Global Catastrophic Risks by Chemical Contamination

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**Abstract**: Global chemical contamination is an underexplored source of global catastrophic risks that is estimated to have low a priori probability. However, events such as pollinating insects’ population decline and lowering of the human male sperm count hint at some toxic exposure accumulation and thus could be a global catastrophic risk event if not prevented by future medical advances. We identified several potentially dangerous sources of the global chemical contamination, which may happen now or could happen in the future: autocatalytic reactions, exposure to multiple subthreshold sources, and long-term unintended consequences, arising from both natural and bioengineered sources. We list several especially dangerous chemicals—dioxin, organiс compounds, and toxic heavy metals. We also discuss the features of such dangerous chemicals—molecules that can stay in the biosphere for a long time and affect it over time. We explore several social processes and scenarios where global chemical contamination becomes possible: large natural catastrophe like meteorite impact, supervolcano eruption, new ways of predicting properties of the chemicals via machine learning and their manufacturing via synthetic biology, uncontrolled “capitalistic” economic development with a corresponding large waste production, quick adoption of many chemicals with unknown long-term properties and unintended side-effects. These are all low probability, so work on other global catastrophic risks should be prioritized, but chemical risks could exacerbate other types of catastrophe contributing to social collapse.

**Keywords**: chemical contamination; existential risks; global catastrophic risk; planetary boundaries; pollution.

**Highlights**:

* Criteria for a chemical to pose a global catastrophic risk are stability in the biosphere, high activity, ability to travel large distances, and slow acting.
* Several known classes of chemicals are capable of causing global toxic contamination: organochloride pesticides, toxic heavy metals, greenhouse gases, protein isomers.
* Scenarios of global chemical contamination include natural catastrophe, Doomsday weapons, unintended consequences of previously unknown chemicals, and the combination of numerous subthreshold toxins.
* Global toxic chemical contamination is unlikely to cause a global catastrophe as technological progress continues, but could contribute to population decline after a different type of global catastrophe.

# 1. Introduction

The risk of human extinction affects not only people alive today, but many future generations. Existential risk includes human extinction, but also drastic curtailment of humanity’s potential (Bostrom 2002). One example of the latter is loss of civilization and the lack of a recovery. Another example is a catastrophe which worsens human values, and those worse values ending up in powerful artificial intelligence. Global catastrophic risks (GCRs) have the potential to significantly harm civilization and therefore have long-term consequences. Work to reduce existential risks and GCRs is of overwhelming importance (Beckstead 2013). The term of catastrophic biological risks (GCBR) was recently suggested (Millett and Snyder-Beattie 2017), but the problem of pandemics was in focus long before it. Another new global catastrophic risk is global loss of electricity/industry and subsequent famine (D. Denkenberger and Pearce 2015). However, the similar field of risks related to global catastrophic chemical contamination is underexplored.

Large-scale chemical contamination caused or may have caused some historical catastrophes. Examples include the Great Oxygenation Event some 2.5 billion years ago (Margulis and Sagan 1986); possible contributions by methane-producing (Rothman et al. 2014) or sulfate-reducing bacteria (Kump, Pavlov, and Arthur 2005) to the Permian-Triassic extinction; possible methane eruption causing Paleocene–Eocene Thermal Maximum (Katz et al. 2001); prion contamination (but it could be regarded as biological risk) as a possible contributor to the decline of Neanderthals (Underdown 2008); lead toxicity as a contributor to the decline of Roman empire; and the creation of holes in the ozone layer by chlorofluorocarbons and related chemicals (Schrope 2000).

The overall global catastrophic risks of chemical contamination are underexplored in existing literature. Some scientific articles describe the global effects of just one pollutant, like mercury compounds (De Lacerda and Salomons 2012). Pollution was a general category in a model which predicted inevitable global decline (Meadows, Randers, and Meadows 2004). Cribb explored in detail persistent low-level chemical contamination in the book *Poisoned Planet: How constant exposure to man-made chemicals is putting your life at risk* (Cribb 2016). Developmental neurotoxicity is especially important as it appears slowly and young brain evolution is especially fragile. Several chemicals were identified as possible causes: like “lead, methylmercury, polychlorinated biphenyls, arsenic, and toluene” and “manganese, fluoride, chlorpyrifos, dichlorodiphenyltrichloroethane, tetrachloroethylene, and the polybrominated diphenyl ethers”, according to (Grandjean and Landrigan 2014), who also claim that many toxins are probably not yet identified.

There are several alarming trends that suggest that some form of dangerous global contamination may be ongoing. The average human male sperm count has declined 60 per cent since the 1970s (Levine et al. 2017), and if the trend continues, European males may have sperm counts so low as to be infertile in the 2060s (Barratt 2017). The incidence of autism has grown to 1 in 58 births, up 15 per cent in 2 years (Baio 2018). Insect biomass has declined 75 per cent in 27 years in protected areas (Hallmann et al. 2017). All of these have been suspected of connection with some form of global chemical contamination (Foster et al. 2008). Significant work on chemical pollution as a global catastrophic risk was done under the framework of “planetary boundaries” (Baum and Handoh 2014; Handoh 2013).

Moreover, current global warming is connected with atmospheric accumulation of CO2 as well as with other greenhouse gases. CO2 alone also may be toxic for humans (Bierwirth 2018). Global warming has increased the spread of other environmental contaminants (Noyes et al. 2009).

Despite claims that 9 of 10 people are breathing polluted above recommended thresholds air and 7 million premature deaths a year occur because of this (WHO 2018), the average global life expectancy continues to grow (GBD 2013 Mortality and Causes of Death Collaborators 2015). This growth demonstrates that other effects are more important than air pollution. Moreover, as a large part of air pollution comes from coal burning (Cheng 2003), which is expected to decline, such pollution should also decline. Home cooking and heating using low-quality fuels, especially without a chimney, also contribute to air pollution (Mestl et al. 2007).

Air pollution especially affects megacities, as such cities create a lot of waste, including industrial air pollution, car air pollution and home waste dumps. While air pollution is a global, and even a catastrophic problem given the number of deaths, which are on same yearly level as military deaths during World War II (Wang 2018), it does not currently appear to be a catastrophe which could wipe out humanity in the near term.

The main reason global catastrophic chemical contamination is theoretically possible is that almost all humans are connected via the atmosphere, with submariners and astronauts the only (temporary) exceptions. The hydrosphere, food chains, and a few other sources can serve as global transport vectors for dangerous chemicals.

In this article, we will describe the field of chemical global catastrophic risks (CGCR). In Section 2, the criteria defining a global catastrophic chemical are explored; in Section 3, physical scenarios of global chemical contamination are presented, and in Section 4, scenarios in which such an event could become possible are analyzed. Section 5 looks at the combinatorial effect of many new chemicals in the biosphere, and Section 6 is devoted to societal processes which may contribute to CGCR. In Section 7, global chemical contamination is assessed as a possible human extinction risk in the wider context of other such catastrophic risks.

# 2. Criteria for classifying a chemical as a catastrophic risk

To become a global catastrophic risk, potentially collapsing civilization, chemical contamination should be able to cover almost the entire surface of the Earth.

However, for most poisonous chemicals, their effects are highly visible immediately and protection measures are straightforward. Such measures may include stopping the source of the contamination, e.g. by shutting down the manufacturing which creates such chemical, or, if that is impossible, using different cleaning technologies like air filtering, chemical reactions with some chelators, etc.

Thus, a truly dangerous chemical must be either difficult to detect or unstoppable. Undetectability could be “achieved”, either by a malicious agent, or more likely, randomly, if the contaminant acts very slowly and indirectly. For example, such an agent might act by affecting human reproduction, e.g. rates of mutation and birth defects, or by increasing cancer rates. It could also act in indirect ways that are not easily recognized. One example of such a threat is a class of chemicals, chlorofluorocarbons (like Freon), which were once used as refrigerants. After years of widespread use, they were found to indirectly affect human health via atmospheric ozone depletion (Solomon 1999).

Based on the above considerations, the following criteria for potentially global catastrophic chemical contamination can be laid out:

1. *Able to act globally*. The chemical can travel large distances via air or water currents or by entering the food chain.
2. *Stable in the environment and the biosphere.* Sunlight and chemical reactions tend to destroy most complex molecules over times. Rain and rivers bury them eventually on the ocean floor.
3. *Causes slow but fatal toxicity, or other non-immediate effects.* These non-immediate effects mayaffect humanity in the future in ways like lower fertility, higher aggression, or gradual mental decline. This type of chemical toxicity would become obvious years or decades after exposure. This condition is self-contradicting, as slower toxicity means lower level mortality as many will be able to reproduce before the onset of the toxic effects.
4. *Indirect mode of action*. The agent acts slowly and is not easily identified or proved to be the main culprit.
5. *Difficult to mitigate*. If the amount or toxicity of an agent is very large, or if no simple antidotes or alternatives are available, the catastrophe could be difficult to reverse.

While these criteria seem to be difficult to meet, the sheer number of possible toxic chemicals, as well as large number and amount of different chemicals created by an industrial civilization means that some contaminants could meet them. Malicious agents may also intentionally attempt to synthesize dangerous chemicals with these properties. We will explore the candidates in the next section.

# 3. Possible types of chemicals which could cause global catastrophic contamination

## 3.1. The case of dioxin as a possible global catastrophic chemical

Dioxins are extremely lethal, with an LD50 (the dose at which half of the experimental animal models die) of about 0.6 micrograms per kilogram of body weight in guinea pigs (Wada 2002) (however, humans could be much less susceptible to the dioxin acute toxicity, and the main risk is long-term development problems). They are also very stable in the environment, putting them in the category of persistent organic pollutants (POPs). A leak of about 25 kilograms of dioxin at Seveso in Italy in 1976 contaminated approximately 17 square kilometers, killing 3,300 local animals within days anda further eighty thousand animals had to be slaughtered to prevent dioxin from entering the food chain (Roche Group 2006).

Dioxins bioaccumulate (Stephens et al. 1990), meaning they reach higher concentrations in animals higher on the food chain. By this mechanism, they contaminate meat and other animal products used as food. The Seveso disaster resulted in no confirmed human casualties, but there were almost 200 cases of chloracne, a severe type of disfiguring acne caused by chemical contamination. The total cost of decontamination exceeded 40 billion lire (47.8 million USD).

## 3.2. Element pollution: heavy metals, phosphorus

The causes of increased rates of autism and Alzheimer disease and the decline in human sperm counts are unknown. Some have suggested that all of these trends may be caused by accumulation of one or several chemicals, most likely metals (Kampa and Castanas 2008). Environmental metal contamination can occur as a byproduct of mining, like in the case of mercury (Duruibe, Ogwuegbu, and Egwurugwu 2007). It has been suggested that metal production is poisoning the biosphere (Nriagu 1990).

Global pollution with cadmium has been observed and correlates with elevated rates of renal disease and hypertension (Satarug et al. 2003). Mercury is used for gold miming in Brazil in large quantities, where it has affected the aquatic food cycle and the health of tropical forests (Salomons 1995), creating what has been called a “chemical time bomb” (De Lacerda and Salomons 2012).Selenium pollution has been recognized as a global issue (Lemly 2004).

Aluminum is known to be neurotoxic; aluminum salts are used by many people as antiperspirants and as an antacid drug.

Widespread contamination by other trace elements has also been discussed (Calabrese, Canada, and Sacco 1985). Products such as electric batteries contribute to metal pollution (Rydh and Svärd 2003), as they have many different metals inside.

Phosphorus, which is globally used as a fertilizer, goes into the oceans. This could trigger an oceanic anoxic event, which has been associated with mass extinction events, probably via producing of H2S (Handoh 2013). It was estimated that at current rates, phosphorus could trigger oceanic anoxic event in a few centuries or millennia (Cordell, Drangert, and White 2009).

## 3.3. Gases

Most toxic gases do not remain in the atmosphere for long, as they tend to be highly reactive. But some gases with environmental effects are quite stable, like chlorofluorocarbons and some greenhouse gases.

Toxic gases like hydrogen sulfide (H2S) may be produced by a supervolcano eruption, or by eruption of a water column saturated by dissolved gas, as happened in Lake Nyos (Kling et al. 1987). A similar effect on a global scale, “ocean overturn” causing a tenfold increase in atmospheric CO2 concentration, has been suggested as a possible mechanism of Permian-Triassic extinction event (Knoll et al. 1996). Global eruption of methane from the ocean has also been considered as a possible cause (Zhang and Kling 2006). It has also been suggested that nickel-consuming bacteria may have worsened the Permian extinction by producing huge amounts of methane (Ghose 2012).

Heavy gases like volcanic CO2 can accumulate in low areas. Radon is a heavy radioactive gas, and is the second leading cause of lung cancer in the US (Field et al. 2000), but it cannot accumulate long-term as it is very unstable; the most stable isotope has a half-life of only 3.8 days.

Global acid deposition has been recognized as threat to forests and crops (McCormick 2013), contributing to a decline in biodiversity, which itself could be a factor contributing to existential risks (Kareiva & Carranza, 2018; Torres, 2016).

It has been suggested that eruption of gases (CO2 and especially SO2) from the massive volcanic province called the Deccan traps contributed to the demise of dinosaurs (Self et al. 2006). The most dangerous effects might have stemmed from SO2, namely global cooling (which is climate risk, but closely connected with environmental pollution) and acid rain. Another gas that could cause a global catastrophe is carbon monoxide, as it is not rained out as strongly (D. Denkenberger and Pearce 2014).

## 3.4. Organic compounds

The organochlorides are a group of toxic chemicals, including chloroform and DDT, which contribute to global pollution (Tanabe, Iwata, and Tatsukawa 1994). There are many different organochloride pesticides which affect the environment (Jayaraj, Megha, and Sreedev 2016). There are controversial claims that the popular pesticide glyphosate is responsible for autism (Williams, Watson, and DeSesso 2012).

Botulism toxin is unstable environmentally but is produces by a phage virus affecting bacteria. Its gene is known to science (Uniprot 2018) and theoretically could be inserted in other genetically modified organisms. While it is chemical, it is typically scientifically explored as a biological weapon (Arnon et al. 2001).

Benachour et al. (2012) wrote:

For one half of a century of intensification of the industrial era, more than 5 million man-made chemicals have been released in the environment without recycling, as if the ecosystems were infinite. These products were often designed either to be stable, as being rather insoluble… and/or to be penetrating and active on the physiology of organisms… These xenobiotics become excellent candidates for the disruption of the hormonal messenger system – known as endocrine…

They also stated that humans are on the top of the global food chain, which results in the accumulation of different contaminants via diet, that 100,000 substances should be evaluated by international legislation, and that 1,500 new molecules are marketed each year. Table 1 in that article presents a list of possible environmental contaminants.

Microplastic contamination is now recognized as a global problem with unknown consequences (Readfearn 2018).

## 3.5. Dust particles

Dust particles of 200 nm size have been found in the brains of Alzheimer patients living in air polluted areas like Mexico-city (Underwood 2017). Dust also contributes to lung diseases. It was calculated that dust particles produce 3.3 million premature deaths per year, mostly in Asia (Lelieveld et al. 2015). Volcanic dust in particular may be extremely damaging (USGS 2018), as it has sharp edges and may form a cement in the lungs, but the most direct dire effect of volcanic dust may be on climate.

Dust particles can contribute to dimming of the sun (Stanhill and Cohen 2001), partly compensating global warming. Removing such a dust shield may produce an unexpected jump in global warming after the end of the coal era (Andreae, Jones, and Cox 2005).

## 3.6. Nanoparticles

There have been concerns that nanoparticles and byproducts of nanotechnology, like nanotubes, could present dangers to human health (Moore 2006). Advanced nanotechnology may help to weaponize already existing poisons by helping them be more environmentally stable. Such technology may also be able to target humans and even specific cells, tissues and organelles inside cells for poison delivery via ligands; such targeting nanoparticles are have already been developed for cancer drug delivery (Sengupta et al. 2005).

## 3.7. Could conventional chemical weapons be used as global catastrophic weapons?

Chemical weapons are usually not considered as Doomsday weapons. There are no academic references of which we are aware that seriously argue that chemical weaponry could be a threat to the survival of the whole human species. However, in the interest of completeness, and considering distant risks, we will address chemical weapons in the context of global catastrophic risks here.

Chemical and biological weapons are completely different. Biological weapons, such as smallpox, may be self-replicating, whereas chemical weapons are not. VX gas, one of the most persistent chemical warfare agents could remain stable in environment below 0˚C (WHO 2004). In the context of global catastrophic risks, much of the globe would need to be saturated with VX in a quantity sufficient to kill a large fraction of people within ten days or less. Given currently available delivery technology, this would not be feasible.

One could imagine swarms of robot-sprayers, similar to slaughterbot drones (Oberhaus 2017; Turchin and Denkenberger 2018a), which would deliver the dangerous agent worldwide. It does seem to be theoretically possible in the distant future, if robotics, nanotechnology, and artificial intelligence continue to advance, and if progress in offensive applications outpaces defensive applications.

There are agents more lethal than VX gas, such as botulinum toxin, for which the lethal dose is only 0.1 micrograms, but it is very unstable in the environment. Such toxins may one day be used as the lethal payload for military microrobots (Phoenix 2004). A relatively small amount of this toxin, less than a kilogram, would be sufficient to kill everyone on Earth, if delivery were feasible.

Recently, a new class of extremely toxic chemicals attracted public attention. It is the family of Novichok toxins, which are said to be more potent than VX gas, and more stable in the environment (Mirzayanov 1995). Some Novichok-class agents have higher density than air and could become concentrated in low-lying areas (Sciencedirect 2018).

Given the enormous amount of possible organic chemicals, some technologically advanced malicious agent could potentially design a chemical that would meet all criteria for a global catastrophic chemical described in Section 2.

# 4. Possible scenarios of global contamination

In the previous section, we looked at possible globally polluting chemicals. In this section, we will analyze the physical mechanisms by which such chemicals may be produced in large quantities and be spread widely; in the following section we will describe social mechanisms which may contribute to such an event.

## 4.1. Natural catastrophes

Global chemical contamination could happen via some natural process, an artificial catalyst, or a trigger accelerating a natural process. The major risk factor is the unity of the terrestrial atmosphere. If enough poison is produced somewhere, it will eventually circulate everywhere.

Some candidates for natural causes of global chemical contamination include supervolcano eruption(Jones, Sparks, and Valdes 2007), kimberlite province explosions (Morgan, Reston, and Ranero 2004), and the release of methane clathrates causing runaway global warming(Rampino and Caldeira 2005).

It has been hypothesized that “Verneshot” events are possible, namely the explosive release of huge masses of gases (CO2 and SO2), creating patterns similar to impacts, like shocked crystals and microspheres (Morgan, Reston, and Ranero 2004). This could affect the atmospheric composition and potentially make it globally toxic.

It has been suggested that the explosive structures now known as kimberlite pipes may have occurred as the result of oxygen-free detonation of heavy hydrocarbons (something like the explosion of ordinary TNT) at a depth of about 90 km in cavities with a diameter of about 20 km (Gorny 2006). These heavy hydrocarbons are formed deep inside the Earth and rise up during its degassing, serving as sources of oil, according to abiogenic origin theories. The strength of such explosions, according to the authors, is 10,000 to 100,000 gigatons of TNT, comparable to the energy of the fall of an asteroid a few kilometers in diameter. The main damage from such an explosion is likely to be the immediate contamination of the earth's atmosphere with a huge amount of hydrocarbons and their combustion byproducts. This will lead both to direct poisoning of living beings, and to radical climate changes. Large amounts of “molten carbon” were recently discovered under the continental US (Hier-Majumder and Tauzin 2017).

Proposed ideas of mantle exploration via molten iron encapsulated probe (Cirkovic and Cathcart 2003) or nuclear probes (V. Aranovich, personal communication) could also trigger eruption and degasification events. Similarly, asteroid impacts may have the potential to produce toxic exhaust and soot clouds (Kaiho and Oshima 2017).

## 4.3. Global extermination through carbon dioxide poisoning

Breathing concentrations of carbon dioxide in air at greater than 3 percent is dangerous over the long term and can cause death by hypercapnia (carbon dioxide poisoning). The normal atmospheric concentration of CO2 is just 0.04 percent. At the Permian-Triassic boundary, there is evidence that CO2 concentrations increased by 2000 ppm and global temperature increased by 8°C (14 °F) in a relatively short period of time, 10,000 years or less. This was probably caused by extensive volcanism. Low-level CO2 toxicity in humans may affect performance, e.g. by lowering intelligence. Detrimental effects have been observed at 1000 ppm (Satish et al. 2012).

Knoll et al. wrote that atmospheric CO2 concentrations might have reached 6000 ppm during the PT extinction event, and thus killed animals directly via hypercapnia. Such jump may be connected with limnic “ocean overturn” described in section 3.3.

## 4.4. Catastrophic methane release from methane clathrate

Catastrophic methane release from methane clathrate deposits in the tundra and on continental shelves would release immense amounts of methane, a gas with 80 times more warming potential than CO2 over a 20-year period, during which most of the gas is oxidized (Phys.org 2018). The half-life of methane in the atmosphere at current levels is 8.4 years (Houghton, Ding, and Griggs 2001); over shorter periods, methane would have an even higher warming potential; this difference is important in cases such as abrupt methane eruption from the sea floor or quick feedback via tundra thawing. Methane contributes about one third of global warming temperature increase.

Some scientists have expressed concerns that methane empowered positive feedback loops in the Arctic could result in dramatic global warming even in this century (Obata and Shibata 2012), but most scientists currently dismiss such worries (Archer 2007).

One hypothesis about the cause of the Permian-Triassic extinction event is methane release caused by a buildup of methane-producing microbes causing a catastrophic global warming episode and triggering anoxia in the ocean and increased aridity on land (Rothman et al. 2014).

It has been suggested that methane eruption from the ocean floor could take the form of a violent eruption, similar to the Nyos lake eruption (Zhang and Kling 2006). Current global warming affects continental shelves in the Arctic, where large deposits of gas hydrates exist, via changes in ocean circulation and warmer river water. Bubbling of methane has already been observed in the Arctic Ocean (Shakhova et al. 2010).

Methane eruption could possibly be artificially triggered, if thousands of nuclear weapons were exploded on the floor of the Arctic Ocean; however, this approach seems impractical as a Doomsday weapon. A malicious state agent may instead produce large amounts of very powerful greenhouse gases, as sulfur hexafluoride has 23,900 times the potency of CO2 (IPCC 2007), but such an approach would still be prohibitively expensive.

## 4.5. Oxygen depletion

Human fossil fuel consumption not only produces CO2, but consumes O2 from the atmosphere, which is normally replaced by a healthy biosphere via photosynthesis. However, deforestation, ozone holes, and other environmental stressors are damaging the balance of global ecology and could potentially limit the ability of the biosphere to generate oxygen (Martin, McKenna, and Livina 2017).

Fossil fuel combustion has reduced oxygen levels from 209,580 to 209,460 ppm from preindustrial era (Ronson 2016). That represents a loss of just 0.06 per cent; however, the long-term impact of global warming on oxygen has been predicted to last up to 100 000 years from now (Shaffer, Olsen, and Pedersen 2009). Oxygen impact on the ocean could be much larger than the air. An ocean anoxic event would be unlikely to constitute a GCR directly, as global fisheries make up less than 3% of human calories (David Denkenberger and Pearce 2014), and surface waters can still produce fish. However, there is the possibility that H2S will be produced (discussed below). It has also been found that oxygen levels fell 0.7 per cent in the atmosphere over the last 800,000 years for unknown reasons not connected with burning of fossil fuels (Stolper et al. 2016), and have fluctuated between 15 and 33 per cent during the history of the Earth (Martin, McKenna, and Livina 2017).

## 4.6. Space catastrophes

While some comets have some cyanide in their composition, it burns during entry to our atmosphere. The bigger danger comes from chemical reactions during impact, the risk of which depends on the chemical composition of the place of impact (Kaiho and Oshima 2017). The energy of impact is enough to vaporize thousands of times more mass than the mass of the comet itself.

## 4.7. Hydrogen sulfide-producing bacteria in ocean

Oceans could be also poisoned by anoxic zones where H2S-producing bacteria dominate (Kump, Pavlov, and Arthur 2005). The Black Sea currently has 13 mg/m3 of H2S, equal to a total of around 100 million tons. If the chemocline of anoxic ocean reached the surface, it would start constant degasification. In Kump’s model, only a small surface area of 4 x 105 km2 (equal to the size of the Black Sea) becomes the source of constant emissions of H2S on the order of 4 gigatons a year. This is 2000 times more than the total global natural emissions of H2S, and could overcome the coping ability of the atmosphere, resulting in step-like jump of global concentration to 100 ppm. That concentration is toxic, with immediate death occurring at a concentration of 500-1000 ppm (U.S. Department Of Health And Human Services 2016). Global warming could contribute to ocean anoxia, as the solubility of oxygen would decline and the ocean would become more stable. This would help H2S-producing bacteria to reach higher levels in water and flourish thus producing large amounts of this toxic gas in the atmosphere, which could also kill terrestrial plants and destroy the ozone layer (Ward 2007).

## 4.8. An auto-catalytic reaction

Another type of a global catastrophic risk is an auto-catalytic reaction extending across the surface of the Earth, in the spirit of “Ice-9” from Vonnegut’s novel *Cat's Cradle* (Vonnegut 1963). The case of the drug Ritonavir is a real example of such a global autocatalytic epidemic (Bauer et al. 2001). Ritonavir has two types of crystal polymorphism, and only one is effective against HIV. In 1998, a new type of polymorphism appeared and quickly “infected” manufacturing facilities in different parts of the world (it was transferred by employers who visited different plants), autocatalytically converting the active form to the inactive; this was a serious problem as it was the only drug at the time able to help AIDS patients. The problem was later solved with refrigerated gel capsules.

It was suggested (but not generally accepted) that Alzheimer disease also could have a prion mechanism and it was shown that the prion could be transmitted by blood infusions (Bu et al. 2017).

## 4.9. Poisoning of the food chain

While it would be difficult to poison the whole food chain deliberately, some dangerous chemicals may accumulate in it, like mercury in predatory fish. As humans are at the top of the food chain, they consume much of the chemicals which accumulate in the food chain. For example, fat-soluble dioxin accumulates in fat and milk.

Market forces may also drive dangerous chemicals into food. One example is the use of pesticides whose toxic nature was not immediately recognized, such as DDT.

Many products use potentially toxic chemicals during their manufacture. For instance, apple juice is brightened by pectinase enzymes (Yamasaki et al. 1967) which are derived from mold (Blanco, Sieiro, and Villa 1999), and molds are known to be able to produce neurotoxic chemicals. It was suggested that some industrial chemicals contribute to chronic toxic encephalopathy (Kim and Kim 2012). Some edible plants require the use of defoliants before harvest, previous versions of which were neurotoxic (Iyer and Makris 2010).

Clean water is also a scarce resource. In Bangladesh, toxic water from wells has resulted in widespread arsenic poisoning (Vidal 2016). Prozac and other pharmaceuticals has been found in drinking water (Margulis and Sagan 1986).

Contamination of soil by metals also contributes to production of lower-quality food, which when combined with the growth of the human population strains the food supply (Kuhlemann 2018).

## 4.10. Biological organisms generating dangerous toxins

The “oxygen catastrophe” 2.5 billion years ago was basically poisoning of the atmosphere by byproducts of photosynthesis (Margulis and Sagan 1986). It has been suggested that one of factors behind the PT catastrophe was H2S production in anoxic oceans (Kump, Pavlov, and Arthur 2005) or methane via acetate conversion into methane by bacteria (Rothman et al. 2014). Just one gene, probably coded on a plasmid, could spread through different populations of bacteria and make them produce an excess of methane, in much the same way as new antibiotic resistant genes spread.

## 4.11. Indirect effects on the biosphere

The biosphere may be less able to protect itself than humans, but its collapse would cut humanity’s food supply; humanity could survive only a few months on existing food supplies (D. Denkenberger and Pearce 2015). We have not yet prepared for such a possible food collapse; however, there is the possibility to be more prepared.

There are many ways chemical agents could affect the biosphere (some already mentioned above). They include:

* *Ozone holes*. Ozone depletion would more affect crops and forests than animals, as plants need sun and thus will be unavoidably exposed to the increased UV radiation.
* *Bee extinction*. Bees pollinate 70 percent of crops, and their populations are decline, probably because of pesticide use and parasites (Close 2018). Stopping pesticide use, though, is not the simple solution to this problem, as that cause crop loss, and could also lead to famine. This is especially true because the overall loss in agricultural production for a loss of all animal pollinators is only 3–8% (Aizen et al. 2009) Insects population declines in alarming rate for unknown reason (McKie 2018).
* *Loss of biodiversity because of pesticides*. Some herbicides kill all plants other than the crops for which they’re intended (Vats 2015).
* *Loss of crop productivity.* Other reasons include climate change.

# 5. Combinatorial effects of many chemicals

## 5.1. New chemicals

Many new chemicals, an estimated 5 million (Benachour et al. 2012), are byproducts of modern civilization that never existed in nature. Quick-acting toxins can be quickly identified; thus, slow-acting toxins are the most dangerous.

Decades may pass before the identity of a slow-acting toxin is pinpointed. This is especially true if it affects reproduction (Wong and Cheng 2011), as its effects will be seen only in the next generation, or if it has an oncogenic effect, which may be observed only decades later.

## 5.2. Combination of subthreshold effects of many weak toxins

One possible problem is combined exposure, where thousands of different pollutants combine to contribute to health effects. If the share of any single chemical is statistically small, its effect cannot be proved with straightforward experiments and it cannot be banned in an economically efficient way. This threat is in some sense similar to the idea of a biological multipandemic (Turchin, Green, and Denkenberger 2017).

For example, if there are 100 environmental pollutants, each of which is lowering human intelligence by an average of one IQ point, combined, they could lower global intelligence below the level needed to support technological civilization. Also, it would be not easy to pinpoint any one such pollutant, as its individual effect would be below the typical error of measurement.

## 5.3. Harmful combinations of benign chemicals

One example of such combination is acetone and n-hexane. Acetone activates cytochrome P450 and increases conversion of n-hexane into the toxic neuropathic chemical 2,5-hexadione; such combined exposure is possible in some automotive plants and painting shops (Luttrell, Jederberg, and Still 2008).

We could hypothesize that some chemical will not cause harm directly but could react with another chemical in nature with harmful effect. In Lem’s novel “The Chain of Chance” this idea is used as the plot device: a series of mysterious deaths is finally explained by a very toxic combination of several harmless chemicals (Lem 1975). The same idea is behind binary chemical weapons.

As around 5 million new chemicals were introduced into the biosphere by the industrial civilization (Benachour et al. 2012), the combinatorial space of all their possible combinations is enormous, which makes safety tests impossible, and also makes the search for harmful combinations, if they exist, extremely challenging.

# 6. Social scenarios of possible global chemical catastrophe

There are two most probable ways global chemical contamination could happen. The first is accidentally, via gradual accumulation of a chemical that acts slowly and indirectly, is also very stable in environment, and does not leave the biosphere because it accumulates in trophic chains, like dioxin or some heavy metals. The second is deliberate creation of the large amount of dangerous chemicals by malevolent actors.

## 6.1. Doomsday weapons

An extremely toxic chemical could be deliberately produced as a Doomsday weapon (Kahn 1959) by a bad agent (P. Torres 2018). This seems unlikely, as such an agent would probably have many other lower cost options for a Doomsday weapon. The discussion in Section 3.1 includes the use of dioxin as a Doomsday weapon.

## 6.2. Unintended and undetectable consequences

Several notable chemical disasters have resulted from unintended consequences of industrial production. However, the worst chemical disasters have been a result of not only unintended, but unknowable consequences. Agent Orange was contaminated with dioxin as a byproduct of its simplified synthesis. Another example is the Thalidomide debacle (Miller 1991).

## 6.3. Uncontrolled “capitalism” and the problem of waste management

Meadows et al. included accumulation of waste as one of the five main parameters of their world model (Meadows, Randers, and Meadows 2004). Recent large emissions of toxic gases from waste dumps near Moscow have highlighted the problem of waste (McCoy 2014).

From one point of view, technological advances could help to improve waste management, but the same technologies allow the manufacture of large amount of goods, leading to more waste. Production of goods is favored by market forces. As resources have become scarcer, recycling has become more prevalent. However, absolute amounts of waste production have generally continued to increase. Some form of regulation is generally needed to create incentives for waste reduction, like carbon quotas.

# 7. CGCR in the wider context of the technological development and other catastrophic risks

The risks of chemical catastrophe are overshadowed by quick technological progress on one side, and the larger risks of more probable catastrophes on the other. If technology develops quickly and without catastrophes, nanotechnology and biotechnology likely will bring effective filters, as well as non-toxic manufacturing methods. Medical technology and AI will likely develop the ability to test the safety of new chemicals more quickly. The problem of unintentional global chemical contamination will abate in several decades, if technological progress continues with acceleration predicted by Kurzweil (Kurzweil 2006). However, slower technological growth will make Meadows et al.’s predictions about resource depletion and global pollution more probable (Meadows, Randers, and Meadows 2004). And even with fast technological progress, this could make intentional release of globally catastrophic chemicals more likely.

There are many more global catastrophic risks including engineered biological pathogens, unfriendly AI, or nuclear war which have higher probability than global chemical contamination.

But chemical contamination may be the factor which could turn social collapse (Hanson 2008; Tonn and and MacGregor 2009) into full-blown human extinction. For example, if the current fertility decline persists, small groups of survivors will not be able to use a high birth rate to overcome the high mortality typical of hunter-gather communities. Survivors will be traumatized by the consequences of the GCR, persistent pollution, lack of survival skills and genetic alleles which helped our ancestors but which probably become less spread in people adapted to live in large agricultural societies. However, biological and weathering processes will probably be able to clean most dangerous chemicals after some time.

# Conclusion

The authors rate global chemical contamination as a low global catastrophic or extinction risk. Our estimate is that the probability of a severe global chemical contamination event is less than 0.1% for the duration of the twenty first century, putting it in the “green” or “white” categories on the Global Catastrophic and Existential Risks Communication Scale (Turchin and Denkenberger 2018b).

As for many catastrophic risks, the current probability is very small, but advances in areas such as nanotechnology would allow for the cheap mass production of dangerous chemical agents. Fortunately, those very same advances would also provide the means to clean up chemical contamination or even enhance living humans to make them immune to chemical contaminants.

Our conclusion is that although contaminating the atmosphere or surface of the planet with chemical agents is theoretically possible, the risk is far outweighed by the risks posed by bio-agents such as viruses. Such agents are not only self-replicating but can be more lethal.

Whatever can be done with chemical weapons can be done much more cheaply and effectively with genetically engineered pathogens. Pathogens also have the fortunate advantage that the default most likely to be used in biological warfare would only threaten humans, not other members of the animal or plant kingdoms.

The amount of planning and implementation needed to seriously threaten all life on the planet with chemical weapons would be immense, and would be more likely put to use in biological warfare. However, humanity should not rule out the use of chemical weapons in a total war type scenario, and should take the potential into account when considering different possible scenarios.

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