# Chemical Pollution in Low- and Middle-Income Countries

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# Contents

# Executive Summary

In the current Millennium Development Goals' framework, three of the eight goals directly refer to health-related issues, while several other goals relate to determinants of health. Although much still needs to be done beyond 2015 to reduce the burden of communicable and non-communicable diseases, a still neglected issue is the health and environmental impact of the unsafe use and management of chemicals. This relates directly to the targets of Millennium Development Goal 7. These targets focus on the loss of environmental resources and biodiversity as well as setting other health targets.

This report draws attention to the neglected issue of anthropogenic chemical pollution in low- and middle-income countries.

The daily use of chemicals is omnipresent and only a few industrial sectors do not use chemical products. Consideration of chemical pollution issues are mainstream in the developed world where policy and practice engage in finding and implementing appropriate solutions. However, limited information and scientific evidence has yet been compiled on the use, fate, and impact of anthropogenic chemical pollutants, such as pesticides, pharmaceuticals, heavy metals from the mining sector, e-waste pollutants, and other industrial chemical substances, in the specific context of low- and middle-income countries.

This situation is alarming and becomes even more severe as chemical production and demand increases with population growth, urban development, improvements in living standards, and increased pressure to achieve high agricultural yields. Furthermore, chemical production is increasingly moved from high-income to low- and middle-income countries to reduce costs and maintain competitiveness. It is inevitable that with increased production of chemical substances and their use, there is a need for a comprehensive global overview of and insight into the exposure and effect of anthropogenic chemical pollutants on human and environmental health. There is also need for an assessment of the awareness and practices of stakeholders.

Looking in detail at the situation in low- and middle-income countries is justified by the increasing production and use of chemicals in these countries and the expected elevated release of toxins into the environment. Often obsolete techniques are applied, governmental infrastructure is lacking, and the disposal of waste is poorly managed, regulated or controlled. Furthermore, compared to the availability of scientific studies in high-income settings, the pathways of anthropogenic pollution in low- and middle-income situations are less evidenced by research and less well understood.

The scarcity of publicly available data currently makes it impossible to fully assess and quantify the risks of chemical pollutants to human and environmental health in low- and middle-income countries. Although different reports and scientific studies are available with site-specific information, a broader framework at the global level is still lacking. This report attempts to fill this gap. It provides a structured framework by distinguishing various types of chemical substances and sectors – pesticides, pharmaceuticals (for human health care and veterinary use), mining, e-waste, and residual industries (cement, paper, rubber, textile, and leather).

This report provides an overview of the current situation based on existing published information and reveals the most important and hazardous sources of those anthropogenic pollutants. It then advocates and encourages further discussion around this sensitive issue. Each section of this report covers different aspects of chemical pollution. Each section starts with a description of the specific chemical characteristics and the groups of chemicals of highest environmental concern. It goes on to describe their input pathways, their use – including trends and impacts – and issues of special concern. The section ends with the best practices observed and documented.

Based on a comprehensive literature search regarding anthropogenic chemical pollutants in low- and middle-income countries, a clear picture emerges of some fundamental issues that show a repeating pattern. Implementation of and compliance with international regulations still need to be significantly improved, especially in low- and middle-income countries. Although several international initiatives, such as the Stockholm, Basel, and Rotterdam Conventions, and the Strategic Approach to International Chemicals Management (SAICM) exist, their application in these countries of concern remains questionable. It is obvious, although difficult to quantify, that the use of hazardous chemicals in low- and middle-income countries poses a grave threat to the environment and to human health, often affecting the already vulnerable and poor fraction of the population. Overall data on industrial production and exports, as well as on the import and use of hazardous chemicals is still significantly lacking. Without a comprehensive overview at the natio-

nal level it is very difficult to assess the overall relevance of the different substances in a specific spatial context. Only when more data on production and use are available or accessible, can better evidence on input pathways, spatial distribution, and the associated risks to human and environmental health be established. At sites already identified as critical, more research is needed to develop efficient and low cost techniques for environmental remediation that are feasible for application in low- and middle-income countries.

The management of chemicals and their use are seldom considered priority issues by government agencies. Developing effective sticks and carrots, by politicians providing clear and enforced legal settings, or governments providing economic incentives, will have the potential to engender improvement. An important step in raising awareness and starting to mitigate the hazardous chemical pollution of the environment and reducing human exposure is to create a sound knowledge base for decision makers and local authorities. This will help them become aware of the existing risks and appropriate technologies that can be applied in the production and consumption of chemical commodities or mining products. This also includes an urgent need to raise the individual awareness of the appliers and consumers related to the effect of chemical compounds on their own and others' health as well as on the environment.

More than 1.5 billion[1] hectare (2012) of arable land are in low- and middle-income countries – around 75% of the global total. The most environmentally hazardous and controversial substances with the highest bioactivity used on these lands are pesticides. The US Environmental Protection Agency (EPA) estimates that worldwide about 2.4 million tonne of active pesticide ingredients – single or a mixture of substances used for preventing, destroying, repelling, or mitigating any pest – are used each year. This amounts to an average annual use of pesticides of about 1.53 kg/ha. With population growth and increased intensification of agriculture, the use and application of pesticides is steadily increasing. Currently, about 1300 active pesticide substances are in use. These can vary significantly in their chemical characteristics, modes of action, effectiveness, and impacts. Pesticides are highly bioactive even at low concentrations and exposure to pesticides is known to impair human and environmental health. Extremely hazardous pesticides, which are banned in high-income countries, are still being stockpiled or even used in low- and middle-income countries. This use, linked to poor education on the handling of pesticides, limited awareness of their toxicity, the lack of regulations, and an overall lack of appropriate measures of risk mitigation, results in millions of people suffering from pesticide poisoning.

The use of pharmaceuticals to treat human and animal diseases is considered indispensable. More than 3000 active pharmaceutical ingredients are currently in use. These include analgesics, antibiotics, anticancer, antivirals, beta-blockers, contraceptives, lipid regulators, sedatives, impotence drugs, and others. The consistent use of pharmaceuticals results in an omnipresent contamination of the environment by active pharmaceutical ingredients or their transformation products. Increasingly, research in environmental toxicology and environmental chemistry, driven by improved analytical techniques, has resulted in better knowledge about pharmaceuticals in the environment and their effects on ecosystems. The occurrence and fate of pharmaceuticals in the environment have been extensively assessed and documented for high-income countries, whereas data is limited for the low- and middle-income country context. This is critical as the bulk of pharmaceutical production is in these countries. For example, China, India, and Pakistan are all producing large amounts of active pharmaceutical ingredients as a result of increasing demand and their lower production costs. Often the wastewater effluents, released without treatment into the environment, are important sources of pollution for such compounds. Use of active pharmaceutical ingredients increases with the availability of cheap generic drugs, improving living standards, and population growth. Finally, the rapid increase in intensive livestock farming (aquaculture and cattle, poultry, and pork) goes hand in hand with an increased use of active veterinary pharmaceutical ingredients. The consequences for human health resulting from the presence of active pharmaceutical ingredients in the environment are the development of antibiotic-resistant strains of bacteria (e.g. tuberculosis) or antiviral drug-resistant influenza viruses. Pharmaceuticals are found in many organisms in the environment and influence their development, reproduction, and behavior. The effects of this pollution with pharmaceuticals carry over into the population and even into the food web interactions in ecosystems.

Rising demand for raw material and ores from low- and middle-income countries relates particularly to metals and resources used in high-technology industry. Extractions of these minerals produce large quantities of waste. As more high-grade ore deposits are depleted, lower grade ores are exploited whereby even more waste is produced. To produce 0.3 mg of gold, 79 tonne of mine waste is generated. For 1 tonne of copper, 110 tonne of tailings (waste ore) and 200 tonne of waste rocks are generated. Mining energy commodities such as gas, oil, coal, or

[1] 1 billion = 1,000 million – $10^9$

radioactive uranium ore, although not discussed in this report, are known to affect environmental and human health significantly. This report distinguishes four steps in the mining sector that are of concern when analyzing the importance of chemical pollution – ore exploitation, extraction and enrichment, transport, and ore refining. The consequences of ore exploitation comprise not only the generation of mining waste, but also waste from the use of explosives. These include the mixtures of ammonium nitrate and fuel oil, trinitrotoluene, and nitroglycerine, which may have adverse effects on environmental and human health by polluting vulnerable ecosystems. Extracting and enriching the compounds of interest often implies the use of chemical substances. Gold, silver, and platinum group elements are often processed by leaching with cyanides or using mercury for amalgamation, which are then released in an uncontrolled way into the environment. For lead, zinc, and copper milling, flotation, smelting, and sulfuric or hydrochloric acid leaching methods are used, whereas iron is principally extracted by magnetic separation. Pollution from small-scale mining operations, which are widespread and typical in low- and middle-income countries, is a serious concern as regulation and control is hardly feasible. Common chemicals of environmental concern, which are used for the processing and extraction of ores and minerals include hydrochloric acids, sulfuric acid, potassium cyanide and cyanide acids, soda ash, sulfur dioxide, coal tar, and aluminum and zinc sulfates. However, the quantities of these chemicals used and the risks they pose to human and environmental health are difficult to assess. This report focuses on the most hazardous heavy metals, metalloids, and minerals that are released accidentally as side products, posing risks to the environment.

The management of waste from electrical and electronic equipment represents an emerging and growing problem. The continuous expansion of the electronics market and shortened innovation cycles stimulating the replacement of electrical and electronic equipment increase the amount of obsolete equipment. This type of waste comprises a diversity of hazardous compounds especially when poorly managed and regulated, which is often the case in low- and middle-income countries. Although international initiatives try to prevent the export and trade of e-waste from industrial countries they have limited impact. The International Labour Organization highlights that 80% of all e-waste that is sent to low- and middle-income countries ends up in informal and uncontrolled e-waste recycling sites. This poses a risk to human and environmental health given the often obsolete recycling techniques used and the very limited health protection measures afforded the workers.

The significance of chemical pollution from other industrial sectors was difficult to assess given the limited data available or accessible. This report describes issues around the use of chemical substances in the textile, leather, paper, and rubber industries. It identifies the major chemicals of concern and their potential negative impacts on human and environmental health.

Despite data being scarce and/or fragmented, it is safe to conclude that the situation is alarming and that there is a trend that this situation is getting worse. In all the sectors evaluated, significant amounts of a large variety of chemical compounds are used, which enter the environment in often uncontrolled manner and can have negative impacts on environmental health. The negative effects of chemical pollution on human health, either caused by direct exposure, or indirectly, e.g. via the environment or food, are also significant. Because of the lack of data, the real threat for humans and the environment can only be estimated. To improve the situation of chemical pollution, the following four recommendations have been made:

## i) data availability and data collection

More comprehensive data, including the complete chemical life cycle, assessments of effects on environmental and human health, and comprehensive risk assessments are needed, on various scales. Data at global scale are needed to support international policy development as well as international conventions and protocols. Increasing international attention will also help national policy makers to make chemical pollution a priority topic. Country-level evidence is crucial for the development of national policies. Finally, since mitigation actions are implemented at local/catchment scale, more detailed information, with significant spatial and temporal resolution, is needed at this level. As a first step, it is suggested that existing data could/should be made publicly available.

## ii) development of concepts and tools for monitoring and data collection

Available concepts and tools for monitoring and data collection need to be adapted or newly developed for LAMICs, so that evidence on exposure routes, environmental concentrations and effects of chemical pollutants can be collected. This under the consideration of i) functionality under the respective climatic situation, ii) efficiency and cost-effectiveness, iii) feasibility of use by local people with limited technical skills and expertise, iv) applicability for all relevant spheres (air, soil, water and an-

throposphere), v) the ability to capture both exposure and effect assessments and vi) the ability to allow the development of locally relevant risk maps and mitigation options.

### iii) development of mitigation options

Despite the fact that chemical pollution is of global importance and influenced by global trends, local mitigation measures are key to improving the situation for human and environmental health. There are no „one size fits all" solutions. A wide portfolio of mitigation options must be developed and evaluated. Ideally, finding and implementing mitigation solutions is a process taking place not in isolation but by including boundary conditions and local challenges and using a base of solid and detailed knowledge about the local situation.

### iv) raise awareness in society, private sector and industry, politics and regulatory authorities as well as support the development & implementation of legislation and management tools

Awareness of the existing problem or the risk of the issue becoming a problem is a precondition for change. Society, including policy makers, regulatory authorities and producing industries must be better informed with clearer messages. In this regard, scientists and research play an important role as they can provide facts in an unbiased and neutral way. Furthermore, scientists can also support decision making under uncertainty. Interdisciplinary research including relevant stakeholders in the research process assures that the critical questions can be voiced and tackled by researchers, that necessary and required data can be collected in a focused, practical manner, that mitigation and management tools can be developed in a concerted action, and that evidence can support and drive policy and legislation.

# Introduction

## Chemical pollution - an underestimated risk

**Many polluted sites are in the low- and middle-income countries of Latin and Central America, Africa, and the Asia-Pacific region.**

Chemical substances play an important role in our daily lives. One example is the common practice of using large amounts of pesticides to increase yields in agriculture. Similarly, the use of pharmaceuticals to treat animal and human diseases is indispensable and widespread. Increasing agricultural and livestock production, population growth, improving standards of life, increased productivity and changes in production sites, and the trade and use of chemicals highlight the increasing importance of chemical substances in the global economy. The increasing production and use of a growing number of substances generally comes hand in hand with higher exposures and thus increased risks for human and environmental health. This is particularly of concern when governmental policies and enforcement are deficient, data on the production, use, exposure scenarios, and toxicities are lacking, or if inappropriate corporate practices are in place. Such concerns are globally relevant, but become increasingly significant in the context of low- and middle-income countries. The shift of production and use from high-income countries to low- and middle-income ones can be clearly observed.

**Unintentional poisoning may often be associated with the inappropriate use and environmental management of toxic chemicals.**

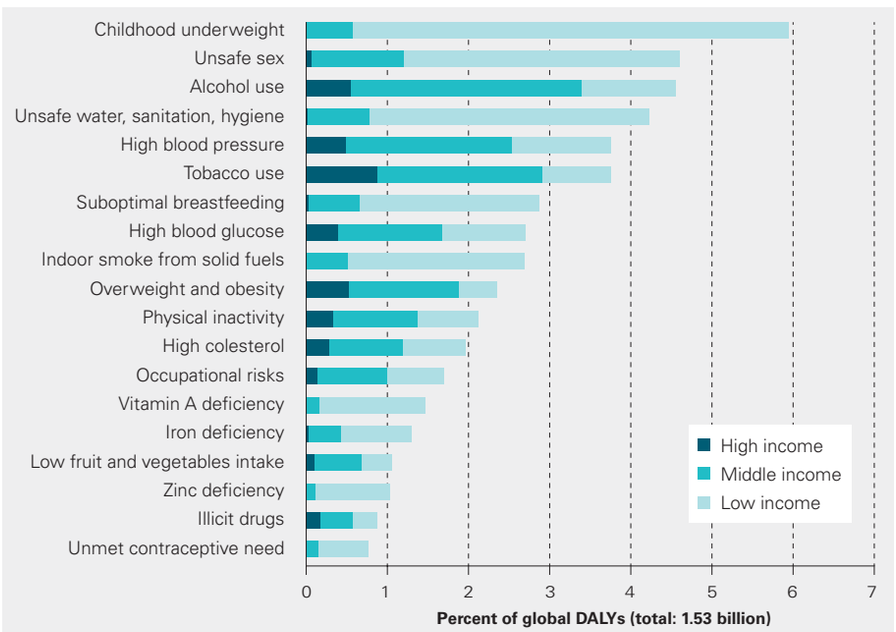


***Figure 1:*** *Proportions of the main health risk factors – in percent of global disability-adjusted life years (DALYs) – for high-, low-, and middle-income countries (World Health Organization, 2009).*

In the past, when discussing the health risks to the populations of low- and middle-income countries, the focus has been on issues such as availability of food, sexually transmitted diseases, and diarrheal diseases. Figure 1 shows the proportions of the main health risk factors – in percent of global disability-adjusted life years[2] (DALYs; World Health Organization, 2009) – for high-income countries and low- and middle-income countries. For low- and middle-income countries the risks of chemical pollutants have not yet been determined as relevant although evidence points to a considerable risk factor.

Few reports are available or accessible that give a comprehensive overview on chemical pollution in low- and middle-income countries. Most reports on global challenges and risks in low- and middle-income countries focus on health, food security, climate change, and socio-economic aspects. Two examples of reports with a focus on chemical pollution are the United Nations Environmental Programme's report on Global Chemicals Outlook – Towards Sound Management of Chemicals (United Nations Environment Programme, 2013c) and the annual reports of the Blacksmith Institute (Blacksmith Institute and Green Cross, 2011, 2012), produced in cooperation with Green Cross, on The World's Worst Pollution. The Blacksmith Institute revealed that the number of people affected by industrial waste (focusing mainly on heavy metals) is comparable to the number of people affected by tuberculosis or malaria when using DALYs as the unit of measurement. The top ten pollution problems with their respective contaminated sites, shown in the Blacksmith Institute's publication, highlight that many of the polluted sites are located in the low- and middle-income countries of Latin and Central America, Africa, and in several countries of the Asia-Pacific region (Blacksmith Institute and Green Cross, 2011).

In low- and middle-income countries, the production and use of pesticides, pharmaceuticals, and chemical substances for ore extraction in mining and use in the construction, textile, and apparel industries are often linked to a release of extremely hazardous and bioactive substances. These substances include heavy metals, pharmaceuticals, pesticides, detergents, solvents, or persistent organic pollutants (POPs). These pollutants, as single compounds or in mixtures, may have negative impacts on human health and the environment (Buccini, 2004; Blacksmith Institute and Green Cross, 2011; United Nations Environment Programme, 2010, 2013c).

A map showing unintentional deaths from poisoning (Figure 2) reveals that in many low- and middle-income countries the annual numbers of deaths from uninten-

tional poisoning range from 30 to 450 cases per million inhabitants, with high levels especially in Belarus, Kazakhstan, Ukraine, South Asia, and West Africa. The World Health Organization (WHO) emphasizes that in such countries unintentional poisoning may often be associated with the inappropriate use and environmental management of toxic chemicals.

The annual report of The World's Worst Toxic Pollution Problems 2011 (Blacksmith Institute and Green Cross, 2012, Figure 3) shows the number of mining sites (e.g. for minerals and ores) as well as polluted industrial and agricultural sites and it becomes clear that most of these sites are in low- and middle-income countries. The impact of anthropogenic chemical pollution is even higher when the emissions or discharges of these substances are not – or are inadequately – regulated, enforced, or controlled, or if obsolete production or treatment technologies are applied. Unfortunately, this is frequently the case in low- and middle-income countries (African Ministerial Conference on Environment and United Nations Environment Programme, 2004; International Labour Organization, 2012; United Nations Environment Programme, 2013c).

**Impact of anthropogenic chemical pollution is higher when the emissions are inadequately regulated, enforced, or controlled, or if obsolete production or treatment technologies are applied.**

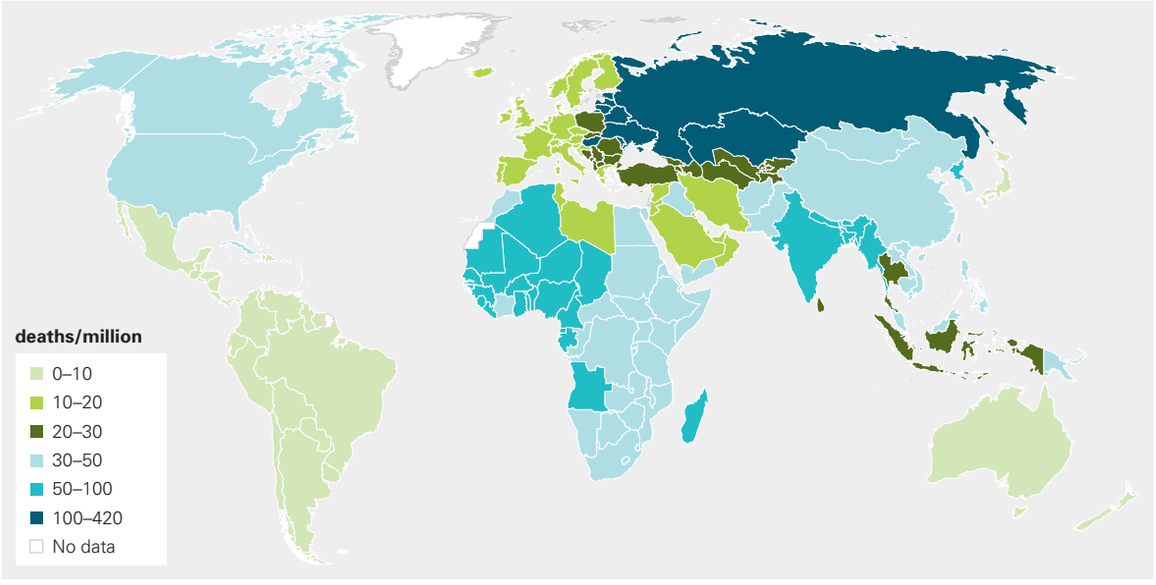


***Figure 2:*** *Global map with estimated deaths from unintentional poisoning in deaths per million (World Health Organization, 2005).*

[2] DALY is used as a measure to integrate the years of life lost from premature death with the years of healthy life lost as a result of illness and disability.

**High human exposure to hazardous substances is also a consequence of poor working conditions.**

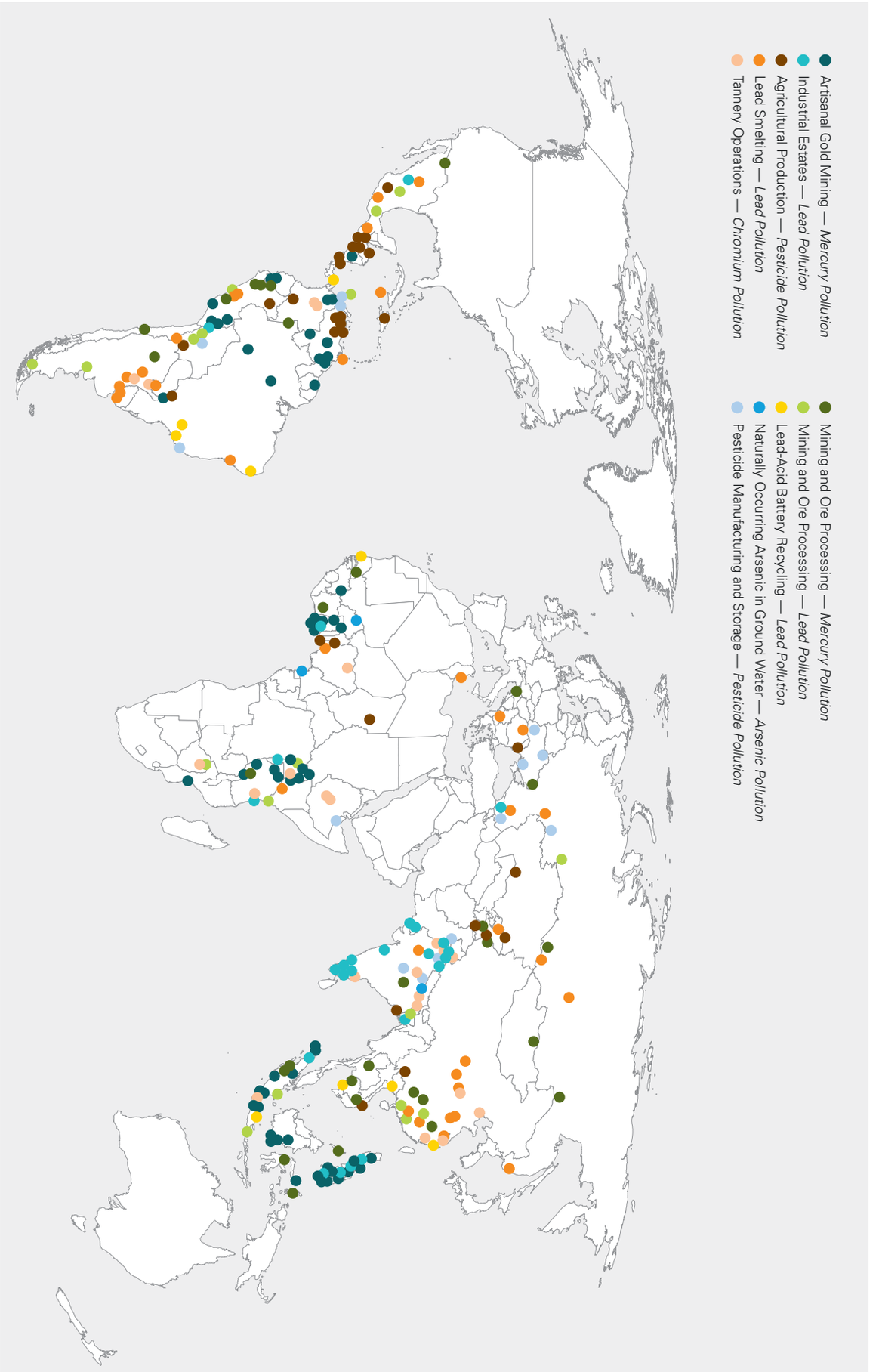


***Figure 3***: *Top ten pollution problems and the major sites of contamination (Blacksmith Institute and Green Cross, 2011).*

The impacts are further exacerbated as industries and dumping sites are often near to or in densely populated areas, thereby increasing the risk of human exposure. High human exposure to hazardous substances, especially for workers, is also a consequence of poor working conditions as safety measures are seldom in place or respected and occupational incidents are frequent (El Sebae, 1993; Quarantelli, 2003; Blacksmith Institute and Green Cross, 2011). Such behavioral aspects, together with awareness issues – the fact that operators, workers and local communities are minimally aware of the consequences and impacts of hazardous emissions – contribute to high exposure and the resulting health risks (Blacksmith Institute and Green Cross, 2012). This problem is, however, not restricted to industrial settings and/or urban environments. The same is true for pesticide use in agriculture. Unawareness, lack of appropriate technology, or incomplete regulations result in increased exposures and risks for human and environmental health (Kesavachandran et al., 2009).

Lack of government enforcement and a disregard of the laws or regulations for the application, production, and disposal of chemicals and other waste material, result in a vast amount of chemicals being released into the environment (Blacksmith Institute and Green Cross, 2012; International Labour Organization, 2012; United Nations Environment Programme, 2013c). Cases are documented where obsolete chemicals were stockpiled under insecure and unprotected conditions. As a result, these chemicals were leached into the soil, contaminated aquifers, or were transported by air or water (rainfall runoff or erosion) and discharged into river systems and lakes (Food and Agriculture Organization, 2001; Elfvendahl et al., 2004). Wildlife and humans living adjacent to insecure dumping sites were drinking polluted water, or eating plants grown in and animals raised on contaminated soil, and, most probably, were taking up increased amounts of hazardous chemicals (Oaks et al., 2004; Tue et al., 2010; Bedi et al., 2013).

In summary, the global situation, the degree of chemical pollution, and the impact on the environment and human health are yet unclear as evidence is limited, especially in low- and middle-income countries. This is a consequence of the limited number of governmental or other independent monitoring systems that have been implemented and/or the lack of capacity to do so. The lack of a strategy and capacity to oversee the use of hazardous chemicals in industrial activities is a major bottleneck to obtaining sound data – a basic requirement to ensure appropriate management. Obtaining a clear oversight of activities is also hindered by the existence of many informal businesses (often small-scale enterprises), which, by definition, are not legalized and are, therefore, also difficult to quantify and monitor (Artisanal Gold Council 2015; International Labour Organization, 2012). Lack of sound data limits the possibilities to undertake a good risk assessment and this again limits the possibilities to advocate for a higher priority at the political level. Showing the consequences of chemical exposure is further complicated as such pollutants often show chronic effects that require the accumulation of data over a long period of time. Monitoring pollutants is also challenging as often there is a lack of analytical technologies and capacity in these countries.

As anthropogenic pollutants are often not considered as significant risk factors, they tend to be disregarded by policy measures. Similarly, the political will is often too low to change this situation and, when working with a limited budget, the issue of chemical pollutants most often does not receive high priority.

**Obsolete chemicals are stockpiled under insecure and unprotected conditions. As a result, these chemicals are leached into the soil, contaminate aquifers, or are transported by air or water (rainfall runoff of erosion) and discharged into river systems and lakes.**

**Impact on the environment and human health are yet unclear as evidence is limited, especially in low- and middle-income countries.**

## The future of chemical pollutants in low- and middle-income countries

Trends show a clear global increase in the production of chemical substances and this increase is particularly large in low- and middle-income countries (PricewaterhouseCoopers, 2012). Expected demographic changes, such as population growth, increasing life expectancy, improving living standards, and modern lifestyles are likely to increase the demand for chemicals and consequently stimulate global production and the increased use of hazardous ones.

The United Nations Environment Programme (2013c) in its Global Chemicals Outlook 2013 shows how the chemical industry has grown continuously over the last decades (Figure 4). Output from the chemical industry has increased globally from US$171 billion in 1970 to US$4120 billion in 2010, although these figures do not consider inflation or changes in prices. When focusing on economies in transition (Figure 4B), an exponential rate of growth is visible for low- and middle-income countries, whereas in developed regions this growth is linear. Rapid growth can be observed especially after the time of the financial crisis around 2008/2009. One explanation for this exponential growth in outputs in low- and middle-income countries is the shift of the production facilities of the chemical industry from high- to low- and middle-income countries.

This trend is confirmed by data from the European Chemical Industry Council (Cefic, 2013) and from figures published in the United Nations Industrial Development

**Rapid growth of global chemical production goes hand in hand with a shift of the production facilities to low- and middle-income countries.**

**Chemical intensification in low- and middle-income countries is stimulated by increase in local demand and increase in the number of producing facilities for the local and global market.**

Organization's International Yearbook of Industrial Statistics 2013 (Appendix Figures 1–4; United Nations Industrial Development Organization, 2013). Recently, several multinational chemical companies have opened new production facilities in low- and middle-income countries to reduce production costs (United Nations Environment Programme, 2013c). Chemical intensification in low- and middle-income countries is thus stimulated by both a local increase in demand as well as an increase in the number of facilities producing for local as well as high-income country markets (United Nations Environment Programme, 2013c).

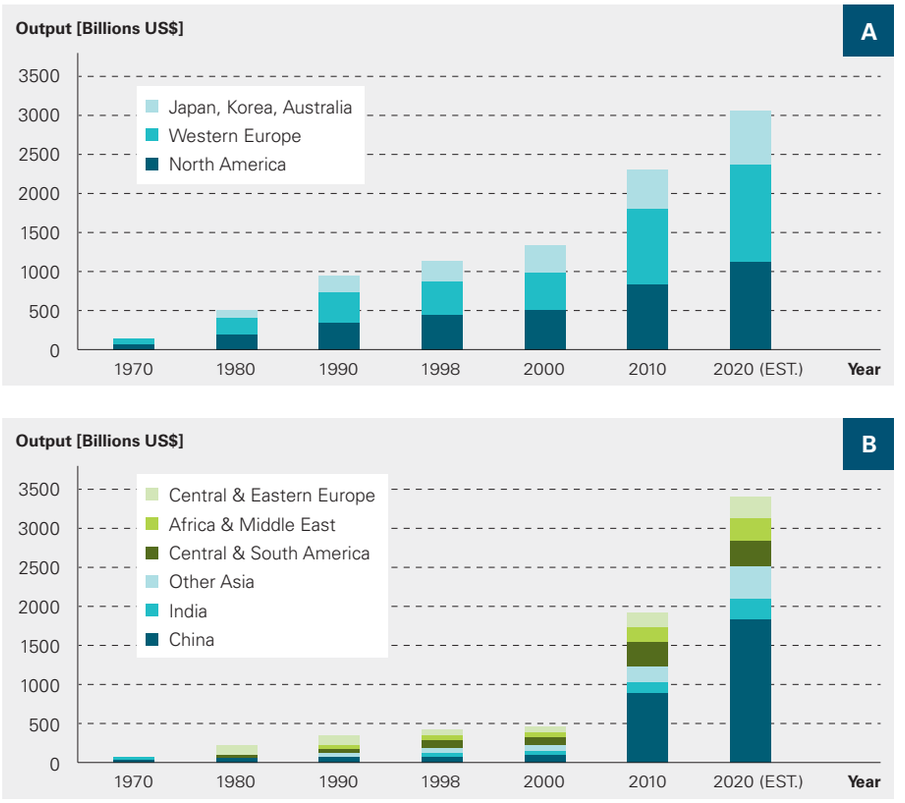


***Figure 4***: *Output of the chemical industry in developed regions (A) and developing regions and countries with economies in transition (B; United Nations Environment Programme, 2013c)*

The increase in the number and size of the production facilities in low- and middle-income countries is likely to go hand in hand with an increase in chemical pollution, exposure, and impact on human and environmental health. Such an intensification of chemical production will affect the lower-income countries most; it is these countries that will face the greatest difficulties in reacting to this increase with appropriate policy, technology, or management measures (African Ministerial Conference on Environment and United Nations Environment Programme, 2004; United Nations Environment Programme, 2013c; European Chemical Industry Council, 2013; United Nations Industrial Development Organization, 2013). In addition, education and raising awareness will be major challenges in general, and in low- and middle-income countries in particular.

## Objectives of this report

As highlighted in the first section **Chemical pollution - an underestimated risk**, the situation regarding chemical pollution in low- and middle-income countries is seldom well documented, and if it is, then it is only in small-scale scientific studies. Nevertheless, several signals point to an alarming situation with a worsening trend.

Therefore, the main objectives of this report are to:

- Develop a systematic structure to describe the different sectors of chemical use, the various chemical substance classes or individual compounds, and their importance and potential impact on human and environmental health
- Obtain the best possible comprehensive overview of the existing situation by studying all the relevant literature for each sector and to assess the main chemicals used, their pathways into the environment, human exposure to them, and their impacts on environmental and human health
- Identify high risk areas in which the welfare of human beings and the environment might be threatened and endangered
- Suggest possible measures to mitigate environmental and human health risks in the production and use of hazardous chemical substances by improving practices to reduce exposure, remediate polluted areas, or encourage innovative 'green' technologies in the production and application of chemical substances (Hanrahan et al., 2007; United Nations Environment Programme, 2013, 2013b)

- Identify significant gaps in knowledge where more research is necessary and use this to advocate for increased research resources to develop evidence that can be used for policy making and in practice to address the environmental conditions in regions at risk

- Advocate for more global attention to the issue of chemical pollution in low- and middle-income countries and for more structured and reliable country-level monitoring that can be complied with at a larger scale to examine the global situation and changes over time.

This report is not written primarily for a scientific audience, but rather it targets bilateral and multilateral organizations, government and non-governmental organizations, and representatives of the industry; anyone with an interest and stake in public health, industrial development, or environmental protection. For the scientific audience it indicates areas where more research is required and seeks to motivate researchers to engage in the overall topic of chemical pollution in low- and middle-income countries. Information about the actual levels of chemical pollutants in low- and middle-income countries and their impacts on environmental and human health is needed. Any possible collaboration with Eawag in providing and exchanging data about the production, export, and release of chemicals into the environment, as well as on the impacts on human and environmental health is welcomed. The aim is to find and establish together strategies to:

- Assess and monitor these hazardous pollutants in the environment
- Assess their impacts on environmental and human health
- Mitigate exposure to the environment and humans, with a strong focus on low- and middle-income countries.

## Categorizing chemical pollutants

A first step when compiling this report was to specify and structure the broad term of anthropogenic chemical pollution. This report differentiates, according to various production sectors, where chemical substances are used and where pollution occurs that is relevant in the low- and middle-income country context (Buccini, 2004; Farrell et al., 2004; Pesticide Action Network Asia and the Pacific, 2010; Blacksmith Institute and Green Cross, 2011, 2012, 2013; International Labour Organization, 2012; United Nations Environment Programme, 2013c; Weber et al., 2014). The sectors covered by this report are:


For each of the sectors, the most relevant chemical pollutants are determined and classified into different categories according to their physicochemical characteristics and/or their environmental behavior. We also describe these characteristics and their potential risks to human and environmental health.

For each sector, the most hazardous pollutants are described, information is compiled regarding their input and exposure pathways, their trend of use, future expected pollution, and their negative impacts on humans and the environment.

Within each sector, cases of significant environmental and human concern are introduced describing causes and effects. An overview is given regarding good practices, which have been implemented already under specific conditions or which are recommended for implementation as mitigation measures to reduce emission or environmental impact, or which would help to mitigate the adverse effects on human health.

The report ends with conclusions and with an analysis of the current research gaps. It recommends future potential research questions and research requirements.

## Limitations of this report

This report is based on an analysis of the literature and databases using scientific publications, news articles, reports, and reliable websites. Furthermore, personal contact was established with specific government and non-governmental organizations specializing in this topic and with individuals with experience of and expertise in chemical pollution. The maps shown in this report were compiled with the help of the geographic information system software ArcGIS, whereby data included in the maps are open source information obtainable from various international, government and non-governmental organizations.

This report does not cover all chemical substances of concern. The authors took an informed decision to leave out certain substances to make it more manageable given the timeframe for finalizing this report, but at the cost of restricting its scope. Natural geogenic pollutants, such as arsenic (As) and fluorine (F), are not covered in this report although it is well-known that high concentrations of these substances in groundwater of certain regions of the world impact severely on the health of humans drinking such water without appropriate treatment. Furthermore the report does not cover nutrients, such as nitrogen and phosphorous, the main causes of eutrophication. Also nanoparticles, chemical substances related to fossil fuels, radioactive compounds, air pollution, and greenhouse gases are not dealt with.

As mentioned in various sections of this report, one major bottleneck the authors faced when compiling this report was the lack or limited availability of chemical pollution data at the country level or with regard to specific industrial sectors in low- and middle-income countries. Only a few databases exist with more or less comprehensive country data on the use of chemicals or the concentrations of chemical pollutants in the environment (Food and Agriculture Organization, 2013; Weber et al., 2014; United States Geological Survey, 2013; Step Initiative, 2015). Data on industrial activity, production, and use of chemical substances is not available to the public, especially in the context of low- and middle-income countries.