Water Disinfection

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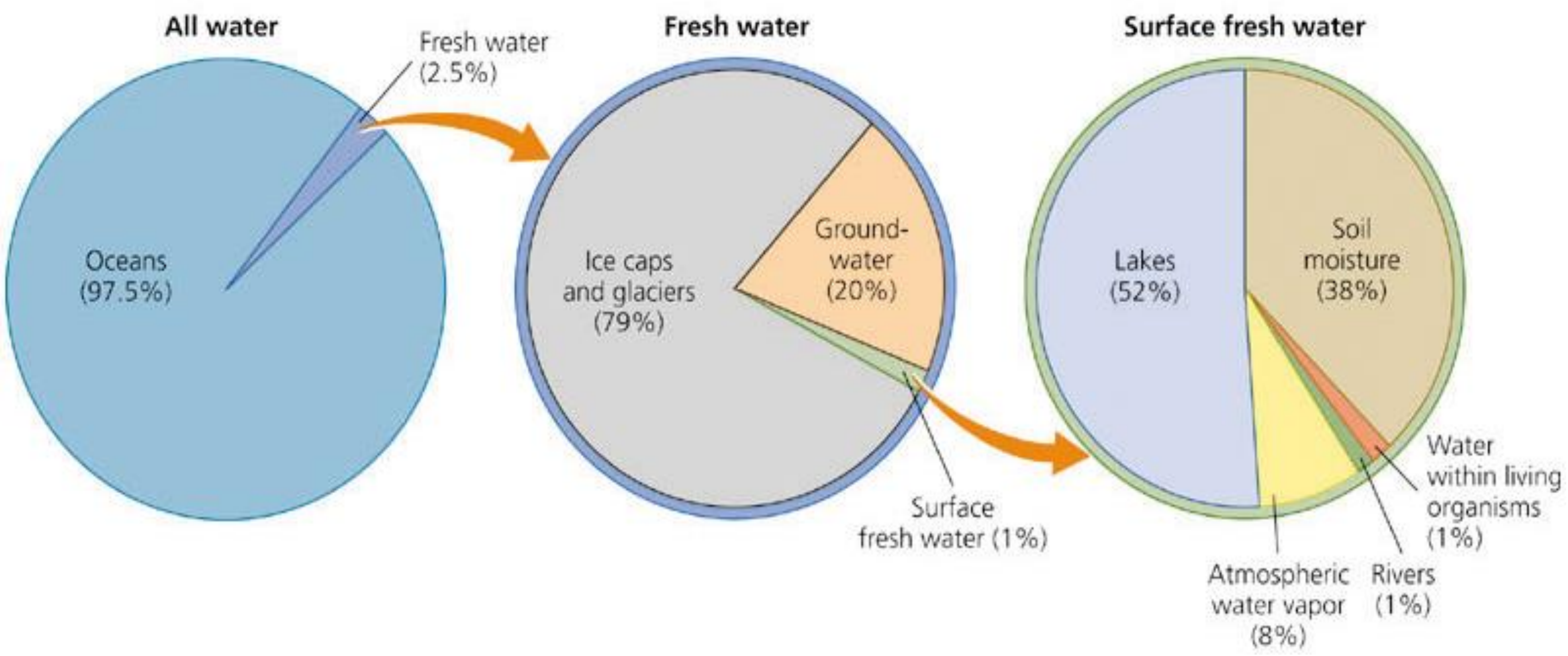
Outline

- Global Water Sources
- Water Contaminants
- Disinfection
- Methods of Disinfection
- Solar Disinfection of Water (SODIS)
- Advanced Oxidation Processes (AOPs) for Water Disinfection

Global Water Resources

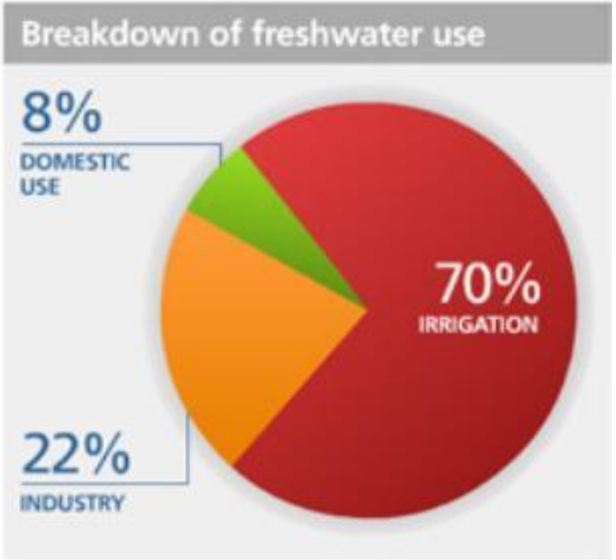
- Only 2.5% of the planet’s water is freshwater, and only 1% of that exists on Earth’s surface as fresh water.



Access to drinking water has been one of the biggest successes of the Sustainable Development Goals (SDGs).

Water Use (WHO, 2023)

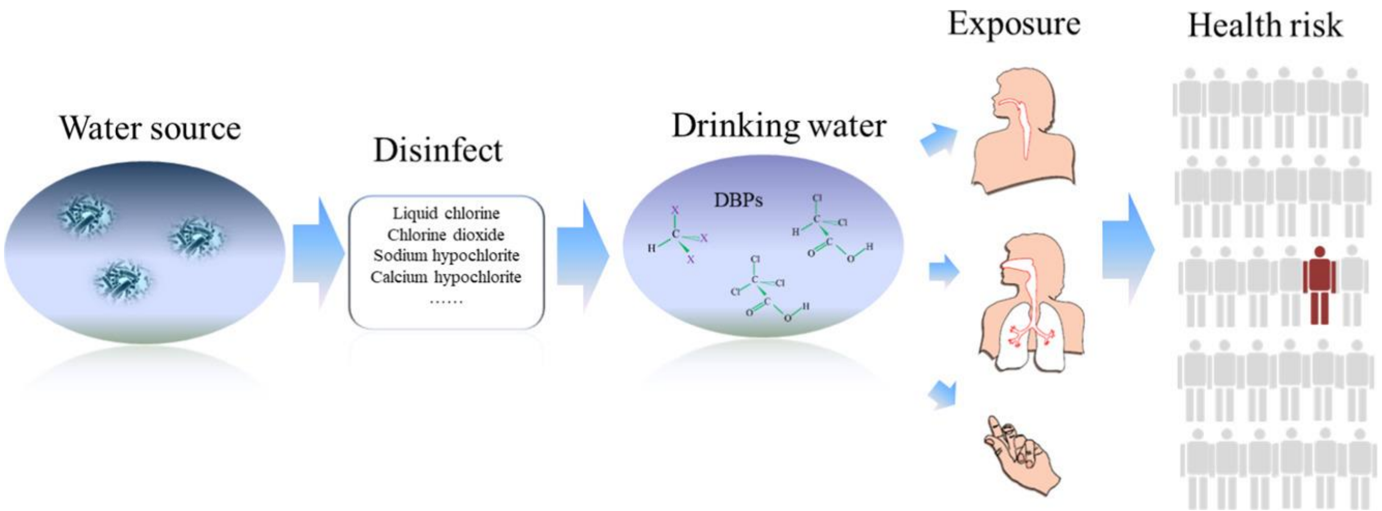
- SDG target 6.1 calls for universal and equitable access to safe and affordable drinking water. 2 billion people still do not use safely managed drinking water. (The world is not even close to being on track to meet the SDGs by 2030)
- The acceleration to achieve universal access, is threatened by the increasing impacts and uncertainty of climate change, competing agricultural and ecological water needs, competing financial priorities and the challenges of existing and emerging threats to water quality.
- Contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio.
- Re-use of wastewater to recover water, nutrients or energy is becoming an important strategy.



https://www.who.int/news-room/fact-sheets/detail/drinking-water (7/21/2024)

Health and Aesthetic Aspects of Drinking Water

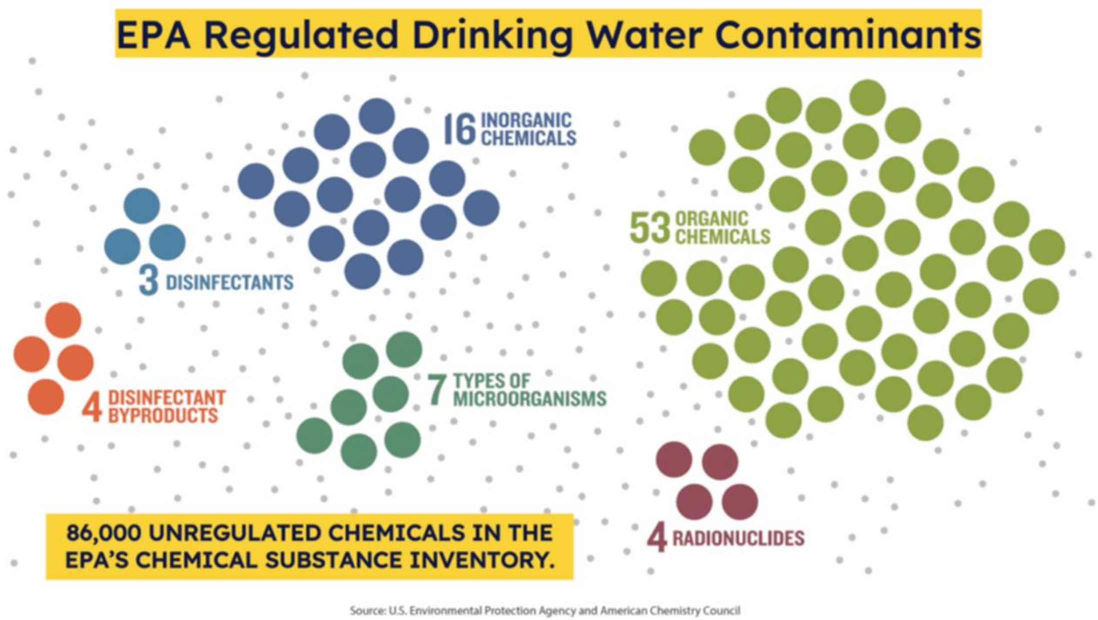
Water quality may be the biggest emerging water problem in the industrial world, with traces of chemicals and pharmaceuticals not removed by conventional drinking water treatment processes now recognized as carcinogens and endocrine disrupters



Du et al., 2021

Categories of Contaminants in Water

- Microorganisms
- Radionuclides
- Inorganics
- Organics
- Disinfectants
- Disinfection by-products

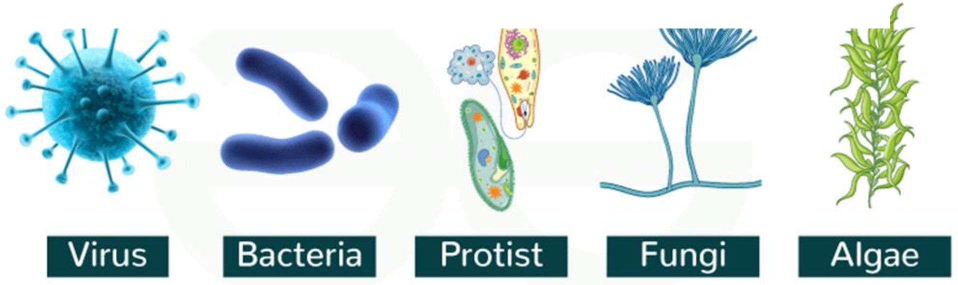


Microorganisms

- Microorganisms are a group of living organisms that include bacteria, viruses, protozoa, algae and fungi.
- While there are many microorganisms that are not harmful to humans, others can make humans sick or even cause death.

S. No	Microbial contaminant	Maximum contaminant level goal (MCLG) in mg/l
1	Heterotrophic plate count (HPC)	n/a
2	Total coliforms including fecal coliforms and *Escherichia coli*	0
3	*Cryptosporidium*	0
4	*Giardia lamblia*	0
5	*Legionella*	0
6	Viruses	0

n/a = turbidity.

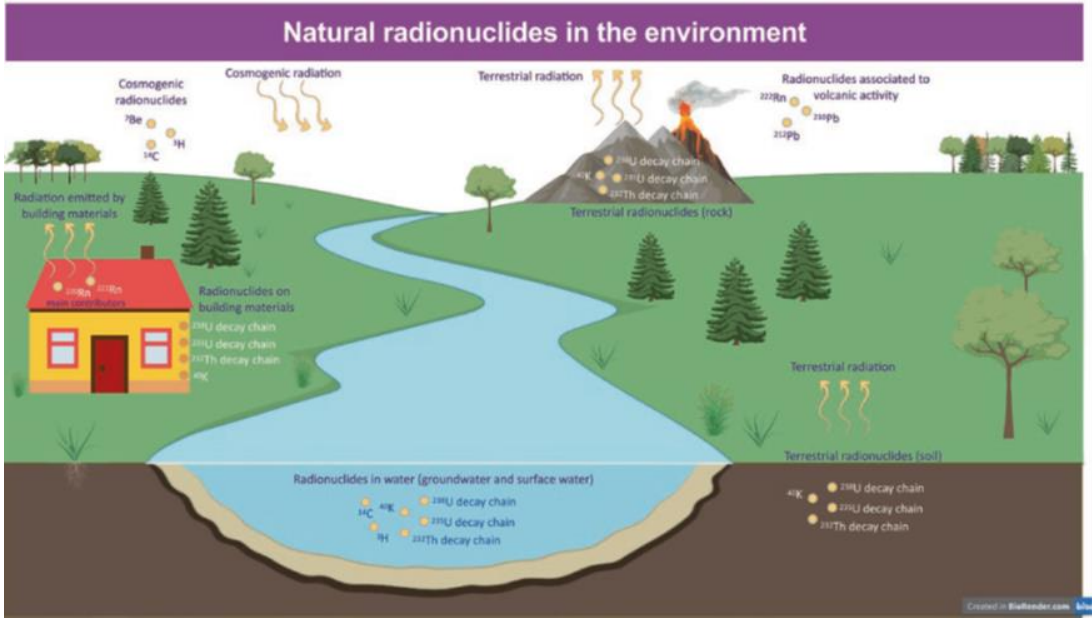


Radionuclides

- Radionuclides are found in the environment (including water) as naturally occurring elements, and produced as byproducts of nuclear technologies.
- The most common naturally occurring radiological compounds include **radium, radon and uranium**, but many more exist.
- Contamination of water with radionuclides results from decay and erosion of natural and manmade deposits.
- As radionuclides decay, they emit radioactive particles such as alpha particles, beta particles and gamma rays.

EPA drinking water standards for radionuclides

Contaminant	Maximum Contaminant Level Goal	Maximum Contaminant Level
Alpha particles	zero	15 picocuries per Liter (pCi/L)
Beta particles and photon emitters	zero	4 millirems per year
Radium 226 and Radium 228 (combined)	zero	5 pCi/L
Tritium	zero	20,000 pCi/L
Uranium	zero	30 ug/L (as of 12/08/03)



Inorganics

- Inorganic substances are of mineral origin.
- Contamination from inorganic compounds may occur from:

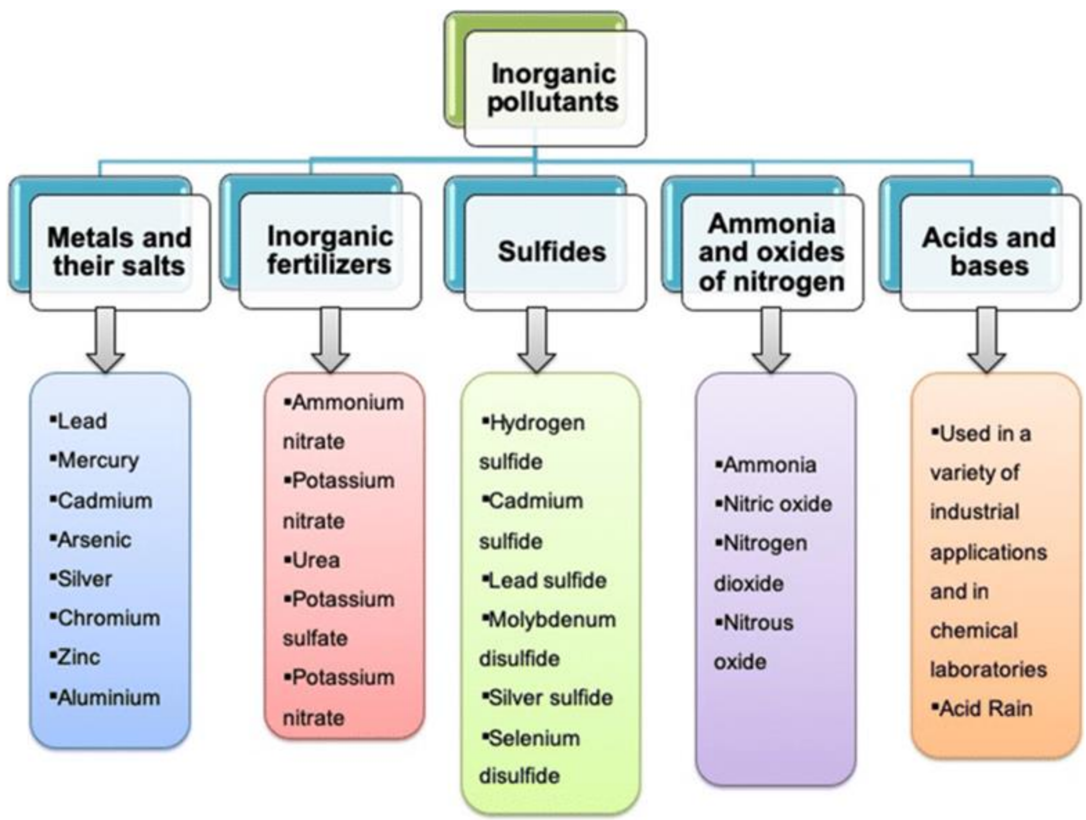
  Erosion of naturally occuring deposits

  Corrosion of pipes and plumbing

  Industrial wastes

  Sewage

  Landfill



Mishra et al., 2019

EPA drinking water standards for inorganic contaminants

Contaminant	Maximum Contaminant Level Goal (mg/L)	Maximum Contaminant Level (mg/L)
Antimony	0.006	0.006
Arsenic	0*	0.010 (as of 01/23/06)
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 million fibers per liter
Barium	2	2
Beryllium	0.004	0.004
Cadmium	0.005	0.005
Chromium (total)	0.1	0.1
Copper	1.3	Action Level=1.3**
Cyanide (as free cyanide)	0.2	0.2
Fluoride	4.0	4.0
Lead	zero	Action Level=1.3**
Mercury (inorganic)	0.002	0.002
Nitrate (measured as Nitrogen)	10	10
Nitrite (measured as Nitrogen)	1	1
Selenium	0.05	0.05
Thallium	0.0005	0.002

Organics

- A term used to refer to chemical compounds made from carbon molecules. These compounds may be natural materials (such as animal or plant sources) or man-made materials (such as synthetic organics).
- Most common sources of organics which have potential health effects are:

  Herbicides and insecticides

  Waste from industrial processes

  Runoff/leaching from landfill

ORGANIC CHEMICALS	MCL (mg/L)[1]
Acrylamide	TT[2]
Adipate (diethylhexyl)	0.4
Alachlor	0.002
Atrazine	0.003
Benzene	0.005
Benzo(a)pyrene (PAH)	0.0002
Carbofuran	0.04
Carbon tetrachloride	0.005
Chlordane	0.002
2,4-D	0.07
Dalapon	0.2
Di[2-ethylhexyl]adipate	0.4
Dibromochloropropane (DBCP)	0.0002
o-Dichlorobenzene	0.6
p-Dichlorobenzene	0.075
1,2-Dichloroethane	0.005
1,1-Dichloroethylene	0.007
cis-1,2-Dichloroethylene	0.07
trans-1,2-Dichloroethylene	0.1
Dichloromethane	0.005
1,2-Dichloropropane	0.005
Di(2-ethylhexyl)phthalate (PAE)	0.006
Dinoseb	0.007
Dioxin (2,3,7,8-TCDD)	3.0×10^{-8}
Diquat	0.02
Endothall	0.1
Endrin	0.002

ORGANIC CHEMICALS	MCL (mg/L)[1]
Epichlorohydrin	TT[2]
Ethylbenzene	0.7
Ethylene dibromide (EDB)	0.00005
Glyphosphate	0.7
Heptachlor	0.0004
Heptachlor epoxide	0.0002
Hexachlorobenzene (HCB)	0.001
Hexachlorocyclopentadiene (HEX)	0.05
Lindane	0.0002
Methoxychlor	0.04
Monochlorobenzene	0.1
Oxamyl (Vydate)	0.2
Pentachlorophenol	0.001
Picloram	0.5
Polychlorinated byphenyls (PCB)	0.0005
Simazine	0.004
Styrene	0.1
Tetrachloroethylene	0.005
Toluene	1.0
Toxaphene	0.003
2-4-5-TP (Silvex)	0.05
1,2,4-Trichlorobenzene	0.07
1,1,1-Trichloroethane	0.2
1,1,2-Trichloroethane	0.005
Trichloroethylene (TCE)	0.005
Vinyl chloride	0.002
Xylenes	10.0

ORGANIC CONTAMINANTS

These are herbicides and insecticides from agriculture applications, organic solvents used in industrial applications, organic byproducts of industrial processes, and chemical byproducts from chlorination of drinking water. Runoff from agricultural spraying or improper application techniques, industrial discharges, accidental spills and improper disposal of hazardous wastes can also become sources of contamination.

TT: treatment technique requirement in effect

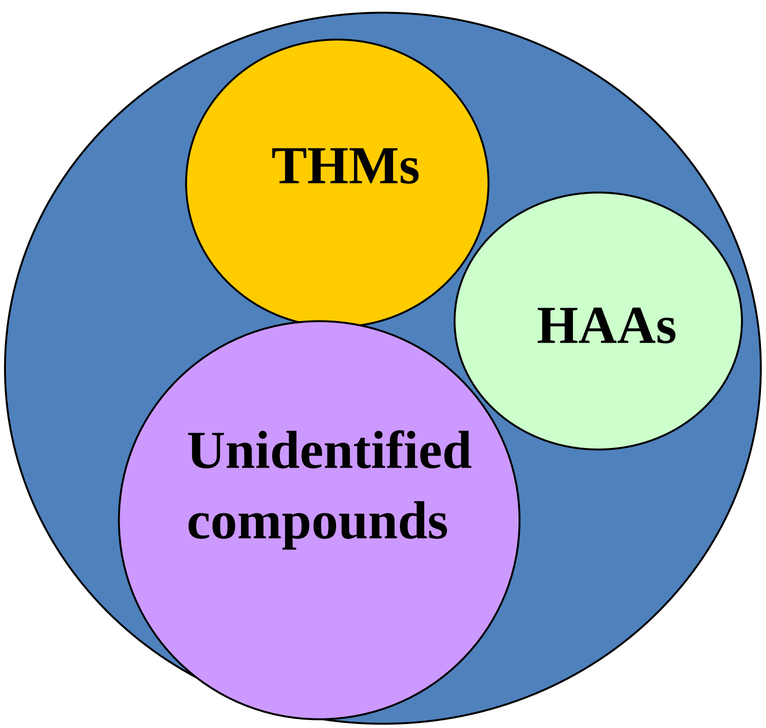
Disinfectants

- Disinfectants are water additives used to control microorganisms
- Chlorine, chloramines and chlorine dioxide
- Potential health effects include: eye/nose irritation; stomach discomfort; anemia

Contaminant	Maximum Contaminant Level Goal (mg/L)	Maximum Contaminant Level (mg/L)
Chloramines (as Cl_2)	MRDLG=4*	MRDL=4.0**
Chlorine (as Cl_2)	MRDLG=4*	MRDL=4.0**
Chlorine dioxide (as ClO_2)	MRDLG=0.8*	MRDL=0.8**

Disinfection byproducts (DBPs)

- Disinfection byproducts form, when disinfectants added to drinking water to kill microorganisms react with naturally occuring organic matter in water.



DBPs range from trihalomethanes (THMs) and haloacetic acids (HAAs) to undefined compounds with molecular weights exceeding several hundred daltons.

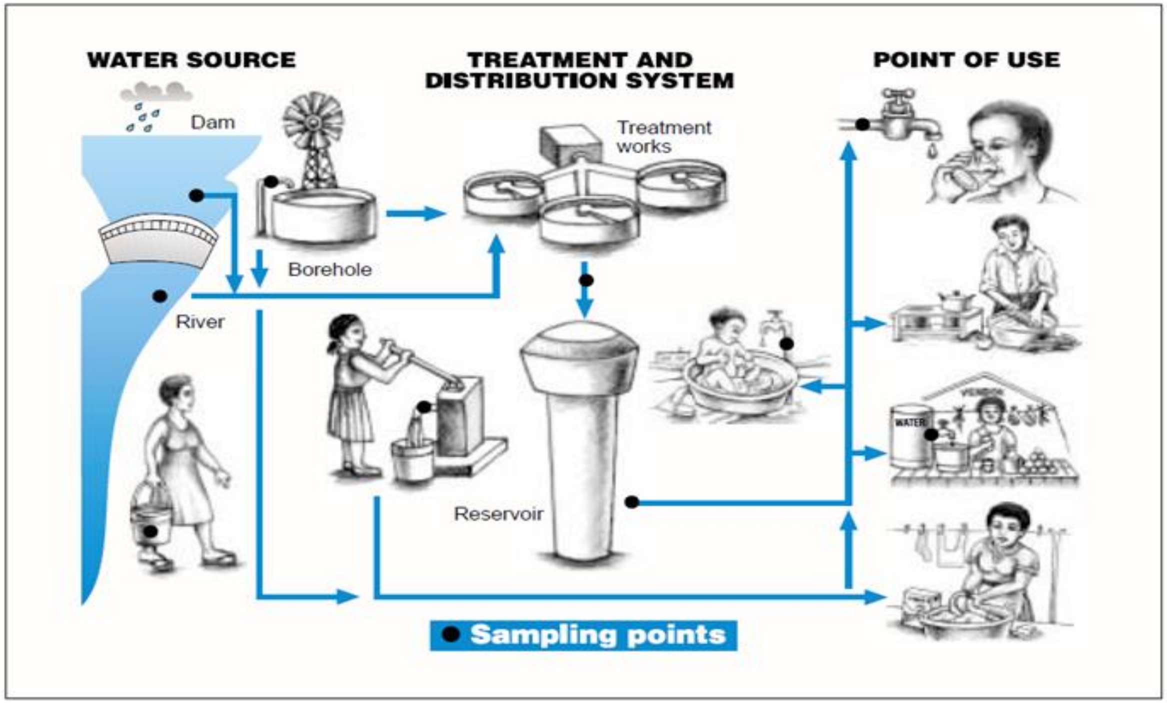
EPA drinking water standards for disinfection byproducts

Disinfection Byproduct	MCLG [1] (mg/L) [4]	MCL [2] or TT [3] (mg/L) [4]
Bromate	0	0.010
Chlorite	0.8	1.0
Haloacetic acids (HAA5)	n/a	0.060
Dichloroacetic acid	0 mg/L	
Trichloroacetic acid	0.02 mg/L	
Monochloroacetic acid	0.07mg/L	
Bromoacetic acid	n/a	
Dibromoacetic acid	n/a	
Total Trihalomethanes (TTHMs)	n/a	0.080
Bromodichloromethane	0 mg/L	
Bromoform	0 mg/L	
Dibromochloromethane	0.06 mg/L	
Chloroform	0.07 mg/L	

Providing Safe Drinking Water: A Multi-Barrier Approach

A multi barrier approach for safe drinking water requires:

- protecting raw source water from contamination
- appropriately treating raw water
- ensuring safe distribution of treated water to consumers' taps



Disinfection

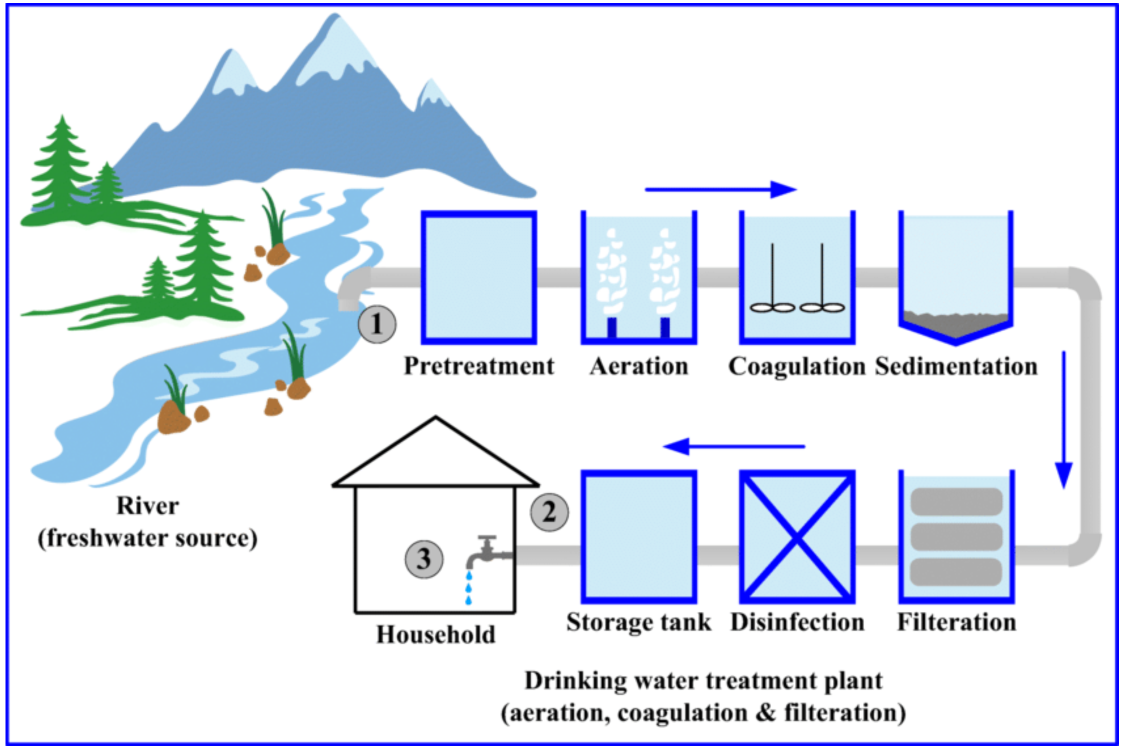
Water disinfection is the process of eliminating or reducing harmful/pathogenic microorganisms, such as bacteria, viruses, protozoa and parasites, in water to make it safe for human consumption.

Disinfection kills or inactivates disease-causing organisms in a water supply and must provide a 99.9 percent inactivation of Giardia lamblia cysts and 99.99 percent of enteric viruses to protect health and to comply with the U.S. Environmental Protection Agency (EPA) regulations.

Disinfection of Drinking Water

Disinfection is the final process to which water is subjected prior to distribution.

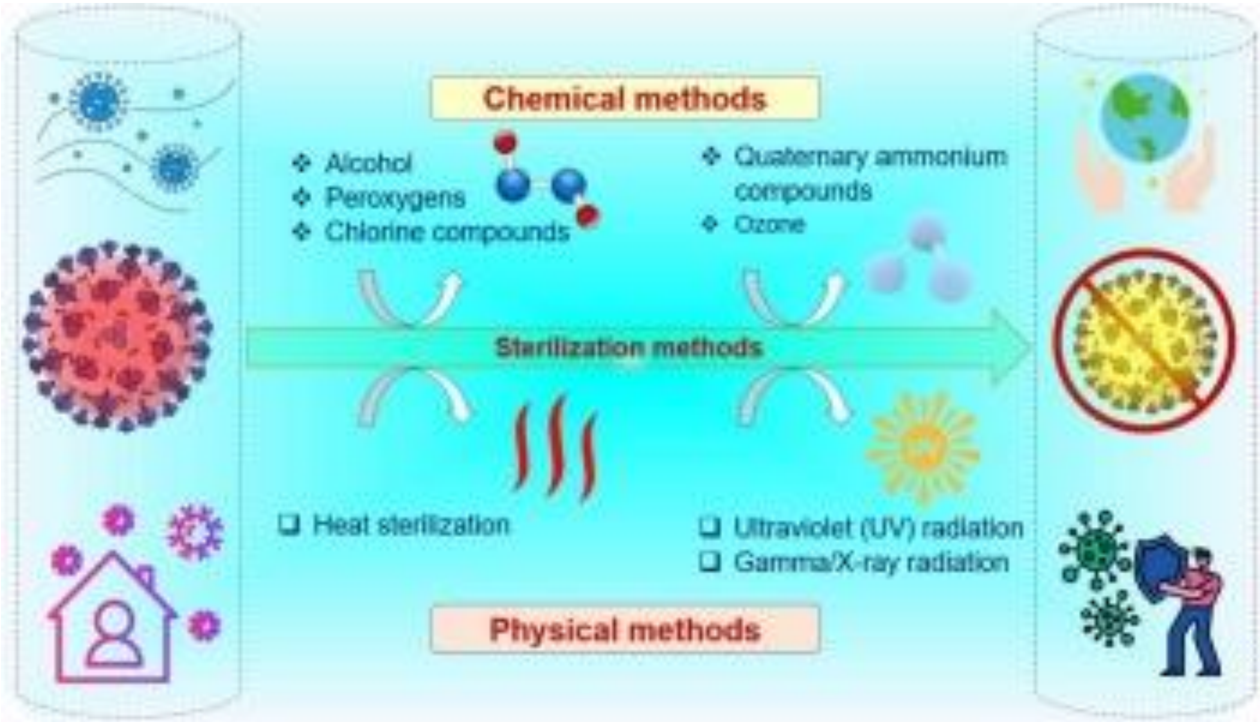
All other treatment processes such as sedimentation, flocculation, coagulation, filtration cannot give guarantee for safe water



Only the disinfection process can assure that the water is safe. In the absence of all other processes, disinfection alone can be employed as a single effective treatment process.

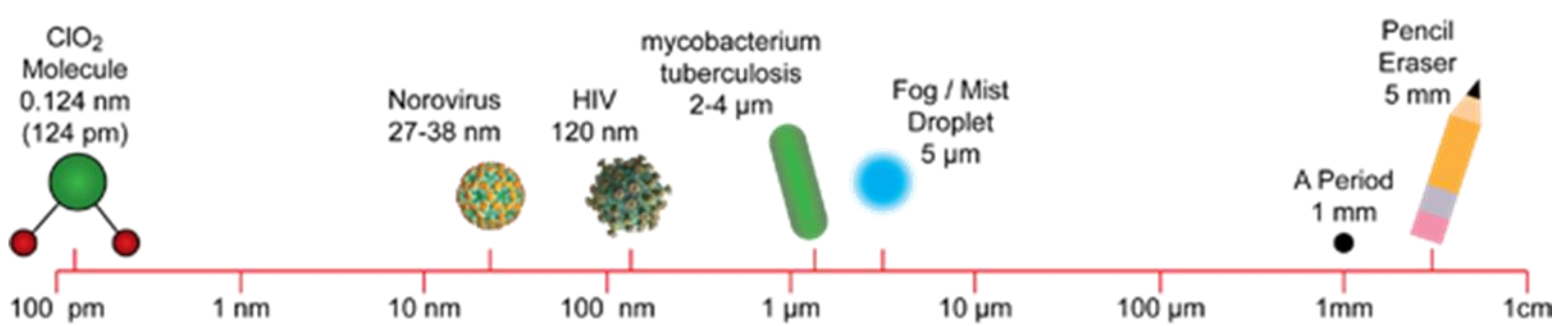
Types of Disinfection

- Chemical disinfection techniques include adding chlorine, bromine, iodine, ozone and other antimicrobial chemicals to water.
- Physical disinfection techniques include heating (boiling), radiation with ultraviolet light, solar light, x-rays, gamma rays and filtration methods.



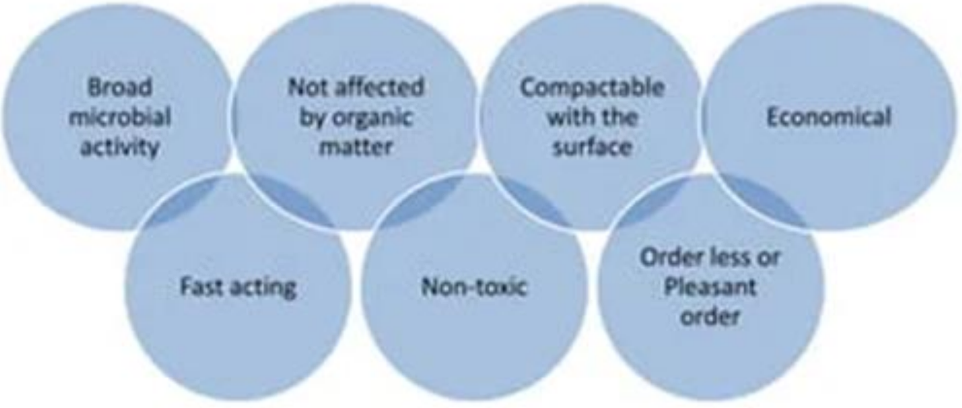
Chemical Disinfection

- Various chemical agents have been used for the disinfection of drinking waters. Each agent has its own advantages and limitations.
- The commonly used agents are chlorine, chlorine dioxide, chloramines, chlorine compounds like chlorinated lime, oxidants like ozone and potassium permanganate and halogens.



Properties of an "Ideal Disinfectant"

- Versatile: effective against all types of pathogens
- Fast-acting: effective within short contact times
- Robust: effective in the presence of interfering materials
  - particulates, suspended solids and other organic and inorganic constituents
- Handy: easy to handle, generate, and apply (nontoxic, soluble, non-flammable, non-explosive)
- Compatible with various materials/surfaces in WTPs (pipes, equipments)
- Economical



Factors Influencing Disinfection

- Type of disinfectant: order of efficacy against Giardia from best to worst
  - $O_3 \leftarrow ClO_2 \leftarrow$ iodine/free chlorine $\leftarrow$ chloramines
  - BUT, order of effectiveness varies with type of microbe
- Disinfectant concentration and time of contact
- Temperature
- Microorganism type: disinfection resistance from least to most: vegetative bacteria $\rightarrow$viruses $\rightarrow$ protozoan cysts, spores and eggs

  Microbial aggregation:
  - protects microbes from inactivation
  - microbes within aggregates not be readily reached by the disinfectant
- Particulates: protects from inactivation; shielded/embedded in particles
- Dissolved organics: protects
  - consumes or absorbs (UV radiation) disinfectant; coats microbes
- Inorganic compounds and ions: effects vary with disinfectant
- pH: effects depend on disinfectant.
  - Free chlorine more biocidal at low pH where HOCl predominates.
  - Chlorine dioxide more microbiocidal at high pH
- Reactor design, mixing and hydraulic conditions; better activity in "plug flow" than in "batch-mixed" reactors.

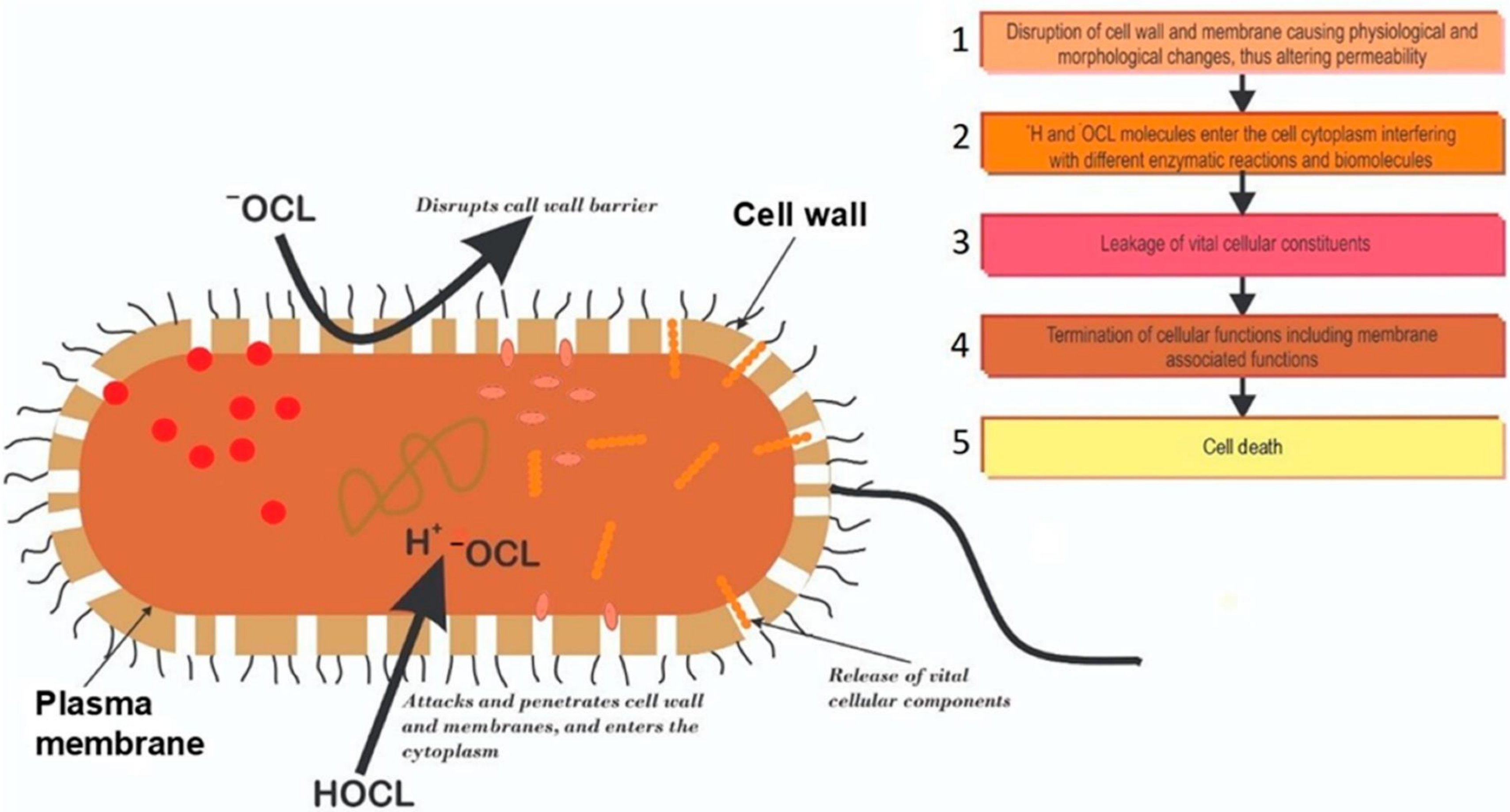
Comparison of Major Disinfectants

Consideration	Disinfectants			
	Cl_2	ClO_2	O_3	NH_2Cl
Oxidation potential	Strong	Stronger	Strongest	Weak
Residuals	Yes	No	No	Yes
Mode of action	Proteins/NA	Proteins/NA	Proteins/NA	Proteins
Disinfecting efficacy	Good	Very good	Excellent	Moderate
By-products	Yes	Yes	Yes	No

Chemical Disinfection by Chlorine

- Chlorine and its compounds are the most widely used chemical disinfectants. They are effective and quick in action. Three different methods of application
  - Cl_2 (gas)
  - NaOCl (liquid)
  - $Ca(OCl)_2$ (solid)
- The chlorination process may be of two types. In pre-chlorination method chlorine is applied prior to any other treatment, usually for controlling algae, taste and odor. In post-chlorination method chlorine is applied after other treatment processes, especially after filtration.
- The chlorine dosage must be sufficient to leave a residual of 0.1 to 0.5 mg/l free chlorine.

Mechanism of Chlorine for Inactivation of Bacteria



Chlorine (Advantages and Disadvantages)

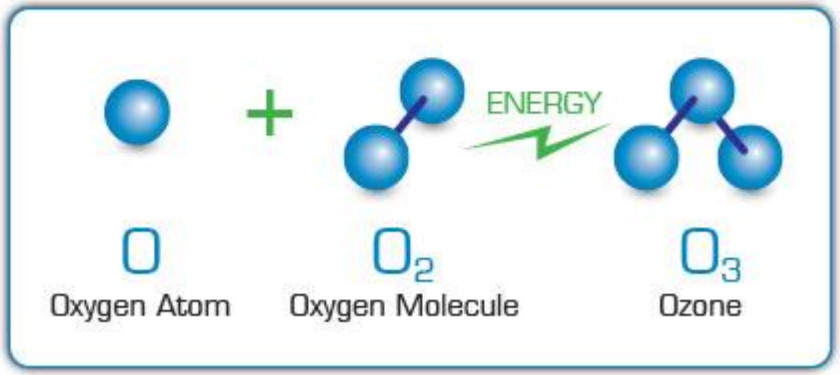
- Advantages
  - Effective against most pathogens
  - Provides a residual in the distribution system
  - Relatively simple maintenance and operation
  - Inexpensive

- Disadvantages
  - Corrosive
  - Highly toxicity
  - Formation of brominated organic byproducts
  - Highly sensitive to inorganic and organic loads
  - Formation of harmful disinfection by-products (DBP’s)
  - Not effective against Cryptosporidium

Ozone

- Increased interest due to the discovery of chlorination disinfection by-products during the 1970's
  - an alternative primary disinfectant to free chlorine
  - strong oxidant, strong microbiocidal activity, less toxic DBPs, relatively unstable

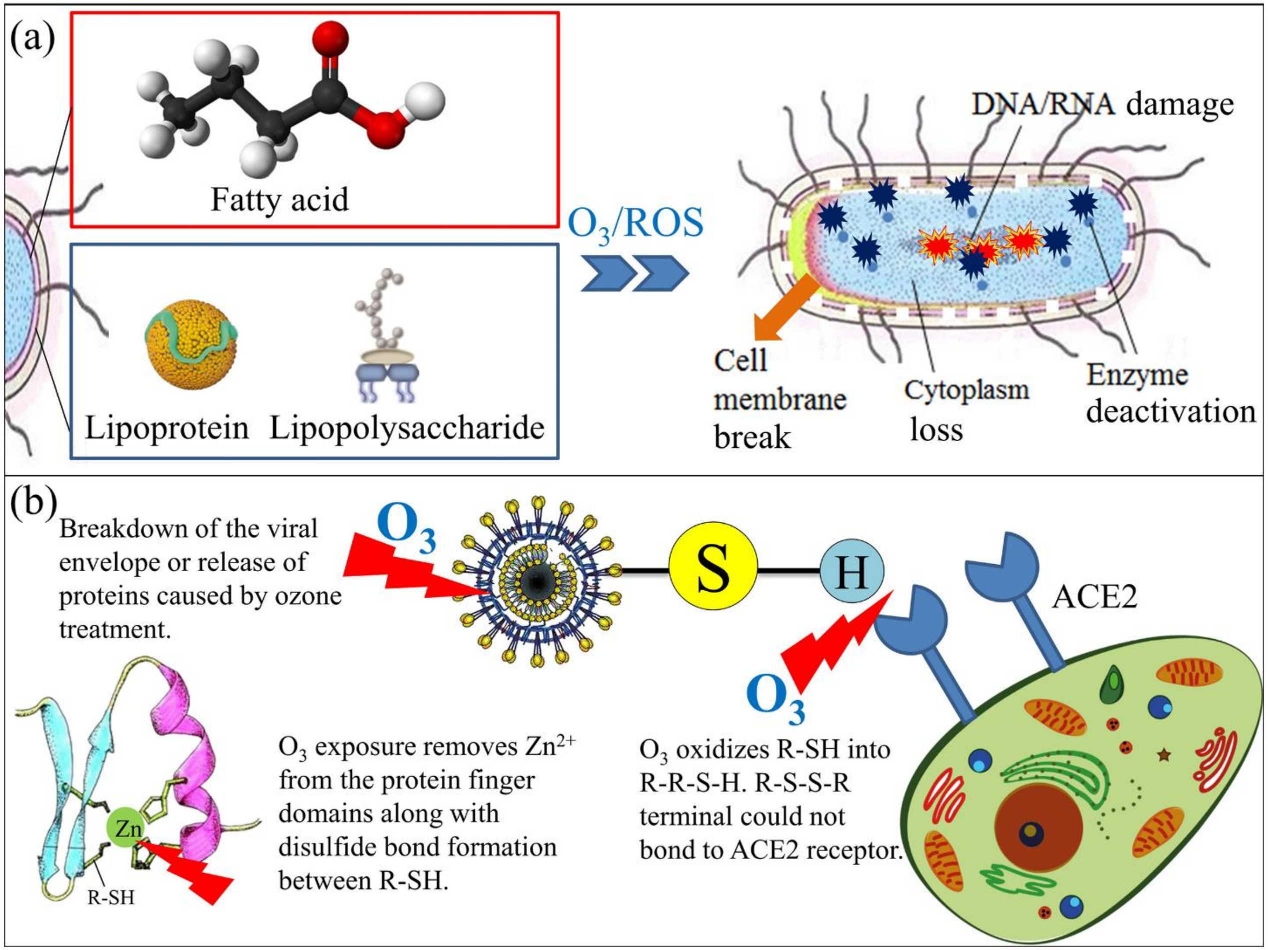
- The method of application
  - generated by passing dry air (or oxygen) through high voltage electrodes (Ozone generator)
  - bubbled into the water to be treated



Chemical Disinfection by Ozone

- Ozone produces hydroxyl free radicals that react with organic and inorganic molecules in water to kill microbes.
- It must be manufactured on site. The high installation and operation costs further reduce its use as a disinfectant.
- It has a more rapid effect than chlorine in destroying viruses and bacteria including spores. It is also effective in eliminating compounds that give objectionable taste and color to water.
- It has no residual disinfection power thus there is no protection against new contamination of the water after disinfection.
- It does not produce trihalomethanes which are suspected carcinogens.
- Bromide reacts with ozone under aqueous conditions typical of drinking water disinfection. Products of the reaction may be hypobromous acid, hypobromite and/or bromate.

Mechanism of Ozone for Inactivation of Bacteria and Viruses



Saravanan et al., 2022

Ozone (Advantages and Disadvantages)

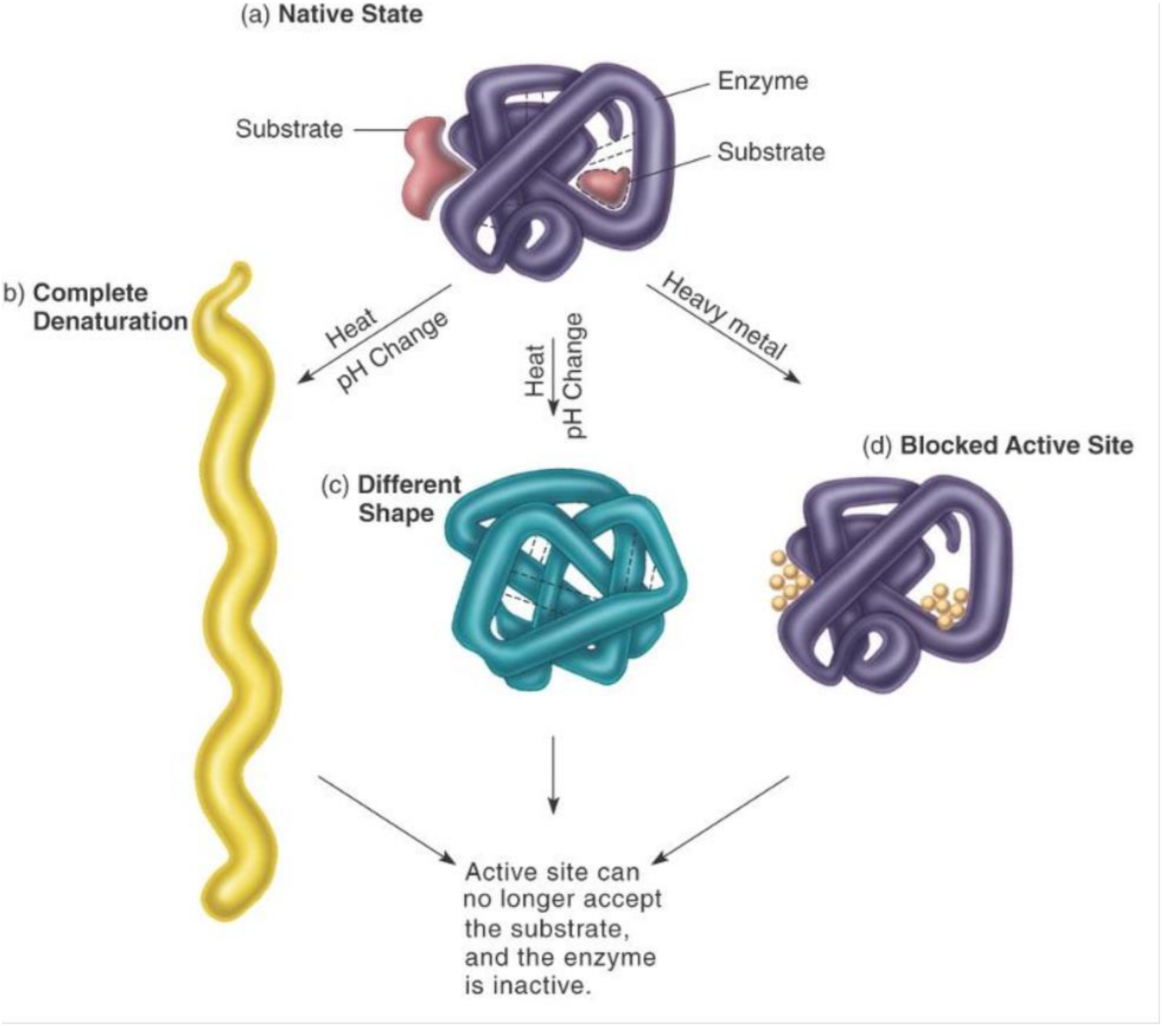
- Advantages
  - Highly effective against all type of microbes
  - Strongest oxidant
  - Does not produce chlorinated THMs, HAAs

- Disadvantages
  - Expensive
  - Unstable (must produced on-site)
  - Highly toxicity
  - Highly sensitive to inorganic and organic loads
  - Forms brominated byproducts (bromate, brominated organics)
  - Forms non-halogenated byproducts (organic acids, aldehydes)
  - Highly complicated maintenance and operation
  - No lasting residuals

Physical Disinfection (Boiling)

- This is the very basic and simplest method of disinfection. Temperature of water is raised to its boiling point and maintained for 15-20 min to kill all the bacteria.
- Boiling kills vegetative bacterial cells, **but spores, viruses, and some protozoa** may survive long periods of boiling.
- Boiling may also volatilize volatile organic compounds (VOCs).
- Boiling is an effective method for small batches of water during water emergencies.
- Boiling is prohibitively expensive for large quantities of water.
- Mechanism of action: denaturation of proteins and DNA, disruption of membranes

Denaturation of Proteins by Boiling

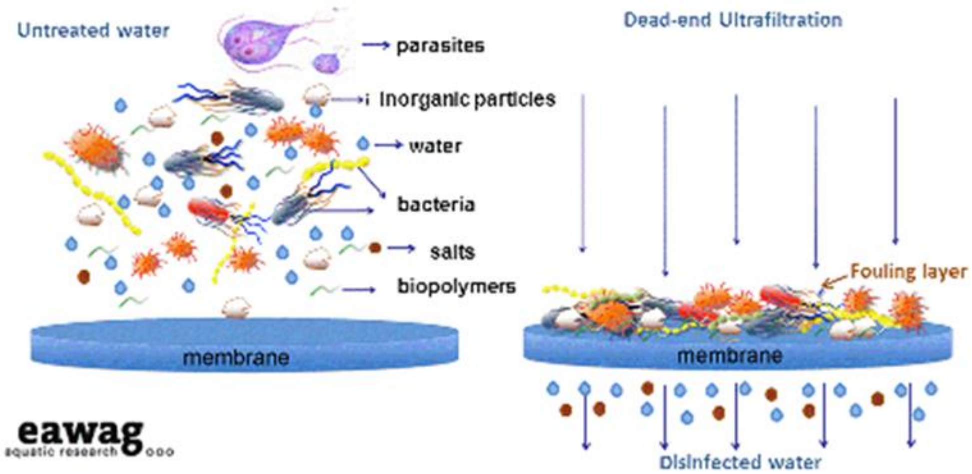


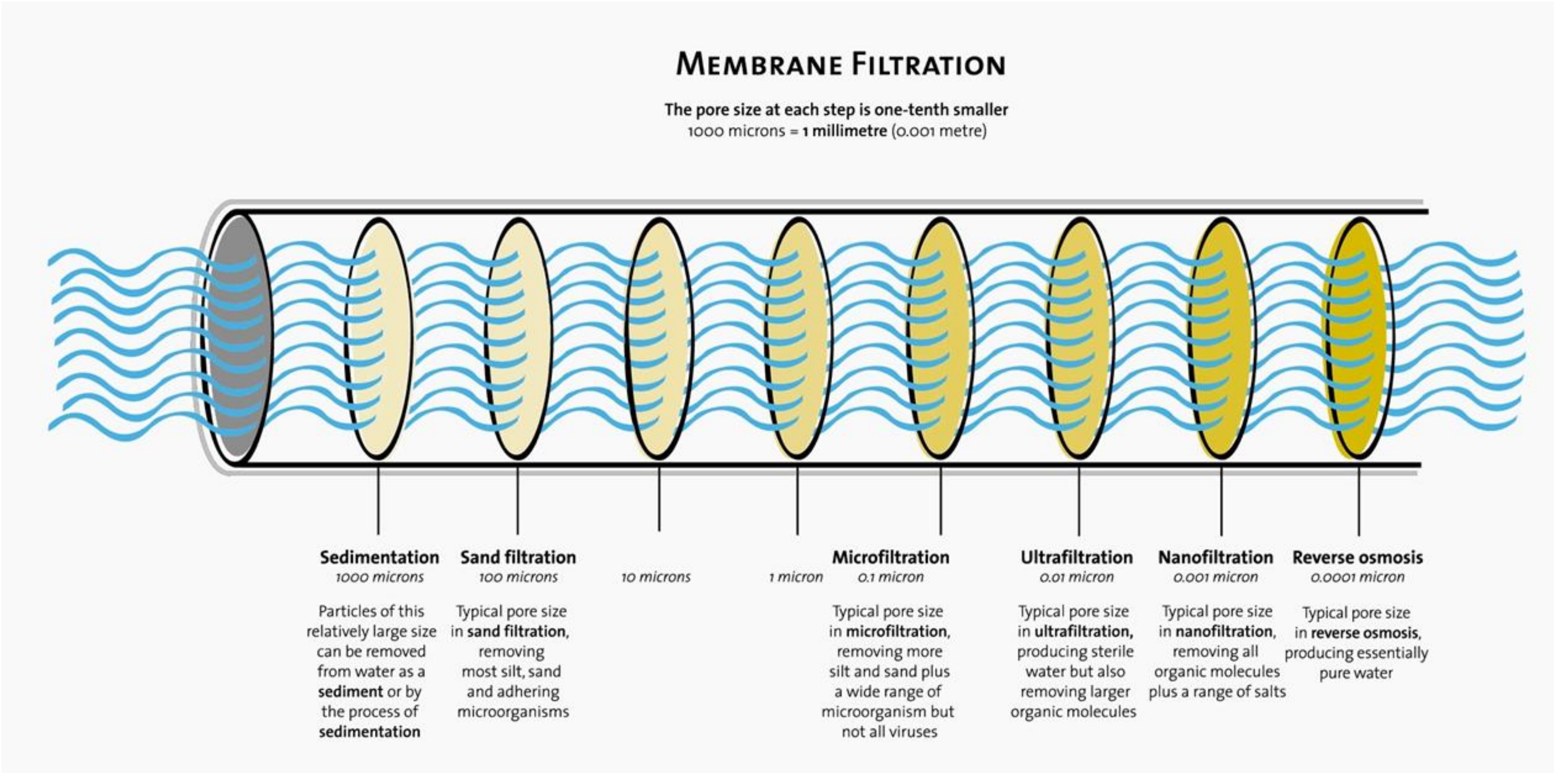
Denaturation is a process in which proteins or nucleic acids lose their native state structure by application of some external stress or compound

Physical Disinfection (Filtration)

- Filtration methods range from simple sand filters for household treatment, to membrane systems (in state-of-the-art treatment plants) like microfiltration, ultrafiltration, nanofiltration and reverse osmosis systems.
- The pore size for filtering bacteria, yeasts, and fungi is in the range of 0.22-0.45 μm.
- 0.01 μm pore size filters retain all viruses and some large proteins.
- Mechanism of action: separation of microbial contamination from liquid
- Sterilization depending on pore size
- Types: depth filters, membrane filters, HEPA filters – High efficiency particulate air filter

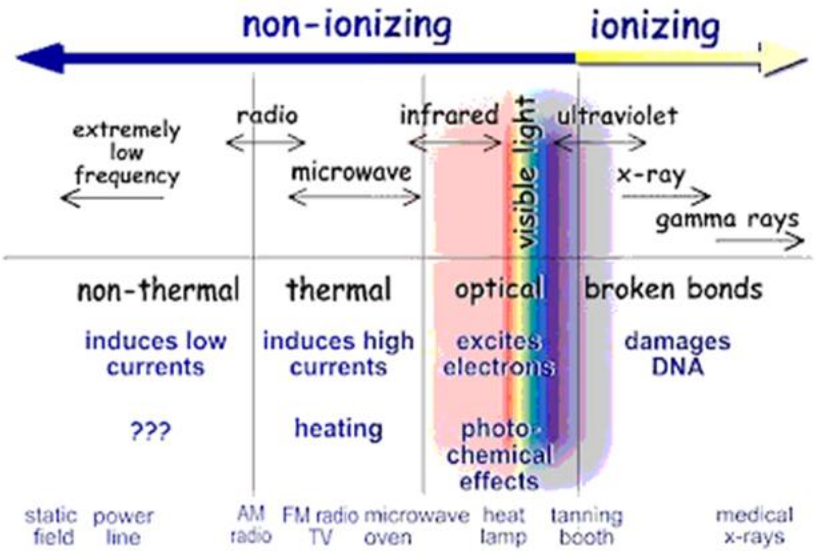
Disinfection by Filtration

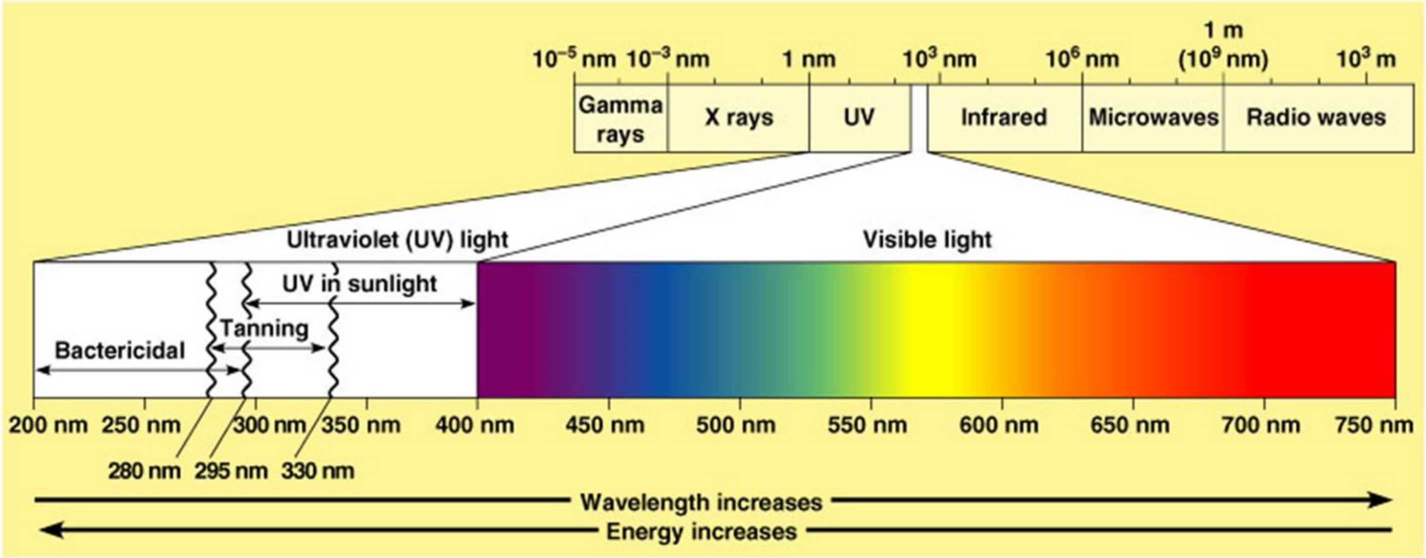




Physical Disinfection (Radiation)

- Physical disinfection by radiation involves:
  - UV radiation (Non-ionizing radiation)
  - Solar radiation (Non-ionizing radiation)
  - X rays, gamma rays (Ionizing radiation)
- Effects of radiation depend on wavelength, intensity and duration

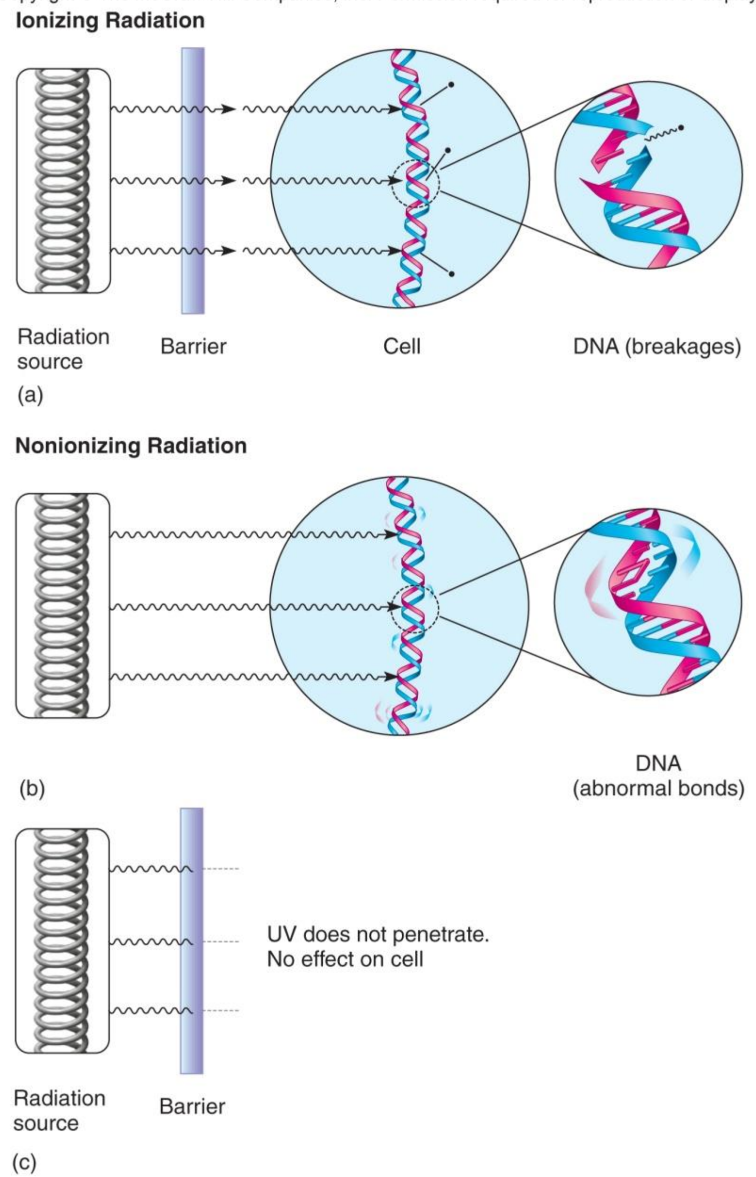




Modes of Action of Ionizing Versus Nonionizing Radiation

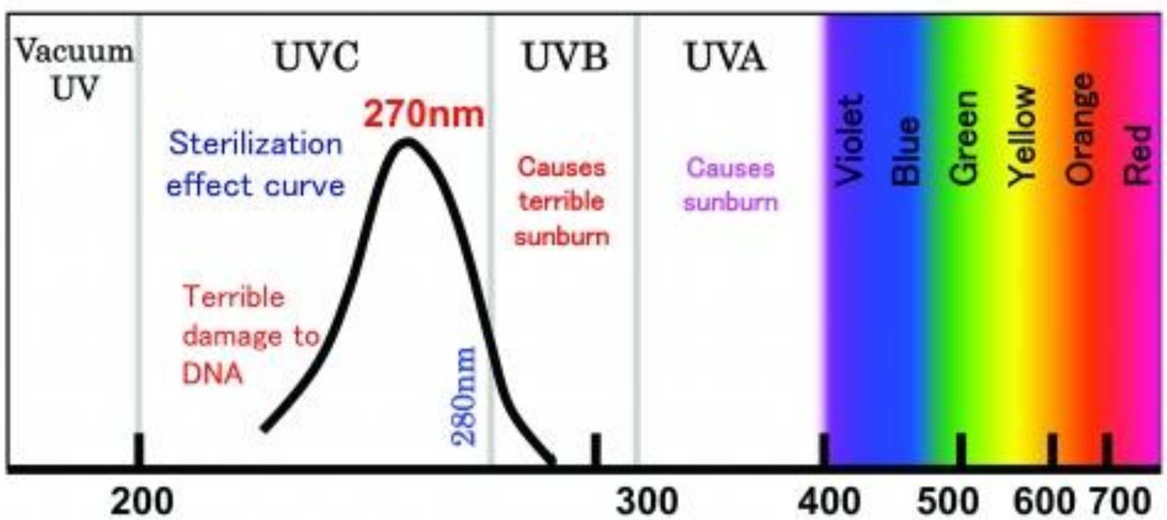
- Ionizing: ejects electron, causing ions and radicals to form
  - High energy
  - Penetrates liquids and solids effectively

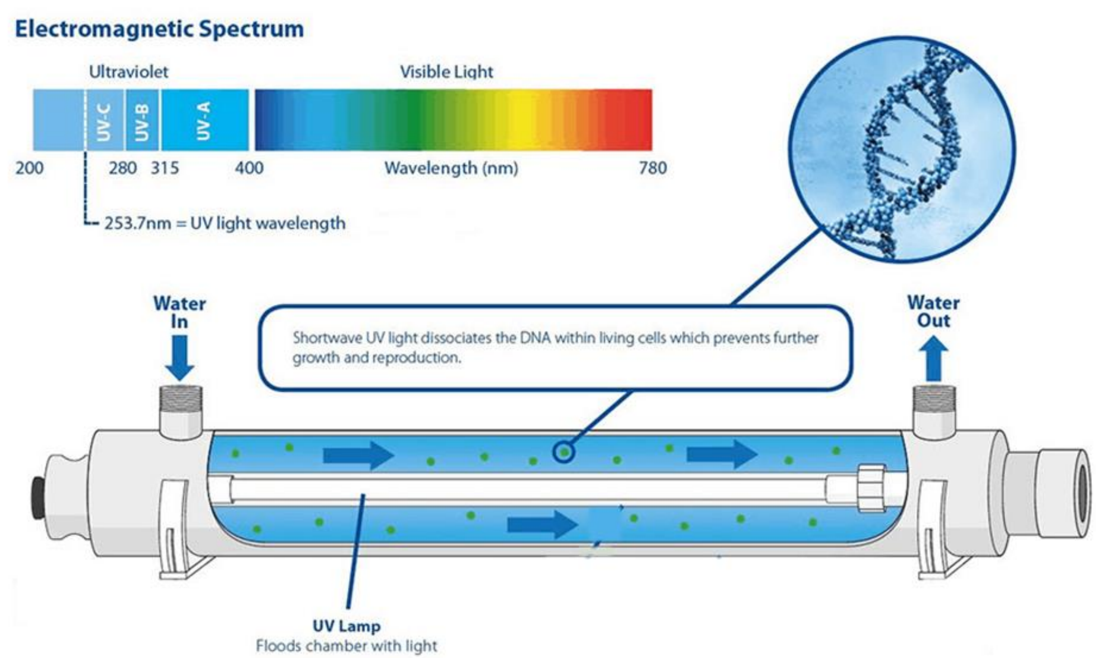
- Non-ionizing: excites atoms to a higher energy state but does not ionize them
  - Low energy
  - Less penetration capability

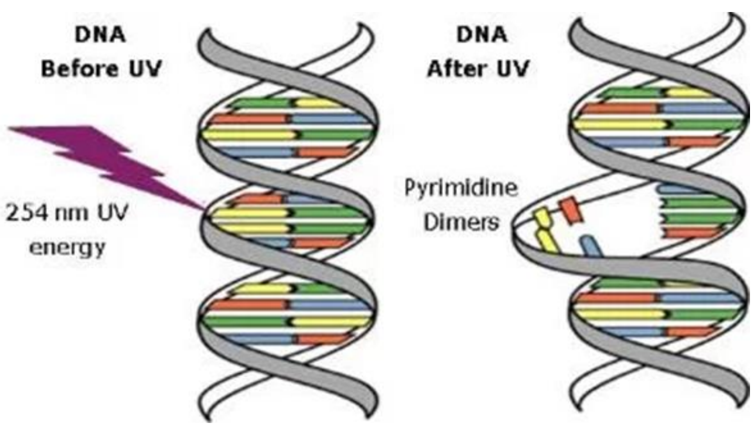


Ultraviolet (UV) Rays

- Wavelength approximately 200 nm to 400 nm
- Germicidal band: 250-270nm
- Powerful tool for destroying fungal cells and spores, bacterial vegetative cells, protozoa, and some viruses







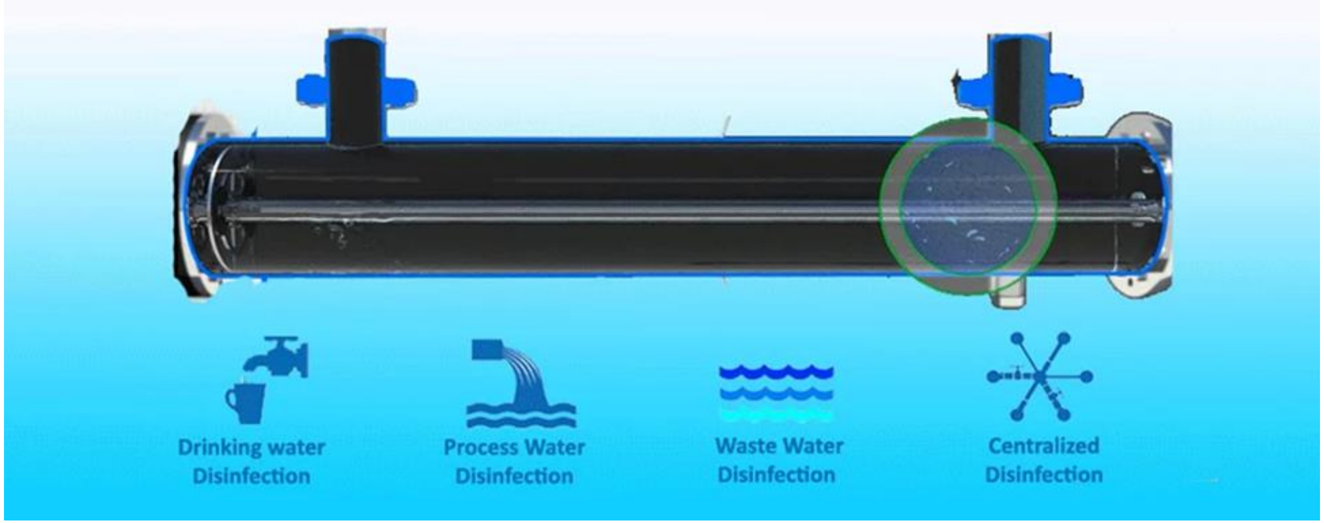
Water Disinfection with UV

- Electromagnetic radiation of ultraviolet range can be used to destroy microorganisms. This process is effective in certain small water supplies where the water is highly polished i.e., filtered, also in industries in breweries, pharmaceutical manufactures, fish hatcheries and aquariums.
- Specific wavelengths, intensities, distances, flow rates, and retention times are required. Optimum ultraviolet light wavelength range for germicidal effect: 250 nm - 270 nm.

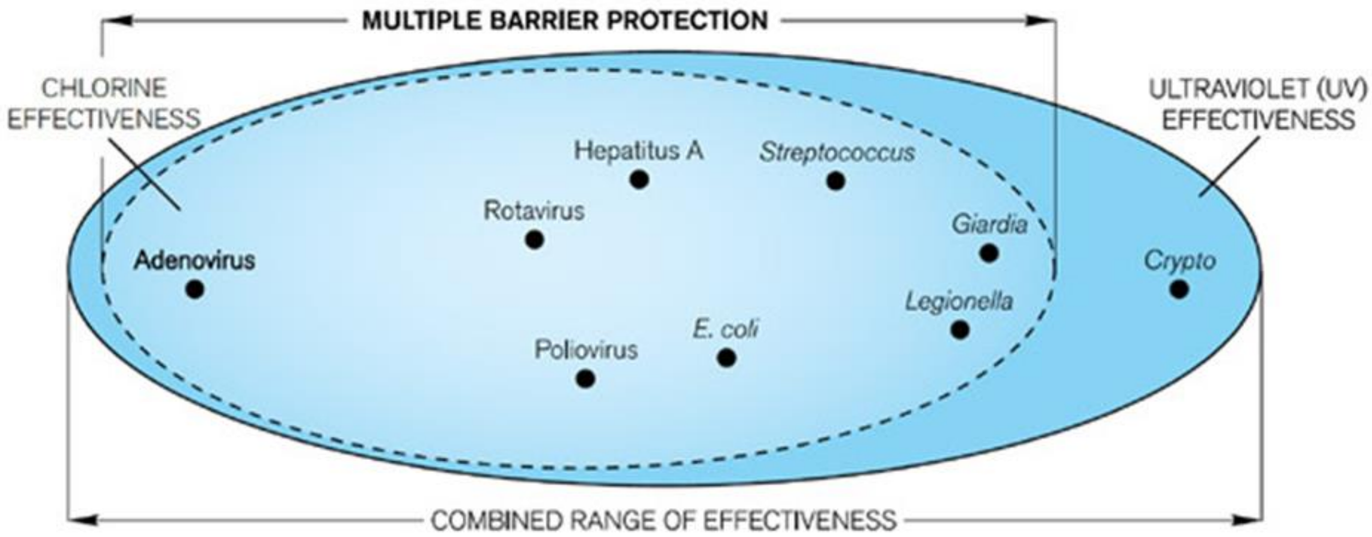
  Low pressure mercury lamp: low intensity; monochromatic at 254 nm

  Medium pressure mercury lamp: higher intensity; polychromatic 220-280 nm

  Xenon lamps, excimer lamps, UV lasers
- Mechanism of action: UV light disrupts DNA of microbial cells, preventing reproduction



UV Disinfection (Advantages and Disadvantages)



Advantages

UV offers a key advantage over chlorine-based disinfection, due to its ability to inactivate protozoa (Cryptosporidium and Giardia)

Independent on pH, temperature, and other materials

No known formation of DBP

No danger of over dosing

Disadvantages

Not so effective against viruses

Inability of UV irradiation to provide a residual disinfection

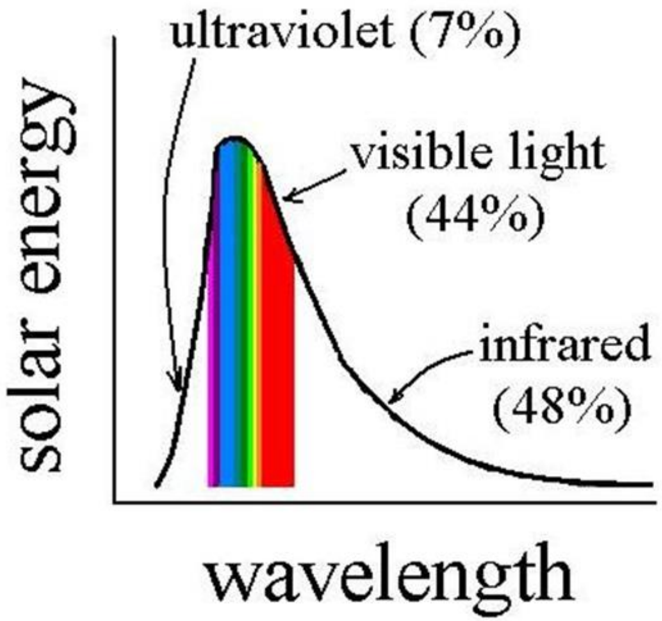
High cost of the system

Cannot penetrate solid or opaque objects

Disinfection by Solar Light

- Solar radiation includes infrared radiation, visible light and ultraviolet light. Over 90% of the solar radiation reaching the Earth's atmosphere is visible light and near-infrared radiation. Ultraviolet light, which has wavelengths from 100-400 nm, makes up less than 10% of solar radiation.

- UV-A, UV-B, and UV-C radiation, are able to inactivate organisms.
- UV-C component of solar radiation does not reach the earth.
- Near ultraviolet (UV-A) light has been found to be the most significant component of sunlight that is responsible for the inactivation of microorganisms, with an increase in effectiveness due to the synergistic effects of UV-A and violet light.



Solar Disinfection (SODIS)

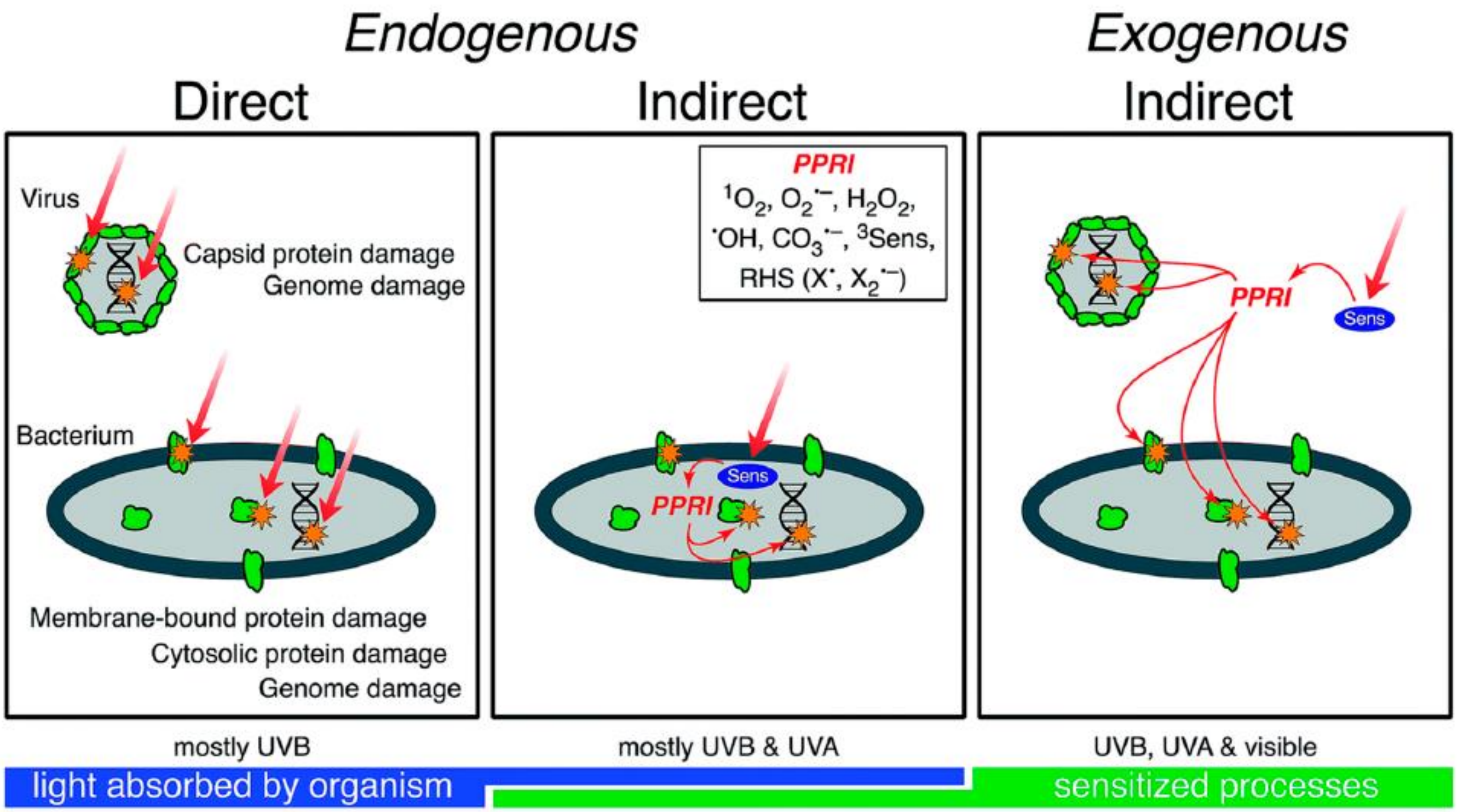
- Solar Disinfection (SODIS), which is typically carried out in rural communities where no centralized water treatment facilities are available or without access to sufficiently disinfected water by conventionally utilized methods.
- SODIS has been accepted by the World Health Organisation (WHO) and recommended for low-income countries and in case of natural disasters or humanitarian crises.
- It involves placing untreated (or partially treated) water into a transparent container which is typically made of polyethylene (PE) or polyethylene terephthalate (PET) etc. and exposing it to sunlight for several hours before drinking. It is the combined effect of UV irradiation and high temperature that leads to antimicrobial action.
- Briefly, water with a maximum level of 30 NTU should be exposed to the sunlight in clean max 3-litre PET bottles for 6 h on sunny days, 48 h on cloudy days, while on days of continuous rainfall, SODIS should not be used.

SODIS

- SODIS has been found to be one of the most appropriate treatments for producing safe drinking water, because it is inexpensive and not dependent on consumables.
- SODIS process is driven entirely by solar energy, and its effectiveness for the removal of pathogens from water has been widely proven (Luzi et al., 2016; Polo-Lopez et al., 2019)
- PET bottles are selected due to their low-cost and wide availability.
- Concerns about chemical contaminants from plastic migration have been addressed by previous studies (Wegelin et al., 2001; Ozores et al., 2020). Water contaminated with non-biological agents such as arsenic, fluoride or industrial agricultural organic contaminants or heavy metals require additional steps to make the water safe to drink.

- Laboratory trials have demonstrated that disinfection with SODIS removes up to 99.99 % of bacteria and > 99 % of viruses as well as protozoa (Giardia and Cryptosporidium rendered noninfective after > 10 h of sun exposure).

Conceptual Model of Solar Inactivation Mechanism in Viruses and Bacteria



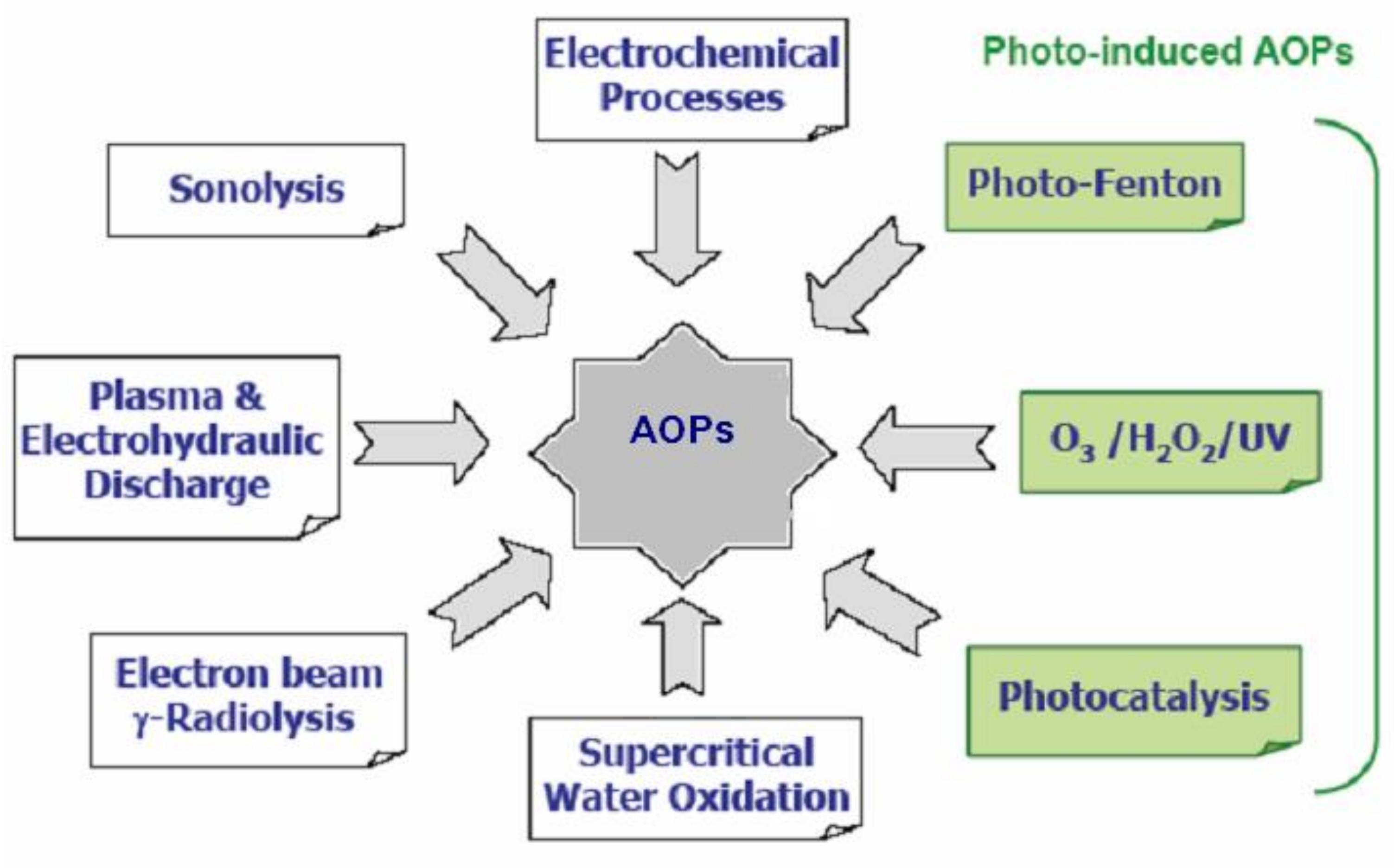
García-Gil, Á.; García-Muñoz, R.A.; McGuigan, K.G.; Marugán, J. Solar Water Disinfection to Produce Safe Drinking Water: A Review of Parameters, Enhancements, and Modelling Approaches to Make SODIS Faster and Safer. Molecules 2021, 26, 3431.

Enhancement of SODIS

- A significant amount of research has been directed toward discovering new ways to enhance SODIS.
- The addition of a photocatalyst has the potential to enhance SODIS to a far greater degree to optimize the method.
- TiO_2 is the most widely studied photocatalyst due to its effectiveness, relative nontoxicity, high stability, and photochemical properties that are conducive to drinking-water purification.

Advanced Oxidation Processes (AOPs)

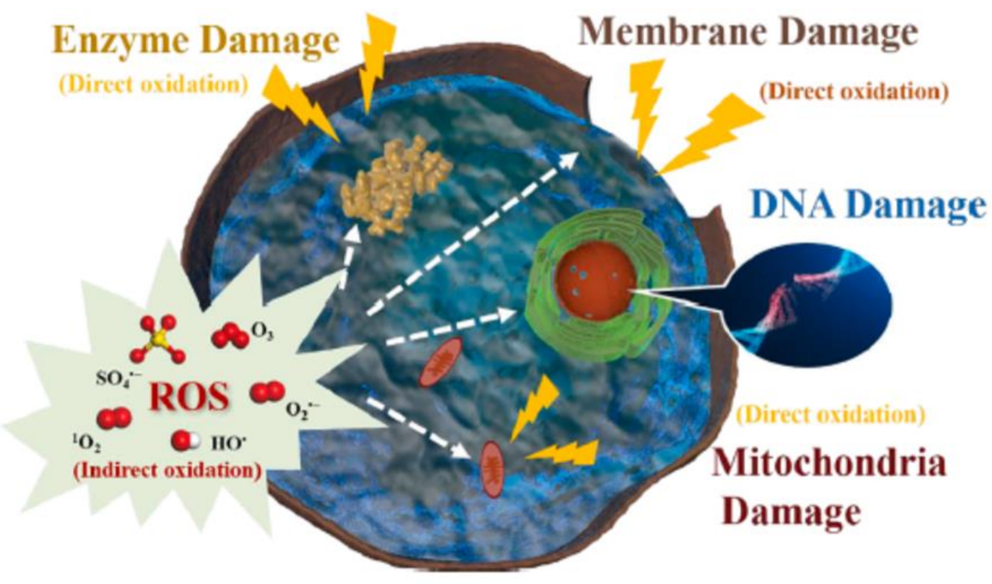
AOPs are redox technologies such as ozonation, ozonation coupled with H_2O_2 and/or ultraviolet (UV) radiation, Fenton and alike reactions, photocatalysis activated by semiconductors such as TiO_2, sonolysis, electrochemical oxidation, and various combinations of them.



Advanced Oxidation Processes (AOPs)

- They are based on the production of highly reactive oxygen species (ROS), characterized by the non-selectivity on the target and can be used as pre- or post-treatment to a biological process.
- The principal oxidizing agent is the hydroxyl radical.
- AOPs have shown a high disinfection potential against a wide range of microorganisms like virus, protozoa, spore-forming bacteria, fungus, and yeasts, mainly through the action of ROS such as singlet and triplet oxygen, anion-radical superoxide, hydroxyl and hydroperoxyl radical, and hydrogen peroxide.

Mechanism of action includes the destruction of cell wall, cell membranes, enzymes, and intracellular genetic material.



Advanced Oxidation Processes

- AOPs can be divided into established and emerging technologies based on the existing literature and the water treatment industry's experience with the technology.
- Emerging technologies are defined as technologies that have very limited applications in drinking water treatment.

Established Technologies	Emerging Technologies
• Hydrogen Peroxide/Ozone (H_2O_2/O_3)	• High Energy Electron Beam Irradiation (E-beam)
• Ozone/Ultraviolet Irradiation (O_3/UV)	• Cavitation (Sonication & Hydrodynamic)
• Hydrogen Peroxide/ Ultraviolet Irradiation (H_2O_2/UV)	• TiO_2-catalyzed UV Oxidation
	• Fenton's Reaction

Summary of previous works

Photocatalytic degradation of NOM/HA since 1999.

Organic matter type: Aquatic and/or terrestrial

NOM/HA types: Commercial samples (Aldrich, Fluka, Roth, IHSS...), natural water samples

Operational parameters: pH, light intensity, TiO_2 type (Degussa P-25, Hombikat UV-100, Millenium 100, 500), doped TiO_2 specimens, non-TiO_2 photocatalysts

Second generation and third generation photocatalysts

Aqueous matrix effect

Common anions: NO_3^-, Cl^-, HSO_4^- /SO_4^{2-}, HPO_4^{2-}/$H_2PO_4^-$ /PO_4^{3-}

alkalinity: HCO_3^- and CO_3^{2-}

Common cations: Hardness causing cations, Mg and Ca

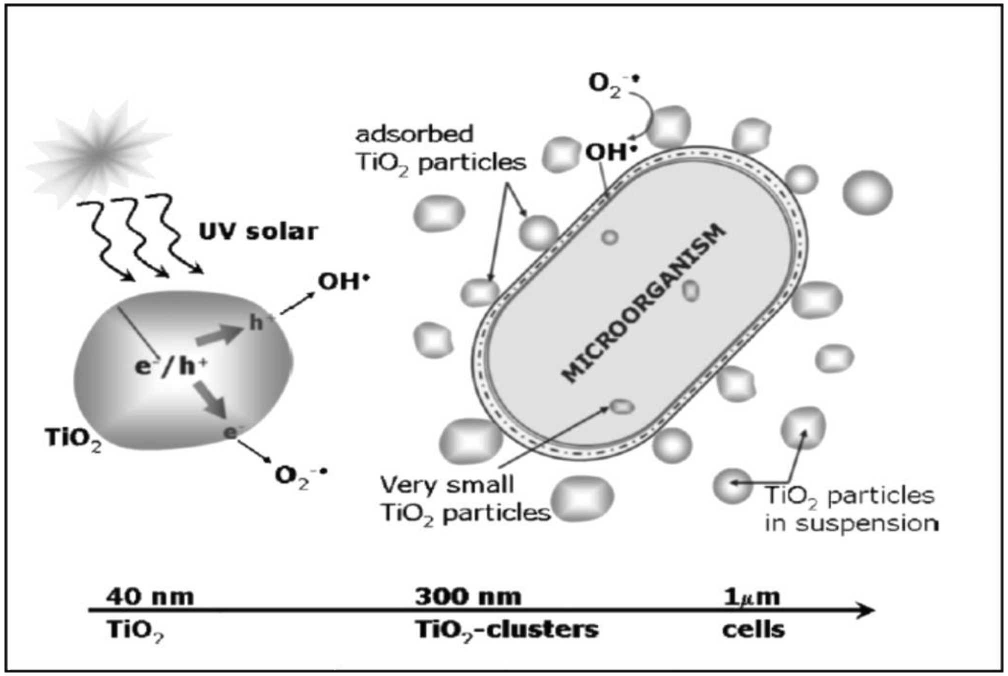
Trace metals: Mn, Cr, Cu, Fe and Zn

Oxidizing species: H_2O_2, HOCl/OCl^-

Photocatalysis

TiO_2 + hν (λ<390 nm) → e^-_{CB} + h^+_{VB} → ROS {•OH/•HO_2/O_2•/} + $(NOM/humic)_{ads}$ →→ via radical reactions → $(NOM/humic)_{ox}$ → → → CO_2 + H_2O

Endo and exo-bacterial organic compounds → ROS → organic acids



Blanco-Galvez et al., 2007

Water - Sustainable Point-of-Use Treatment Technologies (WATERSPOUTT PROJECT, 2016-2020)

- EU H2020 WATERSPOUTT Project: 18 partner organisations from 11 countries, including 4 African partners.
- The goal was to provide affordable access to safe water to remote and vulnerable communities in Africa and elsewhere by designing and developing sustainable SODIS technologies.
- People in sub-Saharan Africa commonly use opaque plastic jerrycans to collect and transport water. However, these containers can be easily contaminated, affecting the quality of the water inside.
- To address this issue, WATERSPOUTT developed jerrycans and buckets suitable for SODIS. These containers have been designed for household use and have been piloted in communities in Ethiopia and Malawi.

Solar Photocatalytic Inactivation of *E.coli* in Water

- Assessment of the relative impact of different natural organic matter (NOM) and its components to bacteria inactivation under simulated solar light.
- The influence of chemical composition of water on NOM photo-assisted process.

NOM analogues → ± Water matrix components → ± *E. coli* → Simulated solar light

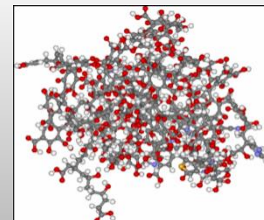
Methodology

E. coli

N_o: 10^6 CFU/mL

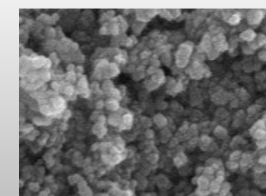
Bacteria

Humic acid



TiO_2, syn TiO_2, doped TiO_2

TiO_2



Atlas Suntest CPS+ Solar Simulator

λ: 290-800 nm

I_o: 250 W/m^2

photocatalyst dose: 0.25 mg/mL

t_{irr}: 0-120 min with 10 min intervals

Photocatalysts

Solar photocatalytic degradation and inactivation in the presence of TiO_2 specimens

Commerical TiO_2

TiO_2 P-25

Anion doped TiO_2

N-doped TiO_2
S-doped TiO_2
S-N co-doped TiO_2

Metal doped TiO_2

Fe-doped TiO_2
Se-doped TiO_2
Se-N co-doped TiO_2

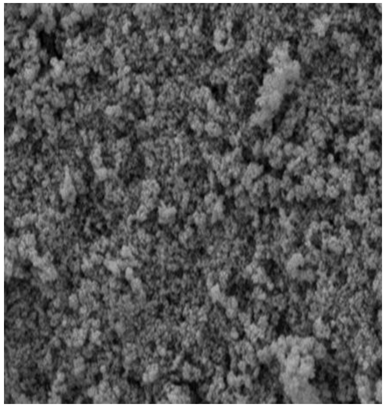
Sol gel synthesized TiO_2

Fe doped synthesized TiO_2

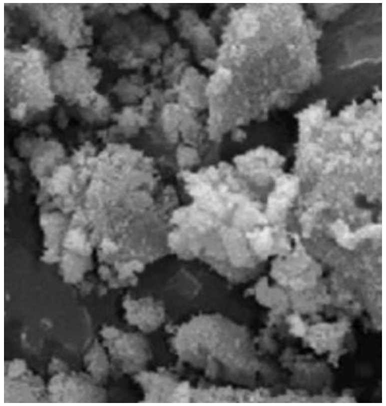
Tracking release of bacterial cell components as as a result of photolysis and photocatalysis

Material Specification

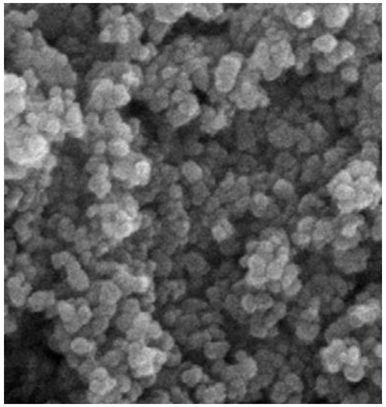
Photocatalysts	BET Surface Area, m^2/g	Crystallite Particle Size, nm	E_{bg}, eV	Wavelength, nm
TiO_2	57	20.4	3.20	388
$SynTiO_2$	50	33.1	3.04	408
0.25% $Fe\text{-}TiO_2$	33	16.4	2.55	486
0.50% $Fe\text{-}TiO_2$	37	17.9	2.48	500
0.25% $Fe\text{-}SynTiO_2$	34	20.7	2.82	440
0.50% $Fe\text{-}SynTiO_2$	55	23.7	2.67	466
N-doped TiO_2	55	18.8	2.79	479
Se-doped TiO_2	53	16.6	2.76	448
Se-N co-doped TiO_2	51	17.4	2.65	467



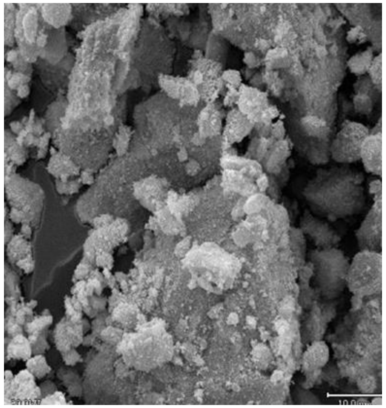
P-25



N-doped



Se-doped

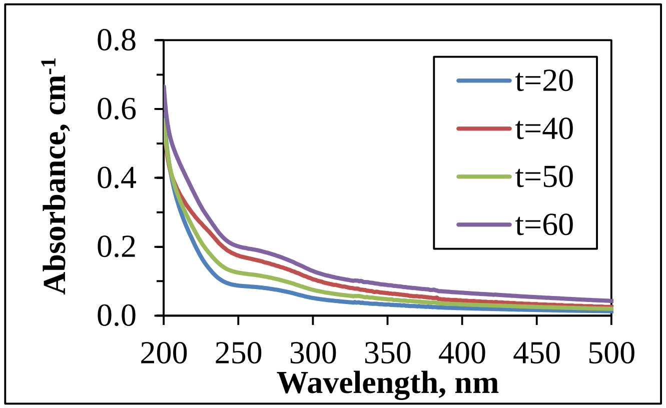


Se-N co-doped

Analytical methodology

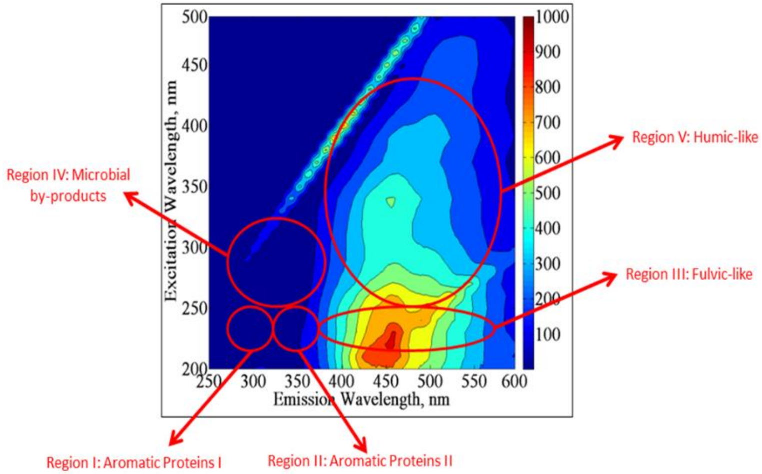
Organic matrix

UV-vis spectra, λ: 200-600 nm



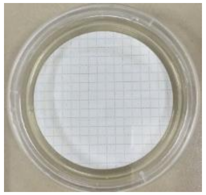
Non-Purgeable Organic Carbon (NPOC) mgOrgCL^{-1}

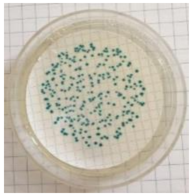
Excitation-Emission Matrix (EEM) fluorescence spectra

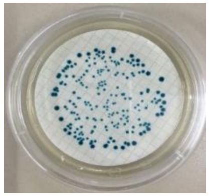


Bacteria

Membrane Filtration Method (Standard Methods) Luria Bertani medium







Enumaration of bacteria, CFU/mL

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Visible light photocatalytic response of Fe doped TiO_2: Inactivation of *Escherichia coli*

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MDPI

Article

Photocatalytic Bactericidal Performance of $LaFeO_3$ under Solar Light: Kinetics, Spectroscopic and Mechanistic Evaluation

Nazmiye Cemre Birben [1], Ezgi Lale [1], Renato Pelosato [2], Ceyda Senem Uyguner Demirel [1], Isabella Natali Sora [2,*] and Miray Bekbolet [1]

Chemosphere 211 (2018) 420–448

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Review

A comprehensive review on the use of second generation TiO_2 photocatalysts: Microorganism inactivation

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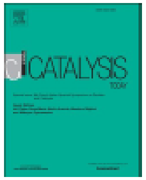

Elucidation of in-situ produced organic matrix effect on the solar photo/photocatalytic inactivation of *E. coli*

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