A Small Dose of Water Pollution
Or
An Introduction to the Health Effects of Water Pollution

A book chapter of
A Small Dose of Toxicology - The Health Effects of Common Chemicals
3rd edition

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Supporting web sites
web: www.asmalldoseof.org - "A Small Dose of Toxicology"
web: www.toxipedia.org - Connecting Science and People
Dossier

Toxicology of Water Pollution

<table>
<thead>
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<th>Name: Water Pollutants</th>
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**Definition of water pollution:** contamination of indoor or outdoor water by any chemical, physical or biological agent that modifies the natural characteristics of the water, reducing its beneficial usability for people and/or ecosystems

**Use:** avoid use of polluted water but drink plenty of clean water

**Recommended daily intake:** none (but water is essential)

**Absorption:** Skin and gastrointestinal system

**Sensitive individuals:** fetus and children, elderly, people with chronic health problems

**Toxicity/symptoms:** depends upon pollutant / contamination

**Regulatory facts:** in the US the EPA sets some standards for water pollutants

**General facts:** caused by emissions of billions of pounds of chemicals and particulate matter every year from a wide range of products and industries, combustion of fossil fuels such as coal and gasoline, and bacterial contamination

**Environmental effects:** widely distributed in environment, affects wildlife and ecological health, and human health

**Recommendations:** minimize water pollution on a global scale, avoid exposure by children and other sensitive groups, expand research on toxicity and alternative sources of energy, adopt precautionary approach, reduce the use of fossil fuels, support international treaties
Case Studies

The Cuyahoga River: Pollution Burns
Strange as it may seem, the Cuyahoga River in Ohio has caught fire at least 13 times, with the first fire occurring in 1868. The Cuyahoga River is located in northeastern Ohio and drains into Lake Erie, one of the freshwater Great Lakes of the US/Canada. In 1969 the river was considered one of the most polluted rivers in the US. It had thick sticky masses of oil several inches thick floating along, often full of garbage, which is a perfect feed for fires. In 1952 a river fire caused $1 million in damages. A fire in 1969 was reported in *Time* magazine and received widespread attention. The pollution and fires helped spur efforts to clean up the river, and some credit the fires with encouraging the passage of the Clean Water Act and the Great Lakes Water Quality Agreement, and the creation of the federal Environmental Protection Agency (EPA) and the Ohio Environmental Protection Agency (OEPA). These new rules and regulations significantly improved water quality by controlling point source pollution from industry.

Flint River Disaster: Lead in Drinking Water
On April 25, 2014 the city of Flint, Michigan switched its source of drinking water from Lake Huron, supplied by Detroit Water and Sewerage Department, to the Flint River. However, Flint failed to add appropriate corrosion inhibitor chemicals to the water, which resulted in lead and other contaminants from the aging pipes leaching into the water. Water from one Flint home was tested and found to contain lead at 13,200 parts per billion (ppb); the maximum contaminant level (MCL) set by the EPA is 15 ppb. Following the change in water sources, the number of children with elevated blood lead levels increased dramatically, particularly in poor neighborhoods. It was estimated that between 6,000 and 12,000 children were exposed to drinking water with elevated levels of lead. The US CDC states that there is no safe level of lead exposure to lead, especially for children. The Flint disaster is particularly tragic because we have known for years that lead exposure has a devastating impact on developing brains. Flint is a poor city with a large number of African American residents, which prompted a concern that the disaster was a case of environmental racism. The simple step of adding corrosion inhibitors to the water would...
have prevented the suffering inflicted on the people of Flint. (see Chapter 8 – A Small Dose of Lead)

**London Well Water: Cholera Outbreak, 1854**

Water can also be contaminated with bacteria that when ingested make people very ill or even cause death. A classic example is the bacterium *Vibrio cholera* (see image) that causes cholera, an infection of the small intestine. The main symptoms are profuse watery diarrhea and vomiting, which rapidly lead to death. Transmission is primarily through consuming contaminated drinking water or food. The severity of the diarrhea and vomiting can lead to rapid dehydration and electrolyte imbalance. Primary treatment is with oral rehydration solution and if these are not tolerated, intravenous fluids. Worldwide, cholera affects 3-5 million people and causes 100,000-130,000 deaths a year as of 2010. About one hundred million bacteria must typically be ingested to cause cholera in a normal healthy adult. This dose, however, is smaller in those with lower gastric acidity. Children are also more susceptible, with two to four year olds having the highest rates of infection. The last major outbreak of cholera in the United States occurred in 1910-1911. Effective sanitation practices, if instituted and adhered to in time, are usually sufficient to stop an epidemic.

A major contribution to fighting cholera was made by the physician and medical scientist John Snow (1813-1858), who in 1854 found a link between cholera and contaminated drinking water in London. He is considered to be one of the fathers of epidemiology, because of his work in tracing the source of a cholera outbreak in Soho, England. Dr. Snow proposed a microbial origin for epidemic cholera in 1849; he famously removed a pump handle from a pump that served an area of London, stopping the cholera epidemic. In his major "state of the art" review of 1855, he proposed a substantially complete and correct model for the etiology of the disease. In two pioneering epidemiological field studies, he was able to demonstrate that human sewage contamination was the most probable disease vector in two major epidemics in London in 1854. His model was not immediately accepted, but it was seen to be the more plausible, as medical microbiology developed over the next thirty years or so.
This incident demonstrates the importance of safe drinking water and public health infrastructure for maintaining the health and well-being of communities.

**Water: An Introduction**

Clean water (H₂O) is essential for life as we know it, and clean water is relatively scarce and becoming more so. Some astonishing facts about water: 1) by body weight we are about two-thirds water; 2) about two-thirds of the Earth’s surface is covered with water but most of this is saltwater; 3) about 3% of this water is freshwater and 2% of that is frozen; 4) therefore only 1% of the Earth’s water is available for use to drink, bathe in, grow food and cook with, and use in manufacturing. The water cycle describes how water circulates between the atmosphere, surface water such as rivers, plants, oceans, and soil. The natural circulation of water is essential for ensuring clean drinking water. In 2016 approximately 1 billion people, out of a global population of 7.4 billion, do not have access to clean water.

**What Causes Water Pollution?**

Of primary concern are the contaminants added to water by people that can cause undesirable health effects in humans or wildlife. There is the old adage that “the solution to pollution is dilution,” but is this really true? To a small extent yes, but in a larger context it is not. One person can use a river or even a stream as his or her personal sewage dump, but managing the volume of waste from a city of 1 million people requires an entirely different approach. Similar to our bodies, rivers and other bodies of water have a limited ability to metabolize or excrete undesirable contaminants.

It is important to distinguish between point and non-point sources of pollution. Point sources such as a pipe dumping material into a river can often be readily identified and stopped, while non-point sources of pollution are diffuse and difficult to address. For example, agricultural runoff or water contaminated by roads does not have one easily identifiable owner or source. Below are different examples of water pollution. It is also important to distinguish between cause and sources of water quality that make it unfit for consumption or use. Chief causes of water pollution include pathogens, mercury, PCBs, nutrients, and organic enrichment/low dissolved oxygen. The causes of impairment include atmospheric deposition, agriculture, hydrologic modifications, and old mines, to name only a few.

**Chemical Pollutants Overview**

Chemical pollutants represent a wide variety of substances that can be categorized in different ways. In addition to the distinction between point and non-point sources mentioned above, we can also consider water pollution as micro vs. macro. Micro-pollution is what we have control over in our homes, workplaces, or schools. For example, flushing used oil down the storm drain or flushing unneeded drugs down the toilet would
be micro-pollution that we as individuals could stop. However, as a community the oil or drugs might be thought of as nonpoint source pollution. Macro-pollution is generally only addressed by community policy decisions such as cleaning up a river and affects a broad area. We have little individual control over macro-pollution. We as stewards of the Earth have the task of thinking four dimensionally: point source vs. non-point source, and macro vs. micro water pollution.

**Volatile Organic Compounds (VOCs)**

Volatile Organic Compounds (VOCs) are a broad classification of chemicals that include fuel products such as gasoline, kerosene, heating oil, benzene, and toluene, as well as chlorinated solvents such as carbon tetrachloride, trichloroethylene, and vinyl chloride. The fuel products have obviously been widely used in the transportation and heating industries. There are a variety of regulations that address VOCs from home oil tanks and gasoline filling station tanks over fears of contamination of groundwater. The chlorinated solvents have been widely used as industrial cleaning and degreasing agents and the leaching of these compounds through the soil has resulted in a variety of efforts to clean up industrial sites. For example, the water near a number of old military sites has been contaminated with solvents. This includes the US Marine Corp’s Camp Lejeune where excess levels of perchloroethylene (PCE), a dry cleaning solvent, trichloroethylene (TCE), a degreaser, and other contaminants were found. VOCs often are present near older industrial sites or landfills.

The health effects of VOCs ingested from water are often complicated by inhalation but can produce neurological disorders and cancers such as lymphomas or leukemia. Usually these VOCs stay in the body for relatively short times (short half-lives) but chronic exposure can be serious, with children being especially vulnerable to exposure and effects. Maximum Contaminant Levels (MCLs) for VOCs in drinking water have been established by many states and the United States Environmental Protection Agency (USEPA) but may not incorporate recent toxicological information.

<table>
<thead>
<tr>
<th>Chlorinated Solvents</th>
<th>Fuel Products and Components</th>
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<tbody>
<tr>
<td>carbon tetrachloride</td>
<td>gasoline</td>
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<tr>
<td>1,2-dichloroethane</td>
<td>kerosene</td>
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<tr>
<td>1,1-dichloroethylene</td>
<td>heating oil</td>
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<tr>
<td>cis-1,2-dichloroethylene</td>
<td>benzene</td>
</tr>
<tr>
<td>trans-1,2-dichloroethylene</td>
<td>airplane and jet fuel</td>
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<tr>
<td>methylene chloride</td>
<td>motor oils</td>
</tr>
<tr>
<td>tetrachloroethylene</td>
<td>methyl tert-butyl ether (MTBE)</td>
</tr>
<tr>
<td>1,1,1-trichloroethane</td>
<td>toluene</td>
</tr>
<tr>
<td>trichloroethylene</td>
<td>xylenes</td>
</tr>
<tr>
<td>vinyl chloride</td>
<td>n-hexane</td>
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Waterborne Organisms
Water often contains a wide array of living organisms including viruses, bacteria, and parasites, some of which can cause health effects if ingested. A recent example is the outbreak of cholera in Haiti after the 2010 earthquake: over 700,000 Haitians were affected and over 9,000 died. Typhoid fever is another disease spread by contaminated water. Toxic algal blooms can produce shellfish contaminated with domoic acid, which is a neurotoxin that causes amnesic shellfish poisoning (ASP). Drinking water contaminated with harmful organisms is more likely to be encountered in developing countries, and travelers should be cautious. Industrialized countries need to invest in water systems in countries around the world where people lack access to clean and safe water. The WHO states: “Globally, an estimated 1.9 billion people rely on water supplies that are contaminated with feces. This requires many to use household water treatment (HWT) technologies to help prevent disease and make water safe for drinking.” This is an ongoing global issue that requires attention.

Radioactive Contamination
The hazard from radioactive contamination of water is complex because it depends on a number of variables. Ionizing radiation emits alpha particles, beta particles, or gamma rays, which have varying amounts of energy. The potential hazard is usually greater if the contamination is ingested, which means cells are close to the emitting contaminant. The Fukushima Daiichi nuclear disaster has highlighted water contamination and subsequent contamination of the food supply, primarily by radioactive strontium or cesium. There is also concern about tritium, which is radioactive hydrogen that easily becomes like water, in essence radioactive water, that can leak from operating nuclear power plants. In addition there are contaminated sites, used during the Cold War to create plutonium, that were usually set next to rivers, such as the Hanford Nuclear Reservation. Naturally occurring radioactive elements such as uranium can be disturbed during mining and become part of the mine tailings. The most relevant radioactive contaminant levels set by the EPA are:

- Alpha particles (low energy) 15 picocuries per liter (pCi/L)
- Beta particles 4 millirems per year (tritium emits beta particles)
- Uranium 30 ug/L (30 ppb)

The general idea is to keep exposure to radioactive contaminants in water below 4 millirems per year. (See Chapter 13, A Small Dose of Radiation.)

Pharmaceuticals in Drinking Water
An increasingly important source of water contamination is pharmaceutical drugs, which can be prescription medicines, supplements or over-the-counter therapeutic drugs, illegal drugs, or veterinary drugs. These are sometimes called environmentally persistent pharmaceutical pollutants. Pharmaceuticals reach water bodies through sewage, which
contains active ingredients or metabolites from human excrement as well as unneeded drugs disposed in toilets, animal waste, personal care products, or landfill runoff. Caffeine from coffee and tea and birth control hormones are commonly found in wastewater. The small size of the pharmaceutical molecules can make them difficult and expensive to remove during the sewage treatment process, and they may enter bodies of water or be recycled back into treated drinking water. The best way to keep unwanted drugs out of the water supply is to implement drug take-back programs where unwanted drugs can be dropped off at specific sites, often drug stores, for proper disposal. Currently there are only four counties in the US—Alameda, King, San Francisco, and San Mateo—that have such programs (more information is at www.takebackyourmeds.org).

**Water Fluoridation**
The addition of fluoride to drinking water to control or prevent tooth decay remains controversial from a scientific and ethical perspective. On January 25, 1945 Grand Rapids, Michigan became the first municipality to add fluoride to drinking water in an effort to prevent tooth decay. Nearby Muskegon’s drinking water was left fluoridated as the experiment's control city for comparison purposes. Following this trial there was no scientific consensus that fluoridation reduced tooth decay in children, yet it was hailed a public health victory. This practice is still supported by the US Centers for Disease Control (CDC) and approximately 70% of municipal drinking water in the United States is currently fluoridated. Fluoride is also present in a range of consumer products including toothpaste (1,000-1,500 parts per million or ppm), mouthwash, and fluoride supplements, and food products made with fluoridated water (such as beverages and canned soups) also contain fluoride. The US EPA has set 4 mg/L, or 4ppm, as the maximum contaminant level (MCL). In some water systems it is a natural contaminant.

**Ecological Concerns**

**Chemical Pollution / Toxicity**
Chemical contaminants often end up in our global oceans or rivers. Fish and shellfish can take up these contaminants from the water directly, or by eating other creatures. One toxic chemical that contaminates water bodies worldwide is mercury, emitted from coal-burning power plants. Released as inorganic mercury, bacteria then convert this inorganic mercury into methylmercury, or organic mercury, which is then passed up the food chain where it biomagnifies (increases in concentration) and bioaccumulates (increases in total amount). While mercury accumulates in the muscle, other compounds, such as PCBs, are stored in fat. This process that starts with contaminated water has a profound effect on wildlife as well as humans that consume fish and shellfish. This has prompted state and federal agencies to issue fish consumption advisories. The concern about fish contamination has in turn driven water cleanup efforts to reduce pollutant levels in the water and thus in the fish.
**Thermal Pollution / Toxicity**
Thermal pollution refers to the effects of raising or lowering the water temperature. The most common and frequent concern is rising water temperatures in a river or lake after water taken from the river or lake is used to cool an industrial process. The most common use is in nuclear or coal-fired electrical power generation plants. In the initial design these plants ran single base operations, where river water was heated to generate steam and then sent back to the river at a relatively high temperature. More modern designs have closed systems that use giant cooling towers to significantly cool the water. The warmer water decreases the water’s oxygen levels and also kills fish and other wildlife that cannot tolerate the high water temperature.

**Mining Contamination and Waste**
Mining is one of the greatest contributors to surface and groundwater contamination. Contamination from mine tailings as well as the ore processing can include high concentrations of chemicals and metals, such as arsenic, mercury, lead, cadmium, and sulfuric acid. For example mercury is commonly used in the extraction of gold and the gold ore can have high concentrations of lead. Acid mine drainage, or the outflow of acidic water, is also a serious problem in metal or coal mines that expose sulfate soils (see picture to the right). Acid mine drainage may also contain elevated levels of nickel and copper. It is also important to acknowledge the disruption of surface water caused by dumping soil from open pits or from mountaintop removal.

**Indoor Water Pollution / Water Quality**
Indoor water or tap water is supplied to most homes in developed countries but is often lacking in developing countries. Public drinking water is regulated by the US EPA under the Safe Drinking Water Act (SDWA) but about 10% of drinking water is from private wells and is not regulated. A great amount is known about managing water to reduce pollutants but in the case of Flint, Michigan, the lack of proper treatment resulted in lead-contaminated water. Groundwater and hence drinking water can also become contaminated with metals such as arsenic from coal ash.

**Control of Water Pollution**
Control of water pollution requires vigilance in controlling all pollution sources, including air and soil contaminants. The easiest to control are point sources such as sewage treatment facilities. Large industrial facilities may operate their own pretreatment facilities or a more complete waste treatment facility designed to deal with particular chemicals. However, even more responsible is designing and using processes that use less hazardous materials. Agricultural and home use of pesticides and fertilizers can be reduced as farms and homes move more toward organic plant management.
Child Health and Water Pollution
Children are small but eat more, drink more, and breathe more than adults, based on body weight. Thus a small exposure is a big dose for a child because of their low body weight. Contaminant-free water is vital for healthy children.

Reducing Exposure
Reducing exposure to polluted water can be challenging, depending upon location and societal commitment.

Regulation of Water Pollution
There are a wide range of laws and regulations that govern water quality, which testifies to the importance of clean water for all of life. Below is a brief summary of some of the most important laws in the United States and internationally.

US Clean Water Act
The Clean Water Act (CWA) was first passed by the US Congress in 1948 and was known as the Federal Water Pollution Control Act. It was completely rewritten and expanded in 1972 in part due to incidences such at the Cuyahoga River repeatedly catching fire, most recently in 1968. Additional major changes were made in 1977 and 1987. The CWA addressed surface waters but not groundwater. Several national laws, notably the Safe Drinking Water Act, Resource Conservation and Recovery Act, and the Superfund act, addressed the contamination of groundwater. (ref. US EPA Summary of the Clean Water Act)

US Safe Drinking Water Act
The Safe Drinking Water Act (SDWA), which became effective December 16, 1974, is administered by the US EPA and intended “to assure that the public is provided with safe drinking water.” The EPA has set water quality standards for microorganisms, organic and inorganic chemicals, and radionuclides. These standards apply to the approximately 155,000 public water systems but not to private wells. Bottled water is regulated by the Food and Drug Administration (FDA) under the Federal Food, Drug, and Cosmetic Act.

EPA Lead and Copper Rule
Acknowledging the adverse health effects of lead and copper, the US EPA issued the first lead and copper rule on June 7, 1991 and followed up with subsequent revisions. This rule not only set the action level for lead at 0.015 mg/L (15 ppb) and for copper at 1.3 mg/L but required monitoring, set standards for allowed lead in pipe and fixtures, and required corrosion control technology. There is considerable controversy over the water sampling procedures. Despite these efforts, incidents like that in Flint, MI continue to occur.
Recommendation and Conclusions

Water pollution knows no boundaries and is thus a regional, national, and international issue. Contaminant-free water requires investment and planning. Municipal water is tested at the source and can be treated, while managing private wells is the responsibility of the user. It should always be remembered that children are more vulnerable and thrive on clean, fresh water.

More Information and References

Slide Presentation

- A Small Dose of Water Pollution presentation material and references online: http://www.toxipedia.org or http://www.toxipedia.org/display/dose/Water+Pollution
  Website contains presentation material related to the health effects of water pollution.

European, Asian, and International Agencies

  “Globally, an estimated 1.9 billion people rely on water supplies that are contaminated with feces. This requires many to use household water treatment (HWT) technologies to help prevent disease and make water safe for drinking.”

  Address primarily bacterial contamination of water and sanitation and need for clean water.


A good summary of individual chemicals “The WHO Guidelines for Drinking-water Quality (GDWQ) cover a broad range of chemicals that can affect drinking-water quality.

  A PDF document.
  The EEA coordinates assessments and regulation of water across Europe.

North American Agencies

  Connecting Middle School Students to Environmental Health Information on water pollution.


Non-Government Organizations


References


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  (Accessed: May 18, 2016)
  A summary of fluoride use, regulation, health effects, and controversy.