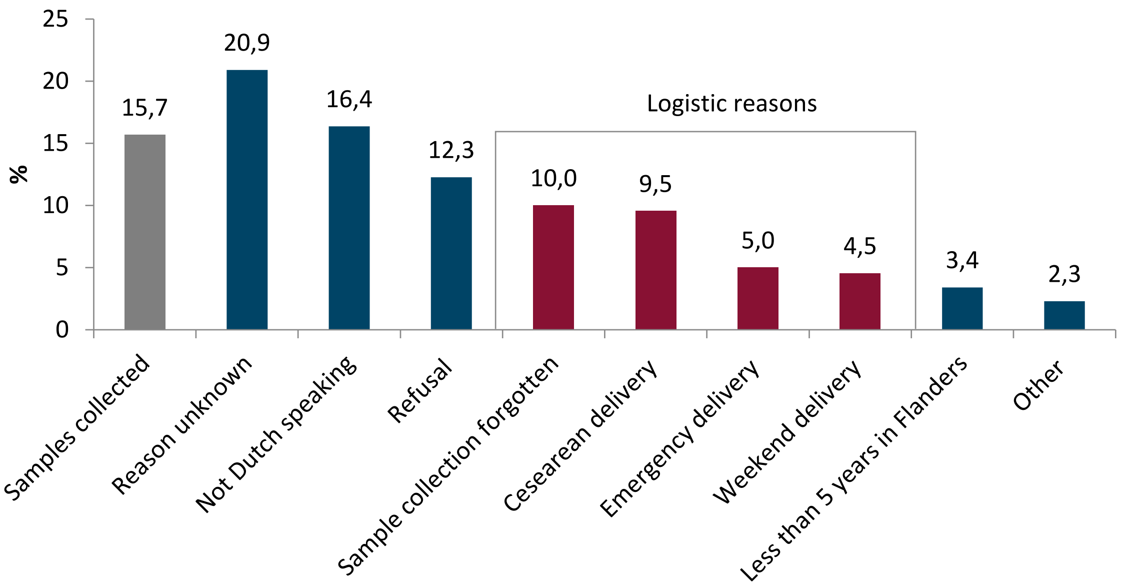
The two most often mentioned reasons for nonparticipation, according to the buddies, were mistrust in the study and lack of husband’s consent. Mistrust was most frequently mentioned as related to anxiety about data abuse. The Turkish buddy mentioned conversations with pregnant women who refused to participate because they believed the placenta sample would be used to clone their baby. The Moroccan buddy observed more religious reservations concerning biological samples. In some Muslim communities, the placenta is perceived as sacred and scientific studies involving tissue donation are believed to be forbidden according to the rules of the Koran (‘haram’). This clearly showed that ethnic minority groups allocate diverse social meanings to and cultural evaluations of placenta donation, and that placental tissue is certainly not universally perceived as biological waste. This has also been documented in other studies (Jenkins & Sugarman, 2005; Yoshizawa, 2013). According to the buddies, other women showed an initial interest in participating but expressed the will to discuss this with their husband. When the buddies contacted these women later, they were reluctant to participate because their husband had not consented.

Second barrier: having a perceived benefit. Reassuring the women that study participation would not involve risks seemed to be a first important step but proved to be inconclusive. The women also needed to be encouraged to complete all elements of the study. The perception of personal utility and benefits of study participation was found to be an important prerequisite, also mentioned in other studies (Barnett et al., 2012; Schmotzer, 2012). Typically, the FLEHS research team attempts to underline the benefits of participation by reporting individual results to participants and offering them a summary of the group results. We also attempted to appeal to the social responsibility and scientific inquisitiveness of potential participants by starting our information brochure with the question: ‘Have you ever wondered whether your child will grow up in a healthy environment? If you have, read on, because we want to answer this question with you’. However, the pilot testing of this brochure with the target group demonstrated that this message was not convincing. The limited scientific literacy and familiarity with research protocols made it difficult to relate to the scientific and societal value of the study. This was also mentioned in relation to our initial catchphrase in the brochure, intended to articulate the policy relevance of our research: ‘When health effects are apparent, the government will take action’. Women living in more deprived conditions could misinterpret this message as entailing the intervention of social services in the domestic arena.

We were advised to frame the utility and benefits of study participation more in terms of ‘personal profit’: firstly, by offering participants more personalized information on how to avoid or protect themselves against exposure to environmentally hazardous chemicals and how to recognize toxic substances in consumer products; and, secondly, by providing more tangible examples of collective policy action being taken in response to the study and emphasizing their valuable contribution to this policy process. We realized, however, that a focus on this information and providing examples required greater familiarity with the study programme and could therefore not effectively be outsourced to the buddies.

Third barrier: avoiding research triage. In theory, the midwives had to briefly mention the HBM study and collect samples from all births during the fieldwork period, except from those women who explicitly refused to participate or did not meet the inclusion criteria. In practice, however, we gradually observed multiple logistical restrictions to the sample collection. For example, during low hospital staffing periods (weekends, night shifts) or very busy periods, midwives did not systematically collect samples. Also, in the case of emergency deliveries or caesareans, women were usually not informed about the study and samples were not taken. A detailed monitoring of the sample collection in one maternity ward over six months revealed effective sampling in only 16% of deliveries (Figure 11). In 29% of deliveries, women did not participate in the study for logistical reasons; for example, the midwives forgot to collect the sample, or it was a caesarean, an emergency or a weekend delivery.

Figure 11: Reasons why samples were not collected in one maternity ward



Although these obstacles relate to all potential study participants, they particularly affect socially vulnerable populations such as ethnic minorities, who are less confident or less able to communicate with the medical staff in Dutch. Additionally, in relation to these groups, the bias could also be reinforced from the opposite direction: study nurses and midwives may feel less confident in explaining study protocols to non-Dutch-speaking women and assume that they are less interested in participating in biomonitoring research. In clinical trial participation this is called physician triage, a well-known mechanism by which physicians and nurses fail to present the option of participation in a clinical trial because they assume that certain patients would not agree, would not understand the study requirements or would not adhere to protocols (Barata et al., 2006; Schmotzer, 2012). Socially vulnerable women also often leave the hospital within 24 hours of delivery and are thus more difficult to reach for the purpose of research studies.

Fourth barrier: filling out the paperwork. Even when samples were taken and consent was given, participants would still be dropped from the study if they did not send back the self-administered questionnaire. Such questionnaires collect data on a broad range of explanatory variables, and they can be long and complex, in our case, including questions about diet, the home environment, medical history and work conditions. The screening of the questionnaire by professionals from a social profit organization indicated that the issue of the simplicity of the questions was a bigger challenge than the language barrier itself, so merely translating the questionnaire was not the best option. The screening of the questionnaire revealed a number of words and phrases that were overly difficult or were confusing to people with weaker literacy skills. At a more fundamental level, a number of questions were identified that would be considered sensitive or offensive and could be expected to result in socially desirable answers. For example, people living in vulnerable social conditions might attempt to minimize the extent to which they engage in unhealthy behaviour, such as smoking and alcohol consumption, or will not respond to questions concerning sexual health or reproduction. To address these risks, study nurses emphasized the confidentiality of the results to the mothers and actively promoted the support of the buddies or themselves in filling out the questionnaire. The buddies completed several home visits to assist participants to fill out the questionnaire. Although this approach was evaluated positively by the buddies, the Moroccan buddy experienced family tensions in some households when the husband of the participant wanted to monitor the answers given.

After a sample period of 13 months, we recruited 281 mothers across Flanders to FLEHS III: 101 were recruited in the two maternity hospitals where we applied the targeted strategy, and 180 were recruited in four maternity hospitals where the standard recruitment strategy was used. In the previous Flemish HBM study, performed in 2008 (FLEHS II), we recruited 255 mothers in a non-targeted manner.

Table 22: Socioeconomic profile of participants recruited in FLEHS III (maternity hospitals with and without targeted strategy) and FLEHS II

		FLEHS III 2014			**FLEHS II 2008**
		(a) Standard strategy in 4 maternity hospitals	**(b) Targeted strategy in 2 maternity hospitals**	**(c) Total in 6 maternity hospitals (a+b)**	**(d) Total in 6 maternity hospitals**
	Recruited participants	**N = 180**	**N = 101**	**N = 281**	**N = 255**
Educational attainment mother	Primary education (less than secondary school)	8.5%	10.4%	9.2%	8.7%
	Secondary education (secondary school)	26.6%	37.5%	30.4%	29.8%
	Tertiary education (college)	65.0%	52.1%	60.4%	61.5%
Ethnic background mother[1]	Turkish/Moroccan	2.2%	20.8%	8.9%	2.0%
	Belgium	87.3%	69.3%	81.1%	94.1%
	Other	10.0%	9.9%	10.0%	3.9%
Household income[2]	Below poverty line	10.8%	25.0%	16.4%	12.5%
	Above poverty line	89.2%	75.0%	83.6%	87.5%

Table 22 indicates that our targeted approach was most successful in recruiting more participants with a Turkish or Moroccan background. In both maternity hospitals where our strategy was implemented (where Turkish and Moroccan buddies assisted) almost 20.8% of the participants had Turkish or Moroccan roots, compared to 2.2% of the participants in the other four maternity hospitals. Moreover, the percentage of participants with a household income below the national poverty line was 2.4 times higher in the maternity hospitals that used the targeted strategy. These percentages must be interpreted with caution since this was not a standard case-control design.

Socioeconomic differences in the samples obtained with and without the targeted recruitment strategy could also be influenced by regional characteristics of the selected maternity hospitals. When we compare the profile of FLEHS III (Column C) with that of FLEHS II where we used the standard strategy in all six maternity facilities (Column D), we see a large increase in the number of participants with a Turkish or Moroccan background, and a moderate increase in participants with a low household income and low educational attainment.

6.4 Discussion

Socioeconomic participation bias in human biomonitoring studies is a form of environmental injustice within research practice itself: those who are most exposed and most vulnerable are least monitored and least represented in research. In an attempt to address this injustice, we designed and implemented a targeted recruitment strategy to enhance the participation of socially disadvantaged pregnant women. We found that women with a vulnerable social background are not a priori less willing to participate, but they do experience at least four barriers that may hinder their participation. These barriers are related to both psychosocial and situational factors. Lack of trust in the researchers and no perceived study benefits are important personal barriers, while the complex study design, with sampling procedures that were outsourced to external midwives and difficult self-administered questionnaires, were equally important barriers.

To address these barriers, we developed a setup that used personal buddies, which enabled both information transfer about study conditions in the pre-parturition period as well as support and follow-up to assist with the self-administered questionnaires in the post-parturition period. This idea was inspired by case studies which used peer support workers to engage hard-to-reach groups in different fields of healthcare (Whittemore et al., 2000). The results of our study revealed the importance of a direct, person-to-person recruitment method over anonymous and population-based recruitment. This finding is supported by other research showing that random probability sampling (e.g. with computer-generated postcode lists) and indirect and passive methods of recruiting and advertising in public places or through the media are often not effective ways to ensure the ethnic and socioeconomic diversity of the sample (Aroian et al., 2006; Gilliss et al., 2001; Mohammadi et al., 2008; Yancey et al., 2006). Adgate and colleagues (2000) found that telephone screening for research participation using a commercial telephone list resulted in the sampling of households with a higher reported income level than the median, thus undersampling the lower socioeconomic groups.

Establishing trust and perceiving the benefits were found to be key to the recruitment process. As other studies have shown, this indicates that people in lower socioeconomic groups perceive biomedical research as more frightening and less beneficial than others (Wardle et al., 2004). The buddies, therefore, invested in personal introductory talks at the maternity ward to discuss the non-invasive and risk-free nature of the study. This gave pregnant women the opportunity to ask questions, discuss participation with their husbands and make a more informed decision when midwives asked for samples at delivery. Placental perfusion studies involving pregnant women in

Finland came to similar conclusions (Halkoaho et al., 2010; Halkoaho et al., 2011): active communication between participants and recruiters and clear and understandable written information prior to the delivery were crucial for creating trust in the research and obtaining informed consent. Thus, in line with the work of Lind and colleagues (2007), we understood recruitment as a matter of involvement rather than persuasion. In addition to trust, perceiving the benefit of study participation was a major facilitator of participation. Schmotzer (2012) concluded that patients who perceive they will personally benefit from study participation are the most likely to report they would participate in a research study. We found that the personal benefits of participation in our human biomonitoring was not in the first instance a monetary reward, but rather the opportunity to receive personalized information about environmental health. Providing the women with tangible evidence of their contribution in terms of resulting policy actions was an additional benefit, which has also been mentioned in other studies (Mohammadi et al., 2008).

Our study also clearly showed the importance of ethnic matching of study design and information materials, and especially of recognizing that husbands act as family gatekeepers. This has also been mentioned in other studies. For example, Dingoyan and colleagues (2012) conducted a study with focus groups of Turkish migrants living in Germany on the willingness to participate in health research. The most often stated reasons for lower participation concerned the role of women, lack of knowledge and interest, mistrust and anxiety. Arion et al. (2006) also emphasized the importance of husbands acting as family gatekeepers. Out of respect for cultural norms concerning men having authority over family matters, their longitudinal study of mother-child pairs in the US offered candidate mothers the opportunity to have data collectors talk with husbands about potential concerns. The main concerns among husbands were disclosing personal details about the family and that study findings might negatively stereotype Arab Muslims (Arion et al. 2006). These examples showed that language is only one barrier that can undermine the communication process alongside other related barriers such as lack of cultural understanding, cultural myths and stereotypes (Hussain-Gambles et al. 2004).

From the perspective of the researchers, we also found barriers that had to be removed in order to improve participant diversity. Here, flexibility turned out to be key. As Schmotzer (2012) stated, researchers have traditionally been rigid in the implementation of protocols. HBM studies with a long-established expertise, such as the Flemish HBM programme, usually benefit from a linear or cyclical research process with fixed routines. However, when recruiting hard-to-reach groups for biomedical research, flexibility and creativity are needed to continually reassess and adjust recruitment methods. This may include, for example, relocating buddies from public places to hospital waiting rooms to approach pregnant women. This approach demands a more organic research process. When efforts to increase sample diversity must fit into an ongoing research project which is based on routines and experience, the linear and organic approaches may conflict, causing friction within the research team. This friction may be further reinforced by the fact that a targeted approach demands extended timeframes and higher staffing and other costs. In our case, the outsourcing of aspects of the fieldwork to buddies and midwives also meant that the researchers lost some control over the recruitment process, which pushed them out of their comfort zone.

If targeted recruitment efforts are to be structurally integrated into future HBM research, it is important to identify solutions that allow flexibility without jeopardizing the scientific quality of the study design. In our research process, we noticed this because our focus on relational ethics – based on empathy and reciprocity – sometimes put pressure on the traditional bioethical principles of autonomy and the privacy of participants. For example, the names and address details of participants, which are usually known only by the study nurses and carefully encrypted, now needed to be shared between study nurses and buddies in order to collect questionnaires and arrange home visits.

This structural integration of a targeted recruitment strategy could be done through the involvement of and deliberation with societal actors early in the research processes, in order to tailor study protocols to specific concerns of the target group. In this respect, investing in more social and cultural diversity in study samples aligns with what could be considered part of the broader EU approach known as Responsible Research and Innovation (RRI). RRI implies that societal actors work together during the entire research process to better align both the process and its outcomes with the values, needs and expectations of society (Owen et al., 2012).

6.5 Conclusions

By investing in direct, person-to-person contact with trusted buddies and supported by practical advice on cultural and linguistic sensitivity, it is possible to increase the participation rate of socially disadvantaged populations, especially of ethnic minorities, in biomedical research. Improving participant diversity, however, involves more than merely instrumentally tackling access barriers or simplifying information materials. It requires openness and flexibility in the study procedures, and, above all, a different mind-set of the researchers involved, which allows study designs to better take into account the experiences and different circumstances of disadvantaged groups.

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Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to privacy restrictions but are available from the corresponding author on reasonable request.

Authors' contributions

BM conceived, designed and implemented the study, and oversaw the writing of the manuscript. EDH helped with the design and the implementation of the study and the drafting of the manuscript. GS coordinated the human biomonitoring study and critically reviewed and revised the manuscript. DC and AC assisted with the writing and editing of the manuscript. TSN, WB and SDH provided critical input on the manuscript. VN coordinated the fieldwork for the human biomonitoring study. IL supervised the study and approved the final manuscript as submitted. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Ethics approval and consent to participate

This study described the recruitment process and protocols of the Flemish Environmental Health Studies which have been approved by the ethical committee of the University of Antwerp, Belgium.

References

Adgate, J.L., Clayton, C.A., Quackenboss, J.J., Thomas, K.W., Whitmore, R.W., Pellizzari, E.D., et al. (2000). Measurement of multi-pollutant and multi-pathway exposures in a probability-based sample of children: practical strategies for effective field studies. *Journal of Exposure Analysis and Environmental Epidemiology*, 10(6), 650-661.

Angerer, J., Ewers, U., Wilhelm, M. (2007). Human biomonitoring: State of the art. I*nternational Journal of Hygiene and Environmental Health*, 210(3-4), 201-228.

Aroian, K.J., Katz, A., Kulwicki, A. (2006). Recruiting and retaining Arab Muslim mothers and children for research. *Journal of Nursing Scholarship*, 38(3), 255-261.

Barata, P.C., Gucciardi, E., Ahmad, F., Stewart, D.E. (2006). Cross-cultural perspectives on research participation and informed consent. *Social Science & Medicine*, 62(2), 479-490.

Barnett, J., Aguilar, S., Brittner, M., Bonuck, K. (2012). Recruiting and retaining low-income, multi-ethnic women into randomized controlled trials: Successful strategies and staffing. *Contemporary Clinical Trials*, 33(5), 925-932.

Bonevski, B., Randell, M., Paul, C., Chapman, K., Twyman, L., Bryant, J., et al., (2014). Reaching the hard-to-reach: a systematic review of strategies for improving health and medical research with socially disadvantaged groups. *Bmc Medical Research Methodology*, 14(1), 1-29.

Brown, P., Morello-Frosch, R., Brody, J. G., Altman, R.G., Rudel, R.A., Senier, L., et al., (2010). Institutional review board challenges related to community-based participatory research on human exposure to environmental toxins: A case study. *Environmental Health*, 9(1), 39.

Brulle, R.J., Pellow, D.N. (2006). Environmental justice: Human health and environmental inequalities. *Annual Review of Public Health*, 27, 103-124.

Dingoyan, D., Schulz, H., Mosko, M. (2012). The willingness to participate in health research studies of individuals with Turkish migration backgrounds: barriers and resources. *European Psychiatry*, 27(Suppl 2), 4-9.

Gasull, M., Pumarega, J., Rovira, G., López, T., Alguacil, J., & Porta, M. (2013). Relative effects of educational level and occupational social class on body concentrations of persistent organic pollutants in a representative sample of the general population of Catalonia, Spain. *Environmental International*, 60, 190-201.

Gee, G.C., Payne-Sturges, D.C. (2004). Environmental health disparities: A framework integrating psychosocial and environmental concepts. *Environmental Health Perspectives*, 112(17), 1645-1653.

Gilliss, C.L., Lee, K.A., Gutierrez, Y., Taylor, D., Beyene, Y., Neuhaus, J., Murrell, N. (2001). Recruitment and retention of healthy minority women into community-based longitudinal research. *Journal of Womens Health & Gender-Based Medicine*, 10(1), 77-85.

Halkoaho, A., Pietila, A. M., Dumez, B., Van Damme, K., Heinonen, S., Vahakangas, K. (2010). Ethical Aspects of Human Placental Perfusion: Interview of the Mothers Donating Placenta. *Placenta*, 31(8), 686-690.

Halkoaho, A., Pietila, A.M., Vahakangas, K. (2011). Ethical aspects in placental perfusion studies: Views of the researchers. *Placenta*, 32(7), 511-515.

Hipp, J.R., Lakon, C.M. (2010). Social disparities in health: Disproportionate toxicity proximity in minority communities over a decade. *Health & Place*, 16(4), 674-683.

Hussain-Gambles, M., Atkin, K., Leese, B. (2004). Why ethnic minority groups are under-represented in clinical trials: a review of the literature. *Health Soc Care Community*, 12(5), 382-388.

Jenkins, G.L., Sugarman, J. (2005). The importance of cultural considerations in the promotion of ethical research with human biologic material. *Journal of Laboratory and Clinical Medicine*, 145(3), 118-124.

Kolossa-Gehring, M., Becker, K., Conrad, A., Ludecke, A., Riedel, S., Seiwert, M., et al., (2007). German Environmental Survey for children (GerES IV) - First results. *International Journal of Hygiene and Environmental Health*, 210(5), 535-540.

Lind, U., Mose, T., Knudsen, L.E. (2007). Participation in environmental health research by placenta donation - a perception study. *Environmental Health*, 6, 36-43.

Mitchell, G., Dorling, D. (2003). An environmental justice analysis of British air quality. Environment and Planning A, 35(5), 909-929.

Mohammadi, N., Jones, T., Evans, D. (2008). Participant recruitment from minority religious groups: the case of the Islamic population in South Australia. *International Nursing Review*, 55(4), 393-398.

Morello-Frosch, R., Brody, J.G., Brown, P., Altman, R.G., Rudel, R. (2009). Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. *Environmental Health*, 8, 6.

Morello-Frosch, R., Zuk, M., Jerrett, M., Shamasunder, B., Kyle, A.D. (2011). Understanding The Cumulative Impacts Of Inequalities In Environmental Health: Implications For Policy. *Health Affairs*, 30(5), 879-887.

Morrens, B., Bruckers, L., Den Hond, E., Nelen, V., Schoeters, G., Baeyens, W., et al., (2012). Social distribution of internal exposure to environmental pollution in Flemish adolescents. *International Journal of Hygiene and Environmental Health*, 215, 474-481.

Nelson, J.W., Scammell, M.K., Hatch, E.E., Webster, T.F. (2012). Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. *Environmental Health*, 11, 10.

Owen, R., Macnaghten, P., Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy*, 39(6), 751-760.

Phalet, K., Deboosere, P., Bastiaenssen, V. (2007). Old and new inequalities in educational attainment - Ethnic minorities in the Belgian Census 1991-2001. *Ethnicities*, 7(3), 390-415.

Porta, M., Gasull, M., Puigdomenech, E., Rodriguez-Sanz, M., Pumarega, J., Rebato, C., Borrell, C. (2009). Sociodemographic factors influencing participation in the Barcelona Health Survey study on serum concentrations of persistent organic pollutants. *Chemosphere*, 76(2), 216-225.

Schmotzer, G.L. (2012). Barriers and facilitators to participation of minorities in clinical trials. *Ethnicity & Disease*, 22(2), 226-230.

Schoeters, G., Den Hond, E., Colles, A., Loots, I., Morrens, B., Keune, H., et al., (2012). Concept of the Flemish human biomonitoring programme. *International Journal of Hygiene and Environmental Health*, 215(2), 102-108.

Sexton, K., Adgate, J.L., Church, T.R., Greaves, I.A., Ramachandran, G., Fredrickson, A.L., et al., (2003). Recruitment, retention, and compliance results from a probability study of children's environmental health in economically disadvantaged neighborhoods. *Environ Health Perspect*, 111(5), 731-736.

Spears, C.R., Nolan, B.V., O'Neill, J.L., Arcury, T.A., Grzywacz, J.G., Feldman, S.R. (2011). Recruiting underserved populations to dermatologic research: a systematic review. *International Journal of Dermatology*, 50(4), 385-395.

Tjonneland, A., Olsen, A., Boll, K., Stripp, C., Christensen, J., Engholm, G., Overvad, K. (2007). Study design, exposure variables, and socioeconomic determinants of participation in diet, cancer and health: A population-based prospective cohort study of 57,053 men and women in Denmark. *Scandinavian Journal of Public Health*, 35(4), 432-441.

Tyrrell, J., Melzer, D., Henley, W., Galloway, T.S., Osborne, N.J. (2013). Associations between socioeconomic status and environmental toxicant concentrations in adults in the USA: NHANES 2001-2010. *Environment International*, 59, 328-335.

Vrijheid, M., Martinez, D., Aguilera, I., Ballester, F., Basterrechea, M., Esplugues, A., et al., (2012). Socioeconomic status and exposure to multiple environmental pollutants during pregnancy: evidence for environmental inequity? *Journal of Epidemiology and Community Health*, 66(2), 106-113.

Wardle, J., McCaffery, K., Nadel, M., Atkin, W. (2004). Socioeconomic differences in cancer screening participation: comparing cognitive and psychosocial explanations. *Social Science & Medicine*, 59(2), 249-261.

Washburn, R. (2013). The Social Significance of Human Biomonitoring. Sociology Compass, 7(2), 162-179.

Wheeler, B.W., Ben-Shlomo, Y. (2005). Environmental equity, air quality, socioeconomic status, and respiratory health: a linkage analysis of routine data from the Health Survey for England. *Journal of Epidemiology and Community Health*, 59(11), 948-54.

Whittemore, R., Rankin, S.H., Callahan, C.D., Leder, M.C., Carroll, D.L. (2000). The peer advisor experience providing social support. *Qualitative Health Research*, 10(2), 260-276.

World Health Organization, (2012). Environmental health inequalities in Europe: Assessment Report. WHO Regional Office for Europe.

Yancey, A.K., Ortega, A.N., Kumanyika, S. K. (2006). Effective recruitment and retention of minority research participants. *Annual Review of Public Health*, (27), 1-28.

Yoshizawa, R.S. (2013). Review: Public perspectives on the utilization of human placentas in scientific research and medicine. *Placenta*, 34(1), 9-13.

Chapter 7 Participant Experiences in a Human Biomonitoring Study: Follow-up Interviews with Participants of the Flemish Environment and Health Study

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Abstract

Communicating individual human biomonitoring results to study participants has been the subject of debate for some time. This debate is dominated by ethical considerations from a researchers' perspective on whether or not to communicate, thereby overlooking more practice-based questions from a participants' perspective on what and how to communicate. We conducted a small-scale follow-up study based on eleven face-to-face interviews with mothers participating in the third cycle of the Flemish Environment and Health Study (FLEHS III 2012–2015) to investigate how they experienced and interpreted individual biomonitoring results. Key findings indicate that respondents were generally satisfied with participating in the biomonitoring study, but the report-back process especially lacked contextualized information and interactive communication options to better comprehend and cope with personal results. These findings also argue in favor of a more tailored approach in which report-back methods, formats and content are diversified according to the type of results and the preferences of participants. A reflexive research practice with active engagement in follow-up research is crucial to improve participants' understanding and use of personal biomonitoring results.

Keywords: human biomonitoring; risk communication; research participation; environmental health; report-back; participant experiences

7.1 Introduction

Human biomonitoring (HBM) measures the concentrations of environmental chemicals, their metabolites and their biological responses in body fluids and tissues, such as blood, urine, breast milk, hair or nails (Needham et al., 2007). HBM is a subdiscipline of molecular epidemiology which can contribute importantly to a better knowledge of chemical exposures and of environmental causes and risk factors for disease. Over the past decade, the number of national or regional HBM-programmes has increased and is often surveillance-based, to monitor nationwide or regional reference ranges of internal concentrations to an increasing number of chemicals, ranging from historic pollution, such as persistent pesticides and toxic metals, to new emerging substances used in plastics, cosmetics, furniture, and other consumer products (Choi et al., 2015; WHO, 2015). HBM is also used in a variety of other settings, such as community-based biomonitoring studies, to respond to local concerns about environmental health risks, or advocacy work from civil society organizations (Morello-Frosch et al., 2009; Washburn, 2013b).

HBM studies most commonly report statistical results and interpretation of aggregated data from (large) study samples. In addition, HBM can also generate personal result reports containing the measured biomarker concentrations of an individual, often accompanied by some comparison to reference or population values. However, there is no universal consensus nor common practice to communicate individual results to study participants (Hintz & Dean, 2020; Ohayon et al., 2017). In fact, there is considerable debate on this topic, making report-back of individual results one of the main challenges of HBM today (Exley et al., 2015; Ohayon et al., 2017; Washburn, 2013b). This debate is often reduced to a principle-based ethical dilemma on whether or not to communicate personal results to study participants (Morello-Frosch et al., 2015). On the one hand, the clinical ethics perspective emphasizes report-back only if concentrations exceed clinical action levels or if the relationship between biomarker levels and health risk is clearly understood. Traditionally, most surveillance-based biomonitoring studies adopt this clinical ethics approach and communicate results only at an aggregated level (Exley et al., 2015; Morello-Frosch et al., 2009). On the other hand, the community-based participatory research (CBPR) approach emphasizes extensive reporting back of personal and aggregated results. In this framework, results should be disseminated to participants not primarily because they have a clinical significance, but rather for its preventative or precautionary significance: to motivate behavior change, to sensitize about environmental health risks and to increase trust between participants and scientists (Ramirez-Andreotta et al., 2016; Washburn, 2013a). The CBPR approach is mostly applied in local biomonitoring studies in the US, often within disadvantaged communities in an environmental justice context (Emmett & Desai, 2010), yet some European surveillance-based HBM studies integrate principles of the CBPR approach in their communication strategy (Exley et al., 2015; Keune et al., 2008; Louro et al., 2019; Middleton et al., 2016).

However, this ethical discussion omits several more practice-based questions and challenges about how to communicate individual results in a responsible and meaningful way. In general, participants want to know their results, but only reporting numerical concentrations of chemicals is deemed not very useful to lay people. Follow-up studies on participant's experiences advocate for a more extensive contextual framework to guide participants with the interpretation of their personal data (Lind et al., 2007; Purvis et al., 2017). Brody, et al. (2007) for example have identified typical participants' questions about HBM results that go beyond a mere list of chemicals detected, such as "is it safe?", "what should I focus on?", and "what can I do?". These questions emphasize the importance of understanding how participants process, interpret and respond to the presence of bodily contaminants, a concept which has been termed "the exposure experience" (Adams et al., 2011; Altman et al., 2008). Participants are not considered as just passive receivers that "get the message", but as active actors that understand and interpret messages according to their past experiences, attitudes and perceptions (Judge et al., 2016). Based on this contextual framework, Brody et al. (2014) and Dunagan et al. (2013) have documented detailed and practical guidelines for communicating personal results to participants. These guidelines, however, are mainly based on experiences from specific community-based studies in the US that use a bottom-up recruitment strategy and study design. Less knowledge and practice are available on national surveillance-based human biomonitoring programs that include randomly selected participants in a more top-down approach, on behalf of a public authority. In this context, the objective to communicate is usually focused on transparency and health promotion, rather than advocacy. In addition, surveillance biomonitoring may experience fewer opportunities to mobilize participants around a shared local concern, and a greater distance between researchers and participants, which challenges meaningful report-back. In this article, we want to investigate how study participants of a surveillance-based human biomonitoring study in Flanders (Belgium) experienced and interpreted their individual biomonitoring results. We conducted a small-scale follow-up study based on face-to-face interviews with mothers that participated in the Flemish Environment and Health Study (FLEHS). Results of FLEHS-studies have already been extensively reported (Colles et al., 2020; Schoeters et al., 2017), as well as their relevance to policy (Reynders et al., 2017), but no research has yet been performed on how results are interpreted by FLEHS participants themselves. We used an explorative set-up to evaluate report-back protocols and generate hypotheses about the participants experiences in the FLEHS-study. Our study aims to provide more insight into how participants understand and interpret their biomonitoring results and to make recommendations to enhance report-back practices for large biomonitoring/surveillance studies.

7.2 Materials and Methods

7.2.1 FLEHS: Flemish Biomonitoring Study of Mothers and New-Borns

In Flanders, the northern part of Belgium, the human biomonitoring program FLEHS has been established since 2001 to measure and monitor internal concentrations of environmental pollutants (biomarkers of exposure) and associated biological effects (biomarkers of effect) in different age groups of the Flemish population (Schoeters et al., 2017). The study is commissioned by the regional Flemish government and carried out by a multi-disciplinary research consortium. The primary objectives are to generate reference values for a diverse set of biomarkers, to follow-up time trends and study exposure determinants and exposure-effect associations. A more detailed description of the FLEHS study design is available elsewhere (Schoeters et al., 2012).

For our follow-up study, we focused on a cross-sectional study with 281 mothers and new-borns carried out between 2013 and 2015, within the third FLEHS-cycle. The aim was to measure internal exposure to hazardous chemicals in a geographically representative sample of the Flemish population. For this HBM-study, women were recruited in five randomly selected maternity hospitals in each of the Flemish provinces. Midwives informed pregnant women about the study and invited them to participate when they registered in the maternity for delivery. All women who resided for at least five years in Flanders were eligible for study participation. Study nurses explained the research protocol in detail on the basis of a brochure and invited them to sign the informed consent form. All participants donated cord blood and consented to take a biopsy from the placenta. Optionally, they agreed to donate a hair sample (collected in the maternity by the study nurse) or a fingernail sample (self-collected for four weeks from the day of delivery). In the days after delivery, the mothers completed an extensive questionnaire (self-administered) providing information on lifestyle, health status, food consumption, use of tobacco and alcohol, residence history, education and occupation. In the biological samples, biomarkers of exposure such as toxic metals, persistent organochlorinated pollutants, brominated flame retardants and perfluorinated compounds, and biomarkers of effect, such as hormone levels and markers of DNA damage, were measured by specialized labs.

7.2.2 Communication Strategy and Report-Back Protocol

Within the FLEHS program, a detailed and transparent communication strategy has been developed (Keune et al., 2008), including a report-back protocol of individual biomonitoring results (based on participants' right to know) and a sequenced communication of research results at a group level in which participants are informed prior to the general public ("participants first" principle). Participants received their individual results by post at their home address at the end of 2015, if they had chosen this option in the informed consent (91.8% of participants did). Undelivered mails were returned to the research institute in case of a move or incorrect address, otherwise we assumed that all participants received their letter well.

Table 23: Illustration of the data format used for individual report-back of HBM results for three out of seventeen biomarkers (translated from Dutch) (2013-2015)

Toxic Metals	**Your Result**	**Results of All Participants**	
		Median	**P90**
Cadmium (µg/L)	X*	0.021	0.034
Lead (µg/L)	Y*	6.07	11.50
Copper (µg/L)	Z*	570.95	685.61

*Note: * is where the personal result is shown*

Together with an introductory letter (see supplementary material[13]), a table format (see Table S1) was used to present results for seventeen biomarkers of exposure. Table 23 below illustrates this data format for three biomarkers.

Individual results for each biomarker were compared with two reference values, i.e., the median and 90th percentile (P90) of all study participants. No health-based guidance values were included since these were not available for cord blood levels at that time. Contact information of the study physician was added in the letter for participants who wanted a personal consultation at two predetermined moments. There was an early notification protocol, in case of high-level results that required further follow-up (values with clinical significance or extreme outliers). The study physician would then personally call participants prior to sending the results. This protocol was described in the introductory letter. Participants also received a document with background information on each pollutant (see Table S2). The document contained information about pollution sources, exposure routes and possible health effects. An illustration is found in Table 24. A referral to the study website was included for exposure reduction advice. Along with the personal results and background information, participants received a one-page summary of the general research conclusion, based on the aggregated results.

Table 24: Illustration of background information for individual-report back of HBM results, for three out of seventeen biomarkers (translated from Dutch) (2013-2015)

Pollutants	What are the main sources in our environment?	How are humans exposed?	What are possible health risks?
Cadmium in blood; exposure measurement of previous 3–4 months	- cigarette smoke - non-ferrous industry, scrap processing industry - in the past: domestic waste incinerators (e.g. battery combustion) and crematoria	- through smoking or exposure to secondhand smoke - eating vegetables from polluted areas (cadmium accumulation in vegetables) - inhalation of cadmium-laden dust	- kidney function disruption - increased risk of osteoporosis and bone fractures - carcinogenic (mainly lung cancer)
Lead in blood; exposure measurement of previous 3–4 months	- leaded paint - leaded drinking water pipes - ferrous and non-ferrous industry	- inhalation of lead-contaminated dust - in regions with historical lead pollution (e.g. near industry or busy roads) lead	- anemia - negative influence on intelligence in children - kidney function disruption - fertility problems

[13] Available online at https://www.mdpi.com/article/10.3390/toxics9040069/s1 (supplement 3)

	- in the past: leaded petrol	particles can settle on vegetables and can pollute drinking water	- probably carcinogenic
Copper in blood; exposure measurement of previous days	- copper mining - landfill sites, waste incineration - timber production - fossil fuel combustion	- inhalation of copper-contaminated dust - in some regions, drinking water contains high concentrations of copper	- low concentrations are essential for good health - in case of prolonged, high exposure: headache, nausea, diarrhea, dizziness

All documents were developed in the field work committee by a multidisciplinary research consortium, taking into account previous experience of the research and input from earlier participant reviews since this was the third cycle of the Flemish HBM program.

7.2.3 Follow-Up Interviews

In March 2018, participants were re-contacted and invited to participate in a personal follow-up interview to discuss their experiences after receiving their biomonitoring results. For practical reasons, invitations were restricted to 85 participants living in the province of Antwerp. They received a written invitation at their home address and could register by email or phone. Follow-up interviews were held at the University of Antwerp or at their home address in April and May 2018. Interviews were recorded with permission. The interview protocol used open-ended questions and consisted of three parts: study participation (how did respondents experience the study?), study results (how did they understand their results?) and study impact (how did they respond to their results?). The interview guideline is included as a supplemented file[14]. All interviews were conducted in Dutch by the corresponding author. Interview audios were transcribed, and answers were categorized into relevant themes and issues.

7.3 Results

Out of 85 invited participants, 11 were willing to cooperate (13% participation rate). Taking the participant's preferences into account, seven interviews took place at the respondent's home, and four at the University. The median interview length was 56 min (range: 28–60 min). Demographic and socioeconomic characteristics of the eleven respondents of the follow-up interview are presented in Table 25. Eight respondents were between 25 and 35 years of age. Eight respondents had a high educational attainment (tertiary education), three had a medium educational attainment (secondary education). Nine respondents were gainfully employed, one was unemployed, and one was a housewife. Four respondents have a migrant background, defined as

[14] Available online at https://www.mdpi.com/article/10.3390/toxics9040069/s1 (Supplement 2)

having at least one parent that was not a native-born Belgian. Compared to the study sample of HBM participants (Table 25), the respondents of the follow-up interview had a higher rate of tertiary education, a high income and home ownership, yet they also had a higher unemployment rate and migrant background status. The age distribution and parity of respondents and participants were comparable. This small sample is not representative of the total participant group nor the Flemish population, nevertheless it includes some meaningful differences in the participant profiles.

Table 25: Demographic and socioeconomic characteristics of respondents

Variable	Respondents Follow-Up Study		Participants HBM Study	
	N	%	N	%
Age				
≤ 25 Year	1	9.1	30	10.7
25–30 Year	4	36.4	111	39.5
30–35 Year	4	36.4	101	35.9
> 35 Year	2	18.2	39	13.9
Educational attainment				
Low (ISCED 0–2)	0	0.0	26	9.3
Medium (ISCED 3–4)	3	27.3	88	31.3
High (ISCED 5–8)	8	72.7	166	59.1
Employment status				
Working	9	81.8	238	87.5
Not working	2	18.2	34	12.5
Equivalent income *				
< 1.250 euro	2	18.2	59	24.5
1.250–2.000 euro	5	45.5	117	48.5
> 2.000 euro	4	36.4	65	27.0
Home ownership				
No	2	18.8	78	27.9
Yes	9	81.8	202	72.1
Migrant background **				
No	7	63.6	220	78.3
Yes	4	36.4	57	20.3
Parity				
1	4	36.4	126	44.8
2	4	36.4	100	35.6
3 and above	3	27.3	55	19.6

*Note * Equivalent income was calculated as the monthly household's income divided by the number of household members. Note ** Migrant background was ascribed to respondents with at least one parent that was not a native-born Belgian.*

7.3.1 Study Participation: How Did Respondents Experience the Study?

Despite the long time span of three years between study recruitment and follow-up interviews, nine respondents remembered that the reason for participating in the biomonitoring study was because they valued the research topic of environmental health and environmental pollution or because they wanted to make a contribution to science (Table 26). For the five respondents, an additional trigger for participation was the fact that they would receive individual results. This was articulated in terms of curiosity to know their body burden and not because of a health concern. Moreover, for two women, the motivation to participate was based on the conviction and expectation that their individual results would be good, because it would reflect their healthy lifestyle or their personal living environment, which they perceived as being safe.

Table 26: Common responses to the topic of study participation

	Reasons for Participating in Biomonitoring Study
Common Responses	- To make a contribution to scientific research - Because environmental health is an important theme - Curious about own results

None of the respondents perceived the legal language in the informed consent as a barrier to participate. Most women immediately agreed to participate and did not need time for consideration. Half of the respondents did not recall reading the information brochure of the study. The other half mentioned that, although the content of the brochure was professional and accessible, the framing was too medical and scientific, which created a mental distance between them and the researchers. For example, the technical description of the different biological samples that would be collected remained abstract. Because the brochure did not mention why these different samples were needed, mothers felt somewhat detached from the broader study objectives and were a bit cautious about donating their samples, especially the hair sample.

> *"The placenta, that's normal. That's what the research is all about. But hair? This is perhaps strange to say, but I can remember that at that moment I felt like: "that is mine". They ask for a lock of my hair... that was weird"* (R7).

Around half of the respondents indicated that the self-administered questionnaire was long and contained many questions. Yet the interviewed women realized that human biomonitoring research inevitably requires a lot of information. Moreover, respondents did not find the questions too difficult or too sensitive to complete. Interestingly, one mother projected certain questions on their personal situation, to make assumptions on risk behavior and exposure determinants, for instance about the use of indoor spray products.

7.3.2 Receiving Results: How Did Respondents Understand Their Results?

When asked about the initial feeling when receiving individual results, four respondents felt confused about their results and indicated the need for additional information about health implications (Table 27). Firstly, participants not only wanted reference values to compare their results with other study participants, but they also wanted health-based guidance values to interpret their exposure levels in safety terms. Secondly, several mothers expected more information and an interpretation of the extent to which their results reflected a transfer of contamination to their baby and potential health effects. In addition to information to evaluate and interpret health risks, the mothers suggested using a visual summary that could guide them through the multitude of results. For instance, by adding an overview with some key takeaway messages, or by transforming the enlisted result tables in a graphical format like a bar chart.

Table 27: Common responses to the topic of receiving results and evaluation of report-back practices

	Initial Feeling When Receiving Individual Results		
Common Responses	- A sense of not understanding the results - A feeling of concern because of an elevated value		
	Evaluation of Report-Back Practice		
	Personal Result Format	**Background Information**	**Option to Consult with Study Physician**
Common Responses and Questions	- How to interpret results in safety terms? - What about transfer of chemicals to baby? - Need for a (visual) summary	- Lack of practical advice - Too much scientific terminology - List of possible health effects caused unpleasant feeling	- No recollection of this option - Option was not inviting or accessible enough - Feeling of not wanting to disturb

Women with a high biomarker result (n=5) expressed a feeling of concern that often overwhelmed them at first. One mother remembered:

> *"I just looked at the deviated values, and lead was very high for me. That did make me feel anxious. Because that was tremendously different from the rest and then I got totally fixated on that"* (R9).

Despite these initial feelings of concern or confusion, none of the respondents mentioned anxiety or panic, in fact only one mother actually phoned the study physician for more information. However, four of the mothers indicated that they did not remember this option or that they found the wording in the letter not inviting or accessible enough. Three other respondents described a certain reluctance to call because they perceived the study to be a large-scale scientific study and not an individual follow-up. They felt that asking personal questions would interrupt the study team and would go beyond the scope of the study. The statement of the early notification by the study team in case of medical significance further contributed to the mother's reluctance to call:

> *"One of those values was really high for me, especially compared to all the rest. And... that was disturbing, personally [...]. Of course, the letter mentioned that if you had any questions you could contact them... and uhm... It's weird, I've always had that in mind: once, I'm going to call for that, I want to know: what could it be? […] But it never really happened and from the research itself, I never heard anything... And at a certain point I made the assumption: no, if it was really bad they would notify me"* (R7).

When asked about the usefulness of a face-to-face consultation with the study physician instead of a phone call, three women felt this would have been a better approach to deal with their questions. The supplemented table with background information about the measured pollutants (see Table S2) was designed to help participants understand and interpret their results. Nevertheless, the majority of respondents considered the information to be too generic and too abstract to be helpful. The lack of practical advice and solutions to reduce exposure especially made the table of limited use for participants. According to four respondents, the focus was on a scientific explanation of the different pollutant sources and exposure routes, thereby ignoring tailored and practical solutions for exposure reduction. Furthermore, the list of possible health effects in the background table triggered a feeling of unease among two respondents, because it did not indicate a threshold exposure level above which these effects can be expected. Six mothers did not remember receiving or reading the summary of the aggregated research results. The other mothers referred to the fact that the summary contained too much text, was too difficult or too generally written.

7.3.3 Study Impact: How Did Participants Respond to Their Results?

Because most respondents indicated having insufficient contextual information to interpret their results, some searched for additional information on the internet (n=3). Only three mothers took more extensive action (Table 28). One participant had a sample of her drinking water analyzed to determine the source of her elevated value of lead. One mother went to her general practitioner to discuss the study results. Another woman removed the chickens from her yard because they were possibly causing expo-sure to a perfluorinated compound. Six respondents did not undertake action, which appeared to be mainly because the results provided not enough tools to take effective action. As a result, information was less likely to be remembered and the importance of acting on behalf of the results quickly faded with time:

> *"I found this package [of results] to be primarily informative and not action-oriented. That's how that whole package was set up and that's how I understood it. And somewhere that is in your head and we kept it in our minds for a while, but in the hustle and bustle of everything you*

leave it behind and then… you have to take too many steps yourself to do something with it, I suppose" (R4).

Table 28: Common responses to the topic of study impact

	Responses to Receiving Individual Results
Common Responses	- Searching additional information on the internet - Taking personal action (e.g., drinking water analysis) - No further steps taken

Furthermore, as the results sometimes failed to resonate with mothers' conscious knowledge and beliefs, four mothers even mentioned they actively wanted to forget or suppress their results: *"I was like, I don't want to know, just leave it like that. I admit it. Don't think about it too much..."* (R3).

7.4 Discussion

The Flemish human biomonitoring program FLEHS places a strong emphasis on comprehensive report-back of study results to participants, both on an individual and collective level. We conducted a small-scale follow-up study to evaluate the report-back process of the individual results of the biomarker measurements from a participants' perspective. Based on eleven semi-structured interviews with mothers who participated in the FLEHS III study on new-borns, we learned that these participants were generally satisfied with participating and preferred to know their own results. However, receiving results did not appear to motivate or inspire most participants to take action, nor did it enhance their knowledge of environmental health. This is probably because the report-back process lacked both contextualized information and interactive communication options. Hence respondents found the human biomonitoring results complex to understand and not really meaningful for their personal lives. The medical and scientific framing of the study during the consent and recruitment phase created a mental distance for these participants and made them reluctant to contact the research team. To compensate for this lack of contextual information and perceived study support, some respondents searched for other information to construct their own interpretation of the results or chose to suppress or ignore their results.

Our follow-up study indicated that this knowledge construction of participants even starts early in the research process. For example, during recruitment and sampling, study documents that were deemed to be value-free and neutral, like the information brochure and the questionnaire, became part of the sensemaking process of participants. When these documents lack clear and transparent information, participants will form their own view about the study objectives. It therefore seems crucial to better explain why the various personal and intimate body samples were related to the general study objectives. According to some respondents, this should have been done with narrative information and oral communication rather than scientific information and written communication

During the report-back process, participants especially lacked health-based guidelines, a summary of key messages, and practical exposure-reduction advice with their personal results. This corresponds well with the typical participant questions identified by Brody et al. (2007). To make the results meaningful, personal results should ex-plain what is known and not known about health implications and exposure reduction (Brody et al., 2014). However, communicating health-based guidelines and exposure reduction actions is not without difficulties. Firstly, for many pollutants, health-based guidance values are subject to scientific discussion or are simply not available (Dunagan et al., 2013). Secondly, most guidelines are derived at the group level, which complicates individual health risk assessment. Thirdly, when participants do get to compare their results with guidance values, there is a risk that participants will either normalize problematic exposure results and have a false sense of safety when their score is below the guideline or cause unnecessary anxiety in case their value is above the guideline (Brody et al., 2007).

Another complexity in reporting back results is providing participants with clear and relevant exposure reduction strategies, as similar issues with health guidelines emerge. Brody et al. (Brody et al., 2007) state that recommendations for action should reflect the level of available knowledge about health effects and exposure reduction methods. Low knowledge of both factors results in recommendations for future research and more precautionary action; high knowledge of both factors results in a recommendation for public health policy and individual action. This requires combining evidence from biomonitoring studies and exposure science.

The abovementioned complexities call for a more tailor-made approach in which report-back methods, formats and content is diversified according to the type of results and the preferences of participants (Boronow et al., 2017). For instance, Rothstein (2006) suggested a “tiered disclosure approach” in the recruitment phase of a study in which participants could select from options for research disclosure, for instance to be notified by a physician or by letter. Buck et al. (2010) used personalized report-back protocols at the end of their biomonitoring study, by designing two versions of standardized letters depending upon participants results being either low or high. Participants with concentrations above a reference value received a “high letter” with extra guidance and additional information.

More recently, Boronow et al. (2017) have used digital methods to reduce practical barriers to report-back and to tailor disclosure preferences. Their Digital Exposure Report-Back Interface (DERBI) produces personalized result reports, based on scientific input and automated decision rules. Within a digital environment, participants can access and explore their personal results more easily and effectively by using a user-centered design and personalized software generated messages, together with a combination of text and interactive graphs. By offering participants complex information using information hierarchy, which combines understandable charts, short messages and text, the understanding of participants is maximized (Dunagan et al., 2013). To consult digital reports in DERBI, participants only need a computer with internet access. No software is required. A more optimal version for smartphone use is currently under development. This is an important adjustment for certain socially vulnerable groups.

Besides contextualized information, our follow-up interviews also revealed a perceived lack of opportunities to communicate and interact with the researchers. Concerning the recruitment and consent phase of the study, the interviewed women expressed the need for more face-to-face information about the study earlier in their pregnancy. This expectation of a timelier dialogue with researchers about the in-formed consent was also reported in other follow-up studies with mothers donating placenta samples (Halkoaho et al., 2010). For the report-back phase, women indicated a face-to-face consultation with the study physician would be a more accessible way to discuss results.

Interactive communication (home visits, community meetings) is an important way to build trust and understanding between scientists and participants (Lind et al., 2007; Perovich et al., 2018), but is especially challenging in cross-sectional and surveillance-based HBM programmes that use a more generalist approach and often have a more extensive timeframe be-tween recruitment and dissemination of results. In addition, a heterogeneous participant group with randomly selected volunteers from the general population is more difficult to mobilize around a specific problem or concern. When recruiting and sampling participants, study nurses invested a lot of time in personal contact to put participants at ease, and this was highly appreciated by the respondents. However, this personal contact could not be sustained until the dissemination of results. If face-to-face interaction after the recruitment phase is not feasible, creating a secure mailing list of interested participants could be helpful to maintain contact with the re-search team, for instance by a digital newsletter with updates of the research progress or an interactive webinar to discuss research results. This has been mentioned as an important tool to keep participants engaged throughout the study (Purvis et al., 2017).

From a researcher's perspective, interacting with participants could also be helpful in the design phase to shape study protocols and report-back materials to local and cultural needs (Ohayon et al., 2017; Perovich et al., 2018). This can be done by organizing an advisory committee and by pre-testing study documents with the target group (Claudio et al., 2018; Hernick et al., 2011).

The approximately 3-year interval between women's initial participation in the study and the follow-up interviews is without doubt a limitation to fully capture participant experiences in a human biomonitoring study. However, respondents were generally able to recall and articulate their initial feelings and experiences during study participation and after receiving results. Similar and even longer time lags are reported in other case studies that evaluate reporting back of personal biomonitoring results (Judge et al. 2016; Buck et al. 2010). Another limitation of this study is the limited sample size and the specific target group of mothers of newborns, which makes it difficult to generalize the results. In addition, the sample was not representative of HBM participants. Still, the study provides interesting insights and recommendations to improve report-back practices, which can be summarized as follows:

- Engage with participants in the designing phase of the study to obtain advice from the target audience and to pretest report-back materials.

- Communicate during the consent process regarding when and how research results will be returned to participants to help set appropriate expectations.
- Provide results reports in multiple formats that participants could choose from and diversify in the presentation of results.
- Define a clear general takeaway message, including practical recommendations, to reduce exposure to chemicals.
- Create opportunities to discuss results directly with researchers and other participants.

This study also contributes to describing European experiences regarding report-back of individual research results. The current literature is mainly based on US experiences, grounded in traditions of environmental justice and public sociology. These traditions have developed differently in Europe (Washburn, 2013b). An interesting question for future research would be whether and how this affects report-back practices.

7.5 Conclusions

The current study sheds light on some critical challenges related to the communication with research participants in the context of a surveillance-based HBM study, by showing how participants experienced the study, what they learned and gained from receiving their personal HBM-results, and the type of information they need. Under-standing the process and considering the sensemaking that participants experience during and after the study is of key importance when designing HBM report-back materials and protocols. We believe a reflexive research practice with active engagement in evaluative follow-up research is crucial to improve participants' understanding and use of personal HBM-results.

Supplementary Materials

The following are available online at https://www.mdpi.com/article/10.3390/toxics9040069/s1: Table S1 Data format used for individual report-back of HBM-results (translated from Dutch) (2013–2015), Table S2: Background information for individual report-back of HBM results (translated from Dutch) (2013–2015); Supplemented materials: Info brochure for HBM recruitment (translated from Dutch), Introductory letter for personal results report (translated from Dutch), Follow-up interview guideline.

Author Contributions

Conceptualization, B.M.; methodology, B.M., D.C. and E.D.H.; formal analysis, B.M.; writing—original draft preparation, B.M., H.J. and D.C.; writing—review and editing, E.D.H., A.C. (Ann Colles), G.S., N.V.L., T.N., A.C. (Adrian Covaci), V.N. and F.V.; supervision, I.L. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The FLEHS study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University Hospital of Antwerp on 7th October 2013 (registration number B300201318591). The follow-up study was approved by the Ethic Committee of the University Hospital of Antwerp with an amendment on 27th February 2018.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available due to privacy restrictions but are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Table S1: Data format used for individual report-back of HBM-results (translated from Dutch) (2013-2015)

Toxic metals	Your result	Results of all participants	
		Median	P90
Cadmium (µg/L)	X	0.021	0.034
Lead (µg/L)	X	6.07	11.50
Copper (µg/L)	X	570.95	685.61
Manganese (µg/L)	X	30.15	46.25
Thallium (ng/L)	X	18.00	26.31
Arsenic (µg/L)	X	0.653	2.845
Methylmercury in hair (µg/L)	X	0.30	0.71
Chlorinated substances			
PCBs (ng/g lipid)	X	24.15	53.19
Metabolite of DDT (ng/g lipid)	X	55.39	143.89
Hexachlorobenzene (ng/g lipid)	X	14.82	27.16
Oxychlordane (ng/g lipid)	X	1.52	2.89
Trans-nonachlor (ng/g lipid)	X	ND	2.88
Lindane (ng/g lipid)	X	3.8	7.7
Perfluorinated compounds			
PFOS (µg/L)	X	1.11	2.56
PFOA (µg/L)	X	1.27	2.14
PFHxS (µg/L)	X	0.37	0.74
PFNA (µg/L)	X	0.21	0.44

Supplementary Table S2: Background information for individual report-back of HBM results (translated from Dutch) (2013-2015)

Pollutants	What are the main sources in our environment?	How are humans exposed?	What are possible health risks?
Toxic Metals			
Cadmium in blood; exposure measurement of previous 3-4 months	• cigarette smoke • non-ferrous industry, scrap processing industry • in the past: domestic waste incinerators (e.g. battery combustion) and crematoria	• through smoking or exposure to secondhand smoke • eating vegetables from polluted areas (cadmium accumulation in vegetables) • inhalation of cadmium-laden dust	• kidney function disruption • increased risk of osteoporosis and bone fractures • carcinogenic (mainly lung cancer)
Lead in blood; exposure measurement of previous 3-4 months	• leaded paint • leaded drinking water pipes • ferrous and non-ferrous industry • in the past: leaded petrol	• inhalation of lead-contaminated dust • in regions with historical lead pollution (e.g. near industry or busy roads) lead particles can settle on vegetables and can pollute drinking water	• anemia • negative influence on intelligence in children • kidney function disruption • fertility problems • probably carcinogenic
Copper in blood; exposure measurement of previous days	• copper mining • landfill sites, waste incineration • timber production • fossil fuel combustion	• inhalation of copper-contaminated dust • in some regions, drinking water contains high concentrations of copper	• low concentrations are essential for good health • in case of prolonged, high exposure: headache, nausea, diarrhea, dizziness
Manganese in blood; exposure measurement of previous days	• Industry: metallurgy, chemical industry, glass production, leather and textile industry, fertilizers • important component in welding	• inhalation of manganese-containing dust near industry • when welding	• harmful to the nervous system
Thallium in blood; exposure period not known	• cigarette smoke • electronics industry, mineral melting furnaces, coal-fired power plants, cement and brick industries	• through smoking or exposure to secondhand smoke • fruits and vegetables grown near industries that process thallium	• prolonged exposure is harmful to the nervous system, heart, lungs, liver and kidneys

Arsenic in blood; measure of recent exposure (1-2 days)	• wood treatment • batteries, conductors, diodes • in the past: used as a pesticide, this is currently prohibited	• the amount of total arsenic reflects the toxic and non-toxic arsenic and is strongly influenced by the non-toxic form • fish is an important source of arsenic, but this is the non-toxic form of arsenic • exposure to toxic arsenic occurs through water, food and through the skin	• carcinogenic • skin diseases and skin irritation
Methylmercury (the toxic form of mercury) in hair	• thermometers, mercury vapor lamps, batteries, electric switches • amalgam tooth fillings • control of fungi	• fish is a major source of mercury • amalgam dental fillings release mercury in saliva • low exposure through air, water and food	• harmful to the nervous system • disruption of kidney function
Chlorinated substances			
PCBs (138, 153, 180) in blood; exposure measurement of last 10-20 years	• currently prohibited • in the past massively used in transformers, capacitors, paints, inks, insulating materials	• due to accidents and mistakes, PCBs have contaminated the food chain; since they are fat-soluble, they are mainly found in fatty foods (fatty fish, meat, dairy products) • PCBs may occur in the air near incinerators, crematoria	• endocrine disruptor; adverse effect on fertility • probably carcinogenic • harmful to the nervous system • disruption of the immune system
Metabolite of DDT in blood; exposure measurement of recent years	• insecticide • banned in Belgium since the 1970s but still allowed in countries with malaria	• DDT is fat-soluble and has accumulated in the food chain (especially high-fat foods like fatty fish, meat, dairy) • Via water, soil, dust, humans come into contact with DDT residues from historical pollution	• endocrine disruptor; adverse effect on fertility • possibly carcinogenic • harmful to the nervous system • disruption of the immune system

HCBB in blood; exposure measurement of recent years	• currently prohibited • fungicide for plants, seeds, cereals • in the past: used in manufacture of fireworks, ammunition and rubber	• HCB is fat-soluble and has accumulated in the food chain (especially high-fat foods such as fatty fish, meat, dairy). • through water, soil, dust, humans come into contact with residues of HCB from historical pollution	• endocrine disruptor; adverse effect on fertility • possibly carcinogenic • harmful to the nervous system • disturbance of the immune system
Chlordanes (oxychlordane, trans-nonachlor) in blood; exposure measurement of recent years	• insecticides on cereals, citrus fruits and in private lawns and gardens • Prohibited in Belgium for agricultural applications since 1981, for all other applications since 1998	• through water, soil, dust, humans come in contact with chlordane from historical pollution • chlordane accumulates in the food chain (fish, birds and mammals)	• harmful to the nervous system • endocrine disruptor • possibly carcinogenic
Hydrophobic perfluorinated compounds			
PFOS **PFOA** **PFHxS** **PFNA** in blood; exposure measurement of recent years	• used to make products water-, and grease-repellent, including tefal pans, cardboard drinking cups, furniture upholstery, carpets,... • used in fire extinguishers, cleaning products, cosmetics, film materials, ...	• perfluorinated food gets into the food through the use of (damaged) tefal pans, drinking cups, etc. • perfluorinated material can bind to dust particles (e.g. from carpets, furniture,...) and can be inhaled by humans. • perfluorinated products accumulate in the food chain (especially fish)	• endocrine disruptor; negative impact on fertility • harmful to the nervous system • harmful to the heart and blood vessels

References

Adams, C., Brown, P., Morello-Frosch, R., Brody, J.G., Rudel, R., Zota, A., et al., (2011). Disentangling the Exposure Experience: The Roles of Community Context and Report-Back of Environmental Exposure Data. *Journal of Health and Social Behavior*, 52(2), 180-196.

Altman, R.G., Morello-Frosch, R., Brody, J.G., Rudel, R., Brown, P., Averick, M. (2008). Pollution Comes Home and Gets Personal: Women's Experience of Household Chemical Exposure. *Journal of Health and Social Behavior*, 49(4), 417-435.

Boronow, K.E., Susmann, H.P., Gajos, K.Z., Rudel, R.A., Arnold, K.C., Brown, P., et al., (2017). DERBI: A Digital Method to Help Researchers Offer "Right-to-Know" Personal Exposure Results. *Environmental Health Perspectives*, 125(2), A27-A33.

Brody, J.G., Dunagan, S.C., Morello-Frosch, R., Brown, P., Patton, S., Rudel, R.A. (2014). Reporting individual results for biomonitoring and environmental exposures: lessons learned from environmental communication case studies. *Environmental Health*, 13(1), 40.

Brody, J.G., Morello-Frosch, R., Brown, P., Rudel, R.A., Altman, R.G., Frye, M., et al., (2007). Improving disclosure and consent: "is it safe?": new ethics for reporting personal exposures to environmental chemicals. *American Journal of Public Health*, 97(9), 1547-1554.

Buck, A.J., Vena, J.E., McGuinness, B.M., Cooney, M.A., Louis, G.M. (2010). Communicating serum chemical concentrations to study participants: follow up survey. *Environmental Health*, 9, 20.

Choi, J., Aarøe Mørck, T., Polcher, A., Knudsen, L., Joas, A. (2015). Review of the state of the art of human biomonitoring for chemical substances and its application to human exposure assessment for food safety. EFSA Support Publ. 12(2), 724E.

Claudio, L., Gilmore, J., Roy, M., Brenner, B. (2018). Communicating environmental exposure results and health information in a community-based participatory research study. *BMC Public Health*, 18(1), 784.

Colles, A., Bruckers, L., Den Hond, E., Govarts, E., Morrens, B., Schettgen, T., et al. (2020). Perfluorinated substances in the Flemish population (Belgium): Levels and determinants of variability in exposure. *Chemosphere*, 242, 125250.

Dunagan, S.C., Brody, J.G., Morello-Frosch, R., Brown, P., Goho, S., Tovar, J., et al. (2013). *When pollution is personal: Handbook for reporting results to participants in biomonitoring and personal exposure studies*. Newton, MA: Silent Spring Institute.

Emmett, E.A., Desai, C. (2010). Community First Communication: Reversing Information Disparities to Achieve Environmental Justice. *Environmental Justice*, 3(3), 79-84.

Exley, K., Cano, N., Aerts, D., Biot, P., Casteleyn, L., Kolossa-Gehring, M., et al. (2015). Communication in a Human biomonitoring study: Focus group work, public engagement and lessons learnt in 17 European countries. *Environmental Research*, 141, 31-41.

Halkoaho, A., Pietilä, A.-M., Dumez, B., Van Damme, K., Heinonen, S., Vähäkangas, K. (2010). Ethical aspects of human placental perfusion: interview of the mothers donating placenta. *Placenta*, 31(8), 686-690.

Hernick, A.D., Brown, M.K., Pinney, S.M., Biro, F.M., Ball, K.M., Bornschein, R.L. (2011). Sharing unexpected biomarker results with study participants. *Environmental Health Perspectives*, 119(1), 1-5.

Hintz, E.A., Dean, M. (2020). Best Practices for Returning Research Findings to Participants: Methodological and Ethical Considerations for Communication Researchers. *Communication Methods and Measures*, 14(1), 38-54.

Judge, J.M., Brown, P., Brody, J.G., Ryan, S. (2016). The Exposure Experience: Ohio River Valley Residents Respond to Local Perfluorooctanoic Acid (PFOA) Contamination. *Journal of Health and Social Behavior*, 57(3), 333-350.

Keune, H., Morrens, B., Loots, I. (2008). Risk communication and human biomonitoring: which practical lessons from the Belgian experience are of use for the EU perspective? *Environmental Health*, 7(1), S11.

Lind, U., Mose, T., Knudsen, L.E. (2007). Participation in environmental health research by placenta donation - a perception study. *Environmental Health*, 6, 36-43.

Louro, H., Heinala, M., Bessems, J., Buekers, J., Vermeire, T., Woutersen, M., et al. (2019). Human biomonitoring in health risk assessment in Europe: Current practices and recommendations for the future. *International Journal of Hygiene and Environmental Health*, 222(5), 727-737.

Middleton, D.R., Watts, M.J., Hamilton, E.M., Fletcher, T., Leonardi, G.S., Close, R.M., et al. (2016). Prolonged exposure to arsenic in UK private water supplies: toenail, hair and drinking water concentrations. *Environ Sci Process Impacts*, 18(5), 562-574.

Morello-Frosch, R., Brody, J.G., Brown, P., Altman, R.G., Rudel, R.A., Pérez, C. (2009). Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. *Environmental Health*, 8(1), 6.

Morello-Frosch, R., Varshavsky, J., Liboiron, M., Brown, P., Brody, J.G. (2015). Communicating results in post-Belmont era biomonitoring studies: Lessons from genetics and neuroimaging research. *Environmental Research*, 136, 363-372.

Needham, L.L., Calafat, A.M., Barr, D.B. (2007). Uses and issues of biomonitoring. *International Journal of Hygiene and Environmental Health*, 210(3-4), 229-238.

Ohayon, J.L., Cousins, E., Brown, P., Morello-Frosch, R., Brody, J.G. (2017). Researcher and institutional review board perspectives on the benefits and challenges of reporting back biomonitoring and environmental exposure results. *Environmental Research*, 153, 140-149.

Perovich, L.J., Ohayon, J.L., Cousins, E.M., Morello-Frosch, R., Brown, P., Adamkiewicz, G., Brody, J.G. (2018). Reporting to parents on children's exposures to asthma triggers in low- income and public housing, an interview-based case study of ethics, environmental literacy, individual action, and public health benefits. *Environmental Health*, 17(1), 12.

Purvis, R.S., Abraham, T.H., Long, C.R., Stewart, M.K., Warmack, T.S., McElfish, P.A. (2017). Qualitative study of participants' perceptions and preferences regarding research dissemination. *AJOB Empir Bioeth*, 8(2), 69-74.

Ramirez-Andreotta, M.D., Brody, J.G., Lothrop, N., Loh, M., Beamer, P.I., Brown, P. (2016). Improving Environmental Health Literacy and Justice through Environmental Exposure Results Communication. *International Journal of Environmental Research and Public Health*, 13(7), 690.

Reynders, H., Colles, A., Morrens, B., Mampaey, M., Coertjens, D., Koppen, G., et al. (2017). The added value of a surveillance human biomonitoring program: The case of FLEHS in Flanders (Belgium). *International Journal of Hygiene and Environmental Health*, 220(2), 46-54.

Rothstein, M.A. (2006). Tiered Disclosure Options Promote the Autonomy and Well-Being of Research Subjects. *The American Journal of Bioethics*, 6(6), 20-21.

Schoeters, G., Den Hond, E., Colles, A., Loots, I., Morrens, B., Keune, H., et al. (2012). Concept of the Flemish human biomonitoring programme. *International Journal of Hygiene and Environmental Health*, 215(2), 102-108.

Schoeters, G., Govarts, E., Bruckers, L., Den Hond, E., Nelen, V., De Henauw, S., et al. (2017). Three cycles of human biomonitoring in Flanders − Time trends observed in the Flemish Environment and Health Study. *International Journal of Hygiene and Environmental Health*, 220(2, Part A), 36-45.

Washburn, R. (2013a). Rethinking the disclosure debates: a situational analysis of the multiple meanings of human biomonitoring data. *Critical Public Health*, 23(4), 452-465.

Washburn, R. (2013b). The Social Significance of Human Biomonitoring. *Sociology Compass*, 7(2), 162-179.

WHO (2015). Human biomonitoring: facts and figures. World Health Organisation, Regional Office for Europe.

Chapter 8 Lucht in je Leven – Een pilootproject rond milieu en gezondheid bij sociaal kwetsbare doelgroepen

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Samenvatting

Informatiecampagnes rond milieu en gezondheid bereiken moeilijk sociaal kwetsbare groepen, terwijl net deze groepen onevenredig getroffen worden door milieugezondheidsrisico's. In een pilootproject werd door Universiteit Antwerpen (UA) en het Vlaams Instituut voor Gezond Leven (VIGL) nagegaan hoe bestaande informatie en sensibilisering over deze risico's beter toegankelijk gemaakt kan worden en meer impact kan hebben bij kansengroepen. Het project toonde aan dat vertrouwen, een intensief en participatief traject, gekoppeld aan een bestaande groepswerking en het plaatsen van milieugezondheidsboodschappen in een positief kader belangrijke randvoorwaarden zijn voor een succesvol traject. Dit project liep in opdracht van het Departement Omgeving.

8.1 Probleemstelling

Dat personen met een lage sociaaleconomische status minder goed bereikt worden als het gaat over milieu en gezondheid werd meermaals vastgesteld, onder andere in het Steunpunt Milieu en Gezondheid (Morrens et al. 2015). Het Steunpunt onderzoekt de blootstelling aan chemische stoffen door het meten van die stoffen in bloed en urine van mensen die gerekruteerd worden in Vlaanderen. De participatie van sociaal kwetsbare groepen – zoals lager geschoolden, mensen in armoede of mensen met een migratieachtergrond – aan dit soort onderzoek wordt vaak gehinderd door verschillende soorten drempels. Het gaat om praktische obstakels en taalbarrières, maar ook om gevoelens van wantrouwen tegenover wetenschappers en bepaalde culturele of religieuze gebruiken (Morrens et al. 2017).

Het beter bereiken en betrekken van kansengroepen is echter belangrijk omdat uit de literatuur en de praktijk blijkt dat net deze groepen vaak een hogere blootstelling hebben aan milieuvervuiling én meer vatbaar zijn voor de gezondheidseffecten van milieuvervuiling (Morello-Frosch et al. 2011; Morrens et al. 2014). Het Departement Omgeving wilde daarom via een pilootproject onderzoeken of en hoe bestaande informatie en sensibilisering over milieu en gezondheidsrisico's beter toegankelijk gemaakt kan worden en meer impact kan hebben bij kansengroepen.

Het pilootproject werd uitgevoerd door de Universiteit Antwerpen (Departement Sociologie) en het Vlaams Instituut voor Gezond Leven. Het project startte met een beperkte literatuurstudie, verkenning van bestaande tools en praktijken en consultatie van een aantal organisaties die werken met kansengroepen. Het resultaat hiervan gaf input voor het opzetten van het project op een concrete locatie. Uit de consultaties bleken twee milieu-en gezondheidsthema's prioritair te zijn om de verbinding met kansengroepen te maken: binnenhuismilieu en lokaal geteelde voeding.

In overleg met de projectstuurgroep werd gekozen voor de Antwerpse wijk het Kiel. Een inbedding van het project binnen de basiswerking van vzw Samenlevingsopbouw Antwerpen stad maakte het mogelijk rond beide thema's een participatief traject op te zetten met twee bestaande netwerken van mensen met een sociaal kwetsbare achtergrond. Het project kreeg in samenspraak met Samenlevingsopbouw de naam 'Lucht in je Leven'.

Dit artikel beschrijft het praktische verloop van het project en vat een aantal drempels en succesfactoren samen.

Het Kiel: bewoners en wijkwerking

Het Kiel is een wijk in Antwerpen, ten zuiden van het stadscentrum met ongeveer 20.000 inwoners. Het is een erg diverse wijk met een hoog aandeel inwoners met een herkomst van een niet EU-Land (45,7%). Bijna 4 op 10 woningen zijn sociale (huur-)woningen, vaak in hoge woonblokken (Stadsmonitor Antwerpen, 2014).

Het team buurtwerk Kiel van Samenlevingsopbouw Antwerpen heeft al enkele jaren een actieve vrouwenwerking opgericht op het Kiel. De vrouwengroep bestaat uit een 30 tal vrouwen van tussen de 40 en de 65 jaar, grotendeels eerste generatie allochtonen. Ze komen wekelijks samen voor activiteiten die steunen op drie pijlers: ontmoeting, leren en taal. Binnen deze groep werd gezondheid al meermaals als prioriteit aangegeven (vooral problematiek van stress, voeding en beweging). Er was echter ook interesse om aan de slag te gaan met gezond wonen. Zowel de staat van de woning als het gedrag van bewoners kunnen een woning minder gezond maken. Bewoners hebben echter weinig mogelijkheden om iets aan de staat van hun woning te doen omdat ze vaak geen eigenaar zijn en voor renovatie of aanpassingen afhankelijk zijn van de eigenaar. Bij dit thema is het daarom erg belangrijk om steeds de omgevingsfactoren te erkennen en niet enkel te wijzen op gedrag van bewoners als oorzaak voor een minder gezonde woning.

Naast de vrouwenwerking is Samenlevingsopbouw sinds 2013 ook gestart met twee kleine collectieve tuinen waar groenten gekweekt worden. Een groep van ongeveer 20 vrijwillige tuinders uit de buurt onderhoudt de tuinen. De tuinen zijn opgestart vanuit de nood aan sociale cohesie in de buurt en hebben een sterke link naar duurzaamheid. Onrechtstreeks is er ook wel een focus op gezondheid, zoals mogelijke bodem- en watervervuiling en gebruik van pesticiden, maar het ontbreekt de organisatie aan mankracht om dit thema systematisch te integreren in het tuinproject.

8.2 Aan de slag

Gezond wonen en gezond tuinieren bleken de thema's die aansluiting vonden bij de bestaande werking van Samenlevingsopbouw. Aandachtspunten waren om bij het thema gezond wonen niet te vervallen in negatieve boodschappen of de schuld te leggen bij bewonersgedrag. Doel was eerder om gezond wonen op een positieve manier in beeld te brengen door het thema te laten aansluiten bij eigen ervaringen van de vrouwengroep. Voor gezond tuinieren was het de bedoeling om milieu- en gezondheidsaspecten te integreren in het bestaande project van Samenlevingsopbouw. Ideaal zou zijn dat de kennis wordt uitgedragen naar andere deelnemers.

Uitgangspunt is ook om het traject mee te laten dragen door de mensen zelf. Daarvoor is het nodig om veel tijd te investeren in het opbouwen van een wederzijdse relatie en meer inzicht te verwerven in wat mensen drijft en te zoeken naar de verschillen in leefwereld. Om dit te bereiken, namen de onderzoekers deel aan verschillende activiteiten.

8.2.1 Gezond wonen

Gezond wonen werd ingepast in de werking van de bestaande vrouwengroep die begeleid werd door Samenlevingsopbouw. De mogelijkheden om het thema te laten aansluiten bij de leefwereld werden bepaald tijdens deelname aan een aantal activiteiten. Drie initiatieven werden binnen het project opgezet: i) een aantal interactieve infosessies tijdens bestaande ontmoetingsmomenten van de vrouwengroep; ii) een integratie van het thema gezond wonen in een Taal*Oor sessie, een ruimere groep van anderstalige buurtbewoners die via informele praatmomenten met vrijwilligers Nederlands leren; en iii) een afsluitende gezondheidsquiz in combinatie met enkele huisbezoeken om de kennis van de vrouwen rond binnenhuismilieu te evalueren. De infosessies werden georganiseerd door de projectmedewerkers van het Vlaams Instituut voor Gezond Leven en de medisch milieukundige van Logo Antwerpen.

De eerste sessie had als doel om inzicht te verwerven en aansluiting te vinden bij de deelneemsters van de vrouwengroep en te peilen naar hun attitudes, kennis en gedrag rond gezond wonen. Werkvormen zonder woorden zorgden dat alle taalniveaus konden deelnemen. Vooral de onderwerpen gezond poetsen, brandveiligheid en gezond bewegen vonden de vrouwen boeiend om meer over te weten.

De volgende sessie ging over gezond poetsen. Cultureel bepaalde beeldvorming (bv. met javel poetsen), beperkingen in de woning en weinig bekendheid met alternatieve en meer gezonde producten bleken vooral aan de oorzaak te liggen van ongezond poets- en onderhoudsgedrag. Een eenmalige sessie leek niet voldoende om hardnekkige mythes en patronen te doorbreken. Toch bleken boodschappen over het belang van verluchten en het gebruik van gezondere producten de vrouwen het beste bij te blijven. Gezondheid werd door de vrouwengroep ook breder bekeken dan enkel milieugezondheidsthema's, gezond bewegen hoort daar voor hen ook bij. De volgende sessie ging daarom over bewegen in hun groepswerking zelf en over de mogelijkheden om te bewegen thuis en in de wijk.

De laatste sessie ging over koolstofmonoxide (CO). CO bleek zowel onbekend als moeilijk voor deze groep. De techniciteit was groot, terminologie en beeldherkenning vroegen bezinktijd. Boodschappen moeten beperkt blijven tot eenvoudige handelingen. Uit de evaluatie bleek hoe belangrijk het is om niet enkel te peilen naar de interesse in een thema, maar ook naar de aanwezige voorkennis en ervaringen. Zo werd vermeden om te snel het gevraagde thema in te vullen vanuit de expertise, achtergrond en aanwezige materialen die al bestaan en niet vanuit de behoeften, kennis en attitudes van de doelgroep.

Naast de infosessies werd gezond wonen als thema ook gebruikt als onderwerp voor twee 'babbel momenten' met Taal*Oor. Taal*Oor werkt aan het verwerven van taal door op een informele manier te praten over allerhande onderwerpen. De begeleiders van die momenten zijn vrijwilligers. Het bleek nuttig om op voorhand een kort mondeling overleg te organiseren met die vrijwilligers om ervoor te zorgen dat ze boodschappen juist weergeven. Een schriftelijke voorbereiding werkte niet omdat de vrijwilligers niet de tijd of de energie hadden om deze op voorhand goed door te nemen. Tijdens de momenten werd gebruik gemaakt van praatplaten, visueel uitgewerkte afbeeldingen van een woonkamer, keuken, badkamer en slaapkamers, telkens opgedeeld in een goede en foute zijde.

Gezond wonen stond dicht bij de ervaring van de deelnemers, zodat persoonlijke verhalen kunnen bovenkomen. Werken met kleine groepen zorgde dat ook persoonlijke vragen aan bod kwamen. De complementariteit met de voorbije werking in de vrouwengroep maakte dat deze deelneemsters ook zelf de boodschap uitdroegen. Ook voor concrete voorbeelden is het nodig om de leefwereld van andere culturen te kennen. Verwijzen naar huisdieren (omgaan met kattenbakken) bleek bijvoorbeeld niet herkenbaar voor de deelnemers van Marokkaanse afkomst. De thematieken die we reeds kenden (zoals ontsmettingsgedrag, cf. de overgenomen attitude t.o.v. javel) kwamen hier terug. Financiële motivatie (als gezond ook minder duur is, bijvoorbeeld zelf gezonde poetsproducten maken) kan helpen voor gedragsverandering.

Het traject in de vrouwengroep werd afgesloten met een gezondheidsquiz die zowel een feestelijk afsluitmoment van het gezond wonen traject was, alsook een evaluatiemoment om te peilen naar de opgedane kennis door middel van eenvoudige meerkeuzevragen. Uit de verwerking van de resultaten bleek dat de inhoud van de sessies goed was onthouden door de deelnemers.

Een aantal vrouwen uit de groep was ook bereid om deel te nemen aan een diepte-interview waardoor dieper kon ingegaan worden op verwerving van kennis en verandering van attitude. De infosessie werd als methodiek gewaardeerd. De vrouwen waren blij dat ze nieuwe dingen hadden kunnen leren. De sessies werden ook niet als belerend ervaren. Het werken met afbeeldingen werd positief bevonden. Uit de interviews bleek dat de kennis over binnenmilieu goed werd opgefrist, een aantal vrouwen wees er ook op dat ze de kennis al hadden doorgegeven aan anderen. Opmerkelijk was dat de vrouwen spontaan spraken over kleine gedragsveranderingen en toegenomen risicobewustzijn, vooral over het belang van gevaarsymbolen op poetsproducten en het risico bij het mengen van producten.

8.2.2 Gezond tuinieren

Net als bij gezond wonen werd bij dit thema ingezet op draagvlakverwerving in samenwerking met Samenlevingsbouw. Daarvoor werden een aantal momenten met de doelgroep georganiseerd om aansluiting te vinden en te peilen naar thema's die interesse opwekten.

Op een startdag werden de thema's gezond bewegen in de tuin, gezonde bodem en gezond water, maar ook taalverwerving en samenwerken naar voren gebracht. Nog meer dan het gezond wonen traject was dit een integrale problematiek waarin verschillende gezondheidsthema's met elkaar verweven zijn. Er lag ook meer eigenaarschap bij de vrijwilligers en hun begeleider van Samenlevingsopbouw. In plaats van trekker zoals bij de vrouwengroep, was de rol van de onderzoekers eerder coaching en ondersteuning en gebeurde de uitvoering in de praktijk meer door Samenlevingsopbouw.

In samenwerking met VLACO (www.vlaco.be) gaven we de eerste insteek vanuit ergonomie. Met 'Gezond bewegen in de Samentuin', een volgende sessie, volgden we de klassieke weg van algemene ergonomische informatie over concrete toepassing in de tuin naar bewegingen oefenen in de tuin zelf. De relevantie en herkenbaarheid ging daarmee in stijgende lijn. Sneller in de 'real world' van de tuin werken met de informatie gaf meer herkenning. Reminders achterlaten (bv. in de vorm van een bundeltje slides met concrete tips) werd positief ervaren om meerdere keren op het geleerde terug te komen. De vorming rond gezond bewegen werd ook door Samenlevingsopbouw positief ervaren, vooral omdat deze in de tuin zelf plaatsvond waardoor de tuinders konden oefenen in hun vertrouwde omgeving en met hun eigen gereedschap.

Om aandacht te wekken voor gezond tuinieren werd een staalname van de bodem en van het putwater in de tuinen uitgevoerd waaruit bleek dat de bodem geschikt was om groenten in te telen. Het putwater had een mindere kwaliteit en kon niet meer gebruikt worden. Deze boodschappen hebben de doelgroep goed bereikt en waren niet te moeilijk of te belerend. Het putwater wordt resoluut niet meer gebruikt in de tuin, enkel nog voor de bloemen. De tuinders geven deze boodschap ook zelf door aan nieuwe vrijwilligers. De vrijwilligers met een hoger taalniveau gingen in de zomerperiode ook geregeld in gesprek met de opbouwwerkers over mogelijke oorzaken en oplossingen voor het putwater.

De sessie 'gezond uit eigen grond' ging zowel over de omgevingselementen als over het eigen gedrag. Op basis van de uitslag van het bodem- en wateronderzoek zocht de groep naar goede oplossingen. Met een spel rangschikte de deelnemers zelf ongezonde en gezonde gedragselementen om dan samen gezonde alternatieven te zoeken voor de ongezonde. Rond elementen zoals gebruik van pesticiden bleek reeds heel wat kennis van gezonde alternatieven aanwezig. De begeleiding bracht enkel waar nodig bijkomende informatie aan. Gebruik van het magnetenspel van het Departement Omgeving was een succes omwille van de combinatie tussen informatieoverdracht en doe-activiteiten. Er was veel interactie met de groep, de sfeer was ontspannen en er werd goed geluisterd.

De onderzoekers wilden een stap verder gaan in het ownership door de groep zelf communicatiemateriaal te laten ontwikkelen over de milieu- en gezondheidsboodschappen. De voorstellen vanuit onze ondersteuning zoals een youtube filmpje of een fotoreportage werden niet goed onthaald omdat sommige tuinders niet graag herkenbaar in beeld wilden komen via online media.. Na een lang proces was er toch eensgezindheid om een informatief kwartetspel Samentuinen te ontwerpen dat niet enkel voor de tuinders handig was, maar ook naar andere groepen gebracht kan worden.

De vrijwilligers begeleidden zelf de verdere brainstorm rond deze thema's, wat meteen ook een goede taaloefening was Het proces leidde uiteindelijk tot een educatief kwartetspel over gezond tuinieren, een combinatie van ervaringskennis en expertise. Bij het uitwerken van het kwartet (thema's bedenken en foto's nemen) werden uiteindelijk 10 à 15 vrijwilligers actief betrokken. Dit was enkel mogelijk omdat we gestart zijn bij samenwerking met de sleutelfiguren, die als enige de positie hebben om anderen mee te trekken. Sleutelvrijwilligers die bv. zorgden voor de brainstorm over het kwartetspel, zorgen voor meer eigenaarschap bij de groep. De keuze van het product, het kwartetspel, lag ook helemaal bij de groep en de uitwerking werd ook door hen uitgevoerd. Dat zorgde ervoor dat de groep ook verantwoordelijk werd voor zowel aanmaak als gebruik. Samenlevingsopbouw zorgde hier ook meer dan bij gezond wonen voor de uitvoering in de praktijk, de onderzoekers stonden meer op de achtergrond. Dit soort methodiek zorgt ervoor dat de werking kan verder gezet worden als het project afgelopen is.

8.3 Succesfactoren en drempels

8.3.1 Koppel het thema milieu en gezondheid aan bestaande groepswerkingen

Uit het project op het Kiel blijkt dat sociaal contact en Nederlandse taalverwerving een belangrijke drijfveer vormen voor vrouwen met een migratieachtergrond, om wekelijks deel te nemen aan de bijeenkomsten van de vrouwengroep. Zowel uit de deelnameregistratie als uit de inhoudelijke evaluaties van deelnemers en praktijkwerkers blijken dit goede toegangspoorten om onze thema's aan te verbinden. In vergelijking met een 'open aanbod' waar op basis van het gezondheidsthema deelnemers geworven worden was het bereik met de bestaande vrouwengroep veel groter, terwijl het thema bij hen ook aansloeg.

Uit interviews met een aantal vrouwen na afloop van het project bleek dat ze sommige boodschappen zelf uitgedragen hadden naar familie of kennissen. Ook de aanwezigheid van de vaste begeleiding creëert een gerust klimaat. Wanneer bepaalde inhoud voor hen niet duidelijk was, deden deelnemers beroep op de groepswerker.

Omdat gewerkt werd in bestaande groepen, voorzien van een sterke en gemotiveerde coaching vanuit de projectmedewerkers die een brug vormden tussen de bestaande groepswerkers van Samenlevingsopbouw en de vormingswerkers (Logo Antwerpen, Vlaco), konden sterkere participatievormen gebruikt worden. Methodieken die goed werkten waren bijvoorbeeld praatplaten en het spel 'gezond uit eigen grond', waarbij de kennis in eerste instantie vanuit de groep boven komt en dan pas aangevuld wordt vanuit expertise. In de tuingroep leidde dit tot een eigen idee (eigenaarschap) van een werkvorm en materiaal waarmee naar buiten gekomen kan worden.

8.3.2 Besteed voldoende aandacht aan voortraject en bouw flexibiliteit in

Tijdens dit project werd duidelijk dat er nood is aan een lange inlooptijd. Die inlooptijd is nodig om vertrouwen te winnen en noden in te schatten en moet dus ook voorzien worden in projecten van de overheid.

Naast dit voortraject bleek uit dit project dat er een organische en flexibele planning nodig is (in tegenstelling tot een lineaire planning die meer gebruikelijk is in onderzoeksprojecten). Er bleek nood aan constante bijsturing en evaluatie van de planning. De inhoud van de infosessies werd aangepast aan de vragen en noden van de vrouwengroep. Voor de tuinders werd een sessie over ergonomie georganiseerd alhoewel dat niet echt een milieugezondheidsthema is (maar wel over gezondheid gaat).

8.3.3 Plaats milieu en gezondheid in een positief en integraal frame

We merkten bij kansengroepen een hoog ‘allergiegehalte’ voor negatieve of belerende boodschappen die te sterk uitgaan van individuele gedragsverandering. Kansengroepen hebben vooral nood aan erkenning en bevestiging en concrete handvaten om tot verbetering te komen. Daarnaast merkten we ook hoe de maatschappelijke beeldvorming rond gezondheid en hygiëne kan zorgen voor gevoelens van schuld en schaamte bij kansengroepen omdat die beeldvorming geworteld is in culturele en sociale praktijken. Zo gaat het veelvuldig gebruik van javel bijvoorbeeld terug op het assimilatieproces van eerstegeneratieallochtonen die met javel moesten poetsen om proper te zijn en zich ‘aan te passen’.

We probeerden in het pilootproject aandacht te hebben en open te staan voor deze context en omgevingsfactoren. Daarom werd ongezond gedrag niet als het resultaat van eigen keuzen gebracht, maar als aandachtspunt voor iedereen. Door kennisdeling en steun in groep kunnen deelnemers op eigen kracht betere keuzes maken en mogelijkheden afwegen. Dit helpt ook om persoonlijke verhalen naar boven te halen en de problematiek te benoemen. Bijkomend worden op die manier nieuwe woorden geleerd waardoor communicatieve vaardigheden versterkt worden.

Gedragssturing bij kansengroepen werd in dit project dus niet top-down opgedrongen maar groeide eerder bottom-up door hefbomen uit de sociale omgeving en sociaal kapitaal in de groep op te bouwen en te ondersteunen. Dit sluit nauw aan bij recente inzichten uit de gezondheids- en gedragswetenschappen die wijzen op het belang van context, sociale praktijken en structuren eerder dan op individueel gedrag en verantwoordelijkheid om sociale ongelijkheden in milieu en gezondheid aan te pakken (Frohlich en Abel 2013).

Positieve framing zoals de organisatie van een ludieke quiz als afsluiter van de infosessies over gezond wonen zorgde ook voor meer impact en zelfs tot uitdragen van die boodschappen naar anderen. De tuinders dachten samen met de vrijwilligers en opbouwwerkers na over een eindproduct om de kennis te kunnen overdragen. Deze co-creatie leidde tot de ontwikkeling en verspreiding van een kwartetspel over gezond tuinieren.

Uit het pilootproject bleek ook dat er nood is aan een integrale benadering van de milieu- en gezondheidsinfo. Beleidsmakers en professionals hebben de neiging om alles rond milieu en gezondheid thematisch op te splitsen (bewegen, voeding, binnenhuis, …). Maar eigenlijk doen mensen dat niet. De boodschap moet dus gebracht worden in een totaalpakket aangepast aan de noden en dagelijkse gewoonten van de doelgroep. De naam van het project ‘Lucht in je Leven’ verwijst naar de integrale kijk van de doelgroep op de problematiek die er voor hun voornamelijk uit bestaat zich zorgelozer, vrijer en weerbaarder te willen voelen.

8.3.4 Besteed voldoende aandacht aan herhaling en visualisatie

Aandacht voor herhaling en visualisatie bij het overbrengen van boodschappen bleek ook in dit project erg belangrijk. Je moet ervoor zorgen dat de boodschap die je wil uitdragen ook ontvangen wordt. Een van de manieren om dat te bereiken is herhalen van de boodschap tijdens verschillende acties en sessies. De evaluatie en interviews met deelnemers gaven aan dat dit niet als belerend werd ervaren.

8.4 Conclusie

Het pilootproject ‘Lucht in je Leven’ heeft in de praktijk aangetoond dat sociaal kwetsbare groepen wel degelijk bereikt kunnen worden met milieu- en gezondheidsboodschappen. Het project toonde aan dat vertrouwen, een intensief en participatief traject, gekoppeld aan een bestaande – en daardoor motiverende – groepswerking en het plaatsen van milieugezondheidsboodschappen in een positief kader belangrijke randvoorwaarden zijn voor een succesvol traject. Dankzij intensieve participatie werd de informatie rond milieu en gezondheid niet enkel opgenomen en toegepast in de groep, maar werd ze ook doorgegeven en uitgedragen naar anderen. Dit proces kan een belangrijke eerste stap vormen om mensen weerbaarder te maken om met milieugezondheidsproblemen om te gaan.

Het Departement Omgeving zal de conclusies van dit onderzoek toepassen bij toekomstige projecten zoals bij de rekrutering van deelnemers voor humane biomonitoring en bij het plannen en uitvoeren van meetcampagnes om de kwaliteit van de binnenlucht in gebouwen te bepalen. Het Departement omgeving wil ook informatie- en sensibilisatiecampagnes beter afstemmen op sociaal kwetsbare groepen.

Het volledige rapport van dit pilootproject kan je terugvinden op de Flanders Research Information Space (FRIS): https://researchportal.be/nl/publicatie/pilootproject-sociale-ongelijkheid-en-milieu

Referenties

Frohlich K.F., Abel T. (2013), Environmental justice and health practices: understanding how health inequities arise at the local level, *Sociology of Health & Illness*, 36(2): 199–212.

Morello-Frosch R., Zuk M., Jerrett M., Shamasunder B., Kyle A. (2011), Understanding The Cumulative Impacts Of Inequalities In Environmental Health: Implications For Policy, *Health Affairs*, 30(5): 879-887.

Morrens B., Loots I., Bruckers L., Colles A., Den Hond E., Schoeters G., Nelen V., Sioen I., Coertjens D., Croes K., Van Larebeke N., Baeyens W. (2014), Hoe milieuongelijkheid op zich ongelijk kan zijn: blootstelling aan milieuvervuilende stoffen bij buurtbewoners van industriezones, in: Dierckx D., Coene J., Raeymaeckers P. (red.), *Armoede en Sociale Uitsluiting, Jaarboek 2014*, Acco, Leuven/Den Haag, p. 229-249.

Morrens B., Loots I., Paulussen M., van de Mieroop E., Den Hond E., Schoeters G., Akhandaf Y., Veldwerkcomité Steunpunt Milieu en Gezondheid (2015), *Een verkenning van de drempels en hefbomen voor deelname van kansengroepen aan de Vlaamse meetcampagne milieu en gezondheid*, Eindrapport haalbaarheidsproject.

Morrens B., Den Hond E., Schoeters G., Coertjens D, Colles A., Nawrot T.S., Baeyens W., De Henauw S., Nelen V., Loots I., (2017), Human biomonitoring from an environmental justice perspective: supporting study participation of women of Turkish and Moroccan descent, *Environmental health*, 19; 16(1): 48.

Demowoning, Lokaal Gezondheidsoverleg: www.gezondheidenmilieu.be/data/files/Actieweek%202015/actiefiche%20demowoning.pdf

Infosessie gezond poetsen, Lokaal Gezondheidsoverleg: www.gezondheidenmilieu.be/data/files/Actieweek%202015/vormingsfiche%20workshop%20proper%20thuis.pdf

Gezond uit eigen Grond, Departement Omgeving, 2016: www.gezondheiduiteigengrond.be

Kwartetspel Gezond tuinieren, 2016, https://samenlevingsopbouw-antwerpenstad.be/wat-doen-we/projecten/buurtwerk-kiel/een-educatief-zond-tuinieren/

Stadsmonitor Antwerpen, 2014, https://stadincijfers.antwerpen.be/dashboard/Stadsmonitor

Chapter 9 General conclusions

In this doctoral thesis, I aimed to disentangle the connections between social inequality and human biomonitoring (HBM) in Flanders in a twofold manner: a quantitative approach to stratify human HBM results according to different social and ethnic indicators and a qualitative approach to make HBM research practices more inclusive and accessible to vulnerable groups. In this concluding chapter, I will summarize the main findings for each approach and link back to the literature. In addition, I discuss some recommendations for each approach to better align a social justice agenda with future human biomonitoring research and its translation into policy.

9.1 Social inequality in human biomonitoring results

A first objective of my dissertation was to examine patterns of inequality within the biomonitoring results of the Flemish Environmental Health Studies (FLEHS). This objective was divided into two research questions: *how are body concentrations of environmental chemicals stratified by socioeconomic and ethnic indicators* (RQ1)? And *how can inequalities in chemical exposure be explained* (RQ2)?

9.1.1 Summary of main findings

Chapters 2 through 4 described the peer-reviewed social stratification results of three consecutive human biomonitoring (HBM) studies with adolescents (FLEHS I, II and III). In addition, chapter 5 contained a preparatory stratification analysis of the HBM study with mothers of newborns (FLEHS III) (results not yet published). Throughout these different chapters, I assessed a total of 23 chemical substances, and for each of them (except for chromium), I found at least one significant relation with an indicator of socioeconomic position (SEP) or ethnic background ($p \leq 0.05$), indicated by dots in the overview Table 29. This means that in Flanders, internal exposure to chemicals is – to some extent – socially patterned. However, the direction of the relationships goes in both directions: a lower SEP or ethnic background is in some cases associated with a higher exposure (red dot in table 1) and in other cases associated with a lower exposure (blue dot). The proportion of negative and positive associations is about equal, but the direction seems to depend on the type of chemical pollutant. Exposure to toxic metals, volatile organic compounds and phthalates is mostly negatively associated with SEP, while exposure to POPs and PFAS is mostly positively associated with SEP. Although not all biomarkers were measured in all studies (indicated by shaded boxes in Table 29), we see that for PCBs and lead, social differences are most consistent across the different FLEHS studies (with a time span of 2003 to 2014).

Table 29: Global overview of all social stratification results from the different chapters

		Chapter 2 (FLEHS I)	Chapter 3 (FLEHS II)				Chapter 4 (FLEHS III)			Chapter 5 (FLEHS III)		
			Genk-Zuid		Menen							
Exposure Biomarkers		Education	Education	Schooltype	Education	Schooltype	Education	Schooltype	Income	Education	Income	Migrant B.
Metals	Lead		● (−)	● (−)	● (−)		///	///	///	● (−)		● (−)
	Cadmium	● (−)		● (−)			///	///	///		● (−)	● (−)
	Arsenic	///					///	///	///	● (+)		
	Manganese	///					///	///	///			● (−)
	Chromium	///			///	///	///	///	///	///	///	///
	Copper	///		● (−)	● (−)		///	///	///	///	///	///
	Thallium	///	● (+)				///	///	///	///	///	///
	Antimony	///		● (+)	● (−)		///	///	///	///	///	///
POPs	PCBs	● (+)	● (+)	● (+)	● (+)	● (+)	///	///	///	● (+)	● (+)	
	DDE	● (+)					///	///	///			● (−)
	HCB	● (+)					///	///	///	///	///	///
	Diox. PCB's	///		● (+)			///	///	///	///	///	///
	Dioxines	///					///	///	///	///	///	///
	BDE-153	///	● (+)	● (+)			///	///	///	///	///	///
	Oxychl	///	///	///	///	///	///	///	///	● (+)	● (+)	● (+)
	B-HCH	///	///	///	///	///	///	///	///			● (−)
VOCs	PAHs				● (−)		///	///	///	///	///	///
	t,t-MA			● (−)	● (−)	● (−)	///	///	///	///	///	///
Phtha-lates	DEHP	///	///	///	///	///		● (−)	● (−)	///	///	///
	MiBP	///	///	///	///	///	● (−)		● (−)	///	///	///
	MEP	///	///	///	///	///	● (−)	● (−)	● (−)	///	///	///
PFAS	PFOS	///	///	///	///	///	///	///	///	● (+)	● (+)	● (+)
	PFOA	///	///	///	///	///	///	///	///	● (+)	● (+)	● (+)

● (−) Significant negative association (p≤ 0.05): higher exposure for lower SEP categories

● (+) Significant positive association (p≤ 0.05): higher exposure for higher SEP categories

/// Not measured

Two additional conclusions can be drawn based on the various stratification analyses.

First, a gradient rather than a threshold was observed for most associations, meaning that internal exposure levels increase or decrease incrementally for each subcategory of educational attainment, school type, income, or migration background. For example, in chapter 2, a positive social gradient (based on parental education) was found for exposure to PCBs, and in chapter 4, a negative social gradient (based on family income) was found for exposure to phthalates in FLEHS III, as illustrated in Figure 12 and Figure 13 respectively. These gradients reinforce the hypothesis that exposure to environmental pollution is a socially graded problem that runs through an entire society and does not only affect the most disadvantaged group. As we saw in section 1.3, the identification of such a social gradient is an important condition for considering an unequal distribution as unjust because it reinforces the notion that inequality is avoidable and has an underlying social cause (McCartney, Popham, et al., 2019).

Figure 12: Example of a positive social gradient: exposure to PCBs in adolescents (FLEHS I), by parental education

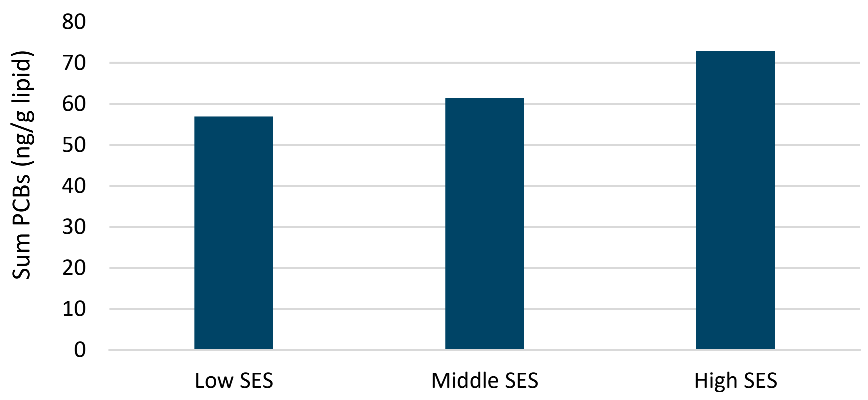
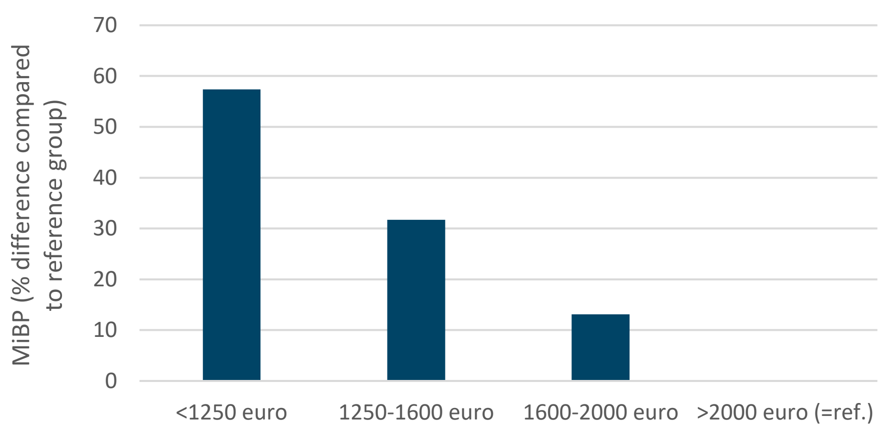


Figure 13: Example of a negative social gradient: percentual difference in exposure to phthalate marker MiBP in adolescents (FLEHS III), by family income



Second, stratification patterns depended on the social or ethnic indicator used, meaning that these indicators are not interchangeable and represent separate influences on exposure. For example, in Chapter 3, I found that social gradients in exposure to metals and volatile compounds were more related to adolescent school type than to the educational level of their parents. In Chapters 4 and 5, emerging chemicals, such as phthalates and PFAS, were found to be most strongly correlated with family income, presumably through the influence of consumption patterns. And finally, in Chapter 5, exposure to long-banned pesticides DDE and lindane was associated with specific migration backgrounds, but not with income or education, presumably through the influence of cultural food habits, imported consumption products or intergenerational exposure.

An integral part of each analysis was a further search for underlying factors to might explain the associations found between SEP and chemical exposure. Throughout the various chapters, I identified several (sets of) factors related to lifestyle, diet, housing, and consumption that contributed to positive gradients (higher exposure for higher SEP) and negative gradients (higher exposure for lower SEP). Positive associations (the red dots in the summary table) could be partially explained by the fact that participants with higher SEP generally: had a lower BMI, were breastfed as infants more often and for longer periods, and consumed fish and dairy products more often than participants with lower SEP.

Negative associations (the blue dots in the summary table) could be explained by the fact that participants with a lower SEP generally smoked more often and were exposed to more second-hand smoke at home, had lower ferritin levels, used more cosmetics and personal care products and consumed organ meats more often.

In Chapters 2 and 3, we found no evidence that social gradients could also be explained by geographical factors such as type of residential area or distance from industrial sources. This strengthens the hypothesis that in highly industrialized and densely populated areas such as Flanders, inequalities in environmental health do not primarily arise from proximity to pollution sources, but rather from vulnerability to exposure impact due to diet, consumption, housing, and lifestyle factors. This means that not only socio-spatial risk patterns, but also socio-behavioral patterns are important to take into account, or more simply put, not only where people live but also how they live is important to determine social inequalities in environmental pollution and health.

9.1.2 Discussion

In short, my dissertation showed that social inequalities in chemical exposure are tangible and persistent, but no consistent pattern emerges. Instead, exposure inequality goes in both directions and appears to vary across chemical classes and across indicators of SEP. Specific factors related to lifestyle and behavior may explain these patterns. Returning to the concepts and frameworks from chapter 1, these conclusions can be seen as nuancing both Beck's theory of the democratization of risk (Beck, 1992; Curran, 2018) and the environmental justice hypothesis (Pellow, 2000; Sze & London, 2008). Human biomonitoring research demonstrates that chemicals are measurable and traceable in every body, thus highlighting the universality of risks from which no one can escape (Daemmrich, 2008). Moreover, from Beck's theory, the observation of social differences in both directions (positive and negative) can be interpreted as a confirmation that risks are no longer distributed according to traditional socio-economic fault lines. Even higher social classes sometimes have higher internal concentrations of chemicals. This could be considered a manifestation of what Ulrick Beck (1992) called ‘the boomerang effect’, in which even the wealthiest cannot escape the risks they have produced and benefited from. From my data, I distill at least three findings that could further support this interpretation.

First, there is the observation that not only health-damaging, but also health-promoting behaviors can increase exposure to chemicals. For example, fish consumption, especially predatory fish such as swordfish and tuna, and shellfish cause higher body burdens of PCBs, mercury and arsenic. These fish are consumed more by people with a higher SEP because they are part of a healthy lifestyle and are generally more expensive food products, especially in non-coastal countries. Breastfeeding is also a practice more common among higher social classes, which can lead to higher concentrations of Persistent Organic Pollutants (POPs) in early life (and which can also persist into later life).

Second (and inversely to the first point), certain health risks may reduce exposure loads. For example, a high body-mass index (BMI) is a risk factor for many chronic diseases and is more common among ethnic minorities and people in poverty. But at the same time, a high BMI also causes lipophilic chemicals to dilute more in adipose tissue and therefore may become less harmful in a body. In addition, high parity is also a known risk factor for various types of cancer and a practice more common in lower social classes. However, for certain chemicals that accumulate in the body, high parity is a mechanism for reducing exposure.

Third, the role of ethnic background often obscures the link between socioeconomic position and exposure because specific dietary habits, cultural practices, and migration pathways influence exposure and health effects independent of traditional socioeconomic parameters. For example, migration from certain countries where environmental regulations are less stringent may result in higher body burdens of persistent substances such as DDT that can even be passed on to subsequent generations, regardless of available income or level of education.

These three points contribute to the fact that social inequality in chemical exposure follows a less consistent and uniform pattern than might be expected on the basis of environmental justice theory, in which socially disadvantaged groups face disproportionate environmental risks. But on the other hand, there is also evidence in my PhD that negative social differences in exposure (higher exposure for lower SEP) are more severe and unjust in terms of health consequences than positive social differences (higher exposure for higher SEP).

First, negative social differences in exposure are more likely to involve an accumulation of several mutually reinforcing factors (e.g., a combination of smoking in poorly ventilated and overcrowded housing with old infrastructure), whereas positive associations are more likely to involve single isolated factors (e.g., specific dietary factors such as oily fish). In terms of health effects, this means that for more affluent people there are less ‘competing risk factors’, a concept that originated in clinical studies (Koller et al., 2012). This may explain why in statistical analyses a certain relationship (e.g., between air pollution and asthma) sometimes appears stronger for people with high social positions, which could be interpreted as a higher vulnerability for higher social positions, when in fact it may only mean that they are relatively better protected to other risk factors affecting health. For less affluent people, on the other hand, exposure to chemicals is only one of the risks that harm their health, on top of, for example, poor working conditions, neighborhood crime, lower access to health care, etc. In more conceptual terms, this relates to what Wakefield and Baxter (2010) described as ‘compounded disadvantage’: the cumulative hardship experienced by marginalized populations as a result of multiple and overlapping risks from the physical and the social environment. According to Wakefield and Baxter (2010, p. 100), a mere focus on the causal relationship between a specific pollutant and a specific disease consequently does little to identify environmental inequities. Instead, a precautionary approach is needed with a focus on broader issues and experiences of vulnerable populations.

Second, negative differences are more likely to be explained by factors over which people have less control (e.g. housing, addictions, working conditions, country of birth). In contrast, positive associations are largely due to nutritional and other factors that, in normal doses, generally promote health (e.g. fish consumption, fresh vegetables, breastfeeding). This means that although people with higher socioeconomic position (SEP) sometimes have higher levels of exposure, this is usually due to side effects of a healthy lifestyle, which generally offer better protection against the health impact of such exposure. For example, although higher fish consumption by people with high SEP might increase the concentration of mercury in their bodies, it can also have beneficial effects on the cardiovascular system and the neurological development that outweigh the hazardous health effects of mercury. In statistical terms, this is called ‘negative confounding’ (Yolton et al., 2013), and it could offer an explanation for the modest health impact of chemical exposure for people with high SEP.

9.1.3 Recommendations

With regard to the first objective, I conclude with three data recommendations for future research.

First, a general observation is that social stratification of human biomonitoring data is not an established scientific practice. In fact, there is a general lack of stratified data, which is described as one of the major weaknesses in research on environmental health in the European region (WHO, 2012) and one of the central dilemmas in the development of biomonitoring strategies in the US (NRC, 2006, p. 96). The lack of adequate data on exposure distributions and potential inequalities within a population could even be considered an environmental inequality in itself, as it jeopardizes attempts to document and assess existing inequalities. I identify two interrelated causes for this lack of social stratification in biomonitoring research. First, most human biomonitoring studies use indicators of socioeconomic position or migrant status only as confounders in statistical analyses.

Consequently, these factors are considered to be background noise to adjust for in order to isolate the potentially causal relationship between environmental exposures and health outcomes (Burris & Hacker, 2017; Wemrell et al., 2016). For example, when studying the negative impact of particulate matter on birth weight, scientists want to control for the possible influence of SES on this relationship. However, controlling for SES will also filter out how social structure can influence or modify the magnitude of the relation between exposure and health outcome, which is called effect modification or interaction effects. Several studies for example showed significant effect modification by education, income and social class in terms of larger and more pronounced health effects of particulate matter in lower SES individuals and neighborhoods (Erickson et al., 2016; Jerrett et al., 2004; Wheeler & Ben-Shlomo, 2005). This illustrates the concept of social vulnerability to environmental pollution in addition to biological susceptibility (for example age). In terms of data analyses, the idea of social vulnerability is captured in the novel concept of ‘sociomarkers’. Ghiara and Russo (2019) proposed that sociomarkers and biomarkers should be used in combination, as part of a broader conception of ‘mixed mechanisms’, in which both biological and social factors have an active causal role in the trajectory from exposure to disease development. Senier et al. (2017), in a similar manner, suggest including sociomarkers into environmental health science, as part of a broader conceptual proposal to transform the ‘exposome’ into the ‘socio-exposome’, and assesses exposures with sociomarkers across the individual, local and global levels (Senier et al., 2017). Second, there is a tendency in HBM studies to focus only on average or mean exposure levels and to aggregate results to make them representative of larger populations. This approach has already been criticized for introducing a white male bias in research with an underlying normative standard (Corburn, 2002; Epstein, 2007), which make certain high-risk groups invisible in statistics and risk assessments. In public health research, this is known as the ‘level approach’ (focusing on average health problems), which should be transformed into the ‘gap-approach’ (focusing on health inequalities and social determinants of health) (Speybroeck et al., 2010). In the domain of sustainable development, this relates to the concept of ‘socially disaggregated data’ put forward in the ‘leave no one behind’ commitment of the 2030 Agenda for Sustainable Development (Gupta et al., 2019; OECD, 2018, p. 145). To prevent invisible groups in existing statistics, data should not be aggregated to national averages but must be disaggregated by income, gender or poverty. Joanna Burger and Michael Gochfeld (Burger & Gochfeld, 2011; Gochfeld & Burger, 2011) apply this approach specifically to human biomonitoring research and recommend a focus on unique or high-end exposure populations, or what they called ‘exposure outliers’ (above the 95th percentile) to identify vulnerable groups. Realizing that this approach involves a small and unrepresentative number of individuals, Gochfeld and Burger (2011, p. 53) argue that from an environmental justice perspective “*these outliers are the ones who need to be protected instead of a focus on means and medians*”. So the first data recommendation to connect an environmental justice agenda to HBM research is to tackle the lack of stratified data. HBM studies must systematically include social stratification into the statistical analyses (to focus on disparities and disproportionalities) instead of merely social standardization (to control for social factors and to focus on averages).

Second, an additional challenge in terms of social stratification analysis is about the choice, interpretation and terminology of the social parameters. International HBM studies mostly use education, income, occupational class or poverty income rate (PIR) to measure individual socioeconomic position. Income and PIR are more commonly used in Anglo-Saxon countries, with education and occupational class being more common in continental European countries. Only a few studies describe the rationale behind the choice of these indicators or report the explanatory power of separate SEP parameters, see for instance Nelson et al. (2012). It has however been shown that these SEP indicators are not interchangeable and may represent different aspects of socioeconomic stratification (Braveman et al., 2005; Galobardes et al., 2006; Krieger et al., 1997). This was also noticeable in my own research. The second data recommendation is thus to include various SES indicators and to report relationships with environmental exposures separately for each indicator. The use of composite SES indices is therefore less relevant. In addition, providing conceptual clarity on the how social indicators are constructed is also important. Simply put, a distinction can be made between structural/economic measures, which are more resource-based and are captured in the concept of 'socioeconomic class' on the one hand, and relational/cultural parameters, which are more prestige-based and are captured in the concept of 'socioeconomic status' (SES) on the other (McCartney, Bartley, et al., 2019). To bypass this distinction, the more neutral term 'socioeconomic position' (SEP) is often chosen because it does not express a preference for the more material or more relational aspects (Krieger et al., 1997). In my publications, I gradually replaced the terminology of SES with that of SEP, because disentangling the social processes behind these constructs (more class- or status-based) was not an explicit goal of my research.

Third, when screening the available literature on social stratification of human biomonitoring data, a striking observation is that the majority of studies does not include factors into their analyses to help explain observed social disparities in chemical exposure. Yet SEP does not directly influence exposure, but rather is a proxy for underlying mechanisms and risk factors. These factors often involve a combination of lifestyle factors, dietary habits, health behaviour and housing conditions, which can also reinforce each other (e.g. smoking in poorly ventilated and overcrowded houses). In addition, there may also be interaction-effects with gender, age or ethnicity. The relationship between SEP and exposure then runs differently for men and women or for black and white people. Given this complex interplay of mediating factors, the practice of a priori controlling for these factors in statistical models implies a risk that certain social differences in exposure will not be detected. For example, Spanish biomonitoring studies showed how correcting for age and parity conceals social differences in exposure to POPs in women, as older women are more likely to have a combination of lower SEP and higher exposure (Gasull et al., 2013; Porta et al., 2012). It is thus advisable for HBM studies to report unadjusted social stratification of exposure concentrations, as well as the influence of mediating factors separately before displaying multiple models. But it is also possible that a number of these factors are too atypical and unique to be detected in traditional risk analysis. For example, religious and cultural practices that may not be mainstream or standard, such as the use of cosmetics or medicinals (containing toxic metals) or traditional food patterns (including contaminated herbs and oils) but can be important risk factors for certain vulnerable subgroups (Burger & Gochfeld, 2011). When designing questionnaires, it is therefore important to properly identify the specific characteristics of the target group.

9.2 Social inequality in human biomonitoring practices

The second objective of my dissertation was to examine barriers and opportunities for vulnerable groups to participate in HBM research and in environmental health promotion. This objective was divided in three research questions representing different steps in the research cycle.

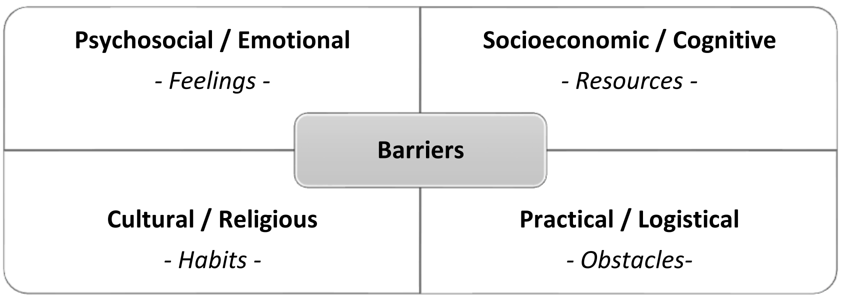
- *How to tackle the participation bias in HBM research?* (RQ3). Chapter 6 described a targeted recruitment strategy to enhance the participation of pregnant women of Turkish and Moroccan descent in the FLESH III human biomonitoring study.
- *How do participants experience and interpret HBM research results?* (RQ4). Chapter 7 presented the results of a follow-up study with in-depth interviews to evaluate the report-back process from a participants' perspective.
- *How to reach and empower vulnerable groups with environmental health promotion?* (RQ5) Chapter 8 contained the results of a pilot project to determine if and how information and education about environmental health risks can be made more accessible and have a greater impact on disadvantaged groups.

9.2.1 Summary of main findings

I summarize the results of this second objective in a generic way, first the barriers identified and then the opportunities that were explored to overcome these barriers.

I found that socially vulnerable groups, especially people with a migration background, are not less willing to participate in environmental health research or promotion but experience more barriers. An important finding from the different projects is that these barriers can take different forms and go far beyond the practical obstacles associated with the study design. Often it is about underlying, subtle and less visible psychosocial and socio-cultural barriers. In chapter 6, I identified four types of barriers related to participation in HBM research. This typology was also noticeable in the other projects on communication (chapter 7) and health promotion (chapter 8).

Figure 14: Typology of barriers related to participation in HBM research



Based on: Bonevski (et al. 2014), Schmotzer (et al. 2012) and Spears (et al. 2011)

First, in recruiting socially vulnerable groups to participate in HBM research, I noticed a (nearly intuitive) sense of suspicion and distrust of researchers and science in general and of HBM research in particular. This stems in part from the fact that donating biological samples is considered personal property, which raises concerns about possible data abuse or stigmatization by scientists or by the government. Feelings of concern were also expressed during the report-back phase of results, due to the lack of a contextual framework and interactive communication opportunities. It was noteworthy that instead of contacting the research team to get more clarification on their results, participants constructed their own interpretation or chose to ignore or suppress the results because they were inconsistent with their perceived lifestyle and behavior.

Second, specific sociocultural barriers were identified. For example, in relation to study participation (Chapter 6), religious objections to donating a placenta sample during childbirth were raised, as the placenta is considered sacred and not biological waste in Muslim communities. The role of husbands as family gatekeepers in obtaining consent from pregnant women of Turkish and Moroccan origin was also important. And finally, in the health promotion project (Chapter 8), I noticed how cleaning and hygiene practices, for example the extensive use of bleaching products, are deeply rooted in cultural processes of assimilation and exclusion and are therefore much more subtly linked to feelings of guilt and shame than may at first appear. This relates to Ami Zota's work on ‘the environmental injustice of beauty’ which framed the high use of skin and hair care products as a practice of whiteness resulting in high chemical exposure and health concerns for African-American women (Zota & Shamasunder, 2017).

Third, socioeconomic barriers were identified concerning the limited experiences with scientific research and low literacy of socially vulnerable groups which made it difficult for them to see the added value and benefits of environmental health research and info. In the follow-up interviews (chapter 8) it was mentioned that the initial framing of the study was too medical and scientific which made participants feel somewhat detached from the broader study objectives. This created a mental distance between them and the research at the start and made them reluctant to contact the research team when they had questions regarding their personal results. I also noticed during the follow-up interviews, but especially during the health promotion project, a strong aversion to negative or pedantic messages about environmental health risks aimed at individual behavior change.

Fourth, also practical and logistic barriers appeared which included research triage and rigid exclusion criteria in the recruitment phase and difficult and complex questionnaires and info material in the sampling and reporting-back phase.

To address these barriers, I designed and implemented a targeted recruitment strategy (chapter 6) and a community-based participatory project on environmental health promotion (chapter 8). In addition, I conducted a follow-up study to better understand and improve the communication process of HBM results to participants (chapter 7).

The targeted recruitment strategy focused on peer-to-peer support through personal buddies. These were third-party women from the same ethnic background as the target population and with a strong social network. They were instructed and trained by the research team to make initial contact with pregnant women and provide them with tailored information about the study and to keep in touch thereafter and follow-up whether these women needed further support in signing the informed consent and completing the postpartum questionnaires. In preparation for this buddy system, study documents and protocols were thoroughly tested, screened and advised through focus groups, interviews and consultations with people from the target population and professional organizations. Although the figures should be interpreted with caution, the targeted strategy proved very successful in recruiting participants with a migration background. In the maternity hospitals where the targeted strategy was implemented, 21% of the participants had Turkish or Moroccan roots, compared to 2% in the other maternity hospitals. The three main recommendations I identified to increase social and ethnic diversity in study participation are: (1) outsource personal contact with the target group to trusted buddies who can actively inform and support participants. (2) Ensure an ethnic matching of the research design by carefully screening and testing all study protocols and info materials for cultural and linguistic sensitivities. (3) Have an open and reflexive mindset to allow for flexibility and creativity in the research process and to acknowledge extended timeframes and resource costs.

In a practice-oriented pilot project, two participatory trajectories on indoor quality and healthy gardening were completed in the Antwerp neighbourhood of Kiel with women from an immigrant background in order to find out how information and knowledge on environmental health promotion can be better tailored to a socially vulnerable target group. To pass on knowledge about a healthy indoor environment, customized interactive info sessions and a health quiz were organized, as well as integration of environmental health info through informal meeting moments around language education. In addition, support was provided for an educational quartet game created by the target group itself in order to easily share tips and advice on healthy gardening with others. The project showed that trust building within an existing and supportive network, as well as placing environmental health messages in a positive and integral framework were important preconditions for reaching and empowering vulnerable people with environmental health information.

The face-to-face interviews with mothers participating in FLEHS III emphasized once again the importance of better integrating participants' experiences into the research process. I noted that a standardized and passive reporting-back protocol led participants to attribute little meaning to their results. Instead, a more tailored approach is needed in which the methods, format, and content of the communication are diversified and contextualized according to the type of results and the personal preferences of the participants, so that they can better comprehend and cope with their results. In addition, a more interactive approach is needed with opportunities to discuss results directly with researchers and other participants.

9.2.2 Discussion

The traditional bioethical principles of autonomy, beneficence, non-maleficence, and justice are important foundations for conducting human biomonitoring research and environmental health promotion, but they have also been criticised for overemphasizing individual rights and failing to incorporate the contextual factors in which research take place. For instance, informed consent protocols are predominantly perceived as static and discrete events for individuals who must be informed about research benefits and risks in order to make autonomous decisions (Barata et al., 2006). The significant role of communal or familial gatekeepers and of cultural norms in the decision-making process are thereby often ignored. The expectations and experiences of participants are also usually not taken into account when reporting-back results, because procedures must be handled in a timely and standardized manner. These examples are often the result of practices called ‘parachute’ or ‘helicopter’ research – dropping into a community to extract data and then leave without providing feedback (Costello & Zumla, 2000). This has left some social groups and communities vulnerable to the negative consequences of research participation or even make them invisible in environmental health data and monitoring. In this regard, the sociologist Alice Mah (2017) identified three key blind spots for socially vulnerable groups, namely those of voice, expertise, and speed. First, the blind spot of voice raises the issue of limited access for marginalized population, as well as the issue of representativeness of monitoring data. Mah argues that making injustices visible involves both identifying the voices of those left behind and examining the mechanisms of exclusion. The second blind spot is that of speed, as the focus on high velocity of real-time big data often neglects the broader historical context of toxic pollution. To address this, Mah proposes – with a reference to Isabelle Strenger – to reclaim the practice of slow science: *“taking the time to ask questions and mull over interpretations, rather than churning out fast results”* (Stengers quoted in Mah 2017: 127). The third related blind spot is the problem of expertise, meaning that scientific experts might easily misinterpret data if they are not in touch with laypeople about lived experience.

These three blind spots were also noted to some extent in my own research. The blind spot of access to research was the starting point to implement a targeted recruitment strategy for hard-to-reach groups. The blind spot of expertise became apparent in the report-back phase as follow-up interviews were necessary to gain insight into how participants experienced and cope with these results. And the blind spot of speed was countered in the environmental health promotion project by taking the time to gain the trust of the group of migrant women before the actual project started.

Ethical guidelines to counter these blind spots are found in new concepts of ‘reflexive research ethics’ (Cordner et al., 2012) or ‘community-based research ethics’ (Morello-Frosch et al., 2009) in which collaboration, mutual understanding and interactive reflection between researchers and community members guide all phases of the research process. Specifically with respect to inequality, this calls for greater attention to the DEI (*Diversity*, *Equity* and *Inclusion*) principles in research designs and teams (Asmal et al., 2022). As summarized above, within my PhD research, I have attempted to address DEI at different steps of the HBM research cycle: in research methods (chapter 6), research dissemination (chapter 7) and research impact (chapter 8). The inclusion of previously underrepresented groups in human biomonitoring research thus involves more than the aim for representativeness in a statistical sense, it also involves taking the considerations, perceptions, and expectations of these groups seriously and incorporating them into the research process.

In terms of research practices, this often-meant opening-up routines and established protocols and following a more organic and flexible rather than a linear or cyclical research design. Powell and Powell (2011) called this: *"creating productive ruptures in deeply ingrained institutional mindsets and scientific practices"*. In many cases, however, it amounts to working out additional efforts tailored to vulnerable groups, on top of the standard operating procedures that apply to all. This relates to the principle of 'proportionate universalism' from health literature, were in order to reduce the steepness of the social gradient in health, actions must be universal, but with a scale and intensity that is proportionate to the level of disadvantage (Marmot Review, 2010). It also required a process of becoming 'culturally competent' as a research team; of being more self-aware of the color-blind nature of biomonitoring studies (Chakravartty, 2019, p. 132), and of being willing to meet the needs of culturally diverse groups without falling into cliché thinking about ethnicity (Lock & Nguynen, 2018, p. 8).

References

Asmal, L., Lamp, G., Tan, E.J. (2022). Considerations for improving diversity, equity and inclusivity within research designs and teams. *Psychiatry Research*, 307, 114295.

Barata, P.C., Gucciardi, E., Ahmad, F., Stewart, D.E. (2006). Cross-cultural perspectives on research participation and informed consent. *Social Science & Medicine*, 62(2), 479-490.

Beck, U. (1992). *Risk society: Towards a new modernity*. London: sage.

Bonevski, B., Randell, M., Paul, C., Chapman, K., Twyman, L., Bryant, J., et al., (2014). Reaching the hard-to-reach: a systematic review of strategies for improving health and medical research with socially disadvantaged groups. *Bmc Medical Research Methodology*, 14(1), 1-29.

Braveman, P. A., Cubbin, C., Egerter, S., Chideya, S., Marchi, K. S., Metzler, M., & Posner, S. (2005). Socioeconomic status in health research - One size does not fit all. *Jama-Journal of the American Medical Association*, 294(22), 2879-2888.

Burger, J., & Gochfeld, M. (2011). Conceptual Environmental Justice Model for Evaluating Chemical Pathways of Exposure in Low-Income, Minority, Native American, and Other Unique Exposure Populations. *American Journal of Public Health*, 101, S64-S73.

Burris, H.H., Hacker, M.R. (2017). Birth outcome racial disparities: a result of intersecting social and environmental factors. *Seminars in perinatology*, 41(6), 360-366.

Chakravartty, D. (2019). *Attending to Differential Environmental Exposures Among Racialized Newcomer Women in Canada: Why so Difficult?* Doctoral dissertation, University of Toronto (Canada).

Corburn, J. (2002). Environmental justice, local knowledge, and risk: The discourse of a community-based cumulative exposure assessment. *Environmental Management*, 29(4), 451-466.

Cordner, A., Ciplet, D., Brown, P., Morello-Frosch, R. (2012). Reflexive Research Ethics for Environmental Health and Justice: Academics and Movement Building. *Social Movement Studies*, 11(2), 161-176.

Costello, A., Zumla, A. (2000). Moving to research partnerships in developing countries. *BMJ*, 321(7264), 827-829.

Curran, D. (2018). Environmental Justice Meets Risk-Class: The Relational Distribution of Environmental Bads. *Antipode*, 50(2), 298-318.

Daemmrich, A. (2008). Risk Frameworks and Biomonitoring: Distributed Regulation of Synthetic Chemicals in Humans. *Environmental History*, 13, 684-694.

Epstein, S. (2007). *Inclusion: the politics of difference in medical research*. Chicago: The University of Chicago Press.

Erickson, A.C., Ostry, A., Chan, L.H., Arbour, L. (2016). The reduction of birth weight by fine particulate matter and its modification by maternal and neighbourhood-level factors: a multilevel analysis in British Columbia, Canada. *Environ Health*, 15, 51.

Galobardes, B., Shaw, M., Lawlor, D.A., Lynch, J.W., Smith, G.D. (2006). Indicators of socioeconomic position (part 1). *Journal of Epidemiology and Community Health*, 60(1), 7-12.

Gasull, M., Pumarega, J., Rovira, G., López, T., Alguacil, J., Porta, M. (2013). Relative effects of educational level and occupational social class on body concentrations of persistent organic pollutants in a representative sample of the general population of Catalonia, Spain. *Environmental International*, 60, 190-201.

Ghiara, V., Russo, F. (2019). Reconstructing the mixed mechanisms of health: the role of bio- and sociomarkers. *Longitudinal and Life Course Studies*, 10(1), 7-25.

Gochfeld, M., Burger, J. (2011). Disproportionate exposures in environmental justice and other populations: the importance of outliers. *American Journal of Public Health*, 101 Suppl 1(Suppl 1), S53-S63.

Gupta, J., Scholtens, J., Perch, L., Dankelman, I., Seager, J., Sánder, F., et al. (2019). Re-imagining the driver–pressure–state–impact–response framework from an equity and inclusive development perspective. *Sustainability Science*, 15(2), 503-520.

Jerrett, M., Burnett, R.T., Brook, J., Kanaroglou, P., Giovis, C., Finkelstein, N., Hutchison, B. (2004). Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada. *Journal of Epidemiology and Community Health*, 58(1), 31-40.

Koller, M.T., Raatz, H., Steyerberg, E.W., Wolbers, M. (2012). Competing risks and the clinical community: irrelevance or ignorance? *Statistics in Medicine*, 31(11-12), 1089-1097.

Krieger, N., Williams, D.R., Moss, N.E. (1997). Measuring social class in US public health research: concepts, methodologies, and guidelines. *Annu Rev Public Health*, 18, 341-378.

Lock, M.M., Nguyen, V.K. (2018). *An Anthropology of Biomedicine*, 2nd Edition: Wiley Blackwell.

Mah, A. (2017). Environmental justice in the age of big data: challenging toxic blind spots of voice, speed, and expertise. *Environmental Sociology*, 3(2), 122-133.

Marmot Review, Patel, C., North, F., Head, J., et al. (2010*). Fair society, healthy lives: Strategic review of health inequalities in England post 2010*. London: University College, London.

McCartney, G., Bartley, M., Dundas, R., Katikireddi, S.V., Mitchell, R., Popham, F., et al. (2019). Theorising social class and its application to the study of health inequalities. *Ssm-Population Health*, *7*, 100315.

McCartney, G., Popham, F., McMaster, R., Cumbers, A. (2019). Defining health and health inequalities. *Public Health*, 172, 22-30.

Morello-Frosch, R., Brody, J.G., Brown, P., Altman, R.G., Rudel, R.A., Pérez, C. (2009). Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. *Environmental Health,* 8(1), 6.

NRC. (2006). *Human Biomonitoring for Environmental Chemicals*. National Research Council, Washington: National Academies Press.

Nelson, J. W., Scammell, M. K., Hatch, E. E., & Webster, T. F. (2012). Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. *Environmental Health*, 11(1), 1-15.

OECD. (2018). *Development Co-operation Report 2018: Joining Forces to Leave No One Behind*. Organization for Economic Cooperation and Development, Paris: OECD Publishing.

Pellow, D.N. (2000). Environmental inequality formation - Toward a theory of environmental injustice. *American Behavioral Scientist*, 43(4), 581-601.

Porta, M., Lopez, T., Gasull, M., Rodriguez-Sanz, M., Gari, M., Pumarega, J., et al. (2012). Distribution of blood concentrations of persistent organic pollutants in a representative sample of the population of Barcelona in 2006, and comparison with levels in 2002. *Science of the Total Environment*, 423, 151-161.

Powell, M., Powell, J. (2011). Invisible People, Invisible Risks: How Scientific Assessment of Environmental Health Risks Overlook Minorities - and How Community Participation Can Make Them Visible. In G. Ottinger & B. R. Cohen (Eds.), *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement* (pp. 149-178). Cambridge, Massachusetts: The MIT Press.

Schmotzer, G.L. (2012). Barriers and facilitators to participation of minorities in clinical trials. *Ethnicity & Disease*, 22(2), 226-230.

Senier, L., Brown, P., Shostak, S., Hanna, B. (2017). The socio-exposome: advancing exposure science and environmental justice in a postgenomic era. *Environmental Sociology*, 3(2), 107-121.

Spears, C.R., Nolan, B.V., O'Neill, J.L., Arcury, T.A., Grzywacz, J.G., Feldman, S.R. (2011). Recruiting underserved populations to dermatologic research: a systematic review. *International Journal of Dermatology*, 50(4), 385-395.

Speybroeck, N., Konings, P., Lynch, J., Harper, S., Berkvens, D., Lorant, V., et al. (2010). Decomposing socioeconomic health inequalities. *International journal of public health*, 55(4), 347-351.

Sze, J., London, J.K. (2008). Environmental Justice at the Crossroads. *Sociology Compass*, 2(4), 1331-1354.

Wakefield, S.E.L., Baxter, J. (2010). Linking Health Inequality and Environmental Justice: Articulating a Precautionary Framework for Research and Action. *Environmental Justice*, 3(3), 95-102.

Wemrell, M., Merlo, J., Mulinari, S., Hornborg, A.C. (2016). Contemporary epidemiology: a review of critical discussions within the discipline and a call for further dialogue with social theory. *Sociology Compass*, 10(2), 153-171.

Wheeler, B.W., Ben-Shlomo, Y. (2005). Environmental equity, air quality, socioeconomic status, and respiratory health: a linkage analysis of routine data from the Health Survey for England. *Journal of Epidemiology and Community Health*, 59(11), 948-954.

WHO. (2012). *Environmental health inequalities in Europe. Assessment report*. World Health Organization, Copenhagen: WHO Regional Director for Europe.

Yolton, K., Xu, Y., Sucharew, H., Succop, P., Altaye, M., Popelar, A., et al. (2013). Impact of low-level gestational exposure to organophosphate pesticides on neurobehavior in early infancy: a prospective study. *Environmental Health*, 12(1), 1-10.

Zota, A.R., Shamasunder, B. (2017). The environmental injustice of beauty: framing chemical exposures from beauty products as a health disparities concern. *Am J Obstet Gynecol*, 217(4), 418.e411-418.e416.

Summary

Environmental justice research suggests that inequalities in the distribution of environmental risks systematically disadvantage the lower social strata of society. The effects of these inequalities on the internal exposure to chemical pollution within the body remain however to a large extend unknown. Human biomonitoring (HBM) is an innovative method to measure the body burden concentrations of chemicals in blood and urine samples. Flanders is one of the pioneers in this type of research, with a long-term and large-scale monitoring network FLEHS that was scientifically set up on behalf of the Flemish government. However, the gap between environmental justice and human biomonitoring research remains considerable, both in scientific analysis and research practices, leaving the potential for cross-fertilization of knowledge underutilized.

In this doctoral thesis, I aimed to disentangle the connections between social inequality and human biomonitoring in Flanders in a twofold manner: a quantitative approach to stratify body burden concentrations of chemicals according to different social and ethnic indicators and a qualitative approach to make biomonitoring research practices more inclusive and accessible to vulnerable groups. This two-part structure is based on the dimensions of environmental justice: distributive justice, focusing on the division of environmental goods and bads and procedural inequality, focusing on opportunities for participation in research and prevention of environmental health issues.

In the first part of the dissertation, I showed that social inequalities in exposure concentrations are tangible and persistent, but that patterns of inequality are more complex and nuanced than the environmental justice hypothesis suggests. In my analyses, inequality goes in both directions and appears to vary across chemical classes and across social and ethnic indicators. Differences in lifestyle and behavior may explain these patterns. In the second part, I found that socially vulnerable groups, especially people with a migration background, are not less willing to participate in environmental health research or promotion but experience more barriers. An important finding was that these barriers can take different forms and go far beyond the practical obstacles associated with the study design. Often it is about underlying, subtle and less visible psychosocial and socio-cultural barriers. In order to enhance the understanding of how to address such barriers, I designed and implemented several practice-based research projects that were centered more on the perspective of the participants. Ultimately, this dissertation points to the potential of human biomonitoring research to demonstrate how social inequality can literally and figuratively get ‘under the skin’.

Samenvatting

Onderzoek naar milieurechtvaardigheid suggereert dat ongelijkheden in de verdeling van de milieurisico's systematisch de lagere sociale lagen treffen van de samenleving. De effecten van deze ongelijkheden op de interne blootstelling aan chemische verontreiniging blijven echter grotendeels onbekend. Humane biomonitoring (HBM) is een innovatieve methode om de lichaamsbelasting door chemische stoffen in bloed- en urinemonsters te meten. Vlaanderen is een van de pioniers in dit type onderzoek, met een langlopend en grootschalig meetnet FLEHS dat wetenschappelijk werd opgezet in opdracht van de Vlaamse overheid. Er blijft echter een grote kloof bestaan tussen onderzoek naar milieurechtvaardigheid en humane biomonitoring, zowel in de wetenschappelijke analyse als in de onderzoekspraktijk, waardoor het potentieel voor kruisbestuiving van kennis onderbenut blijft.

In deze doctoraatsthesis ontrafelde ik de verbanden tussen sociale ongelijkheid en humane biomonitoring in Vlaanderen op een tweeledige manier: met een kwantitatieve benadering om de concentraties van chemische stoffen in het lichaam te stratificeren volgens verschillende sociale en etnische indicatoren, en met een kwalitatieve benadering om onderzoekspraktijken van humane biomonitoring meer inclusief en toegankelijk te maken voor kwetsbare groepen. Deze tweeledige structuur gaat terug op de dimensies van milieurechtvaardigheid: distributieve rechtvaardigheid, gericht op de verdeling van milieuvoordelen en -nadelen, en procedurele ongelijkheid, gericht op mogelijkheden voor participatie bij onderzoek naar en preventie van milieugezondheidskwesties.

In het eerste deel van het proefschrift toonde ik aan dat sociale ongelijkheid bij interne blootstelling aan chemische stoffen tastbaar en hardnekkig is, maar dat patronen van ongelijkheid complexer en genuanceerder zijn dan de hypothese van milieurechtvaardigheid suggereert. In mijn analyses gaat de ongelijkheid in beide richtingen en blijkt zij te variëren naargelang de chemische groepen en naargelang de sociale en etnische indicatoren. Verschillen in levensstijl en gedrag kunnen deze patronen verklaren. In het tweede deel blijkt dat sociaal kwetsbare groepen, vooral mensen met een migratieachtergrond, niet minder bereid zijn om deel te nemen aan milieugezondheidsonderzoek of -promotiecampagnes, maar wel meer belemmeringen ervaren. Een belangrijke bevinding was dat deze belemmeringen verschillende vormen aannemen en veel verder gaan dan de praktische obstakels in verband met het onderzoeksopzet. Vaak gaat het om onderliggende, subtiele en minder zichtbare psychosociale en sociaal-culturele belemmeringen. Om het inzicht te vergroten in hoe zulke barrières aan te pakken heb ik verschillende concrete onderzoeksprojecten ontworpen en uitgevoerd waarin het perspectief van de deelnemers meer centraal stond. Uiteindelijk wijst dit proefschrift op het potentieel van humane biomonitoringsonderzoek om aan te tonen hoe sociale ongelijkheid letterlijk en figuurlijk 'onder de huid' kan kruipen.

Appendix 1 – Author contributions

Chapter 2: Social distribution of internal exposure to environmental pollution in Flemish adolescents

- Doctorandus, Bert Morrens: conception of the study, setup of the method, data interpretation, drafting and revising of the manuscript.
- Supervisor, Ilse Loots: critical revision of and feedback on the manuscript.
- Colleague, Liesbeth Bruckers: data analysis.
- Other colleagues: feedback on the manuscript.

Chapter 3: Hoe milieuongelijkheid op zich ongelijk kan zijn: blootstelling aan milieuvervuilende stoffen bij buurtbewoners van industriezones

- Doctorandus, Bert Morrens: conception of the study, setup of the method, data interpretation, drafting and revising of the manuscript.
- Supervisor, Ilse Loots: critical revision of and feedback on the manuscript.
- Colleague, Liesbeth Bruckers: data analysis.
- Other colleagues: feedback on the manuscript.

Chapter 4: Blootstelling aan hormoonverstorende stoffen in consumptieproducten. Op zoek naar linken tussen duurzaamheid, gezondheid en sociale ongelijkheid

- Doctorandus, Bert Morrens: conception of the study, setup of the method, data interpretation, drafting and revising of the manuscript.
- Colleague, Liesbeth Bruckers and Ann Colles: data analysis.
- Colleague, Dries Coertjens: feedback on drafting of the manuscript.

Chapter 5: Assessing environmental health inequalities in early life: social stratification of maternal and neonatal biomonitoring results in Belgium

- Doctorandus, Bert Morrens: conception of the study, setup of the method, data interpretation, drafting and revising of the manuscript.
- Supervisor, Ilse Loots: critical revision of and feedback on the manuscript.
- Colleague, Ann Colles: setup of the method, data analysis, feedback on the manuscript.
- Colleague, Liesbeth Bruckers: data analysis.

Chapter 6: Human biomonitoring from an environmental justice perspective: supporting study participation of women of Turkish and Moroccan decent

- Doctorandus, Bert Morrens: conception and implementation of the study, setup of the method, drafting and revising of the manuscript.
- Supervisor, Ilse Loots: critical revision of and feedback on the manuscript.
- Colleague, Elly Den Hond: implementation of the study and feedback on the manuscript.
- Other colleagues: feedback on the manuscript.

Chapter 7: Participant Experiences in a Human Biomonitoring Study: Follow-up Interviews with Participants of the Flemish Environment and Health Study

- Doctorandus, Bert Morrens: conception of the study, setup of the method, fieldwork, data analysis, drafting and revising of the manuscript.
- Supervisor, Ilse Loots and Frédéric Vandermoere: critical revision of and feedback on the manuscript.
- Colleague, Elly Den Hond: feedback on the conception of the study and setup of the method.
- Colleague, Hans Jonker and Dries Coertjens: drafting of the manuscript.
- Other colleagues: feedback on the manuscript.

Chapter 8: Lucht in je Leven – Een pilootproject rond milieu en gezondheid bij sociaal kwetsbare doelgroepen

- Doctorandus, Bert Morrens: conception and implementation of the study, drafting and revising of the manuscript.
- Supervisor, Ilse Loots and Frédéric Vandermoere: critical revision of and feedback on the manuscript.
- Colleagues, Bruno Buytaert B., Ann Verdeyen: conception and implementation of the study, feedback on the manuscript.
- Commissioners, Mart Verlaek and Karen Van Campenhout: feedback on the manuscript

Appendix 2 – List of abbreviations

BMI	body mass index
BPA	bisphenol A
CI	confidence interval
DDE	dichlorodiphenyldichloroethylene
EDCs	endocrine disruption chemicals
EEA	European Environmental Agency
ETS	Environmental tobacco smoke
EPA	Environmental Protection Agency
FLEHS	Flemish Environmental Health Study
GM	geometric men
HBM	human biomonitoring
HCB	hexachlorobenzene
OR	odd ratio
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PFAS	perfluoroalkyl chemicals
SEP	socioeconomic position
SES	socioeconomic status
UBA	Federal Environment Agency
VOCs	volatile organic compounds
WHO	World Health Organization