SPOTLIGHT

Air Pollution

Highlights:

- Air pollution is made of many different chemical substances that are largely byproducts of industrial processes and vehicles that burn fossil fuels. They have various negative impacts on human health, especially increasing the risks of respiratory, cardiovascular, reproductive and neurological conditions and multiple cancer types.
- Air pollution composition and distribution is highly seasonal. Levels are usually highest over winter months (Nov-March in the northern hemisphere, due to power generation, agricultural activities, dust storms and heating.
- The health impacts of air pollution are disproportionately felt by young children and those with chronic conditions; and it is also an important health issue to MSF staff and the communities we serve.
- Air pollution is influence by predictable weather and climatic patterns like wind, wildfires and temperature. Therefore, monitoring, forecasting and early warning tools can be used to help prepare for periods of air pollution peaks and action can be taken to better protect ourselves and our patients.

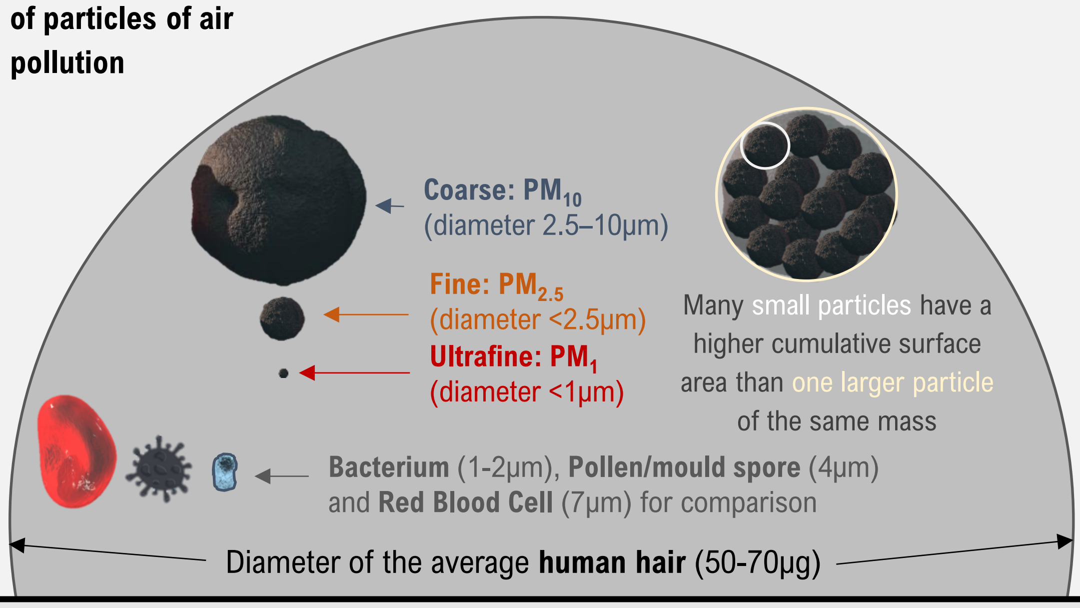
What is Air Pollution?

With every breath we take, we potentially inhale billions of invisible particles of pollutants. Many of these particles can harm our airways and lungs, enter our bloodstream, and be carried to damage our heart and brain, triggering other health complications. The most dangerous of these include black carbon (soot), soil dust and fine (<2.5µm) or coarse (<10µm) particulate matter ($PM_{2.5}$ or PM_{10}, respectively), and aerosolised/airborne microplastics, surface level ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and heavy metals but many other non-particulate air pollutants exist. Most of these chemicals are released into the atmosphere by human activity, through fossil fuel burning, construction, vehicles and industrial activities, and the burning of biomass and crop residues. Some pollutants also come from non-anthropogenic processes like volcanic eruptions, sea spray, pollen, dust storms and wildfires. More detailed information on this is **Annex Table 1, page 6**.

Figure 1: Vehicles produce air pollution in urban areas [WHO]

Air pollution, a major form of **environmental degradation**, harms the atmosphere, humans, animals, and plants. It is the **2nd largest risk factor for premature death globally** (causing 6.7-8.0M deaths annually; 12% of global deaths), only behind high blood pressure, and is the single largest environmental risk factor for premature death globally [UNDP]. Of all premature deaths, 4.5 million are linked to outdoor (ambient) pollution and 2.3 million to indoor (household) pollution [GBD]. In 2021, chronic obstructive pulmonary disease (COPD, 48%), lower respiratory infections (30%), ischemic heart disease (28%) and stroke (27%) were the most common causes of death attributable to outdoor air pollution [UNDP]. It is important to note that there is **no proven safe threshold for air pollution exposure** [Hoffman et al], yet, in attempting to minimize harm, the WHO publishes recommended limits to protect populations health. In 2021, recognizing health risks at even very low pollution levels, the WHO lowered its $PM_{2.5}$ guideline to <5µg/m³. With this new target, it is estimated that >99% of the global population currently are exposed to well above the limit [WHO].

Figure 2: Relative sizes of particles of air pollution



Particulate size and surface area: The size and type of particles greatly affects where in the body they become distributed, and how damaging they can be. Fine ($PM_{2.5}$) and ultrafine (PM_1) particles can penetrate deeper into the lungs, through alveolar walls, into the bloodstream and are deposited in peripheral organs and can even cross the blood-brain barrier. They also have a much greater cumulative surface area than the same equivalent mass of larger "coarse" particles like PM_{10}, allowing them to carry more harmful chemicals on their surfaces. Molecules of air pollution e.g. CO, NO_2, SO_2, O_3, and heavy metals are ~0.0001µm, far smaller than PM, and not visible to the scale in **Fig 2**. Similarly, "greenhouse gases" like CO_2, CH_4, N_2O, F-gases are far too small to be seen on this scale.

The Humanitarian Action for Climate and Environment is an MSF-Canada choice initiative established in 2020 **to support Climate Change Adaptation within the movement.**

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Health Impacts

Air pollution has significant impacts on many body systems, as detailed below and in this short video. PM is a pragmatic classification and the easiest to actually monitor, but **its components are wide ranging** (e.g. pollen, dust, heavy metals or NO_2, SO_2, CO etc) and can vary in composition in different places (e.g. near a factory, a desert or an open mine) and at different times, therefore subsequent health effects also vary (see Annex Table 1, page 6).

Neurological Effects and Mental Health: Air pollutants are responsible for ~27% of all stroke deaths [UNEP]. Certain pollutants, particularly heavy metals and neurotoxins damage the brain leading to cognitive decline and increased risk of neurodegenerative diseases in adults and developmental delay in children. Dust particles can increase the risk of meningitis, especially in the Sahel. Headaches and anxiety are associated with SO_2 exposure. Ultrafine PM poses a high risk as it damages the blood-brain barrier – a delicate membrane that protects the brain from toxins – causing neuro-inflammation. There is emerging evidence that living in areas with high levels of air pollution increases anxiety and depression, partly because the witnessing of environmental degradation worsens stress and physical health outcomes.

Table 1: Particle size and penetration [Manisalidis et al]

Diameter	Passage and penetration of:
>11µm	Nostrils and upper resp tract
7 - 11µm	Nasal cavity
4.7 - 7µm	Larynx
3.3 - 4.7µm	Trachea-bronchial area
2.1 - 3.3µm	Secondary bronchial area
1.1 - 2.1µm	Terminal bronchial area
0.65 - 1.1µm	Bronchiole penetration
0.43 - 0.65µm	Alveolar penetration into bloodstream and across blood-brain barrier and placenta

Eye, nose, ear and throat irritation is increased by O_3, PM and NO_2 and acid rain (which air pollution increases the risk of). Rhinitis, sinusitis, otitis media, skin irritation (dermatitis), allergic symptoms and nasal and skin cancers are related to prolonged exposure of air pollution, especially heavy metals [Shusterman].

Respiratory Issues: Air pollution harms the immune system and is associated with allergies and increases the risk of respiratory infections. Long-term exposure to PM_{10}, SO_2 and NO_2 is associated with increased incidence of TB [Xiang et al]. Air pollution, especially from PM and chemicals like NO_2 irritates the lungs, trigger exacerbations of asthma, bronchitis, and COPD and damage the mucosal lining, increasing susceptibility to respiratory pathogens. Air pollution is responsible for around 48% and 30% of all COPD and lower respiratory tract infection deaths, respectively [UNEP]. There is increasing evidence of the accumulation of aerosolised microplastic particles accumulating in the lungs, and viral and bacterial microbes can adhere to these particles [Radhan et al].

Cardiovascular Problems: Pollutants such as PM, O_3 and SO_2 can cause atherosclerosis, inflammation and damage to blood vessels and can make the blood hypercoagulable increasing the risk of clots [Irfan et al]. In 2021, outdoor air pollution was responsible for 28% of ischemic heart disease and 27% of stroke deaths globally [UNEP].

Cancers: Long-term exposure to certain pollutants, especially benzene and heavy metals, is associated with various cancers, especially lung [Nduka et al] but also brain, liver, breast and thyroid cancers [Kresovich et al]. Air pollutants are responsible for an estimated 19% of all lung, tracheal and bronchus cancer deaths [UNEP].

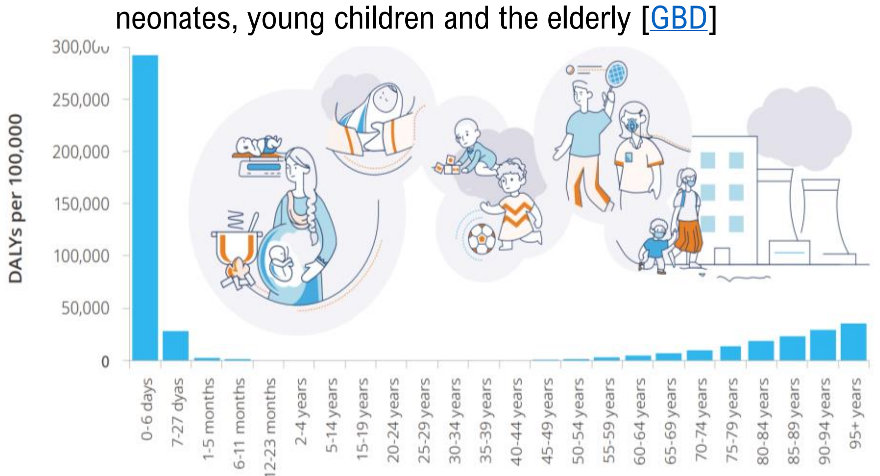
Liver, Gastrointestinal and Kidney disease: Bioaccumulation of air pollution, especially heavy metals (when it settles in soil, water or food) causes nephrotoxicity, hepatotoxicity and gastrointestinal inflammation [Mitra et al]. It is also associated with development of diabetes, with 18% of all deaths from Type 2 diabetes attributed to air pollution [UNEP].

Reproductive and Developmental Issues: Pollution can affect fertility, reducing sperm-count and negatively affect pregnancy outcomes, including low birth weight and developmental delays in children. There is an increased risk of spontaneous abortions associated with high levels of SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$ [Liu et al]. Heavy metal exposure is especially related to birth defects and air pollution is responsible for almost 1 in 3 neonatal deaths [GBD].

Overall Mortality: Prolonged exposure to high levels of air pollution leads to increased all cause mortality. Reducing pollution exposure significantly improves public health outcomes, emphasizing the importance of environmental protection efforts.

Health justice and equity: Air pollution impacts are not equally felt, with 89% of global deaths occurring in Low-Middle Income Countries [WHO]. In fact, many of the locations of our MSF coordination centres, offices, projects and the communities that we serve have dangerously high rates of exposure to air pollution. Exposure builds up over time, increasing the risk of health consequences over decades. Furthermore, certain groups, including those with chronic conditions, pregnant women, children, and the elderly are the most vulnerable to the impacts of air pollution. Exposure to neonates, **especially in the first few days and weeks of life** has a monumental impact compared to older children and adults [GBD]. Those who are most deprived often have the highest exposure, poorest underlying health and reduced access to healthcare due to social-inequalities.

Figure 3: Air pollution disproportionately impacts neonates, young children and the elderly [GBD]



Distribution & Seasonality air pollution

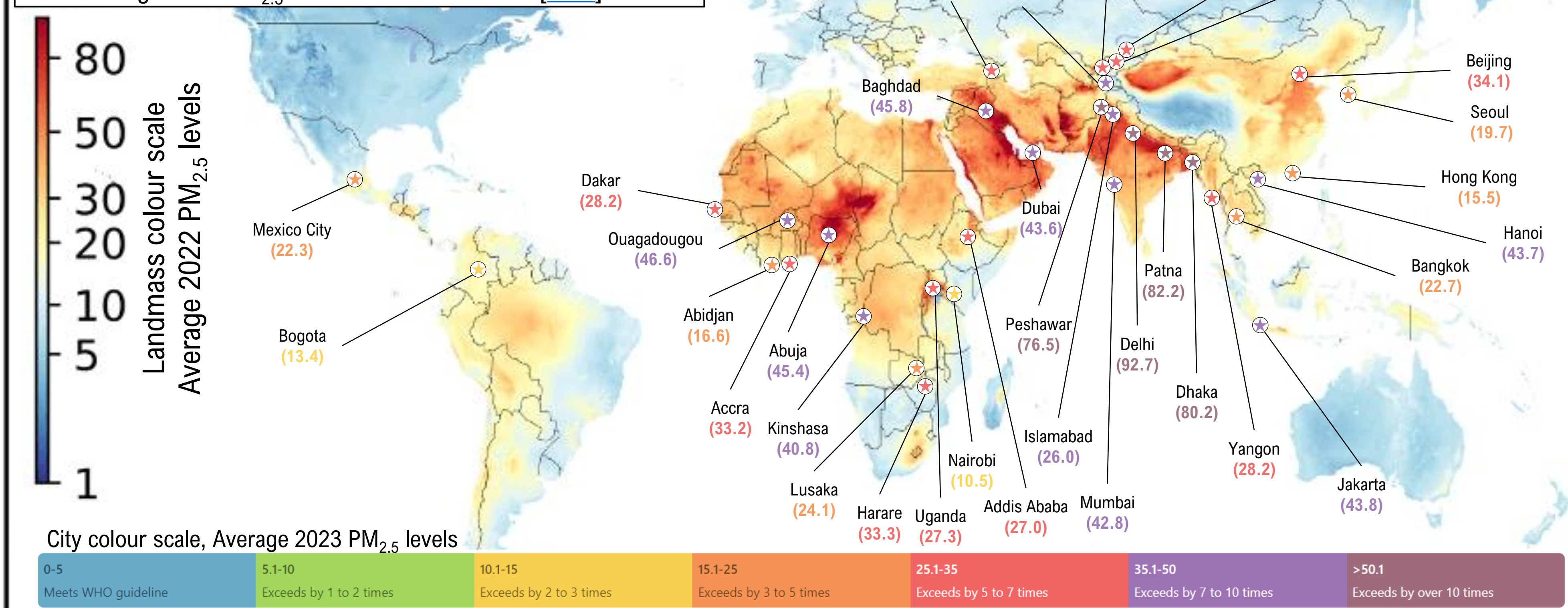


Figure 4: Map colour shows average $PM_{2.5}$ levels from Jan-Dec 2022 [Shen et al]. Cities where MSF is present are marked with their average 2023 $PM_{2.5}$ levels below in brackets [IQair].

Air pollution exposure is distributed unevenly as shown in **Figure 4**. Most cities experience an average level many fold higher than the WHO target of <5µg/m³ for $PM_{2.5}$, e.g. in Delhi the average is >18x fold higher. The highest recorded levels have consistently been in cities in Pakistan, India, Bangladesh and China. Yet **there is a huge inequity in global monitoring station distribution**, with most in Europe, North America and China and very few located in Africa or Central/West Asia where air pollution is a fast-growing, under-recognised issue [see IQair map] and mostly (>50%) due to windblown dust [UNEP]. Recently, cities like Ouagadougou (Burkina Faso), Abuja (Nigeria), Kinshasa (DRC), Dushanbe (Tajikistan) and Baghdad (Iraq) are recording extremely high levels >40 µg/m³. The average person could live 2.3yrs longer if $PM_{2.5}$ levels were reduced to meet the WHO target, but the countries with the highest number of life-years lost are Bangladesh (-6.8 years), India (-5.3 years), Nepal (-4.6 years) and Pakistan (-3.9 years) [AQLI].

Table 2 shows the highly seasonal pattern of $PM_{2.5}$ air pollution as seen in 2023 in many of the most polluted cities where MSF is present. In most cities in the northern hemisphere, **the highest levels of air pollution are seen from October/November until March/April** [IQair]. The composition of PM is also seasonally variable in most places (more detail in Annex Table 1, page 6), whereby depending on the main local PM source and the local seasonal activities, the components of PM changes dramatically. For example, during the dry windy season in the Sahel (Dec-March), PM is mainly composed of dust and sand, carrying an increased risk of meningitis. In northern India, following the harvest and as winter begins, biomass and stalk burning leads to smog PM containing soot and heavy metals from the soil, causing respiratory infections and cancers. Furthermore, during the winter months in Central Asia, low temperatures mean more coal is burned for power and residential heating, increasing CO, NO_2 and SO_2 exposure [Amini et al]. NO_2 and SO_2 emissions are closely linked with more frequent acid rain. there is also a close relationship between SO_2 levels and spontaneous abortions (foetal deaths). In Ulanbataar, this mostly comes from coal burning in "Ger" stoves for domestic heating [Fig 5, Enkhmaa et al].

Fig 5 SO_2 in Ulanbataar and fetal deaths

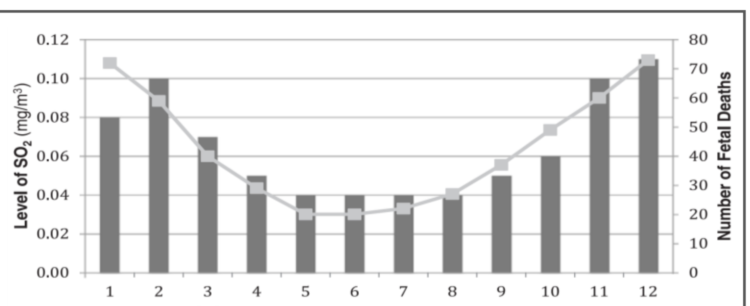


Table 2 – City, Country	MSF offices / projects	J	F	M	A	M	J	J	A	S	O	N	D
Baghdad, Iraq	4	79.5	60.1	52.5	28.6	48.4	26.7	21.8	32.4	32.1	43.8	63.1	53.8
Tashkent, Uzbekistan	2	82.5	25.9	19.7	17.6	14.6	20.2	18.4	15.9	22.3	33.9	31.2	38.5
Dushanbe, Tajikistan	6	64.4	38.5	24.2	38.4	33.5	35.5	41.7	33.1	51.2	44.7	64.4	92
Almaty, Kazakhstan	1	81.7	55	31	17.2	12.3	10.6	8.8	7.8	13.5	18.9	31.1	34.4
Bishkek, Kyrgyzstan	2	94.6	45.8	23.7	14.5	11.8	12.6	10.6	10.2	11.4	16.3	24.6	36.1
Yerevan, Armenia	4	74.3	36.1	26.4	14.9	12.6	11.4	11.4	14.4	16	18.6	28.9	51.9
Dubai, UAE	1	25	32.5	39.8	35.6	33.8	40.9	59.9	61.5	59.3	52.4	32.7	48.6
Delhi, India	5	171.8	114.3	77.4	71	67.4	42.9	35.3	34.8	39.7	106.3	255.1	210
Lahore, Pakistan	0	143.2	117.3	73.8	52.9	52.4	46.4	39.8	42.2	53.8	125.9	251	197.5
Dhaka, Bangladesh	2	175.5	107	82.5	61.6	49.2	42.7	23.6	44.8	39	74.9	101.6	160.3
Patna, India	1	170.1	112.5	83.3	78.4	61	54.3	33.9	38	34.2	61	138.5	124.6
Islamabad, Pakistan	3	70.4	47.5	32.4	21.2	21.5	27.8	23.3	31.9	31.4	41.2	66.7	93.6
Mumbai, India	2	85.5	77.6	61	34.9	21.4	17.1	14.6	16.5	20.4	59.7	58.5	60.2
Seoul, South Korea	1	25.3	29.9	30.2	21.5	18.3	17	16.4	12.9	11.2	15	17	21.8
Peshawar, Pakistan	2	135.9	78.7	53.3	34.2	39	42.9	35.5	44	52.8	83.1	155.8	166.3
Jakarta, Indonesia	1	20.6	19.2	31.2	28.4	49.8	48.7	55.3	58.3	53	61.1	53	44.3
Bangkok, Thailand	1	28.9	35.1	37.6	38.4	20.3	8.9	7.3	9.6	9	18.1	21.8	26
Hanoi, Vietnam	1	73.8	46.1	54.4	47.3	33.8	27	22	28.2	30.8	40.7	58.6	61.3
Hong Kong, SAR	2	21.5	19	20.7	18.5	16.5	7.9	7.6	8.8	9.1	15.9	17.9	22.6
Beijing, China	1	32	53.9	58.6	41.4	30	19.4	18.2	21	27	35.9	30.1	43.2
Yangon, Myanmar	5	52	47.8	56.8	47.4	24.4	11.7	6.1	13.8	8.3	15.1	23.3	32.7
Ouagadougou, Burkina Faso	4	63.3	81.5	45.9	56.2	43.1	41.8	41.6	39.7	40	37.1	28.4	18.6
Nairobi, Kenya	9	8.8	10.5	8.8	7	7.6	12.1	13.8	12.2	12.6	8.8	9	14.6
Harare, Zimbabwe	3	6.6	8.8	28.5	47.5	46.9	32.7	43.2	34.8	58.1	45.6	26.5	12.4
Accra, Ghana	0	70	59.2	26.8	21.5	20.2	22.7	28.4	22.6	16.7	18.1	23.1	68.8
Dakar, Senegal	3	33.7	45	30	30.8	26.4	14.5	15.8	8.6	8.8	22.6	34.1	49.3
Kampala, Uganda	4	46.4	38	24.3	15.1	25.9	28.2	41.8	28.7	34.3	24.1	15.9	20.2
Addis Ababa, Ethiopia	4	23.1	24.4	28.3	24.6	31.5	36.1	34.2	30.3	34.6	17.3	18.1	21.4
Lusaka, Zambia	0	9.9	13.2	12.5	13.9	20.6	30	27.5	23.4	63.9	39.8	18.6	13
Abidjan, Ivory Coast	4	36.6	25.1	13.4	12.7	8.4	9.5	14.5	11.2	8.2	8.1	13.2	39.2
Abuja, Nigeria	8	111.8	89.2	43.8	34.9	23.6	15.8	24.5	23.3	17.2	35.4	47.6	80.3
Kinshasa, DRC	10	12.6	20	24.6	53.3	83.9	92.4	63.4	--	--	34.8	16.1	30.6
Mexico City, Mexico	5	32.2	25.9	27	28.5	30.5	21.8	15.7	14.6	18.2	13.5	17.4	22.1
Bogota, Colombia	3	15.8	20	21.1	16.6	11.4	6.9	7.5	9.7	11.3	14.4	11.9	14.9

Climate Change and Air Pollution

Air pollution & Greenhouse Gases

The greenhouse gases (GHGs) responsible for the vast majority of climate change are Carbon Dioxide, (CO_2, ~76%), Methane, (CH_4,~16%), Nitrous Oxide, (N_2O, ~6%) and Fluorinated gases (~2%). Whilst air pollutants reviewed in this Spotlight (PM, NO_2, SO_2, CO, heavy metals and O_3) don't have a significant contribution to global warming, some can have localised meteorological effects such as increasing cloud formation or causing heating or cooling in a local area. Another example of local effects is black carbon (soot) accelerating ice melting as it settles on glaciers or ice sheets by lowering its albedo (reflection) absorbing more heat. Just like GHGs, air pollutants are intrinsically linked with unsustainable processes of extraction, industrialisation and the burning of fossil fuels.

Figure 6: Fossil fuel burning is responsible for climate change and a significant part of air pollution

Air pollution & Heat

Increased heat can cause dehydration, heatstroke, and heat stress. When combined with air pollution, particularly O_3 and PM, the health impacts of heatwaves are greater, leading to more hospital visits and straining healthcare systems. Put simply, **when temperatures rise, air pollution spikes** [WRI], there are several mechanisms for this**.** This can happen by promoting conditions such as wildfires, accelerating organic waste degradation, or directly favouring the chemical formation of certain pollutants as it is the case for O_3. Sunlight and heat speed up reactions between volatile organic compounds (VOCs) and nitrogen oxides (NOx), producing more O_3. **High temperatures can also exacerbate physiological responses to air pollutants toxicity** [Schwarz et al], and this is especially relevant for cities, as human activities such as industry and transport, generate both heat and pollution. Additionally, cities are characterized by impervious surfaces and heat-absorbing materials in buildings, roads, and infrastructure, as well as a lack of trees to provide cooling. These factors contribute to the **urban heat island effect,** where cities are significantly hotter than their surrounding rural areas**.** Geographic features can also trap heat and pollution. Valleys, mountain basins, and areas at the end of air pollution corridors are especially prone to high concentrations. Thermal inversions, where a layer of warm air traps cooler air and pollution near the ground, worsen this issue. Thermal inversions peak in winter, and the lowest levels of PM are often found in transitional seasons (spring and fall) [Chen et al]. Thermal inversions are more common above cities where cold, dense air gets trapped in mountain basins or valleys. **Our world is heating up at an unprecedented rate due to climate change.** We are already seeing extreme heat events worldwide that would not have otherwise happened e.g. the deadly 2022 heatwave in India and Pakistan was made 30x times more likely due to anthropogenic climate change [WWA]. Temperatures >39.6C combined with dust storms are synergistic risk factors for invasive pneumococcal diseases, e.g. pneumonia and meningitis. Today, >½ of the world's population – 4.53 billion inhabitants – live in cities [UN-Habitat], a ratio expected to increase to ⅔ by 2050 globally, with some countries across Sub-Saharan Africa, Asia and Latin America, likely to see even larger percentages. Whilst in some cities air pollution levels have decreased, cardiovascular and respiratory mortality due to NO_2, SO_2 and $PM_{2.5}$ is increasing, possibly due to the increasing toxicity of the air pollution mix and its sources, differences in socioeconomic factors, population changes and heat [Schwarz et al and Rai et al].

Droughts, Plants & Wildfires

Another way in which climate change increases the risk of and changes the distribution of air pollution, (especially dust) is via increased risk of droughts. As greenhouse gases cause both our world to heat up and rainfall patterns to change, certain areas are seeing more drought and desertification, which brings with it a higher risk of sand and dust storms. These have a negative impact on human and animal health and on crops, increasing food insecurity and malnutrition [FAO]. Droughts can also reduce flows in rivers which concentrates pollutants in the water.

There is vicious cycle of climate change, heat, drought, wildfires and air pollution with each factor exacerbating the other [WMO]. As our world gets hotter and some areas drier, this creates a flammable tinderbox, increasing the risk of devastating wildfires as seen in Indonesia and Australia. These wildfires destroy forests and plants, meaning even less air pollution and greenhouse gases are absorbed and desertification increases, as has happened in parts of China, India, Kazakhstan and Mongolia [Qi et al]. Air pollution also limits photosynthesis and can slowly suffocate plants, damaging crops, agriculture and increasing the risk of malnutrition [WMO]. Air pollution can reduce crop yields by 5-15% and solar energy yields by 25%.

The impact of war and conflict on air pollution and the environment

Dust from explosive weapons and collapsing buildings is a significant air pollution and environmental degradation source, and a cause for concern since it increases the risk of many infections, lung diseases and cancers. Exposure lasts throughout the conflict and during clean-up and recovery operations. Inhalation of fine PM can be especially harmful when the dust generated during the bombing of structures and infrastructure including industrial sites is contaminated with **heavy metals** from munitions, **asbestos** and other **hazardous materials** and can spread easily following blasts. Wind and rain may carry these contaminants in the dust into the soil, groundwater and coastal waters, spreading impacts beyond the site of original damage or to locations where debris is disposed.

Figure 10. October 2023, bombardment in the Gaza Strip
© UNRWA Photo by Ashraf Amra

E.g. In Gaza, UNEP have previously found asbestos in debris from many buildings, in roofs and walls. People can be exposed to **asbestos** through inhalation of asbestos fibres in the air causing lung cancer, mesothelioma, larynx and ovarian cancer and fibrosis of the lungs, also called asbestosis [UNEP].

Adaptation - What can we do?

1. Campaigning, Advocacy and Community Education:

Bearing witness (or témoignage) and campaigning with local community groups to reduce fossil fuel burning and polluting activities is an important aspect in addressing the root causes of the problem. At MSF we have a long history of bearing witness to and speaking out about health issues; as air pollution is one of the great killers of our age, we should also bear witness on its impact where it affects our staff, communities and patients.

Community education: In the past, MSF has helped raise awareness and reduce exposure to indoor pollution in Kenya. Resources exist: WHO has developed a 'train-the-trainers' approach to community education which been an efficient tool in Ghana and there is an open course for all here. Campaigns for low/no-cost public transport and factories to be moved / closed (e.g. in India) are gaining momentum [e.g. Mahila and CEEW] and a framework to reduce NO2 and SO2 levels has been proposed [Jion et al].

Figure 11 - Murals for raising awareness about air pollution in Delhi, a project by Mahila housing trust.

2. Forecasts and monitoring:

Early warnings and forecasts: Air pollution can sometimes be visible (as smog or haze) but is often invisible; good satellite or ground-level monitoring is thus key. A number of air-quality monitoring (e.g. IQair) and forecasting models exist for different geographic regions that show real-time hourly air pollution levels and others that provide short-term forecasts for the upcoming 24-, 48- or 72-hours Air Quality Forecasting Models: Real-time and Historical and a 5-day pollution forecast is available from Windy and other similar national tools exist e.g. for most cities in India. Others are being developed to monitor and provide early warning for sand and dust storms e.g. CanAIRy. NASA, CARPHA, UNCCD and Copernicus. Many places however are lacking accurate and regularly updated public websites for air pollution monitoring and early warning.

Longer-term seasonal forecasts: When weather and climatic conditions are forecasted to be drier and hotter than usual, droughts are more likely, which increases the risk of dust storms and wildfires (the commonest natural source of air pollutants) [WMO]. Furthermore, predictable long-term climatic patterns like the El Niño Southern Oscillation can increase temperatures and dry season duration in some areas, meaning air pollution levels stay higher for longer (e.g. in Jakarta, WRI). Monitoring of fire risk is available e.g. from CS3 and Windy. Also, if forecasts predict unseasonally colder than usual temperatures, this can alert us to the likelihood of increased power generation (e.g. coal and gas burning), localised residential heating and car usage, and therefore more air pollution in certain areas. Regularly monitoring regional seasonal forecasts is key, e.g. from the East Asia Winter Climate Outlook Forum (EAWCOF) or globally from IRI.

3. Action measures - When early warning systems sound the alarm, there are many things we can do to reduce exposure:

Masks: Certain tight-fitting masks with filters can protect people from larger air-pollution particles such as soot, dust and PM_{10}, but these don't keep out the smallest PM, which can be the most damaging to health. Surgical and cloth masks are not effective, but N95 masks are beneficial if tightly fitting and worn appropriately [See Table 2 from Velasco et al]. Unfortunately, it is often those who are the most vulnerable (e.g. with chronic lung diseases or small children) who cannot wear tight masks as they can feel uncomfortable and worsen breathlessness.

Avoid exposure: If you are able to stay inside on high pollution days, closing windows and doors can help reduce exposure. If you must go outside, avoid peak-hours, take quieter back-streets and walk further from the road. If in a vehicle, keep windows closed especially in slow-moving traffic [Asthma&Lung]. Acquiring indoor air purification equipment or reviewing and fixing any windows and doors that are broken before air pollution levels spike can help to keep indoor areas as safe as possible, especially in workplaces, hospitals and clinics.

Improving clinic and hospital preparedness: The months and weeks with higher air pollution exposure will require increased capacity and medical supplies (inhalers, nebulisers, oxygen, CPAP, Ventilators, ICU beds etc) for the treatment of asthma and COPD exacerbations, so that healthcare facilities are not acutely overwhelmed. A previous GIS mapping project of air pollution and asthma exacerbation incidence from has identified hotspots of high risk in Port-au-Prince, Haiti (OCB and HACE, 2022).

No driving days: Some cities have implemented policies to ban private cars on certain days of the week, with good effects in Mexico City. When forecasts predict high levels of pollution, a car ban or limitation can be implemented as an 'anticipatory' or 'early' action. Another forecast-based-finance activity that has been proposed is providing cash assistance to help those who cannot otherwise get to work safely or for those who rely on outdoor work to compensate for missed income staying at home.

Indoor air purification: When implemented during pregnancy, stand-alone air purification to mitigate impacts of residential coal smoke exposure can improve birth weight outcomes [Barn et al], IQ [Ulziikhuu et al] and childhood cognitive development [Ulziikhuu et al].

Nature based solutions: Trees help to absorb air pollution, and whilst of course they take time to grow, protecting the trees we have is key.

Annex Table 1: Health Impacts & Sources

MEDECINS SANS FRONTIERES

Indicator (WHO AQ Guidelines*)	Health Impacts	Main sources
PM_{10} (Annual = 15µg/m^3) (24-hours = 45µg/m^3) **$PM_{2.5}$** (Annual = 5µg/m^3) (24-hours = 15µg/m^3)	Particulate Matter (PM) includes everything in the air that is not a gas, so it is made up from a huge variety of chemical compounds and materials, some of which are toxic. Larger coarse PM_{10} deposits in the throat, eyes and large airways causing irritation and inflammation and triggering asthma and COPD exacerbations, whereas $PM_{2.5}$ is smaller and can reach the alveoli, bloodstream, and internal organs, thereby posing a significant toxic effect across the body where deposition occurs. Long-term exposure to $PM_{2.5}$ is associated with about 1/3 of all global asthma deaths [Ni et al]. $PM_{2.5}$ exposure is also linked with increased risk of COPD, lung infections like pneumonia and tuberculosis, lung carcinoma and other cancers as well as myocardial hypertrophy, atherosclerosis, coronary syndrome, hypertension, and diabetes, testicular damage, ovarian dysfunction and even Alzheimer's disease [Nan et al].	The majority of PM constitutes black carbon and dust, mixed with volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons, silica, pollen and spores, sand, ammonium, carboxyl compounds, aerosolised microplastics, salts, heavy metals and the other chemicals in this table. **The composition of PM varies geographically and temporally.** "Primary" PM is emitted directly (e.g. soot) and "secondary" PM forms in the atmosphere by breakdown of larger particles or reactions between smaller components of aerosolised pollutants (e.g. VOCs). Most monitoring methods for PM_{10} also counts levels of $PM_{2.5}$ within it. Many sources create both PM_{10} and $PM_{2.5}$, such as **combustion** from vehicles and industrial processes, **residential cooking or heating** with wood or coal and **agricultural activities** like stalk burning. **Construction and demolition** produce more PM_{10} than $PM_{2.5}$. PM_{10} is more likely to accumulate from indoor fire cooking and is more influenced by **natural sources** like wildfires, volcanoes, sea spray salts and dust. $PM_{2.5}$ is more influenced by combustion and **secondary formation** through atmospheric chemical reactions of smaller precursor gases like SO_2, NO_X and VOCs. In Africa, Windblown dust 52%, Fires 13%, Residential 11%, Energy 5%, Transport 5%, Industry 3% and Waste 2% are the main sectors that contribute to $PM_{2.5}$, whilst in western Asia it is windblown dust 58%, Energy 15%, Transport 6%, Industry 6%, Agriculture 4%.
NO_2 (Annual = 10µg/m^3, (24 hour = 25µg/m^3, (1 hour = 200µg/m^3)	NO_2 can trigger exacerbations of respiratory conditions like Asthma and COPD, and prolonged exposure can reduce lung growth and development in children and decrease lung function in adults. NO_2 damages the immune system, increasing the risk of respiratory infections [Manisalidis et al]. NO_2 increases the risk of cardiovascular conditions by causing hardening of arteries (atherosclerosis), and subsequent hypertension, strokes and heart attacks. NO_2 damages crops and causes acid rain when it mixes with water vapour in clouds to form HNO_3. Acid rain can irritate eyes and skin and damages soil, affecting crops and agriculture and contaminating water sources, damaging ecosystems and increasing risk of malnutrition.	In cities across Asia, ambient sources of NO_2 results from high-temperature combustion of fossil fuels for heating, transportation, industrial activities and power generation [Jion et al]. Household sources of nitrogen oxides (NO_X) include furnaces, fireplaces, gas stoves and ovens. NO_2 contributes to the formation of $PM_{2.5,}$ and can react with VOCs and sunlight to form surface level O_3. Natural sources include lightening which produces high temperatures and forces N_2 and O_2 gases to react in the air. Wildfires and volcanic activity also produces some $NO_{2,}$, and some comes from plants, microbes in the soil and phytoplankton in the oceans.
SO_2 (Annual = 40µg/m^3) (10-minute = 500µg/m^3)	SO_2 is an irritant and is strongly associated with asthma/COPD exacerbations and irritation of the eyes, throat, nose and mouth. It is associated with reduced lung function and reduced overall lung capacity. Chronic exposure can weaken immunity and the respiratory system making people more susceptible to respiratory infections like pneumonia and bronchitis. Cardiovascular impacts of SO_2 include increased risk of hypertension, strokes, heart attacks and arrhythmias. It is also associated with worsening allergic reactions. SO_2 contributes to acid rain formation when it reacts with water vapour and cloud, to form H_2SO_4. This can irritate eyes and skin, cause environmental degradation, eroding soil and lowering its pH which damages vegetation, agriculture and ecosystems [Manisalidis et al].	In Asian cities, SO_2 mainly comes from coal-burning, power plants, industry biomass burning, brick and kiln production [Jion et al]. Residential heating (burning coal and wood) is a significant source in some countries. Desulfurization of crude oil and combustion of sulphur-containing fuels is part of the refining process for petrochemical plants and oil refineries. Older diesel vehicles emit sulphur compounds, but modern vehicles emit much less. Waste incineration, mining, cement manufacturing and smelting of metals (especially for copper and zinc production) also produce SO_2 as a byproduct. Volcanic eruptions are the main natural source of SO_2 into the atmosphere, but wildfires releases some and sea spray can contain dissolved sulphur compounds.
Black Carbon (Soot) & dust mass	Black carbon is associated with respiratory (e.g. Asthma/COPD), cardiovascular (e.g. atherosclerosis, stroke, IHD) and neurological diseases (e.g. dementia). It is classified as a Group 1 carcinogen by the International Agency for Research on Cancer, especially increasing the risk of developing lung cancer as it contains polycyclic aromatic hydrocarbons and other carcinogens that damage DNA in lung cells. Pregnant women exposed to black carbon are at a greater risk of complications such as low birth weight and preterm birth, and particles also affect foetal development, leading to long-term health problems for the child. Dust storms increase the risk of respiratory and cardiovascular conditions, conjunctivitis and allergies [Aghababaeian et al]. Dust damages the mucosal barrier and inhibits immune defences, facilitating bacterial invasion [Jusot et al]. Viral diseases (e.g. Influenza and viral pneumonia) increase in Asian dust events [Schweitzer et al]. Certain microorganisms (e.g. N. meningitidis, Strep. pneumonia and fungal spores of coccidiomycosis) are carried in dust, especially if lifted from soil contaminated with human or animal waste [Seidel et al].	Black carbon, also known as soot, is produced by the incomplete combustion of any carbon-based fuel. Larger vehicle emissions (especially with diesel engines) like trucks and buses are major contributors in urban settings and the shipping industry is responsible for a lot due to the combustion of heavy fuel oil which is high in sulphur and carbon. Large ships the Arctic can also cause soot to settle on ice which accelerates melting. Residential burning of biomass and coal is another significant source, especially for indoor air pollution if stoves are inefficient and uncovered. Wildfires and seasonal burning of agricultural waste leads to substantial emissions of black carbon in some areas. In the dry season, sand and dust particles from the Sahara and other deserts are blown thousands of miles, e.g. Saharan dust reaches India, Europe and even the Caribbean and Amazon rainforest.
Heavy Metals E.g. Lead, Mercury, Cadmium, Arsenic and Chromium	The main route of exposure for heavy metal air pollution is inhalation, and ingestion if it settles on food or water sources, increasing risk of gastrointestinal issues. Prolonged air exposure can cause skin irritation and absorption. Heavy metals are potent carcinogens associated with various cancers, especially lung. Hexavalent **chromium** and its compounds are particularly linked to nasal cancers and other respiratory conditions (e.g. asthma and COPD), and skin conditions e.g. dermatitis, ulcers and rashes, and prolonged exposure leads to liver, kidney and brain damage (cognitive decline in adults and developmental delays in children). Long-term exposure to **arsenic**, is strongly linked to an increased risk of several cancers, including skin, lung, bladder, and liver cancers. It also causes hypertension, neurological damage (peripheral neuropathy) and developmental and cognitive issues for children. **Cadmium** exposure causes kidney disease, where it accumulates and is a risk for kidney and prostate cancer. Cadmium can also interfere with calcium metabolism, potentially causing bone weakening and osteoporosis. **Lead** is a potent neurotoxin even at low exposure levels, particularly harmful to children (hampering neurological development, growth and hearing). Lead and Cadmium can also cause infertility and developmental problems in pregnancy. The earlier in a foetus's development or a neonate's life the exposure occurs, the greater the negative impact can be [Manisalidis et al].	Various heavy metals are produced by different chemical plants and factory processes e.g. battery manufacturing and disposal (lead), coal-fired plants (mercury, arsenic and lead), gold-mining (mercury) and waste incineration (mercury, arsenic, cadmium, lead), steel production, welding and metal smelting (cadmium, zinc, chromium). Cement and concrete production releases chromium and cadmium. Oil refineries in particular emit arsenic as a byproduct. Vehicles, especially older ones that burn leaded gasoline emit lead pollution where this has not been phased out. Break-pads and tire wear can also contribute to air pollution of copper, zinc and lead. Stalk burning after harvests can release some heavy metal particles from the soil into the atmosphere, especially if agricultural chemicals containing them were used. Whilst manmade sources are the primary contributors, there are some natural processes (e.g. volcanic eruptions) that release heavy metals into the atmosphere. Wildfires and dust storms can cause heavy metal particles from soil or that has accumulated in biomass to aerosolised. Rocks, cliffs and mountains that contain heavy metals are weathered by the wind and waves, causing small heavy metal particles to be lifted into the atmosphere – especially where metal deposits are already being industrially mined in open pits.
Surface O_3 (Peak season*= 60µg/m^3) (8-hours = 100µg/m^3) **Peak season 8-hr mean for 6-m period with highest levels*	Surface level O_3 causes respiratory irritation, (e.g. COPD exacerbations) in the short term, and in the longer term causes cardiovascular issues and may increase sensitivity to allergens. It increases the risk of respiratory, cardiovascular and all cause deaths [Manisalidis et al]. Surface O_3 also creates reactive oxygen in plants which reduces leaf growth, photosynthesis and therefore reduces CO_2 absorption. This reduces crop growth and agricultural productivity, impacting food security and increasing the risk of malnutrition. Ozone also reduces plant's ability to manage water as it impacts the stomata's function in regulating transpiration, meaning plants are less able to conserve water, increasing drought risk.	Surface level (tropospheric) ozone – not to be confused with the 'ozone layer' in the upper atmosphere – is a major constituent of photochemical smog. It is not directly emitted but is rather primarily formed through chemical reactions between VOCs and Nitrogen Oxides (NOx) in the presence of sunlight (UV radiation) or heat (e.g. from lightening). Vehicle emissions, industrial factories and power plants are the main sources of these precursors. VOCs are also released by natural sources like plants and are produced by solvents like paints and cleaning agents, and are emitted from landfills of decomposing organic matter. Agricultural activities involving fertilizers can produce ammonia, which can interact with other pollutants to form O_3.
CO (24 hours = 4µg/m^3) (8 hours = 10µg/m^3) (1 hour = 35µg/m^3) (15 min = 100µg/m^3)	CO is a poisonous gas as it binds to haemoglobin 200x more powerfully than O_2, forming Carboxyhaemoglobin (CO-Hb). This reduces the blood's ability to carry oxygen to tissues and organs, leading to oxygen deprivation (hypoxia) and acute damage to the heart, lungs and brain. Acute poisoning from gas leaks or fires leads to headaches, dizziness, confusion and can quickly lead to loss of consciousness and death. Long-term lower concentration exposure leads to chronic health problems like cognitive impairment, cardiovascular issues and worsening chronic lung diseases [Manisalidis et al].	Carbon monoxide is a colourless, odourless and tasteless toxic gas produced by the incomplete combustion of carbon fuels such as wood, petrol, charcoal, natural gas and kerosene. It is released into the atmosphere in high quantities from anthropogenic industrial process such as vehicles (especially those with old, inefficient engines), petroleum refining and chemical production, and residential heating and cooking, and from natural hazards like volcanic eruptions and forest fires.

*N.B. There is no approved "safe or healthy" level of air pollution, as there is evidence of harm from all levels of most pollution, however pragmatic and politically realistic targets have been set in order to minimise harm. More information on particulate matter air pollution sources for different world regions is shown here UNEP