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Review

A rapid systematic scoping review of research on the impacts of water contaminated by chemicals on very young children

Eniola Shittu [a,b], Monica Lakhanpaul [b], Carol Vigurs [c], Kaushik Sarkar [d], Marta Koch [a,b], Priti Parikh [e], Luiza C. Campos [a,*]

[a] Department of Civil, Environmental and Geomatic Engineering, Faculty of Engineering, University College London, London WC1E 6BT, UK
[b] UCL - Great Ormond Street Institute of Child Health, University College London, 30 Guildford Street, London WC1N 1EH, UK
[c] Social Research Institute, University College London, 18 Woburn Square, London WC1H 0NR, UK
[d] Institute for Malaria and Climate Solutions, Malaria No More. India
[e] Engineering for International Development Centre, The Bartlett School of Sustainable Construction, UCL Faculty of the Built Environment, 1-19 Torrington Place, London WC1E 7HB, UK

HIGHLIGHTS

- Pre-natal and very young children are at greater risk of harm than other age groups.
- There are gaps in research on specific health impacts on different age groups.
- Most of the studies were of groundwater contaminated by chemicals from manufacturing and agriculture.
- Few studies report on effective interventions for treating or preventing chemically polluted water.

GRAPHICAL ABSTRACT

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ABSTRACT

Low-income countries are struggling with the health impacts of both surface and groundwater chemical contamination. Although the impact of biological contaminants on children's health is acknowledged, the long-term effects of these and emerging contaminants on young children may be underestimated. To map the existing evidence on health impacts of water contaminated with chemicals on young children (<5 years), we conducted a scoping review to select and organize relevant literature. Of the 98 studies in the review, 24 revealed that the hazard ratio of arsenic, nitrates, cadmium, and fluoride (all of which are on the World Health Organisation's list of 10 chemicals of public health concern) was higher in very young children than in older age groups. Anthropogenic activities (textile manufacturing, waste disposal, and intensified agriculture) are leading contributors to the release of chemicals to groundwater used for drinking. Three major pathways for chemical contamination exposure in young children were confirmed: maternal transmission during pregnancy and breastfeeding, and early school years. Children exhibited acute and chronic disruptions to their neurological, skeletal, reproductive, and endocrine systems, as well as cumulative carcinogenic risks, amongst other life-altering consequences. The lack of research on emerging contaminants' effects on young children in low-income countries is worrisome, as their increased use may compound the issues caused by the existing problem of "legacy chemicals." Precautionary principle should regulate the operation of industries producing these chemicals in a robust manner. Evidence from major producers and exporters in high-income countries is sufficient to warrant

* Corresponding author.
E-mail address: l.campos@ucl.ac.uk (L.C. Campos).

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action, even without waiting for direct harm to be observed in low-income countries. Literature recommends prioritising prevention of contamination over demand side treatment or finding alternative water sources, especially in water-scarce areas affected by climate change. Local and transnational efforts are required to enforce safer industry practices and prevent further water quality deterioration in low-income countries.

Contents

1. Introduction

Water pollution is a serious and growing public health problem. It is estimated that 2 billion people around the world do not have access to clean and safe drinking water according to the United Nation World Water Development Report (UN, 2023). Chemical pollution is a growing threat to drinking water sources as tonnes of chemically active material are discharged into the environment, from numerous sources (Cribb, 2021). The World Health Organisation (WHO, 2020) lists 10 chemicals of public health concern, and 8 of those are contaminant of water, nevertheless, the impact of chemical contamination on global health burden and the universal understanding of the threats posed by chemically contaminated water remains fragmented (Naidu et al., 2021). Current drinking water standards rely primarily on animal toxicity data, and there is a scarcity of robust epidemiologic studies that include accurate exposure assessment. The current risk assessment approach typically focuses on individual chemicals and fails to consider the potential synergistic or interactive effects of exposure to mixtures of contaminants, particularly at low levels (Villanueva et al., 2014). Presently, the majority of treatments for water are for microbial contamination and the costings surroundings treatment approaches (where they exist) for chemical contamination have not been fully considered or accurately calculated (Amrose et al., 2020). Accurate testing to determine the extent of chemical contamination is also expensive (Cordner et al., 2021), therefore the extent and impact on chemical contamination on global health burden may be underestimated. Systematic reviews of chemical contamination have demonstrated children may be at greater risk than other age groups. Very young children have the greater potential to accumulate toxins over a longer period having started earlier in their lives, even before birth from mother to foetal transfer of chemical contaminants via cord blood or mother to baby transfer in breast milk. Health risks tend to increase with the duration of exposure and the same toxins will be at a greater concentration in a smaller body than a larger adult body.

Children are more vulnerable than other age groups because they are a rapid and critical stage of complex brain structure development, skeletal growth and intricate hormonal systems development, where disruptions to this developmental pathway can cause irreversible harm. Cognitive impairments particularly impact the level of education attained by children and their future livelihoods as well as potentially lifelong morbidity. At a population level, the wider social and economic impacts of increased population mortality and morbidity strain health and social care services and is linked negatively to GDP and economic development. According to some estimates decreasing morbidity is met by long run growth of around the same percentage points and this effect is stronger in lower income countries than in higher income countries (Rocco et al., 2021).

This research is part of an overarching project to advocate and increase the prioritisation of children when resolving development challenges globally. Therefore, this research goes beyond just reinforcing the significance of providing adequate sanitation facilities and increasing access to clean water for daily activities i.e., drinking and cooking. Rather its purpose is to increase the prioritisation of addressing the harm posed by chemically contaminated water on very young children in developing contexts. In turn this will contribute to achieving Sustainable Development Goals (SDGs) such as SDG 3 (Health and Wellbeing), SDG 6 (Improved Water and Sanitation), SDG 10 (Reducing Inequality Amongst Countries), SDG 11 (Sustainable Cities and Communities) and SDG 17 (Facilitating Partnerships).

We conducted a rapid systematic scoping review of research literature according to PRISMA guidelines with the following objectives: (1) to assess the nature and extent of research on the exposure of children from conception to age 5 (i.e. very young children) to chemicals in water in LMICs; (2) to map the reported effects of these chemicals on child and prenatal health; (3) to identify potential interventions to reduce exposure and impacts; (4) to identify areas for future research; and (5) to produce recommendations to support decision-making.

2. Literature review of systematic reviews of chemicals contaminants, causes and impacts

Systematic review studies have found exposure to different chemical contaminants, from different sources, and evidence of harm to children in a variety of ways. Heavy metal chemicals in water such as lead used in water infrastructure (Collin et al., 2022) are well known to affects children's cognitive development and abilities. Arsenic, used in mining, pesticides, animal feed and wood preservatives (Tyler and Allan, 2014) is linked to skin conditions and cancer. Pre- and post-natal exposure to cadmium (which can occur naturally but also as a contaminant from mining activities and fuel combustion) and manganese (from compost and waste run off) were linked to behavioural and developmental disorders and intelligence quotient (IQ) deficits in children (Chandravanshi et al., 2021; Kullar et al., 2019) Larger concentrations of copper (Manne et al., 2022; Taylor et al., 2019) leaching from plumbing into drinking water, as well as from mining wastewater, sewage treatment, agricultural fungicides and fertilizers, and industrial pollution is associated with liver toxicosis in infants and children. Other commonly found chemicals of health concern in drinking water include nitrates (Lin et al., 2023) which are commonly used in agriculture and were associated with disruptions to reproductive system development in children and pre-term birth while the review found the impacts on weight for gestational age and heart defects were inconclusive. Excessive fluoride in drinking water can arise from industrial emissions, pesticide residues, and certain pharmaceuticals that can release fluoride (Choi et al., 2012; Grandjean, 2019) are associated with neurotoxicity in early development. In addition to these well-known chemicals, systematic review evidence finds new and emerging chemicals of concern in water such as polychlorinated biphenyls used in plastic production (Ribas-Fitó et al., 2001), tetrachloroethylene used in textile cleaning (Guyton et al., 2014), phthalates (Ejaredar et al., 2015), and perfluorinated compounds (PFAS) used in waterproofing items or non-stick coatings (Rappazzo et al., 2017) can disrupt normal endocrine development in children, which in turn can impact on prenatal growth, thyroid function, glucose metabolism, obesity, timing of onset of puberty, and fertility. There were fewer systematic reviews on pharmaceuticals and personal care products (PPCPs) and the most recent published systematic review (Adeleye et al., 2022) had no data on specific harms to children. Evidence in reviews from lower income countries was also scant, but the review did find the highest wastewater contamination was in India for antibiotics, antipsychotics and antihypertension medications while data of extent of contamination in Africa and South America was limited. Nano and microplastics (NMPs) have been shown to kill human cells in a review (Danopoulos et al., 2022). Another review found NMPs in the human placenta and infant stool, while NMPs are usually found by degradation of larger pieces of plastic in litter, NMPs have been found in breast milk, infant formula and drinking water (Sripada et al., 2022), but the impact on very young children in this vulnerable developmental window is still not known with certainty.

There is a lack of reviews investigating and discussing specific impacts on very young children being exposed to contaminated water in low- and middle-income countries (LMICs). It is crucial to understand which evidence exists and where there are gaps in our knowledge to best inform and influence public health policy in LMICs and decide future research priorities. Typically, LMICs lack sufficient regulatory frameworks and necessary infrastructure to adequately manage wastewater and prevent water contamination from anthropogenic activity. Very young children conceived and living in LMICs are significantly exposed to contaminated sources of water, hence have an increased chance of experiencing health complications, particularly those in urban settings near highly polluting industrial facilities (Srivastava et al., 2017). When living in environments where water pollution is common it is difficult to protect children from being exposed to the effects that result from consuming, playing, bathing etc. in chemically contaminated water.

3. Methods

3.1. Review approach

We conducted a systematic rapid scoping review using the Arksey and O'Malley framework (Levac et al., 2010) to guide each step of the review, these being: (1) specify the research question, (2) identify relevant literature, (3) select studies, (4) map out the data, (5) summarize, synthesize, and report the results, and (6) include expert consultation. To be rapid, we limited our searches to those sources that were most relevant to the topic area and extracted data from only the title and abstract.

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to guide and make transparent all decision making throughout the reviewing process.

To identify the research literature that could answer the research questions. We unpacked and described the concepts, definitions and assumptions within the research questions to develop the inclusion and exclusion criteria that studies had to meet to be included for review. And we developed a search strategy of key terms to find them in academic journal databases and in the grey literature.

3.2. Search strategy and eligibility

The rapid nature of the search strategy limited the search to research conducted in the last 20 years, and to the primary medical and engineering journals bibliographic databases of PubMed, MEDLINE, SCOPUS, and Web of Science. We hand-searched for reports on Google and Google Scholar. We searched for grey literature on websites of relevant organisations such as government and non-government organisations. We contacted experts from donor/philanthropic organisations and other key child health, water and sanitation and development specialists for unpublished work and seminal papers in the field. Searches took place between March 2021 and August 2022.

We used free text and subject headings for synonyms describing very young children, contamination and water. For example, for very young children we used words like “foetus”, “baby” and “infant”, to describe contamination words like “pollution”, “seepage”, while “stream”, “aquifer”, and “groundwater” were used to describe water. These synonyms were combined using AND/OR to develop Boolean queries used to search operators. The results of the search from each database and hand-searching process were exported into EPPI Reviewer (Thomas et al., 2010), a systematic review information management software. After deduplication records, titles and abstracts of the studies were screened against the inclusion criteria to find the final set of studies to be included in the review.

The screening tool was piloted against the inclusion criteria with random samples of studies and blind coded, results were compared, and any discrepancies discussed until consensus is reached. Where consensus could not be reached a third reviewer was called upon to adjudicate, boundary issues of inclusion were discussed in regular reviewer meetings with other members of the team and topic experts.

The criteria for inclusion were as follows:

- Published in English due to time and resource constraints, studies not published in English were not included.

- Population was very young children defined as under the age of 5 years and/or pregnant women but with a focus on the effects of water contamination on very young children.
- The study was an empirical study, studies of any design where the study objective was to describe, measure, or evaluate prevalence, strategies, tactics, processes, and/or methods.
- The study setting was in a LMIC as defined by the World Bank Atlas method at the time of study.

3.3. Data extraction and synthesis

We extracted relevant data from each study's title and abstract using a data extraction checklist for the following characteristics: country where the contamination took place; date of publication; type of chemical contamination; type of water contaminated; setting and contextual details; what health impacts or risk to health were reported, what age groups of population impacted, tools used to measure water contamination, causes, solutions or recommendations proposed by the authors.

3.4. Stakeholder workshop for expert consultation

Once the data extraction process was complete and the findings have been categorised and analysed, we coordinated a workshop where we presented the findings of the systematic literature review and led discussions related to the findings with key stakeholders from across the world i.e., government representatives, NGOs, tech start-ups and academic experts in Child Health, Engineering and International Development. The purpose of the event was to gain context specific insight on the challenges being observed in LMICs, to understand if the findings of the systematic literature review reflect the observations made in the field. Furthermore, the workshop was used to help streamline findings by highlighting priority topics to focus on as findings for systematic literature reviews can be extensive and broad in the themes explored.

4. Results and discussion

4.1. Results and study characteristics

After screening 9718 "hits" against the inclusion criteria 98 studies were included in the review (see Fig. 1). There was a greater number of studies that were excluded as not stating the population of interest in the abstract. To achieve rapidity in the review, we included the studies that were explicit about their analysis for younger age groups in the abstract. We checked a sample of studies (20 %) that did not specify the population

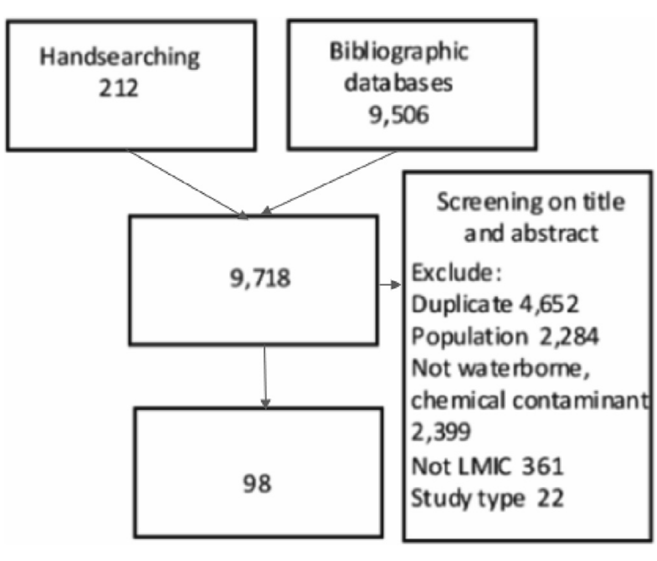

Fig. 1. Flow of studies through the review.

in the abstract to see if it was then mentioned in the main body of the text or if they were systematically different in some way.

4.2. Geographical distribution of studies

Upon reviewing and extracting the relevant information, the literature revealed that the most researched country is India with 25 reports in studies investigating how chemically contaminated water cause health implications in children under 5, followed by Ghana (17) Nigeria (15) Bangladesh (14), Pakistan (11) Thailand (7). These 6 countries represented 75 % of the geographical distribution of studies (Fig. 2), suggesting the urgent research need on this topic in most LMICs.

Publication dates showed that since 2012 the number of published studies investigating the health impacts of chemically contaminated water on children under 5 in LMICs has increased steadily from 2012 to 2021. 2022 shows a lesser figure as it was only a partial publication year at time of the review, with the most literatures being published in the last complete year of 2021 (Fig. 3). This could reflect the growing concern about the global disparities in the level of water quality and the drive by researchers to highlight this issue and the short- and long-term repercussions it had on local communities.

4.3. Chemical contaminants reported

We found 43 different chemical contaminants discussed and recognised as causing health impacts in very young children (Fig. 4). The chemical contaminants that appeared the most in the articles were nitrate, arsenic, lead, and fluoride. There was a diverse range of chemical contaminants in the studies, however, this may not be a complete list, as it represents those studies of chemical contaminants of water that also provided measures, or of those that could be measured, of health impacts on very young children and/or pregnant women to meet our inclusion criteria.

Several chemicals identified in studies conducted in low-income countries are known as "legacy chemicals", meaning that they were banned from sale and use due to their harmful effects. The legacy, is that chemicals tend to break down slowly, and as a result, they continue to be released into the environment long after their initial deposition. We noted that there were fewer studies that reported on the emerging contaminants of endocrine disrupting chemicals (EDCs), polycyclic aromatic hydrocarbons (PAHs), PFAS and NMPs. For comparison we revisited the studies that were excluded at the screening stage as being set in a high-income country and data extracted these for the chemical contaminants that were reported in these studies.

The profile of chemical contaminants of water in research set in higher income countries differed to that for lower income countries. There was a similar proportion of studies on contamination with heavy metals (Fig. 5), but within this group, a greater emphasis on research on lead contamination. Nearly a third of these studies were specifically about the contamination of the water supply in Flint, United States from 2016. There were slightly higher proportion of studies on EDCs, PFAS and PPCPs (Figs. 6 and 7). Still, no studies were found in either high- or low-income countries that included measures of the impacts of water contamination of nano and micro-plastics on very young children. This confirms the findings of recent reviews (Danopoulos et al., 2022; Sripada et al., 2022) that the impacts on water contamination of these kinds of "forever chemicals" on very young children are largely unknown.

4.4. Contamination impacts reported

Some studies (19) did not specify the health risk associated with some chemical contaminants (of multiple contaminants) and the harm they pose to children under 5 years. Measures of carcinogenic or non-carcinogenic risk were the most frequently reported health risk in the literature. However, younger children were at greater risk of bioaccumulation of some chemical, as they were being exposed for a longer period of time in their life compared to adults, and at a vulnerable and critical stage in their development, the specific risks and impacts that were

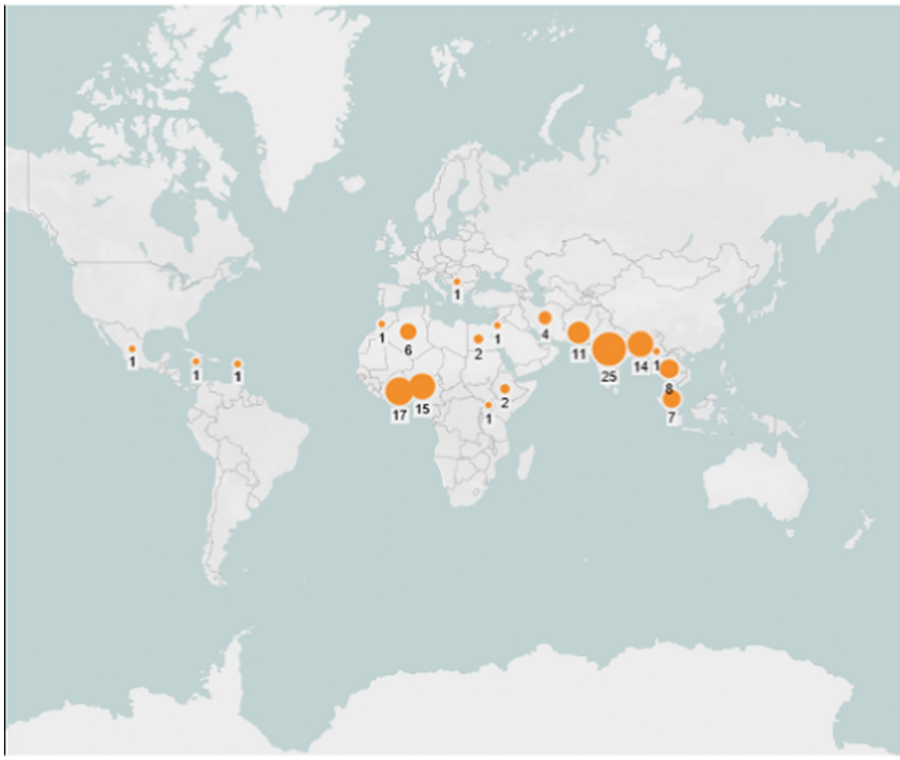

Fig. 2. Geographical distribution of studies.

reported for very young children either directly, or through maternal to foetal transfer were neurological, skeletal, reproductive, or endocrine developmental related issues (Fig. 8).

A small number of studies (24) reported the order of hazard ratio for different age groups in their abstracts and this is shown in Fig. 9. The most reported chemical contaminant in these studies were for fluoride (9), nitrates (9) and cadmium (2), followed by one study which reported on greater hazard for infants, including copper, nickel, lead and magnesium. However, this represents a minority of the chemical contaminants reported in the studies, meaning there is a gap in our knowledge about the order of hazard for very young children for most of the chemical contaminants of water reported in the studies.

Both geological features and human activity interacted to create fluoride exposure dosage for infant and children which was twice that of adults in a study of groundwater samples in Lalitpur, India. Similarly, in Gujurat, India findings report that fluoride concentration in groundwater were observed in the range of 0.66–1.61 mg/L (2014) and 0.86–1.77 mg/L (2019) which indicates that 62 % samples are unfit for drinking purpose (Panseriya et al., 2022) and increased non-carcinogenic health risks.

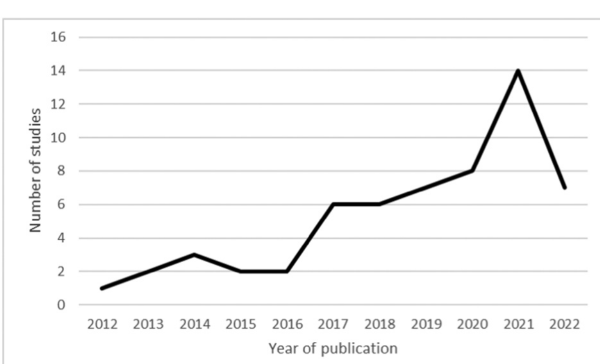

Fig. 3. Publication year.

Naderi et al. (2020) found high fluoride concentration in the water supply attributed to dental fluorosis in children and adults, infants were less at risk of developing this condition as typically babies consume breast milk in the early stages of their life (Naderi et al., 2020). However, mother-to-child transfer of fluoride through the placenta has been shown to occur, particularly in endemic fluorosis areas may be associated with adverse effects on brain development in children through the transfer from mother to child (He et al., 2008).

4.4.1. Contamination pathways: from mother to child during pregnancy

There were two main ways a mother could transfer contaminants to an infant discussed in the literature: pre-birth via transfer through cord blood and across the placenta to foetus and post-birth through breast feeding.

Nadaraja et al. (2015) discuss how exposure to perchlorate triggers a hormone imbalance which results in an overactive thyroid gland. They further explain that thyroid disorders in pregnant women can result in severe consequences such as miscarriage, preterm birth, and low birth weight amongst other implications. Similarly, Rahman et al. (2018) report that although small, there is a significant association between exposure to arsenic and preterm birth in Bangladesh. However, Rahman et al.'s (2018) findings reflect the social context and cultural practises i.e., child marriage which cause health implications for both the mother and the foetus. Therefore, exposure to arsenic further contributes to the likelihood of complications arising.

According to Valeri et al. (2017) water sources contaminated with a mixture of contaminants may induce different dose-responses relationships in communities. They explain that previous studies in populations with lower- exposure levels (below 5:8lg = dl), have an inverted 'U' relationship between manganese and neurodevelopment. This reveals that at a mid-range level (5:8lg = dl), exposure to manganese can be beneficial, however at lower and higher levels of concentrations it can be toxic (Valeri et al., 2017). Furthermore, Valeri et al. (2017) highlight that the neurotoxicity caused by high exposure (above 5:8lg = dl) to manganese plateaus and does not increase even in cases where the water sources is contaminated by a mixture of contaminants i.e., lead and arsenic. Although the research does not make clear what the health implications children who are exposed

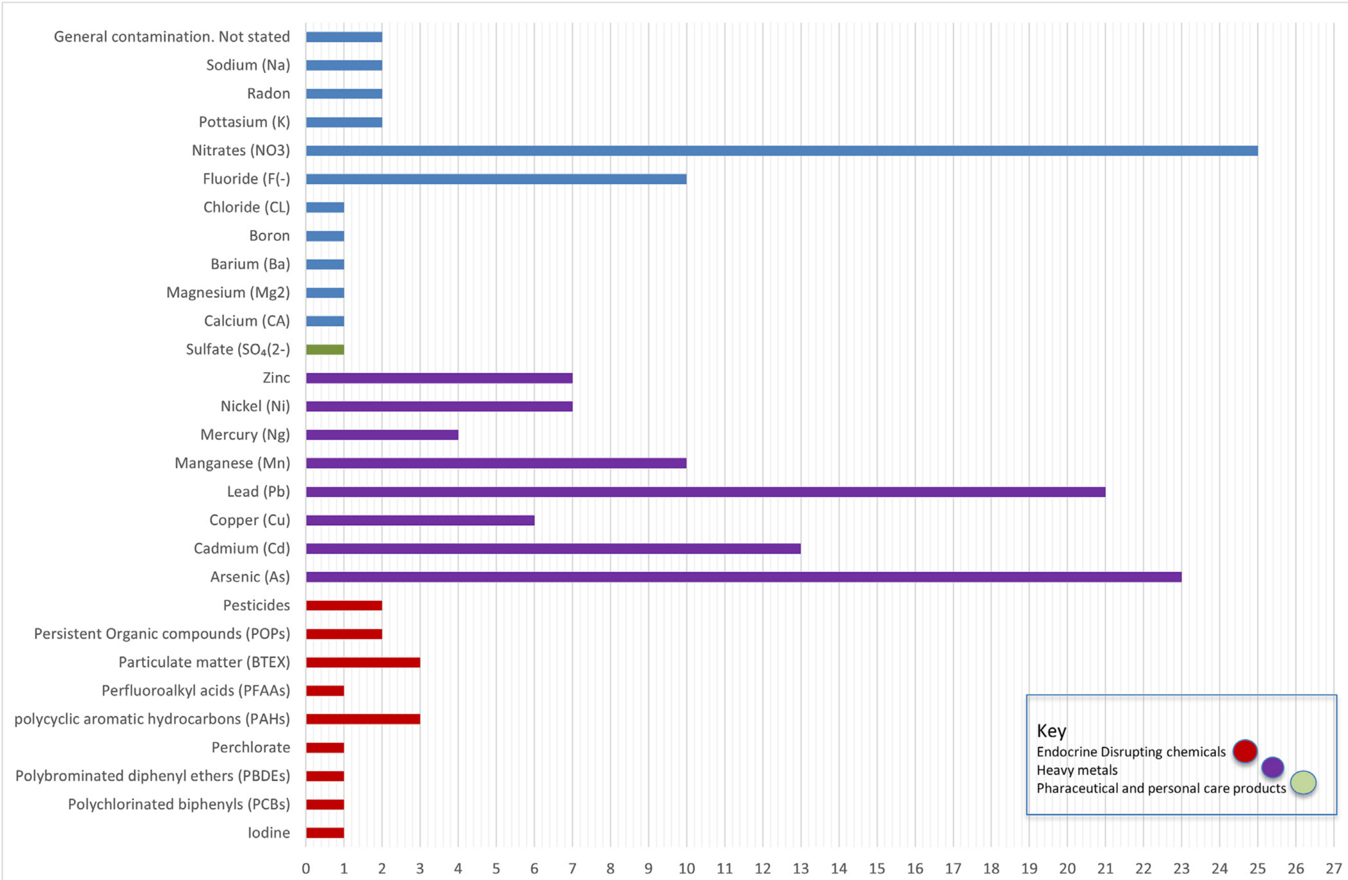

Fig. 4. Chemical contaminants reported in the studies.

to manganese, however based on existing research in this area children can experience limb weakness loss of intellect, cognitive and behavioural problems. Similarly, Forde et al. (2014) found water sources, in the 10 Caribbean countries studied, were contaminated with polychlorinated biphenyls and dioxin-like compounds in varying degrees. However, the maternal blood persistent organic pollutant (POP) concentrations were found to be relatively low in the Caribbean in comparison to Canadian and US datasets (Forde et al., 2014). Amongst Caribbean countries Bermuda was found to have significantly higher levels (11.47 μg/kg) of polybrominated diphenyl ethers (PBDE) contaminations and Jamaica was found to have lower levels (Forde et al., 2014, p216). Despite these finding, Forde et al. (2014) conclude that POPs still pose a risk to the neurological and other physiological development of unborn children. Therefore, they suggest that the government should establish monitoring programs or systems to reduce chances of consuming contaminated water. Although not all methodological expectations were achieved, for some Caribbean countries it was difficult to find 50 pregnant women due to a small population, regardless, the study still reflected and reinforced the potential health risk of chemically contaminated water to foetuses.

Another health risk discussed within the literature is Methemoglobinemia or "Blue baby syndrome" (BBS). Panda et al. (2022) investigated aquifers contaminated with nitrate in South India and found that infants, children and adults all had high health quotient (HQ) hence they were exposed to non-carcinogenic risks. Infants specifically were at risk of developing BBS as they are more sensitive to nitrate and their gastrointestinal tracts are still underdeveloped (Indrio et al., 2022). BBS can cause developmental issues in children and hinder weight gain. Mullin et al. (2019) also looked at babies particularly on the correlations between birth weight for gestational age and pregnant mothers' blood arsenic concentrations, where they concluded that during the earlier stages of pregnancy, there were no significant associations. However, in the third-trimester women with higher blood arsenic levels (≥100 μg/L in urine) have an increased likelihood of experiencing both small and large gestational age.

4.4.2. Contamination pathways: from mother to child during breastfeeding

Other studies investigate the contamination of mothers' breast milk. Mandour et al. (2013) found that mothers who drink groundwater ingest more lead, and this also impact the level of lead present in mothers' breast milk. This transmission from mother to infant results in infants having high blood lead levels despite not directly consuming contaminated water (Mandour et al., 2013). Reinforcing the importance of environmental health especially for infants as despite not directly consuming contaminants through water, based on the findings breastfeeding has been shown to transfer contaminants to infants more than the amount passed through mothers to the foetus during pregnancy. By protecting mothers, we are indirectly protecting infants' health as mothers create a pathway for contamination to reach and impact the health of infants.

Nitrates are also naturally occurring, but nitrate pollution can accumulate in groundwater that to levels that are unsafe for drinking as a result of human activity, mainly through leachate from soil surface from fertilizers for agriculture. Domestic wastes, septic tank spillages, and animal wastes also contribute to nitrate pollution of groundwater supplies, (Rao et al., 2021). Studies such as Suvarna et al. (2020) found levels of nitrate in groundwater in Andhra Pradesh. India exceeding the WHO guidelines for safe drinking (45 mg/L) in majority of samples (61 %) nitrate concentration in groundwater samples ranged from 2.50 to 760.12 mg/L, with a mean value of 86.13 mg/L (Adimalla and Qian, 2019). In Nalgonda district of India, 95.5 % of samples total non-cancer-causing health index was observed to be more than the acceptable limit of 1.0 with the greater hazard for infants due to the longer lifetime time of daily exposure to unsafe levels of nitrates and greater concentrations in lighter body weights of infants compared to children and adults (Rao et al., 2021).

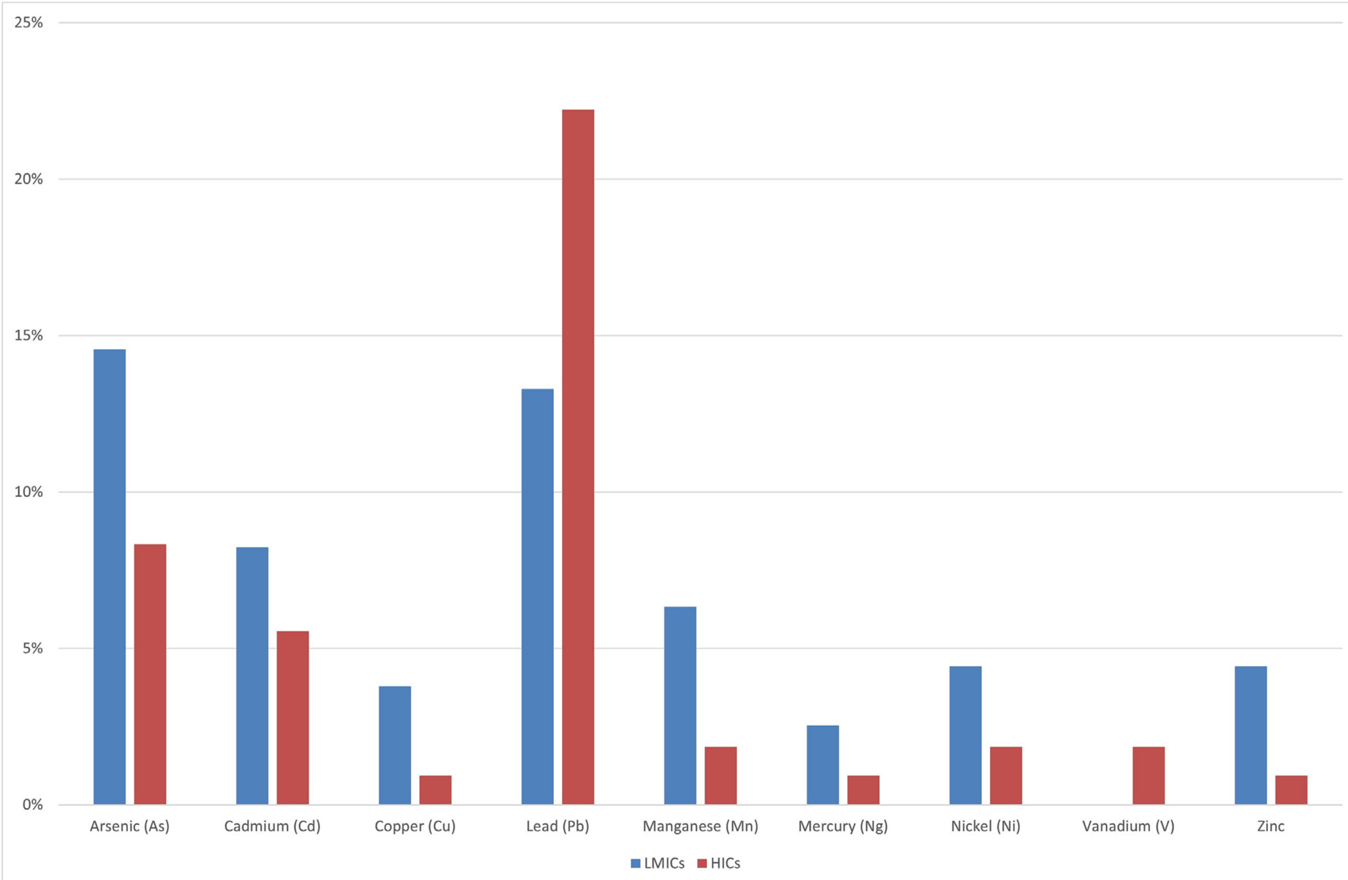

Fig. 5. Proportion of research on types of chemical contaminants: Heavy metals in low-income compared to high-income countries.

The Qasemi et al. (2019)'s study evaluated the order of hazard for infants, children and adults for cadmium pollution in a rural area of Iran. Cadmium again is toxic and naturally occurring at low concentrations, but pollution from cadmium increases to higher levels in locations close to metal mining and smelting activities. The WHO considers 4 heavy metals including cadmium, arsenic, lead, and mercury in its list of 10 chemical elements as an important public health concern and cadmium is one of the most hazardous metals posing serious risks to human health. Cadmium is slow to secrete from the human body and accumulates to harmful levels over time, so younger children are at greater risk from longer term exposure. Prolonged exposure to cadmium through contaminated drinking water can cause anaemia and cancer.

The cancer-causing risks of chromium, copper, magnesium and lead were all measured in one study of groundwater contamination near an open waste dump in Thailand (Aendo et al., 2022). Municipal solid waste dumps are associated with leachate from heavy metals (mercury, arsenic, zinc, lead, nickel, cadmium, manganese, iron, cobalt, chromium, aluminium, and copper). They found concentrations of lead, nickel, cadmium, manganese, iron, chromium and arsenic in groundwater exceeded both WHO and USA Environmental Agency (USEPA) standard limits, and the water quality index measure showed the water samples from the nearby groundwater unsuitable for drinking. Lifetime cancer risks were higher for very young children than for adults.

4.4.3. Contamination pathways in the early school years

A further pathway for contamination identified by the literature is during the early school years, this period is when mothers have stopped breastfeeding and their infant start to develop their independence away from their mothers either by attending school or socialising with other local children. UNICEF and Pure Earth (2020) explain that contaminated water and toxic social environments are a risk to children's health, and this rationale is further reflected by Majumdar and Guha Mazumder's (2012) research which investigated the effects of children drinking arsenic-contaminated water. They concluded that children could develop skin conditions (e.g., pigmentation change and keratosis) as a result of being exposed to chemical contaminants like arsenic (Majumdar and Guha Mazumder, 2012).

The literature reflects the challenge associated with cleaning up contaminated water sources, as once chemical substances enter these natural or manmade sources of water it is difficult to trace the contaminants. Majumdar and Guha Mazumder (2012) recognise that a common pattern observed was that various sources of water often contain multiple contaminants because multiple human activities contribute to the contamination. This makes it challenging to contain and isolate the immediate cause.

In Telangana India, Vaiphei and Kurakalva (2021) found that the water quality was deteriorating over time. Sixty percent of water samples feeding from the river to provide drinking water for local people are considered poor or unfit for drinking. Adimalla et al. (2020) found similar results in the groundwater in South India where more than half of the groundwater sample sites were contaminated by fluoride and nitrate. Vaiphei and Kurakalva (2021) do not clearly specify what health implications are caused to infants as a result of consuming contaminated water, this is a common limitation with some of the literature included in our review.

Aside from the general risks children face when being exposed to contaminated water, some literature focuses on school facilities being a route for contamination. Shezi et al. (2022) investigated carcinogenic risk in pre-schoolers, they found heavy metals in the soil and river near a preschool in Cape Town. Findings revealed that the accumulative carcinogenic risks exceeded the acceptable limits (Shezi et al., 2022). Although the heavy metals in Kuils river do not have any known immediate effects, in the long-term infants can develop cancer as a result of repeatedly ingesting contaminated water (Shezi et al., 2022). Equally, Debebe et al. (2020)

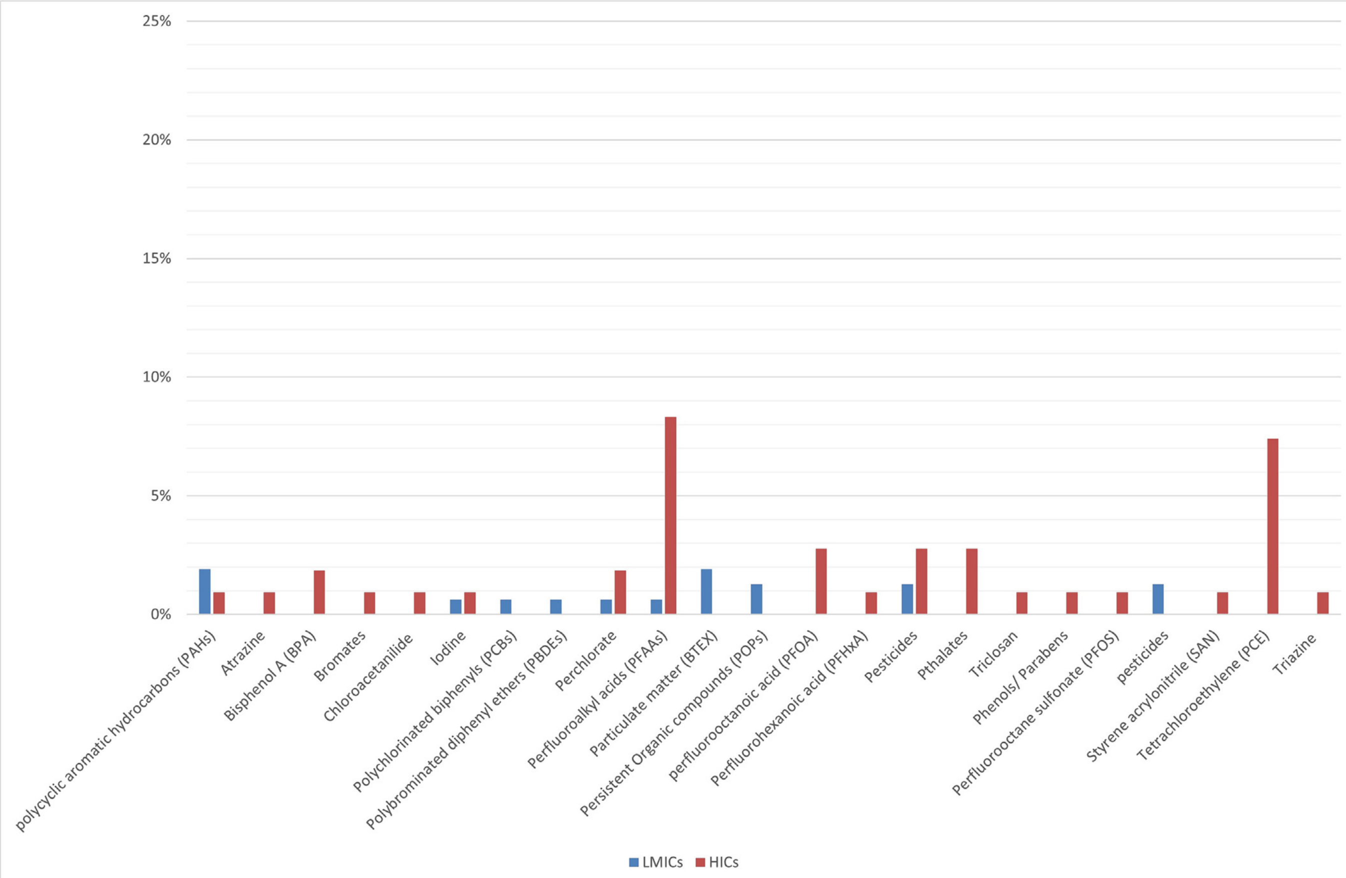

Fig. 6. Proportion of research on types of chemical contaminants: Endocrine disrupting chemicals in low-income compared to high-income countries.

investigated lead contamination in school drinking water in Ethiopia, where they found that there were high blood lead levels amongst the children. Having high blood levels impacts children's neurological development thus it can reduce IQ and cause learning difficulties (Debebe et al., 2020). Rodrigues et al. (2016) also focused on the neurodevelopmental outcomes of infants aged 2 to 3 with elevated blood lead levels in Bangladesh. The findings revealed high blood lead levels (>10 μg/dL) were associated with decreased cognitive scores, the effects of lead are dominant as the effect of other contaminants like manganese and arsenic are undetected (Rodrigues et al., 2016). Poor educational performance for children attending school may be perceived as counterintuitive as they attend school to learn. However, drinking from contaminated water sources near educational institutions impact children's neurodevelopment which prevents them from learning and succeeding academically.

It can be argued that children attending school may still be better off overall despite the health implications. If they were not attending school literature reveals that children are still likely to be exposed to contaminated water, and regardless will be at risk of developing health complications. Akers et al. (2015) also argue that proximity is a leading factor in why children consume contaminated water. Children are more likely to drink from local water sources that are close by. Therefore, if children are not attending school to avoid consuming contaminated water, it is likely that they may still live in close proximity to other contaminated water sources i.e., rivers and wells. Akers et al. (2015) further demonstrate this rationale in their findings, which reveal that 15 to 70 % of children in Tamatave, Madagascar are on the cusp of developing elevated blood lead levels (>5 μg/dL). This is due to infants drinking from their nearest pump system despite it being contaminated. Hasan et al. (2019) discuss that the lack of effective monitoring of water supply systems combined with poor awareness and education increases the likelihood of consuming contaminated water. Although their research was based in Bangladesh, however, these observations are relevant in other geographical contexts (Hasan et al., 2019).

4.5. Limitations of literature reviewed

Aside from the obvious concerns identified in the literature regarding the dangers of chemical contaminants on children's health, the studies also highlight key challenges that prevent resolving this complex issue.

4.5.1. Measuring contamination

Amongst the literature, it is acknowledged that there was a diversity of regulations and standards against which to measure water quality and the extent and severity of water contamination in LMICs. Although the measurement of water quality is complex, technologies for accurate measurement are prohibitively expensive for LMICs and a definitive measure of the extent of chemical contamination is likely to be underestimated. There are various regulations guiding safety standards referred to across different countries and agencies. For instance, there were 10 different measures of water quality mentioned in the literature, this ranged from intergovernmental organisations like USEPA and WHO and other nationally established systems i.e., the South African national standard and the Turkish drinking water standard. As a result of having various systems of measurement, it makes it difficult to compare results and findings from studies researching the same country. For example, Panda et al. (2022) and Vaiphei and Kurakalva (2021) both focus their research on nitrate contamination in India, however, they are both guided by different regulators. Panda et al. (2022) follows the guidance of the UESPA and Vaiphei and Kurakalva (2021) use the Water Quality Index and guidance from the WHO. Both kinds of literature convey different approaches in their findings and conclusion. For example, Vaiphei and Kurakalva (2021) suggest that nitrate contamination is worsened by the monsoons hinting that otherwise

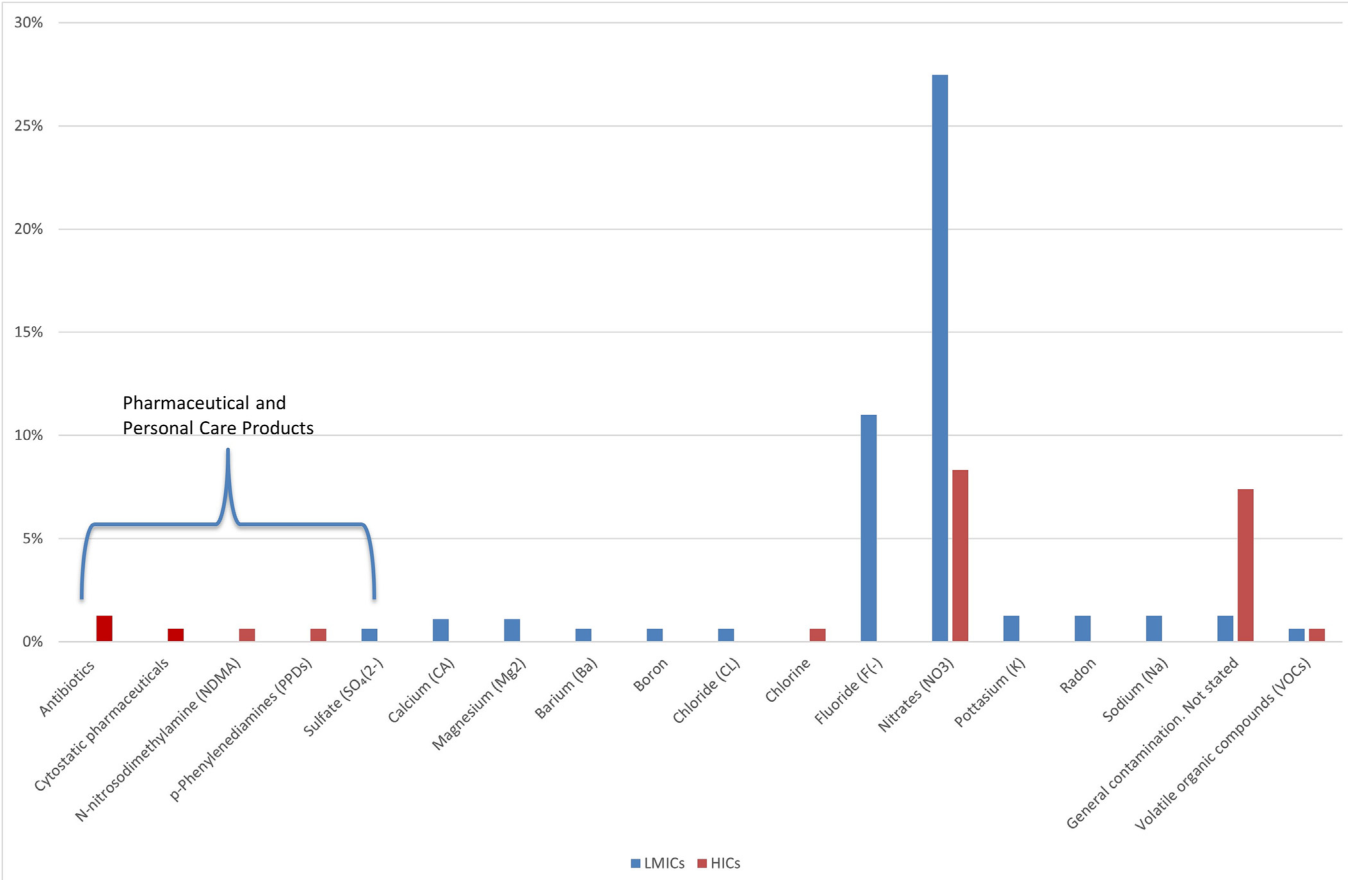

Fig. 7. Proportion of research on other types of chemical contaminants: in low-income compared to high-income countries.

the level of contamination found could be significantly reduced in the groundwater. The WHO (2018) explains that flooding in LMICs has resulted in the relocation of chemical contaminants as previously they may have been isolated in one area due to the industrial activities occurring locally. However, with floods, such chemicals are carried to other parts and thereby contaminate cleaner sources (WHO, 2018), equally, droughts have increased the concentration of contaminants in water sources. In contrast, Panda et al. (2022)'s findings are more hopeful as they suggest that insufficient infrastructure contributes to increased nitrate levels, hence by improving infrastructure conditions and by implementing management strategies health conditions of local people will improve. These differences in tone could be due to the variances found in the result of the two pieces of literature; this could be attributed to the use of different measurement guidelines, amongst other factors. Without there being a frequently used universal regulator is difficult to convey an accurate depiction of the scale and extensiveness of the issue.

4.5.2. Categorisation and sample of under 5

Another area of inconsistency recognised in many of the studies relates to the categorisation of children, as different studies defined this population group in different ways. Definitional issues, and the lack of specific information about the composition of the sample size being studied and discussed, made this difficult to compare across studies. Some literature referred to under 5 s as infants, and some refer to them as young children or pre-schoolers. For example, Debebe et al.'s (2020) study focus on preschool children in Ethiopia, generally, children in Ethiopia can attend preschool from the age of 3 to 7. However, Rodrigues et al. (2016) focus on school children in Bangladesh but there are not many preschools in this context, hence the majority of children particularly those from low-economic households start primary school at 6. Hence, having some of this detail disclosed in the literature provides crucial context for readers and allows for better comparison and comprehension of the findings. Furthermore, sharing specific figures about how much of the research population are of a particular age also adds further context.

In addition to the unclear identification and categorisation of children under 5, studies were vague on the impacts particularly experienced by those under 5 s as often the results generally recognised that children were at risk. However, they do not specify or differentiate how different age groups within the sample population are impacted. Hence, this resulted in the generalisation of findings, which may fail to convey the seriousness of this issue by minimising the threat it poses to infants. It is crucial that this information is included in the findings of studies as this information is essential to helping decision-makers realise the scale and severity of chemical contamination as they are not experts in this field hence such issues may be overlooked and easily deprioritised. Presently the dominant approach decision makers, intergovernmental organisations, and NGOs are using to address water contamination is by providing ways to filter and clean water at the consumers' end and developing man-made sources of water i.e., wells, dams, canals, pipes, water towers. However, more efforts need to be put towards developing more sustainable longer-term solutions such as implementing preventive measures, and regulations and improving water system infrastructure. Given that some types of chemical water contamination may be untreatable or the effective treatment as yet unknown, it is essential to preserve existing water sources as the demand for clean water is increasing (Boretti and Rosa, 2019).

4.5.3. Unspecified health risks

Many of the studies that were included in the review did not specify the health risk associated with chemically contaminated water, instead, they measure harm as cancerous and non-cancerous. Those that specified the health implication caused by chemical contaminants, listed a wide range of potential health impacts through the life course, from birthweight,

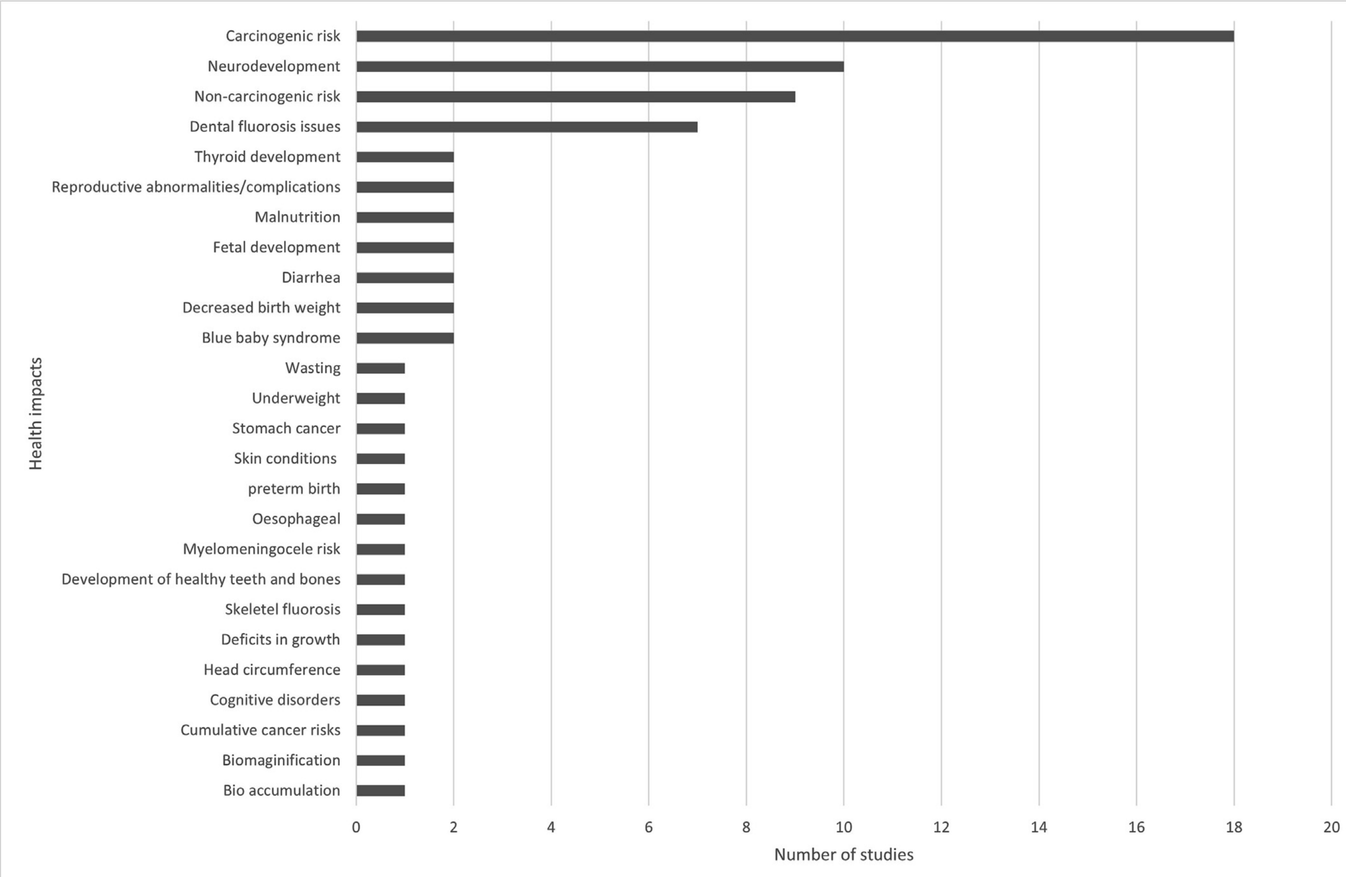

Fig. 8. Contaminants and risk to health reported.

brain development, skeletal and dental development endocrine development to childhood and adult cancers (Fig. 5). Many studies' lack of focus on identifying the associated health risks could be due to multiple reasons, for example, there may not be enough early literature that provides concrete evidence of the specific health risks associated with exposure to different types of contaminants and the differential harms for various groups of people. Furthermore, Amrose et al. (2020) explain that finding and understanding the adverse health impacts caused by chemical contaminants will require gathering information about specific contaminant concentrations, exposure duration, water intakes, population nutritional and health status and dose-response relationships for various health effects, which may be challenging to achieve. The studies that were able to describe the different levels of harm for different populations consistently found that harms were greater for very young children than for other age groups.

The failure to measure for specific health risks results in a loss of opportunity to further highlight life-altering or threatening conditions that very young children in these contexts experience. Furthermore, as chemical contamination is complex and ever-increasing due to production and uses in industry, i.e., manufacturing, agriculture, waste disposal, and mining, concentration levels may be changing and evolving; therefore, it is essential to track these changes to have updated information on contamination levels.

5. Discussion

5.1. LMICs and children under 5

This research has set out to investigate the health implications of chemically contaminated water on children under 5. The literature reveals chemicals such as lead, arsenic, fluoride or nitrate, and emerging chemical contaminants from PFAS, were found present in many water sources in LMICs. Etzel (2020) explains that children are more vulnerable than adults as they metabolize chemicals differently than adults hence, they are at a higher risk of developing anaemia, neurological disturbances amongst other health implications. According to UNICEF and Pure Earth (2020), chemicals like lead pose a risk to children in the prenatal stage as the build-up of lead stored in expectant mothers' bones is released during pregnancy resulting in the lead levels found in foetus, reflecting the levels present in their mother. The presence of lead can result in bleeding, miscarriage, stillbirth, premature birth, and minor malformations (UNICEF and Pure Earth, 2020) with no safe levels of lead known (CDC, 2022). This reflects how far-reaching the impacts of chemical contaminants are as the impacts can be life-altering. This further supports our reasoning for investigating children in LMICs as the results revealed that children specifically living in these countries have reduced access to health services to monitor, treat and prevent health complications. In cases where these services are available children's parents limited economic capabilities are one of many social and economic factors preventing children from accessing health services for frequent check-ups as they develop. For example, it is found that women in LMICs particularly in sub-Saharan Africa (SSA) have a higher percentage of home births (Hernández-Vásquez et al., 2021) and this is confirmed by UNICEF's (2023) observation that SSA and South Asia have the lowest levels of antenatal care. The pandemic has exacerbated these conditions as it is estimated to have reduced antenatal care by at least '18 %, and possibly up to 51.9 %' and a similar trend can be acknowledged in postnatal care (Kotlar et al., 2021). According to Konje et al. (2021), postnatal care is essential in ensuring the health of both the mother and baby after birth, hence during this stage of care neonatal screening is used to identify defects or abnormalities in the baby. The continuation of this trend in LMICs could result in babies and infants experiencing health complications resulting from the exposure and consumption of chemically contaminated water.

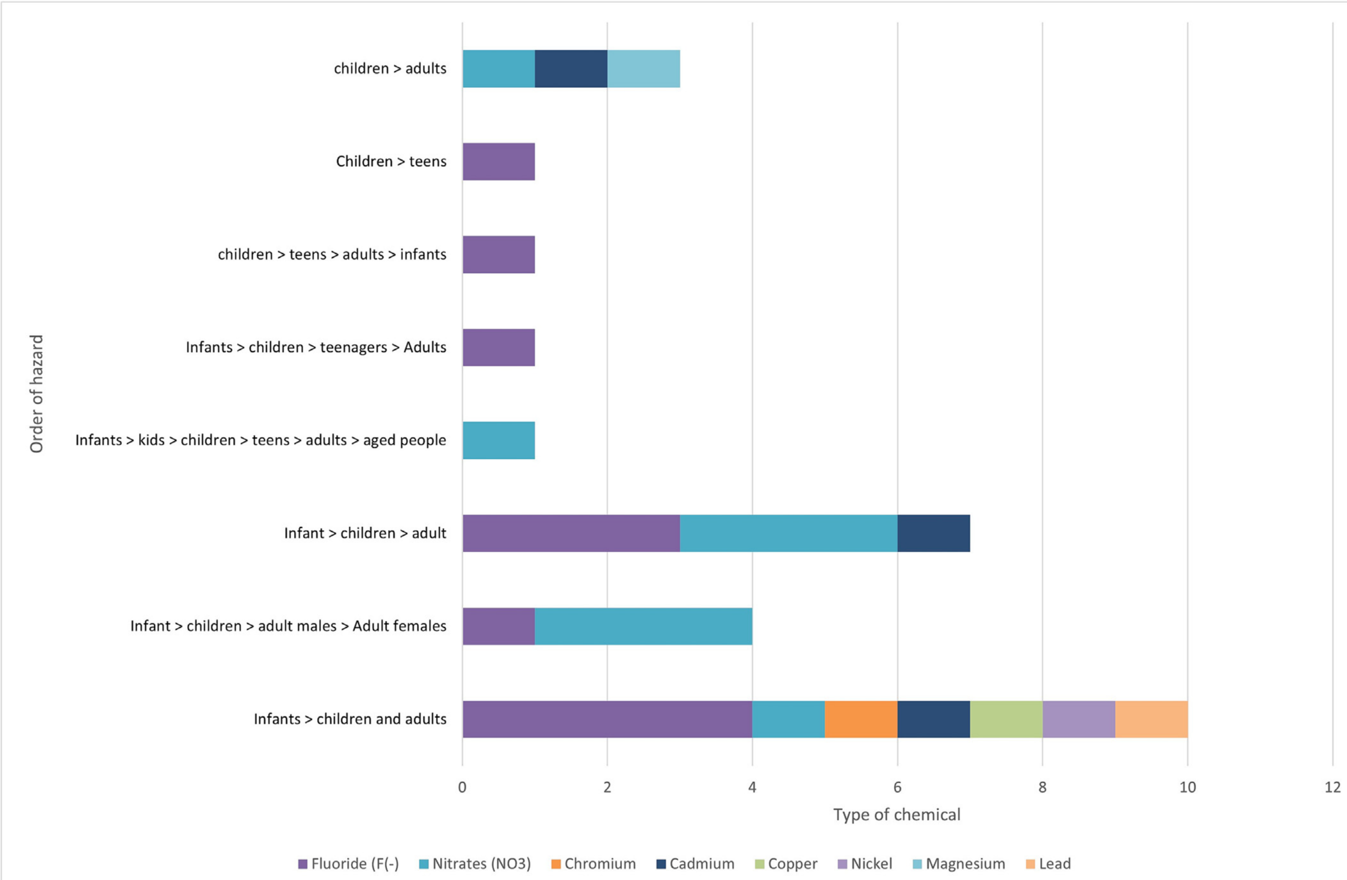

Fig. 9. Number of studies reporting order of hazard by chemical contaminants.

A dominant theme in the literature is that due to LMICs' developing status, most of the countries lack the appropriate infrastructure, facilities, resources, and technology to provide sufficient clean water to local communities (Amrose et al., 2020). For example, tube wells were frequently mentioned as a primary method used to access drinkable water. However, Maertens et al. (2018) mention the unintended harm that these instruments can cause if they are not routinely checked and replaced, as they can contribute to contaminating the drinking water. Other mitigation strategies include seeking alternative sources of water and using arsenic filters, for example, wells dug at a depth of <7.6 m deep or wells deeper than 61 m tend to tap low-arsenic aquifers, hence safer for drinking (Ahmed et al., 2006). The continued installation of tube well suggests that this will continue to be a popular form of accessing water in LMICs in the foreseeable future, therefore effective mitigation strategies need to be implemented to ensure the safety of these facilities.

In addition to making existing water infrastructure in LMICs safer, the literature reinforces that LMICs' pursuit of rapid industrialisation and urbanisation has proven to be detrimental to the water quality of both surface and groundwater resources. (Yadav and Karmakar, 2019) explain that the textile and apparel, manufacturing, and pharmaceutical are crucial industries for LMICs' economic development but equally these sectors are the largest consumers of water and significantly contribute to the chemical contaminants present in water sources. The chemicals identified in LMIC's water sources are in line with those found in industrialised countries with heavy industrial activity. This is not to say HICs do not encounter chemical contamination; however, they experience different kinds and at different degrees. For example, the European Environment Agency (2019) reported the emergence of PFAs in water sources in Europe, this reveals that HICs are encountering similar challenges with chemical contaminants, however because they tend to have more robust regulatory and legal frameworks for the management of liability and resources for prevention and treatment. Coupled with sophisticated water and waste management systems the effects of chemicals are minimised. We found a similar picture of difference in the characteristics of research in HICs compared to LMICs, with the chemical contamination profile of research differing in terms of having a greater emphasis on; with heavy metals in the LMICS and EDCs in HICs; research on harm to very young children associated with water contamination by PAHS, PPCPs and NMPs are still very few; contamination from chemicals that may be considered “legacy” in HICs, can be considered current in LMICs as economic development through industrialisation finds new contamination pathways with old chemicals (such as lead) and the continuing market for banned chemicals, such as with some kinds of pesticides, due to weak regulation and controls.

At present LMICs are grappling with countless socio-economic challenges as well as overarching issues like the impacts of climate change. Hence, it is essential to refocus and redirect decision-makers time and efforts towards addressing chemical contamination as the seriousness of this issue can be lost amongst other priorities.

5.2. Policy intervention and accountability

According to the review's findings, the impact of chemically contaminated water has reached critical levels. The application of solely bottom-up, approaches is insufficient in mitigating and eliminating toxic sources from water, this is supported by Champion et al. (2022) who explain that bottom-up approaches such as educating relevant people in LMICs about the dangers of consuming contaminated water are co-interventions that should be combined with more rigorous far-reaching strategies. Hence, aggressive top-down approaches are necessary in reviving the quality of water resources in LMICs. Thus, far policies and regulations have failed in deterring manufacturing, recycling, and other polluting industries from incorrect and unsafe disposal of chemical contaminants (Landrigan and Fuller, 2015). Filippelli et al. (2020) explain that the lack of effective regulations preventing chemical pollution is due to poor governance which has consequently led to poor management of financial resources. LMICs' lack of economic power places them in a predicament where they are unable to properly explore remedial solutions and robust and rigorous interventions or clean-up operations. This reinforces the significance of also holding government officials accountable for the mismanagement of resources as with unstable and self-motivated leadership it will be challenging to develop adequate policy and regulatory initiatives to help prevent further industry contamination.

The continuation of unenforced environmental policies, and poor work protection laws etc. result in the exploitation of communities in LMICs. This results in a feedback loop as western corporations continue to rely on workers in countries in SSA and South Asia for their manufacturing services (Yadav and Karmakar, 2019). Consequently, workers develop occupational health complications due to chemical exposure, which leads to local communities and nearby settlements experiencing health implications because of improper disposal of waste in factories (Yadav and Karmakar, 2019). This creates a pathway of contamination where children are the end receivers as they are directly or indirectly exposed to toxic chemicals. Developing legislation that protects the health of workers, local communities, and the environment coupled with harsh sanctions can help to prevent children under 5 in LMICs and their communities from experiencing life-long health implications. This will help to hold corporations accountable and responsible for their contribution to the degeneration of the quality of water sources.

The drivers behind chemical water pollution from industrialisation have been shown to be directly linked to the level of direct foreign investment from Global North to the Global South. Understanding and preventing the causes of chemical contamination of drinking water from industrialisation may need a global policy response (Jorgenson, 2009).

The severity of chemically contaminated water has wider implications beyond the health impacts acknowledged in children under 5. Gradually, the world is witnessing the consequences of overlooking the issue of chemical contamination as seen in some cases water treatment is not enough to revert water sources back to safe and drinkable conditions. For example, the river Buriganga in Bangladesh amongst other rivers surrounding the capital of Dhaka has been classified as untreatable (Kamruzzaman and Najmus Sakib, 2022). It is recognised that addressing chemical contamination is complex and challenging as there are various aspects to address as well as the level of cooperation needed to address such a vast issue will require the participation of local communities, parents, decision-makers in LMICs, HICs, and intergovernmental organisation in interventions and initiatives.

Furthermore, due to LMICs' limited economic capacity, it is essential that economically viable solutions are developed and implemented to ensure the longevity of the interventions. For example, implementing affordable and safe drinking water and sanitation systems at community level and encouraging the use of household water filtration devices may reduce the water contamination risks.

The involvement of researchers is key to the success of the potential strategies. Researchers develop an intricate understanding of the barriers to addressing and the impact of chemical contamination, thus they have a more intimate relationship with the local communities and groups included in their studies, understand the regional differences and contexts, thus can design targeted interventions based on the best available evidence. Furthermore, researchers have a greater insight into the severity of the issue and the challenges people in LMICs encounter, therefore they can help amplify the voices of underserved communities in deliberations. Jessani et al. (2020) explain that collaborations between the government and researchers are essential for evidence-informed decision-making. In addition, it is important that corporations also contribute to being part of the solution by prioritising the health of their employees and their family, this could look like corporations including frequent health check-ups for improving health and wellbeing at the workplace (Wipfli et al., 2018).

5.3. Life course: intra-generational implications

Presently there is not enough research discussing the intra-generational harm and damage being caused to children, however, amongst the literature that does, Rebuzzini et al. (2022) express their concern about the potential alterations of genes that may occur due to exposure to chemical contaminants in food and water. They explain that genetic changes could make infants predisposed to the development of pathologies that could emerge years later in childhood or adult life, which may even be transmitted across generations. The failure to address chemical contamination in surface and groundwater in LMICs threatens not only children of today but also future generations' right to live healthy lives.

Moreover, the literature reveals that aside from the health implications children may develop, their exposure to chemically contaminated water will also have an impact on their life prospects. For example, education is globally perceived as a great equalizer as it can open the door to more life opportunities i.e. jobs and resources that can help individuals not only survive but thrive (Giovetti, 2022). According to UNESCO, if all students in low-income countries only had basic reading skills an estimated 171 million people could escape extreme poverty. Neurological disturbance is one of the most common health impacts discussed in the literature in relation to children's exposure to chemically contaminated water. Hence, leaving such issues unresolved poses a threat to children and future people in LMIC's chance of breaking out of the cycle of poverty as being in chemically contaminated environmental conditions may hinder their ability to actualise their true educational and life potential. Although it may not be fully realised, the knock-on effects of chemical contaminants could have negative socio-economic impacts on children under 5 s life. This reinforces the importance of investments in further research into effective measures for minimising children's exposure as well as developing sustainable strategies to protect future generations in LMICs.

Fig. 10 summarises the findings of this scoping review, highlighting the main pathways of contamination for very young children and their lifelong impacts by water polluted with chemicals.

5.4. Further consideration: climate change

To develop sustainable frameworks to tackle chemical pollution strategies must anticipate and account for additional variables which may obstruct attempts to address this issue. For example, extraneous variables like climate change were mentioned in the review literature as adding a layer of complexity when addressing chemical contamination. Climate change results in variability and extreme climatic conditions, i.e., changes in temperature, rainfall patterns and precipitation that heavily impact water quality and, subsequently, human health (Ahmed et al., 2020). Globally, almost all countries are experiencing the impacts of climate change, particularly developing countries are most vulnerable and prone to disasters like extreme floods, droughts, storms and heatwaves (Ahmed et al., 2020). Moreover, evolving climatic conditions intensify and increase the occurrence of disasters i.e., earthquakes, tsunamis, hurricanes, these events significantly exacerbate and contribute to the spread of chemical contamination (United Nations, 2021). Extreme climatic events can result in the displacement of chemical contaminants and increased toxic runoff (WHO, 2020). Kibria (2014) explains that the build-up of arsenic contamination in groundwater in Bangladesh results from extreme flood and drought periods that have occurred in previous years. Strategies against chemically contaminated water must reflect and factor the additional burdens associated with climate change. Although the impact of climate change is not yet fully realised and quantifiable, however, it is recognised that climate variations will slow and undermine efforts to address chemical contamination (WHO, 2018), as infrastructures are destroyed, people are displaced, and the government is preoccupied. Hence, it is essential to adapt legislations, and interventions to ensure they are resilient and robust enough to perform well across a range of possible futures (Cooper, 2020). Equally ensuring climate-resilient systems and water management approaches are flexible and able to respond to unexpected shocks and uncertainties, as

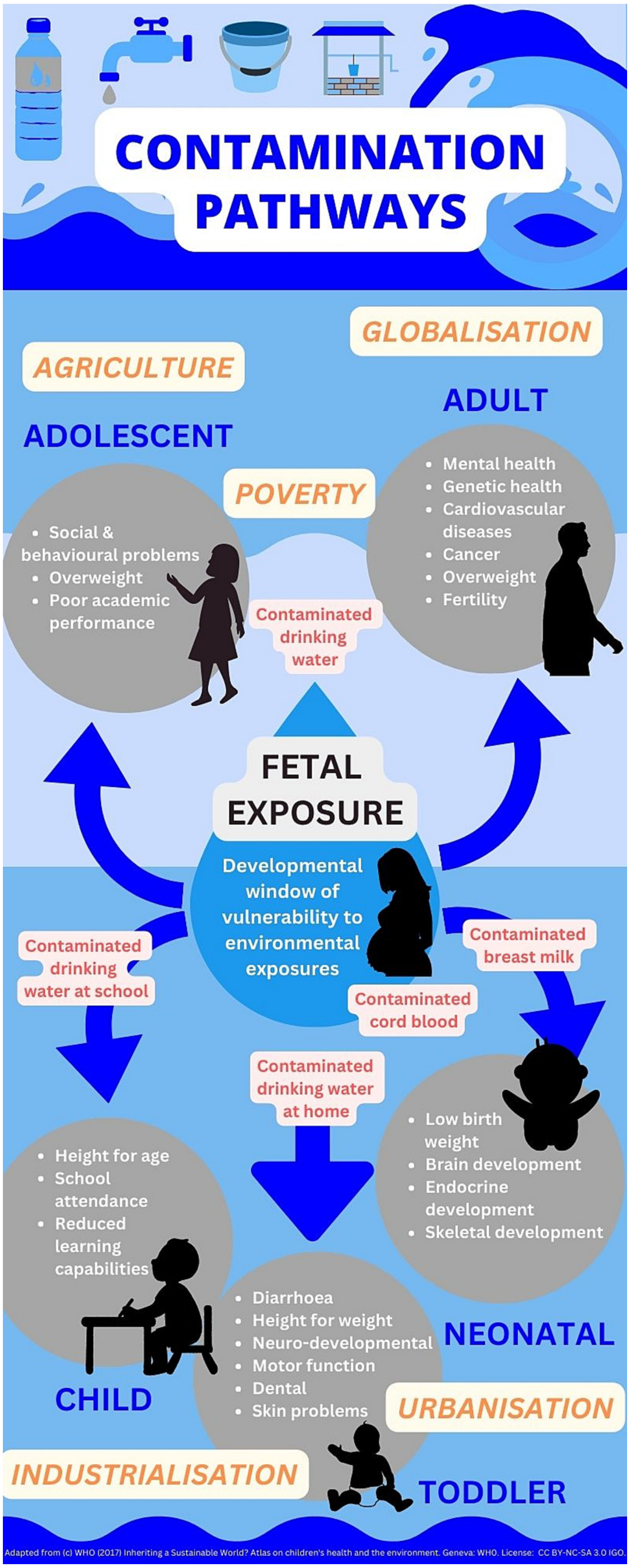

Fig. 10. Pathways of contamination for very young children by chemical pollution in water and their lifelong impacts.

this would help mitigate against the impacts of extraneous variables and help to progress efforts towards eliminating chemical contamination in water (Cooper, 2020).

5.5. Limitations of review methodology

Aside from the limitations typically associated with conducting rapid reviews i.e., restricted database search, limited inclusion criteria, etc. (Moons et al., 2021), there were limitations more specific to this review. For example, the decision to focus on LMICs was challenging to navigate during the selection process as the review was focused on only relevant literature published in the last decade. Hence, within this time frame, some countries had experienced economic growth. Therefore although economically they may no longer be considered LMICs, they still exhibit similar challenges to LMICs regarding chemically contaminated water sources.

Another challenge and limitation of the review is the rapidity of the reviewing process meant that a proper full assessment of the literature was not able to be conducted, rather the abstract was used to support the inclusion or exclusion of specific literature. Hence, this may have impacted the number of studies included in the review as relevant studies may have been excluded because the abstract had limited detail. Moons et al. (2021) explain that taking methodological shortcuts can make rapid reviews more vulnerable to bias and errors as the search for existing studies may be less comprehensive.

Aside from potential bias, when assessing the literature, deductions had to be made as some literatures were vague about which age groups represented children under 5 as the majority of literature just referred to infants and children. Hence, we had to deduce that when 'children' were mentioned the researchers were referring to children above 5 and when 'infants' were mentioned they were referring to children below the age of 5. Further deductions were made as some of the literature was not specific about which age group of the population sample experienced health implications. Therefore, based on a further understanding of the different health implications mentioned, made it easier to understand which health issue was most common in each age group. For instance, cancer is more commonly seen in older people (Webb et al., 2022), hence in cases where the literature was ambiguous about infants' risk of developing cancer this baseline understanding allowed deductions to be made that those infants were less likely to be at risk of developing cancer.

Overall, rapid systematic maps are valuable in helping to give an overview of the characteristics of a body of literature, to identify key themes related to the issue of chemical contamination in a timely fashion, and gaps in the literature where areas of research effort may be suggested for primary research or for systematic review (Moons et al., 2021).

6. Conclusion

Numerous reviews have evidenced the health impacts of different chemical contamination of water and the impacts on children globally. However, this review sought to investigate the gap in knowledge about the health implications of chemically contaminated water in LMICs on very young children, as a particularly vulnerable population.

As anticipated, the literature review revealed that exposure to chemical contamination in water is of greater risk to health for very young children in LMICs. Unlike adults, who are directly exposed to contaminated water directly through their consumption of contaminated water, findings confirm that in the prenatal and early postnatal stages, children are indirectly exposed. During pregnancy, chemicals ingested by the mother may be transferred via the placenta to the children or when breastfeeding. Once children enter preschool they may then be directly exposed to chemical contamination as their consumption of water increases and they are reliant on surrounding sources for their water needs.

Half of the 10 chemicals of public health concern listed by WHO have been shown to be of greater hazard to children under 5 years old compared to other age groups, (arsenic, cadmium, lead, and fluoride). The use of these chemicals is increasing worldwide, particularly in LMICs due to globalisation, as HICs can outsource their most hazardous industries to lower income countries which seek to attract foreign investment, grow their economy and secure livelihoods.

In addition to this, HICs such as Denmark, Germany, United Kingdom, Switzerland and the United States are manufacturing and exporting hazardous chemicals and pesticides that have been banned for sale and use domestically (Gaberell and Hoinkes, 2019). In 2022, France became the first country to impose a ban on the export of banned pesticides, after a legal challenge by agrochemical companies was defeated in 2020. Ensuring that adequate policy frameworks and interventions are implemented and enforced to encourage industry best practise in the use and disposal of chemical contaminants is paramount. This approach can be coupled with bottom-up approaches i.e. initiatives to raise awareness and provide education about children's environmental health to parents, carers, educators, local government, etc. but also global commitments to the end of sale of domestically banned chemicals from HICs.

Finding effective and low-cost water treatment options for multiple contaminants in groundwater used for drinking remains a challenge and it is the prevention of contamination through robust regulation at a local level and global policy and transnational commitments to safe handling and disposal of chemicals in industry and agriculture is likely to be more cost-effective.

This rapid scoping review identified the nature and extent of the research literature and identifies gaps in the research and suggesting areas for further research. Future research should focus on understanding more about synthetic chemicals and their impacts on different age groups, as over 167 million chemicals are registered, yet <1 % of these chemicals have been tested for toxicity. Another focus for future research should be ensuring that individual LMICs have enough research surrounding this topic as not all country's data were represented or reflected in the review as often the countries with the most research shaped the scope of the findings. Hence, this highlights a gap as it cannot be assumed that a lack of research means the problem does not exist in the unmentioned countries. Lastly, exploring the potential impacts of climate change on the existing spread of chemical contamination in water sources should also be prioritised in future research as the findings from the review suggests that contamination in specific locations may fluctuate i.e., intensified and reduced chemical concentration levels due to rising global temperature and sea levels. Acknowledging evolving global climatic conditions is valuable to establishing sustainable and effective strategies to tackle chemical contamination, allowing for better prioritisation and distribution of resources.

CRediT authorship contribution statement

Eniola Shittu: Investigation, Formal analysis, Writing – original draft, Visualization. **Monica Lakhanpaul:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition. **Carol Vigurs:** Methodology, Investigation, Formal analysis, Writing – original draft. **Kaushik Sarkar:** Methodology, Formal analysis, Writing – original draft. **Marta Koch:** Writing – review & editing, Visualization. **Priti Parikh:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition. **Luiza C. Campos:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition, Project administration.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

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

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