Swimming pool disinfection

Let's go for a swim!
Oh, I forgot: the pool is closed this morning for cleaning and chlorination

Photo by Oleksandr Pidvalnyi: https://www.pexels.com/photo/kids-jumping-on-the-pool-12615996/

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Storyline

Public swimming pools provide many health and social benefits for both children and adults. Swimming improves physical fitness, cardiovascular health, sleep, stress reduction, and social interaction, while swimming lessons can help prevent drowning. However, pools also carry risks, especially from water-borne pathogens spread through contaminated water containing feces or urine. Common pathogens include bacteria, viruses, and protozoa such as *Cryptosporidium* and *Giardia*, which can cause gastrointestinal, ear, eye, and respiratory infections.

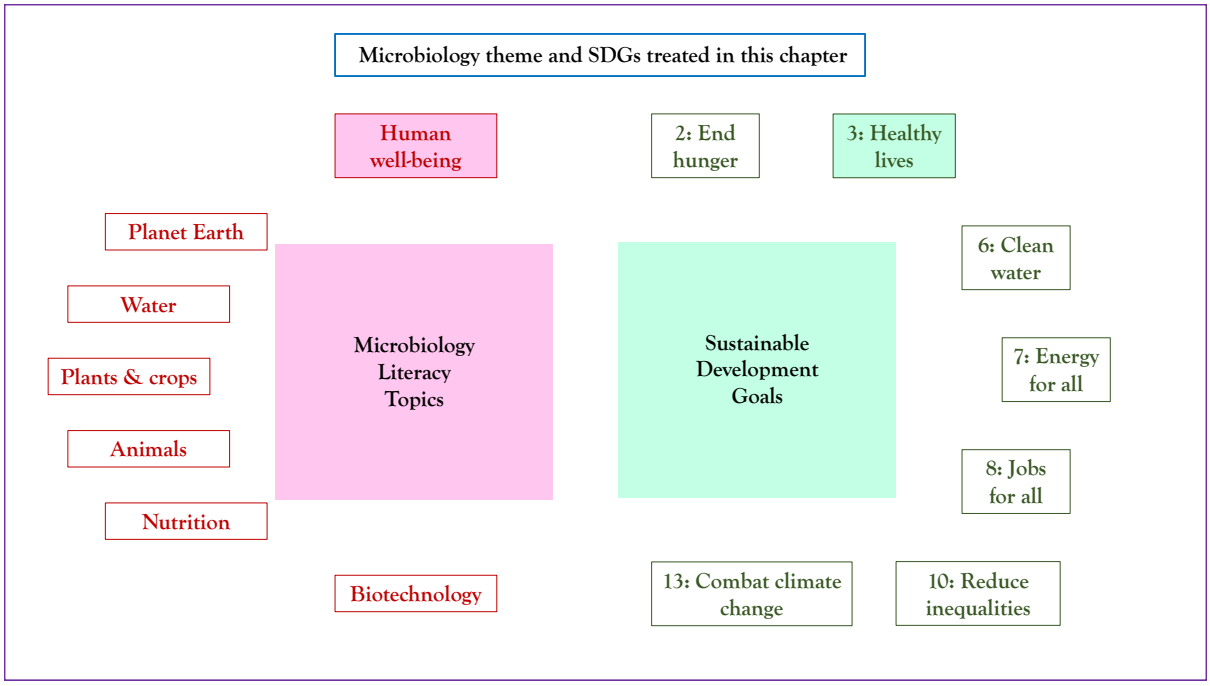
To reduce these risks, swimming pools require proper cleaning and disinfection. Cleaning removes dirt and waste, while disinfection kills microorganisms. Chlorination is the most widely used method, with chlorine levels and pH carefully controlled to ensure effectiveness and safety. Although chlorine kills most bacteria quickly, some pathogens such as protozoal oocysts are highly resistant and may require "shock chlorination" and temporary pool closure.

Chlorine itself can also create problems. High chlorine levels and chloramines formed from reactions with urine and sweat can irritate eyes, skin, and airways, and damage pool materials. Proper hygiene practices are therefore essential. Swimmers should shower before entering the pool, avoid swimming when ill with diarrhea, and ensure babies use swim nappies and regular toilet breaks.

Overall, swimming pools are valuable for public health and well-being, but maintaining hygiene and effective pool management is essential to minimize infection risks while preserving the benefits of swimming.

The Microbiology and Societal Context

The microbiology of swimming pools focuses on water-borne pathogens such as bacteria (*E. coli*, *Legionella*), viruses (norovirus, hepatitis A), and protozoa (*Cryptosporidium*, *Giardia*) that spread through contaminated water and can cause gastrointestinal, respiratory, ear, and eye infections. Proper cleaning, chlorination, and hygiene practices are essential to control microbial growth and prevent disease transmission. From a *sustainability perspective*, swimming pools support health, well-being, physical activity, and child development, contributing to Sustainable Development Goal 3 (Good Health and Well-being). Sustainable pool management depends on responsible hygiene practices, safe disinfection methods, regular maintenance, and public education to balance human health benefits with safe water use and reduced chemical risks.



Swimming pool disinfection: the Microbiology

1. ***Swimming pools are great!*** There are many benefits attributed to going to public swimming pools. For children, recreational activities improve social skills through increasing interactions with other children, getting children away from electronic devices and television, increasing physical exercises making bedtime easier after spending a few hours at the pool, and improving cardiovascular health generally. There also may be some additional benefits for children with certain health conditions, such as asthma, and children with disabilities. For infants, baby swimming has been shown to improves gross, fine, and total motor skills. Importantly, aquatic competencies in children can be linked to drowning prevention.

For adults, most of the accepted benefits relate to well-being and physical exercises. Regular swimming has been associated with lower stress levels, reduced anxiety and improve sleep patterns, reduced risk of cardiovascular diseases, and help in recovering from physical injury since water helps in supporting body weight.

2. ***But swimming pools come with risks.*** Of course, we can always slip on the side of the pool, so we need to be careful on wet surfaces and especially avoid running on them, to minimize injuring ourselves. And we need to take care when diving and jumping into the water that we do not risk hitting anyone else or the bottom or side of the pool. But in addition to these visible, physical risks, there are also invisible ones. Swimming pools are not always the cleanest. And pathogens, microorganisms that can cause an infection, thrive in water contaminated with faeces and urine.

3. ***Water-borne pathogens in swimming pools.*** A water-borne pathogen is a microorganism that causes an infection and is transmitted via two major pathways: drinking water and recreational water. Microbial pathogens flourish in polluted water, particularly water

contaminated with faeces and urine. Unfortunately, faeces and urine are released from people in the pool, mainly from the gut, but also from the skin.

The US Centers for Disease Control and Prevention (CDC) estimated that on average 0.14 grams of faeces remain on people's skin and can be released in the water (https://www.cdc.gov/healthywater/swimming/swimmers/rwi.html). This does not take into account accidental faecal release from babies and toddlers. Considering a swimmer swallows water whilst exercising, approximately 37 mL during a 45-minute swim (CDC data 2006), twice as much with children, there is a risk of swallowing inadvertently a pathogen. The swallowed pathogens can then colonise the gastrointestinal tract, grow, cause disease and be released in faeces starting a new cycle.

In the US, the CDC recorded 208 outbreaks linked to pools and hot tubs between 2015 and 2019. These outbreaks led to 3,646 infections, 286 hospitalizations and 13 deaths (Hlavsa et al. 2021).

4. ***The infection culprits.*** There are different types of water-borne pathogens, the predominant ones for swimming pools being bacteria, viruses and protozoa. Each of these microorganism types can cause a range of symptoms, predominantly referred to as "gastro symptoms" which include diarrhoea, nausea, vomiting and stomach cramps. Ear, eye and respiratory infections can also be acquired.

a. Bacteria. Among bacteria, those that reside in the gut are predominant including *Escherichia coli* and *Shigella* spp. and, to a lesser extent, *Campylobacter* spp. *Salmonella* spp. (gastrointestinal infections, dysentery), although other bacteria such as *Pseudomonas aeruginosa* (ear infection) and *Legionella pneumophilia* (respiratory infection) can also occur. *Pseudomonas aeruginosa* tends to be more associated with hot tubs where the higher temperature and steam promote bacterial growth and spread via aerosolized water droplets ~~(Shelton et al. 2000)~~.

b. Viruses. Water borne viruses that include hepatitis A virus, norovirus and adenovirus are also responsible for "gastro" like symptoms, although complications can arise, for example liver damage with hepatitis A virus.

c. Protozoa are unicellular parasites that have a complex life cycle. The living and reproducing parasite that causes disease symptoms is called a trophozoite. At one point in the life cycle, a dormant but infectious form called the oocyst is produced and released in the faeces. Swimmers inadvertently ingest oocysts during swimming, which can then develop into trophozoites in the gastrointestinal tract. The main water borne protozoal pathogens are *Cryptosporidium* and *Giardia*. They are highly infectious. An infected individual will release millions of oocysts with their faeces, but only 10 ingested oocysts are needed to cause disease.

According to the CDC, the main causes of outbreaks from recreational water (pools and hot tubs) in the US between 2015 and 2019 were *Cryptosporidium* (37%), *Legionella* (31%), *Escherichia coli* (2%), *Giardia* (1%) and norovirus (1%). To decrease the risk of catching an infection by water borne pathogens, cleaning and disinfection of swimming pool are essential. Chlorination is one of the most widespread disinfection methods used in swimming pool.

5. ***How to remove the pathogens: cleaning and disinfecting the pool.*** Cleaning and disinfection are fundamentally different processes. Cleaning is the physical removal of soiling, dirt, etc., and can be improved with the use of detergents on surfaces or in textiles. Disinfection is the killing of microorganisms.

a. Disinfection and the issue of infectious dose. The purpose of disinfection is the reduction of harmful microorganisms to a safe level. Although this definition might appear vague as to what safe level means, it allows to accommodate for different pathogens. The infectious

dose of *Cryptosporidium*, the dose needed to give you an infection and make you ill, is as low as the ingestion of 10 oocysts. An infectious dose of Norovirus is also very low: 10 viruses, just a tiny fraction of the millions of viruses released in faeces and vomit. Infectious doses of other pathogens tend to be higher: the infectious dose for *Escherichia coli* has been reported to be in the thousands, although for particularly virulent bacteria such as *Escherichia coli* 0157, a particularly nasty pathogen which can lead to organ failure, the dose may as low as one hundred bacteria.

b. Cleaning and disinfection are often combined. Cleaning usually precedes disinfection, because soiling, for example, faeces, vomit, blood, can dramatically reduce the efficacy of some disinfectants, rendering them inactive against pathogens that need to be killed. With swimming pools, cleaning would be the removal of faeces and any other soiling, such as rubbish, vegetation or insects blown in by wind.

c. Disinfection and general toxicity: the issue of safe levels. Disinfectants are not only active against pathogens, they are active against organisms in general, including us. This is why we cannot simply increase the concentration of disinfectants to high levels in order to kill all pathogens under all circumstances. We have to limit disinfectant concentrations to levels which are safe for us.

d. In some instances, for example after accidental faecal release, a disinfectant needs to be used at a concentration that is not safe for us, so the pool must be closed. And in extreme cases, the swimming pool will need to be emptied for cleaning and disinfection of surfaces (floor and walls). Of course, swimming pools are regularly emptied for cleaning and disinfection of surfaces as part of their normal maintenance schedule.

6. ***Disinfection agents typically used for swimming pools.*** Disinfection can be achieved by chemical (for example chlorination) or physical (for example ultraviolet (UV) irradiation) means. For swimming pools, the most used chemical disinfectant is chlorine. Other chemicals such as bromine and polyhexamethylene biguanide supplemented with hydrogen peroxide (in the US) are also used. At their recommended concentration and pH, chlorine (1-3 parts per million, ppm) and bromine (3-8 ppm) kill most microorganisms in the water.

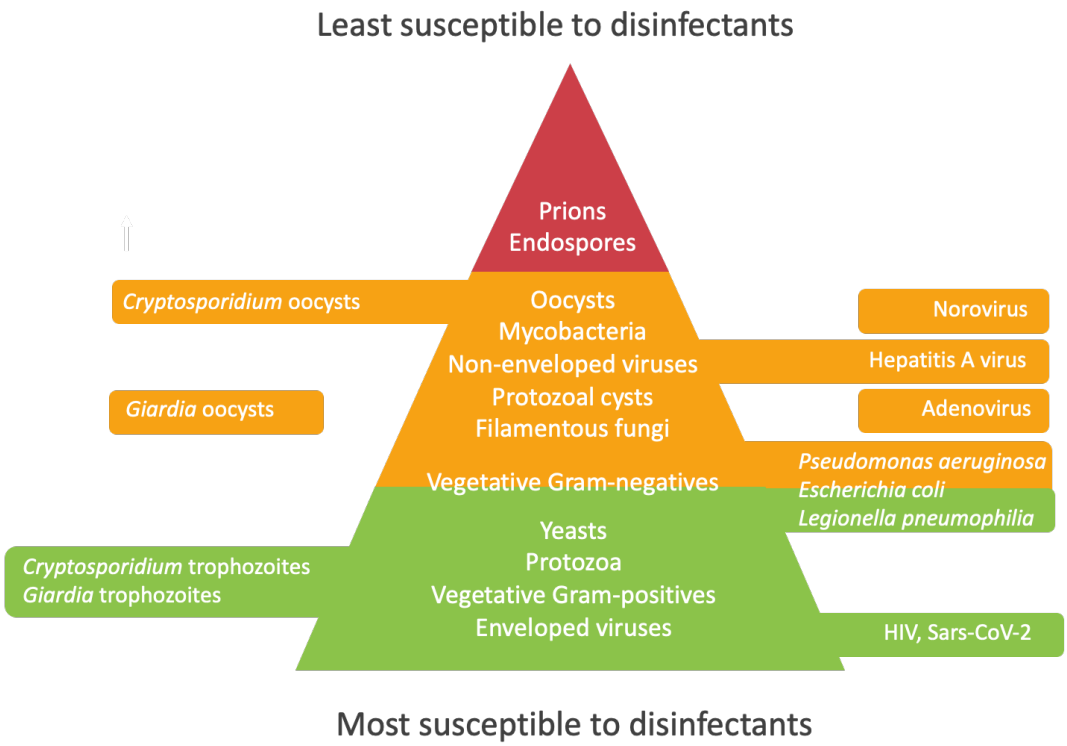
7. ***Adding a disinfectant does not necessarily mean job done.*** There are many factors that decrease the killing efficacy of chemical disinfectants. The most important one is concentration. If the concentration is too low, microorganisms will survive. In public swimming pools, the concentration of chlorine in the water is recommended to be 1-3 ppm, although some authorities might recommend concentrations of 3-5 ppm.

In the US, 10% of public pools, hot tubs/spas, and water playgrounds were closed after too low chlorine or bromine concentration were measured during routine inspections (CDC 2016). Another factor is soiling. Organic matter in the water decreases the efficacy of a disinfectant. Accidentally released faecal material needs to be physically removed and to account for the additional organic matter, chlorine concentration will be increased to 10-20 ppm free chlorine – this process is often called super chlorination or shock chlorination. For chlorine and its active hypochlorous acid, a weak acid, pH is also important to consider. In swimming pools, the pH needs to be 7.2-7.8. Another factor is the type of microorganisms.

8. ***Different water-borne pathogens are not equally susceptible to disinfectants.*** Different types of microorganism have different susceptibility to chemical disinfectants. Bacterial endospores, which are a highly dehydrated form of some but not all bacteria, are among the least susceptible, whilst enveloped viruses, such as HIV and SARS-CoV-2, are the most susceptible.

Enveloped viruses are viruses with a lipid membrane around their protein core called the capsid. The lipid membrane which is essential for virus infectivity, as it contains receptors that enable virus attachment to their specific host cells, is very susceptible to chemical disinfectant. For pathogens commonly found in swimming pool, protozoal oocysts are the least susceptible, followed by non-enveloped viruses (for example norovirus, hepatitis A virus, adenovirus) and then bacteria.

For example, chlorine at 1 ppm should easily kill bacteria within 1 minute contact, but it might take 15 min and more to kill hepatitis A virus, and several days for the same concentration of chlorine to kill *Cryptosporidium* oocysts. In this case, higher concentration of chlorine (super chlorination or shock chlorination) might need to be used and the pool needs to close. Whilst chlorine is most used disinfectant, it does come with some safety issues.



Susceptibility of different types of microorganism to disinfectants. Examples of microorganisms found in swimming pools are provided. Prions are the agents responsible for mad cow disease for example. Protozoal cysts are a form of protozoal resistance to chlorination. Cysts are distinct from oocysts released in faeces. Gram refers to a staining technique highlighting a special structure in bacterial cells. Gram-negative bacteria, for example *Escherichia coli*, are generally less susceptible to disinfectants than Gam-positive bacteria, for example *Staphylococcus aureus*.

9. ***Chlorination.*** Chlorination is the process of adding chlorine to water. Chlorine can come from a number of different chlorine compounds such as sodium hypochlorite (bleach). Although the concentration of free chlorine is often specified – the concentration of chlorine that remains unbound with soiling/material and free to interact with microorganisms – it is hypochlorous acid that is responsible for killing microorganisms. Hypochlorous acid is a weak acid, unstable and difficult to formulate, that forms when chlorine dissolves in water, creating powerful oxidising agents (ClO^-, HClO and ClOH) that strongly interact with microorganisms.

These oxidisers target multiple structures which differ between microorganisms. Generally, disinfectants do not have a specific target site to interact with a microorganism, which is the major difference with other antimicrobials such as chemotherapeutic antibiotics. Instead, a chemical disinfectant interacts with non-specific targets, usually interacting first with external structures of the cell, then with targets within the microorganisms. The number of targets interacted with, and the overall damage imparted to these targets, will define the overall killing efficacy of the disinfectant. The chlorine-derived oxidisers will oxidise mainly proteins and lipids, outside and within the cells, and nucleotides, thereby damaging the cells' DNA.

10. ***But chlorine is not just toxic to microbes: why we can get sore eyes.*** Chlorination does come with some issues. At high concentrations, it is toxic and damaging to various materials. Free chlorine concentrations in excess of 5 ppm can produce itchy skin and irritated eyes and/or airways and/or dry hair. At 10 ppm chlorine will damage bathing suits. This is why swimming pools need to be closed during shock chlorination (10-20 ppm).

The release of chloramine (gas) is also an issue. Chloramines are responsible for the chlorine-smell and also causes eye and skin irritations. Chloramine is formed when hypochlorous acid reacts with ammonia resulting in monochloramine (NH_2Cl), then dichloramine ($NHCl_2$), and trichloramine (NCl_3). In swimming pools, ammonia mainly comes particularly from human urine, but also from perspiration, saliva, and mucus, or other biological substances (insects, pests).

In addition, the highly reactive chlorine, as an oxidiser, will corrode metals, pools' walls and floors. The detrimental impact of chlorine is compounded with an inappropriate pH. Acidic pH (<7.0) will further contribute to pools' and materials' damage, eye, airways and skin irritation. An alkaline pH (>8.0) will decrease the efficacy of chlorine to kill microorganisms and contribute to eye and skin irritations.

11. ***Getting the best from swimming pools while reducing risks.*** Public swimming pools are great but can be associated with the risk of getting an infection. The use of disinfectants, and chlorination in particular, can kill potential pathogens but chlorination can result in eye, airways and skin irritation. Swimmers should therefore be encouraged to keep pathogens out of the pool in the first place, notably by not going swimming if they suffer or recently suffered from diarrhoea, taking regularly babies and infants to the toilet, using swim nappies, regularly changing swim nappies (away from the pool), and by showering before going in the pool.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages.** Going to swimming pools is important for child social development. Swimming lessons may decrease the risk of drowning. Swimming contributes to healthy lives and promote well-being for all at all ages. Swimming is an adjunct to exercise following physical trauma helping patients' recovery. But there are risks , including the risk of infections. Hygiene is everyone's responsibility. The risk of getting an infection from going to a public swimming pool is associated with poor hygiene and poor hygiene practices. Showering before going in the pool, decreasing accidental faecal release by regularly taking babies and infants to the toilet, changing regularly swimming nappies away from the pool are easy practices to implement.

Potential Implications for Decisions

1. ***Individual***
   - **a.** I had diarrhoea a couple of days ago: should I go swimming with my friends?
   - b. Is it important to shower before getting into the pool, and why?
   - **c.** The antifungal disinfection basin on the way to the pool is cold and some of my friends jump over it: can I also? If I do the same, what might happen?

2. ***Community policies***
   - **a.** Providing educational information at pools and to schools on the risks public swimming pools carry and the need for good hygiene practices.
   - **b.** Ensuring proper maintenance of public pools
   - **c.** Providing regular monitoring of pool water quality

3. ***National policies***
   - **a.** Creating educational information about the risks public swimming pools carry and the need for good hygiene practices.
   - **b.** Providing guidelines and regulations for the design and maintenance of public swimming pools on
   - c. Regular updating of guidelines for the use of disinfectants in pools

Pupil Participation

1. ***Class discussion about***
   - a. the importance of swimming
   - b. what is cleaning and what is disinfection – provide examples (hand hygiene, soap and water: cleaning vs. hand gel: disinfection; shower with soap: cleaning vs. using chlorine in swimming pool: disinfection; washing a cut: cleaning vs. using an antiseptic: disinfection)
   - c.

2. ***Pupil stakeholder awareness***
   - a. Which are the different types of water-borne pathogens and which ones are likely to pose a risk to me and under which circumstances?
   - b. What are the steps I need to take to minimize infection risks: to me? To others?
   - c. While disinfectants are safe for most people at the prescribed concentrations, they can be problematic for a few of us by exacerbating existing medical conditions. Do I experience worse reactions than my friends when I go swimming?
   - d. Am I aware of the 'no go' decision before going swimming?
   - e. What is the cost of maintenance of public swimming pool? (Large volume of fresh water to maintain safe for swimmers. Cost of chemicals used for maintaining the water safe for swimmers. Cost of heating the water. Cost of the staff (including life guards) to ensure the safety of swimmers.)
   - f. Disinfectants are by definition environmental pollutants if they get into the environment. How can we avoid environmental contamination?

3. ***Exercises***
   - a. List 3 main benefits from going to the swimming pool
   - b. List 3 negative impacts in going to the swimming pool.

c. What can be done to decrease the risk of getting an infection from gong to the swimming pool?

d. What factors will decrease the efficacy of chemical disinfectants such as chlorine?

e. Are all microorganisms equally susceptible to disinfectants? In order from the most to the least susceptible, list microorganisms' susceptibility to chemical disinfectants.

The Evidence Base, Further Reading and Teaching Aids

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Glossary

Bacteria – Microscopic single-celled organisms, some of which can cause infections in swimming pools.
Chloramines – Chemical compounds formed when chlorine reacts with sweat, urine, or other organic matter, often causing the "chlorine smell" and eye irritation.
Chlorination – The process of adding chlorine to pool water to kill harmful microorganisms.
Cleaning – The physical removal of dirt, waste, and debris from surfaces or water.
Cryptosporidium – A protozoan parasite that causes gastrointestinal illness and is highly resistant to chlorine.
Disinfectant – A chemical or physical agent used to kill microorganisms and reduce infection risks.
Disinfection – The process of killing or inactivating harmful microorganisms.
Endospore – A highly resistant dormant form produced by some bacteria that can survive harsh conditions.
Escherichia coli (E. coli) – A type of bacteria found in the intestines; some strains can cause serious illness if swallowed in contaminated water.
Free Chlorine – Chlorine in pool water that remains available to destroy microorganisms.
Giardia – A protozoan parasite that spreads through contaminated water and causes diarrhoea.
Hypochlorous Acid (HClO) – The active form of chlorine in water responsible for killing microorganisms.
Infectious Dose – The minimum number of microorganisms needed to cause an infection.
Legionella – A bacterium that can cause respiratory infections, especially in warm water environments such as hot tubs.
Norovirus – A highly contagious virus that causes vomiting and diarrhoea.
Oocyst – A resistant, infectious form of certain protozoa, such as Cryptosporidium and Giardia.

pH – A measure of how acidic or alkaline water is; pool pH affects chlorine effectiveness and swimmer comfort.
Shock Chlorination – The use of very high chlorine levels to eliminate resistant pathogens after contamination incidents.