CVL100: Environmental Science

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1^{st} class

Water Pollution:

Overview

Water Pollution

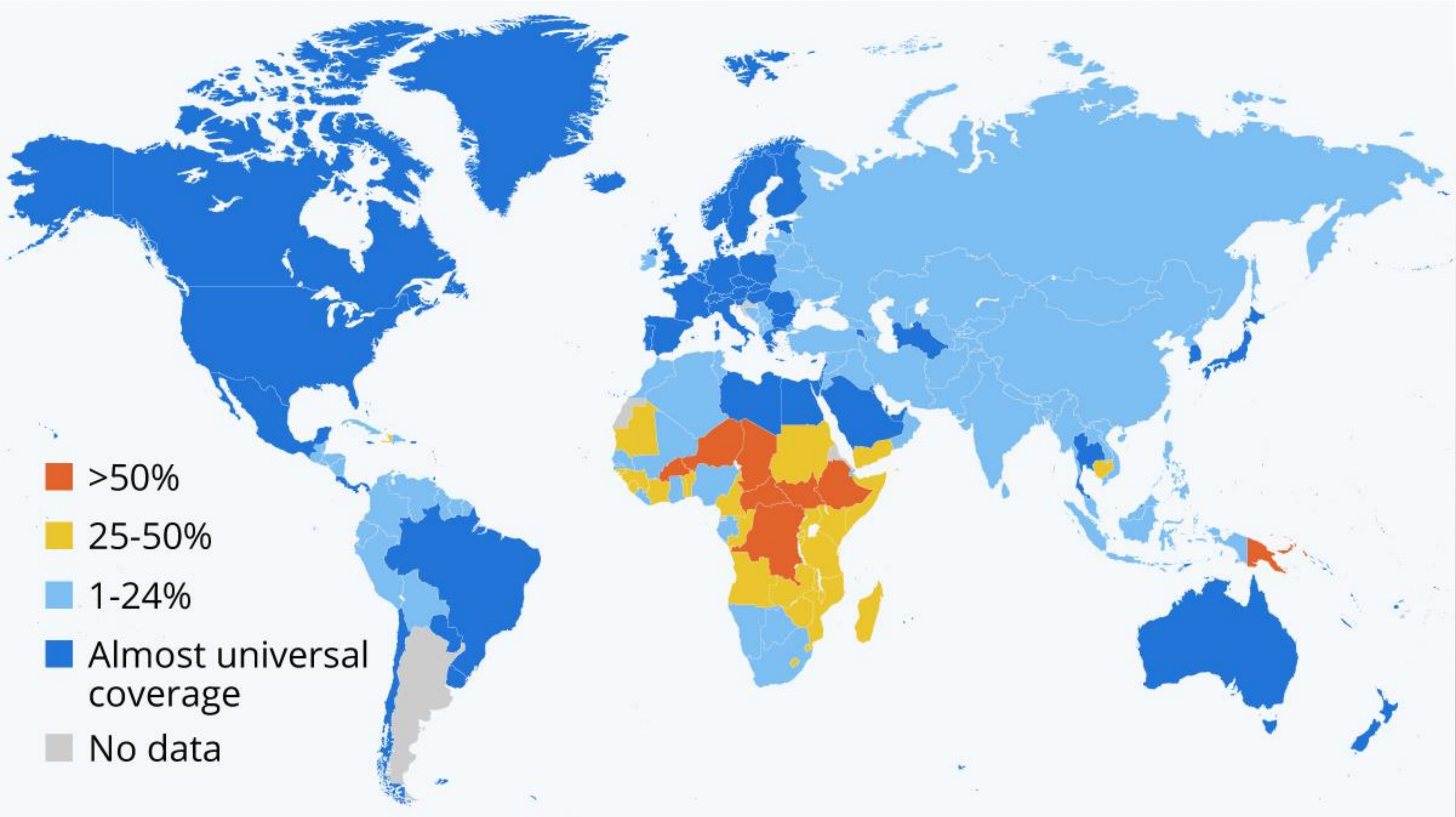
Water pollution can be defined as an alteration in **water's physical, chemical, and biological** characteristics through **natural** or **human activities**, making it **unsuitable** for its designated use.

Water pollution in the environment and its sources

Water pollution (cont..)

- During the Middle Ages, diseases such as **cholera and typhoid fever** broke out all across Europe. These epidemics were **directly related to unsanitary conditions** caused by **human and animal wastes, and garbage.**
- By the 1800s, people began to understand that **unsanitary living conditions and water contamination contributed to disease epidemics.**
- In the mid-1850s, Chicago built the first **major sewage system in the United States** to treat wastewater
- The World Economic Forum has identified **water scarcity** as one of the **major global risks**
- **Two-third of the world's population** live in areas facing **water scarcity** for at least a month in a year and about **50% of this population lives in China and India**
- Only **37%** of wastewater produced in India is getting treated
- More than half of the Indian cities fall under **water stress regions**

Water pollution (cont..)



Share of people **without** access to safe drinking water worldwide as on 2020

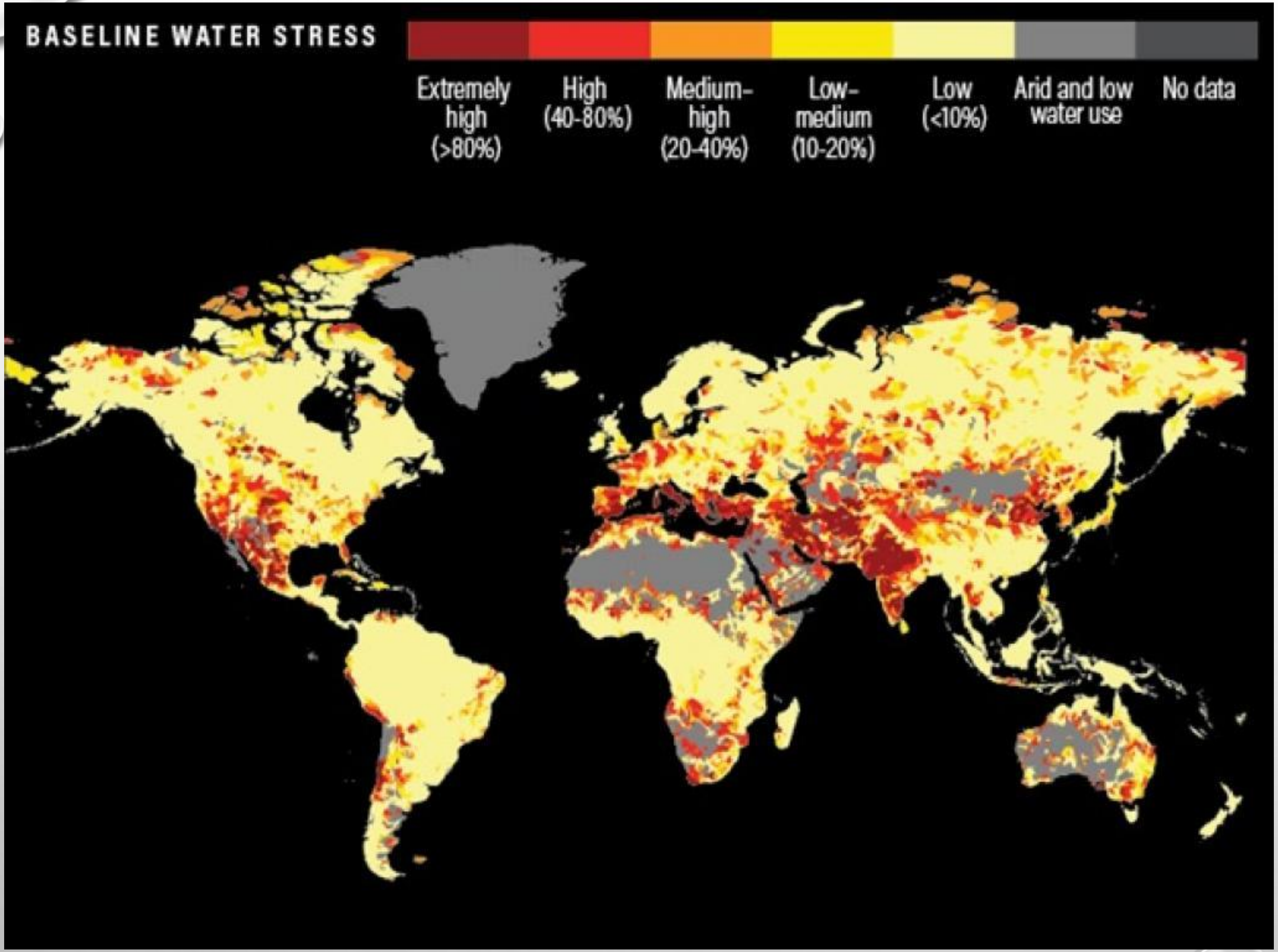
Sustainable development goals (SDG) of UN

17 sustainable development goals with interlinked objectives designed to serve as a "shared blueprint for peace and prosperity for people and the planet, now and into the future."

SDG 06
Clean water and sanitation

- Ensure **availability** and **sustainable management** of **water and sanitation** for all
  - ✓ TARGET 6.1: Achieve universal and equitable access to **safe and affordable drinking water** for all
  - ✓ TARGET 6.2: Achieve access to adequate and equitable **sanitation and hygiene** for all and **end open defecation**, paying special attention to the needs of **women and girls** and those in vulnerable situations
  - ✓ TARGET 6.3: **Improve water quality** by **reducing pollution, eliminating dumping** and minimizing the **release of hazardous chemicals and materials**, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
  - ✓ TARGET 6.6: Protect and restore **water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers, and lakes
- Water quality is addressed also under other SDGs such as the **goals on health, poverty reduction, ecosystems, and sustainable consumption and production**, recognizing the links between **water quality and the key environmental, socioeconomic, and development issues** (Goals 1, 3, 12, 15 and Targets 1.4, 3.3, 3.9, 12.4, 15.1).

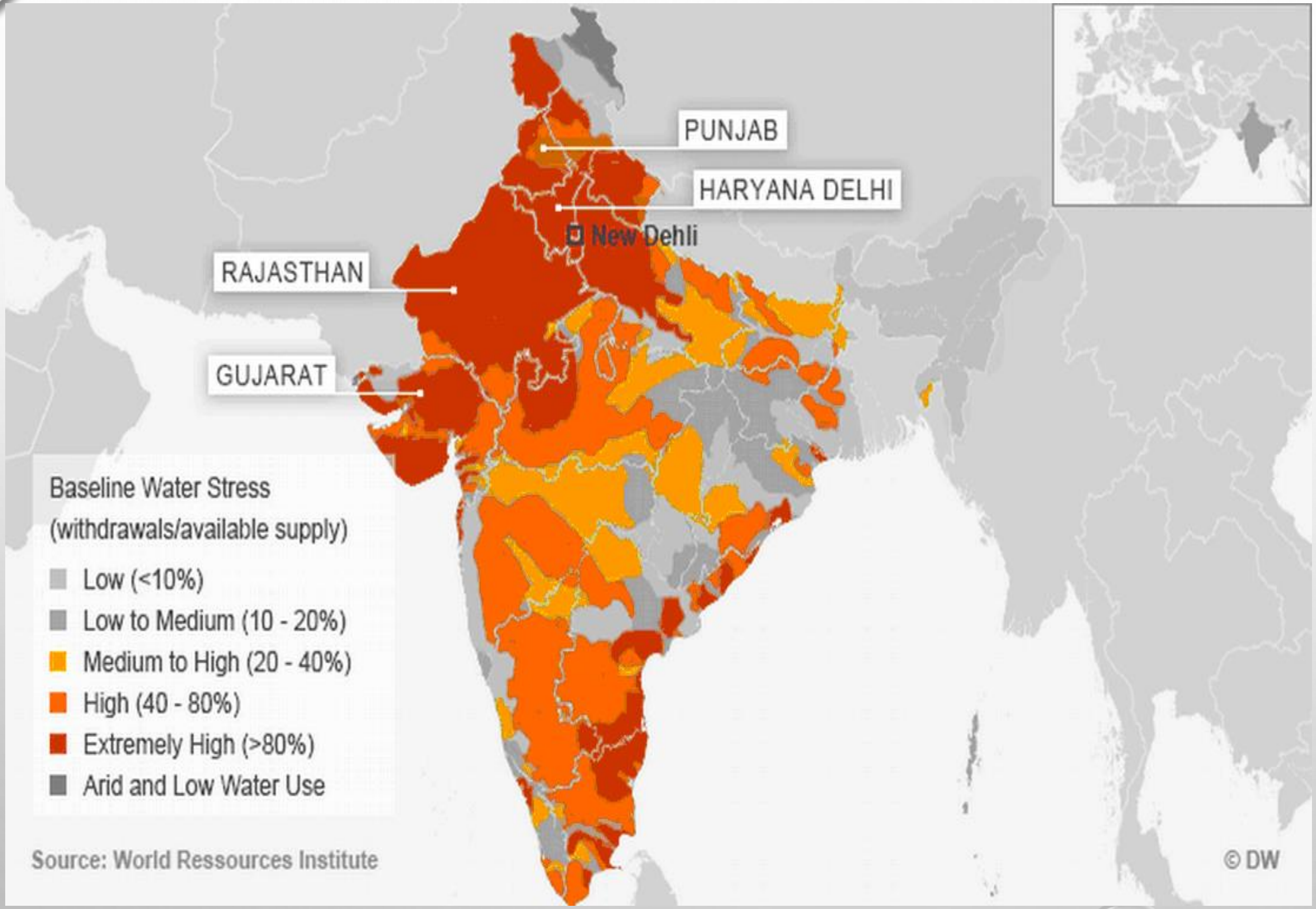
Baseline water stress (Worldwide)



Total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percent of the total annual available flow as on 2019

India placed **thirteenth** among the world's 17 **'extremely water-stressed'** countries, according to the **Aqueduct Water Risk Atlas** released by the World Resources Institute (WRI)

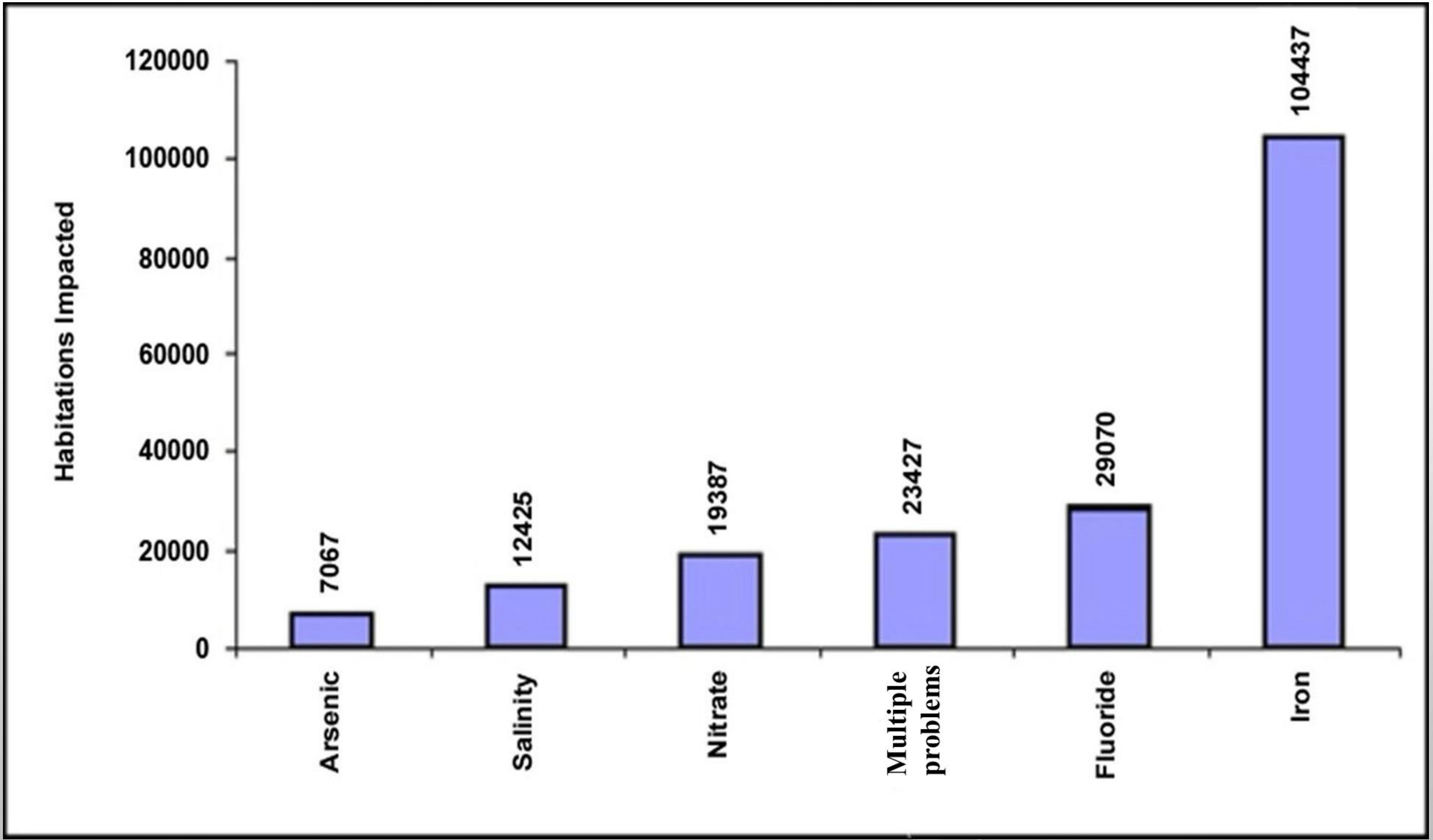
Baseline water stress (India)



Water stress in India as on 2019

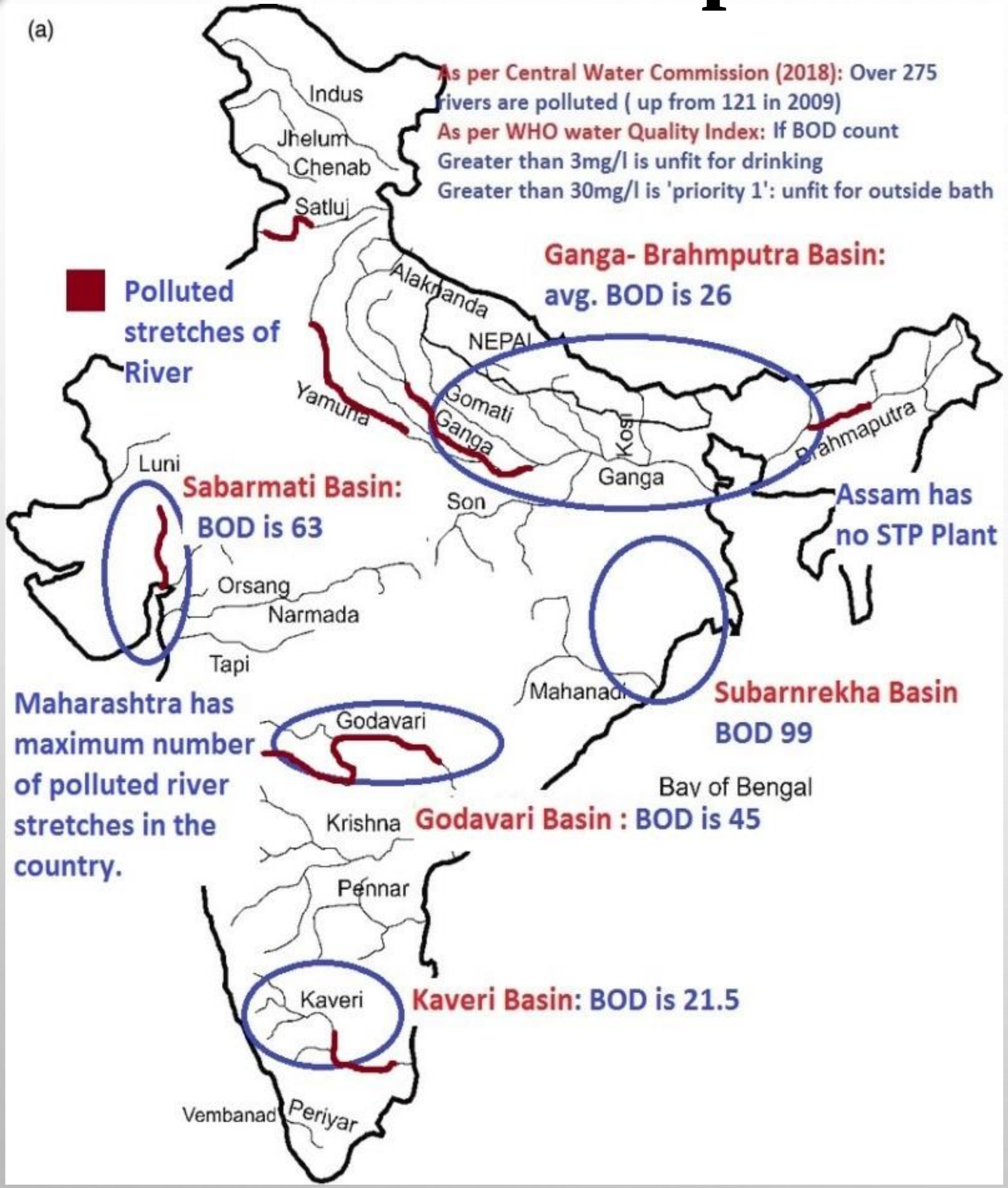
Orange and dark-orange areas in the map show highly or extremely highly water-stressed areas, meaning that **more than 40 percent of the annually available** surface water is used every year.

Water quality impact



Number of habitations affected in total by water quality problems in **rural India** as on 2009

Water pollution scenario in India



Data on polluted rivers in India as on 2022

RIVER GANGA

- ✓ Approximately **1 billion litres** of raw, untreated sewage is **dumped** in Ganga regularly.
- ✓ Ganga contains **60,000 fecal coliform** bacteria per 100 mL, which is a threat to human health.
- ✓ Ganga is considered to be the **most polluted** river in India.

RIVER YAMUNA

- ✓ More than **57%** of Delhi's waste is thrown into the Yamuna river.
- ✓ Only **55%** of Delhi's residents are connected to a proper sewerage system.
- ✓ According to Centre for Science and Environment (CSE), around **80%** of Yamuna's pollution is due to raw sewage.

Sources of Water Pollution

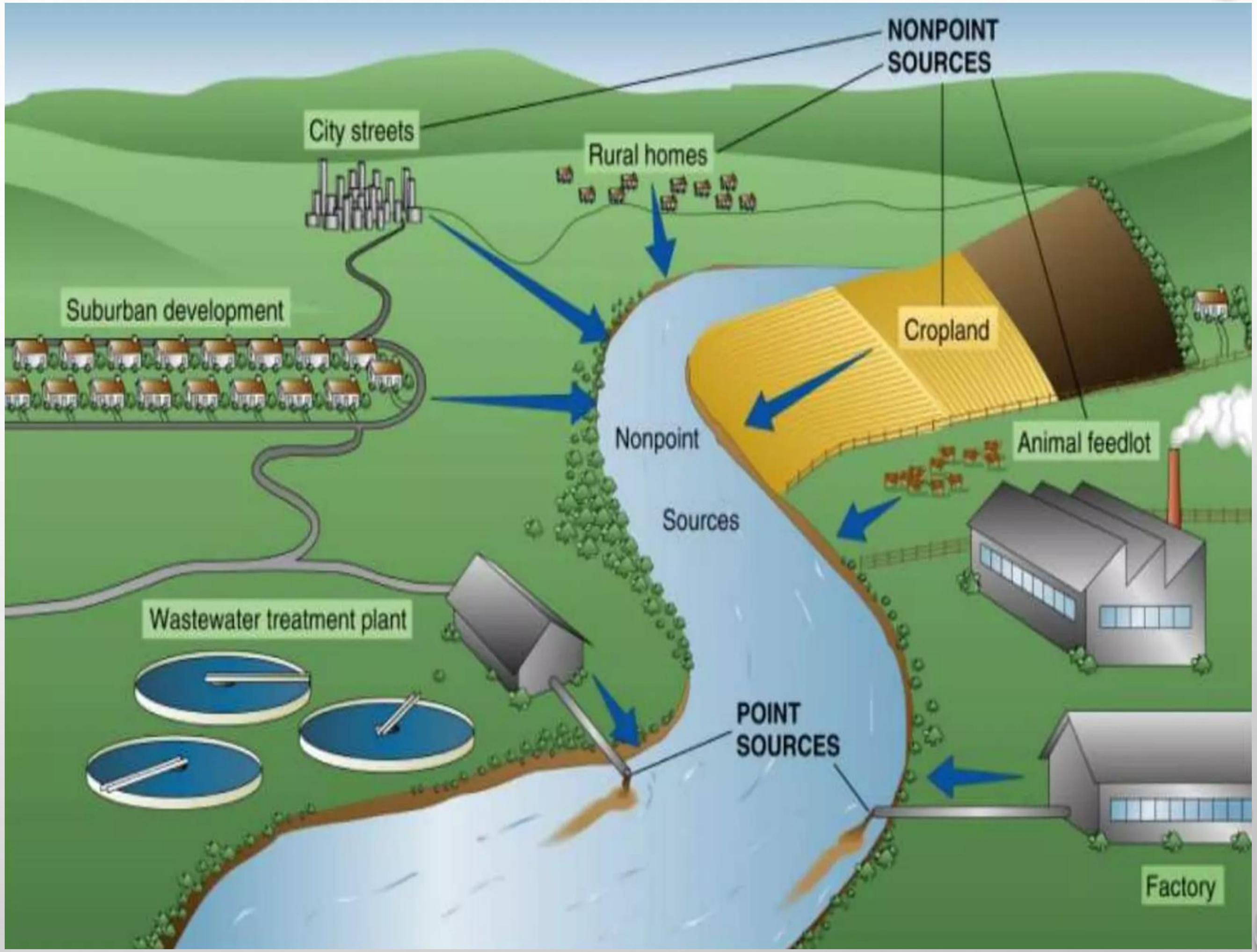
- **POINT SOURCE POLLUTION**

A point source is a **single, identifiable source** of pollution, such as a pipe or a drain. Industrial wastes are commonly discharged to rivers and the sea in this way.

Example includes **pipe attached to a factory, oil spill from a tanker, effluents coming out from industries.**

- **NON-POINT SOURCE POLLUTION**

When the source of water pollution is not known or pollution **does not come from single discrete source of pollution** is known as non-point source pollution. It is very difficult to control and may come from different sources like **pesticides, fertilizers industrial wastes** etc.



Point source and non-point source of water pollution in environment

Surface water pollution

Surface water pollution occurs in three ways: **naturally, accidentally, and intentionally**.

- Naturally: Flooding or tsunamis, that pick up fertilizers, pesticides, debris, and other contaminants.
- Accidentally: Oil spills and agricultural runoff.
- Intentionally: Industries dumping waste directly into waterways

Surface water pollution in environment

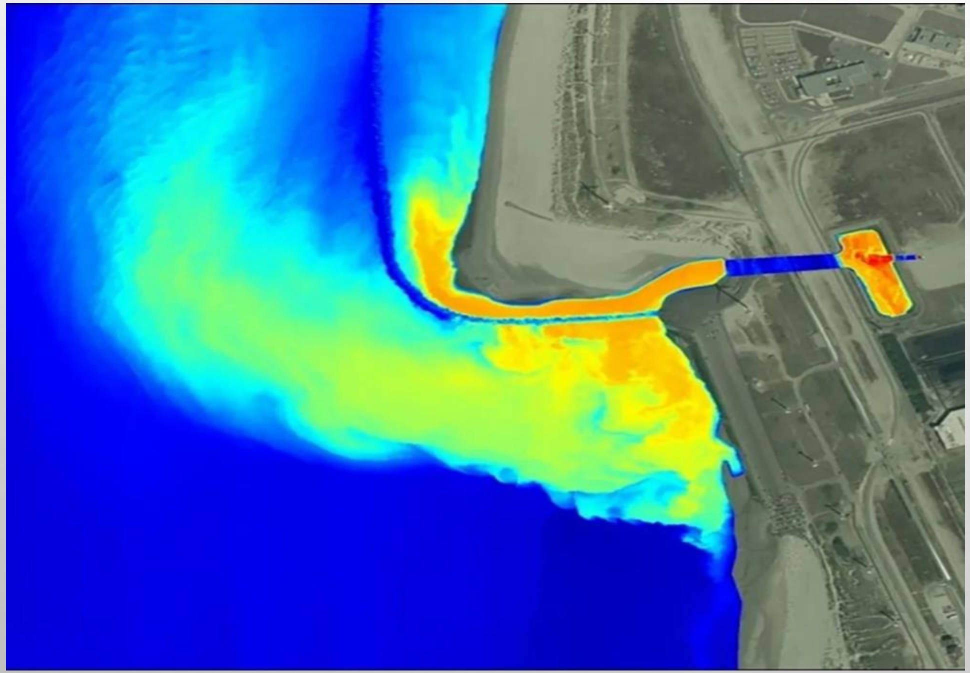
Groundwater pollution

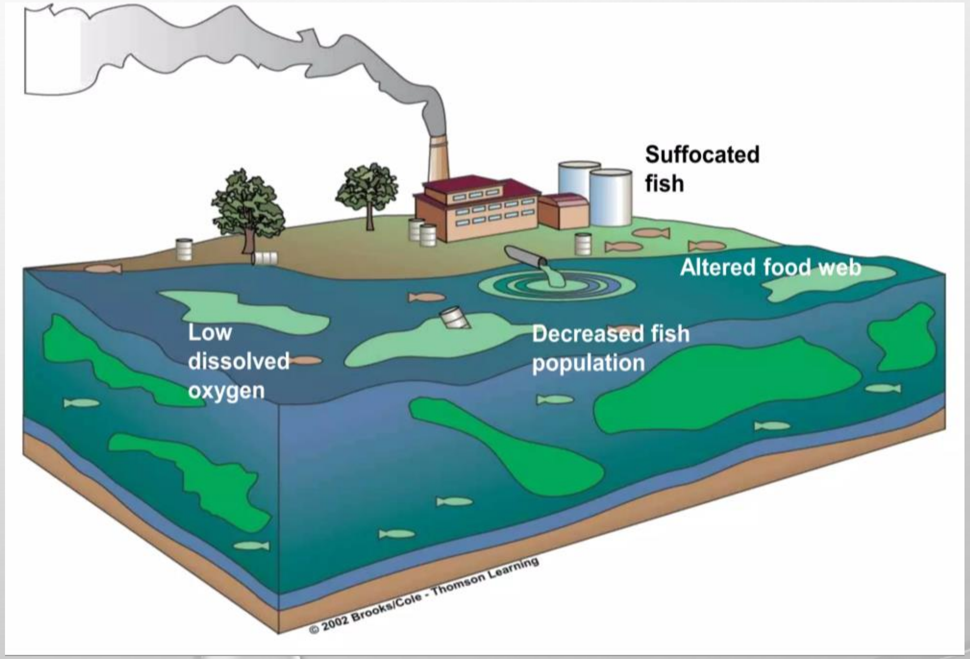
- A key source of water pollution that ends up in groundwater resources comes from **agriculture. Fertilizers and pesticides** applied to farmland are easily absorbed into the ground, or they can be transported as **runoff during rainfall**.
- Groundwater can also become contaminated when waste from **landfills and septic systems** leaches into the ground.

Ground water pollution in environment

Thermal pollution

- Heat is also considered a type of water pollution, as it reduces the ability of water to hold dissolved oxygen (DO); as the **temperature of water increases, the level of DO decreases**. Thermal pollution also **increases the rate of metabolism in fish and damages larvae and eggs in rivers**.
- The main source of thermal pollution comes from **power plants discharging cooling water** into rivers. The **raising of temperatures due to global warming** is also thought to be a type of thermal water pollution





Thermal pollution in the environment

Causes of Water Pollution

Agricultural runoff

- **SOURCES** - Farmland Irrigation, Rainfall Events, Livestock Operations, Overland Flow etc.

- Here are some ways in which agricultural runoff can cause water pollution:

  - Runoff carries **nitrogen and phosphorus** from **fertilizers**, leading to nutrient pollution in water bodies.
  - Rain and irrigation water can transport **pesticides and herbicides** into rivers and lakes, **impacting aquatic ecosystems.**
  - Exposed soil from **farming activities** can be eroded by water, carrying sediment into water bodies.
  - Runoff from **areas with livestock** can contain bacteria, nutrients, and pathogens, contributing to water pollution.
  - Lack of **vegetation cover** to trap and filter runoff allows pollutants to reach water bodies more easily.

Agricultural runoff in environment

Industrial discharge

- Sources:
  - Liquid waste discharged **directly into water bodies** from industrial processes
  - Rainwater carrying pollutants from **industrial areas** into nearby rivers and streams
  - **Unintended releases** of chemicals or pollutants during industrial activities

Industrial discharge in the environment

Deforestation

- Deforestation can contribute to water pollution through various mechanisms, and the **impact is often indirect but significant**. Here are some ways in which deforestation can be a cause of water pollution:
  - Soil Erosion
  - Runoff of Chemicals
  - Loss of Riparian Zones (banks)
  - Altered Water Flow
  - Loss of Biodiversity
  - Increased Risk of contamination

Municipal sewage

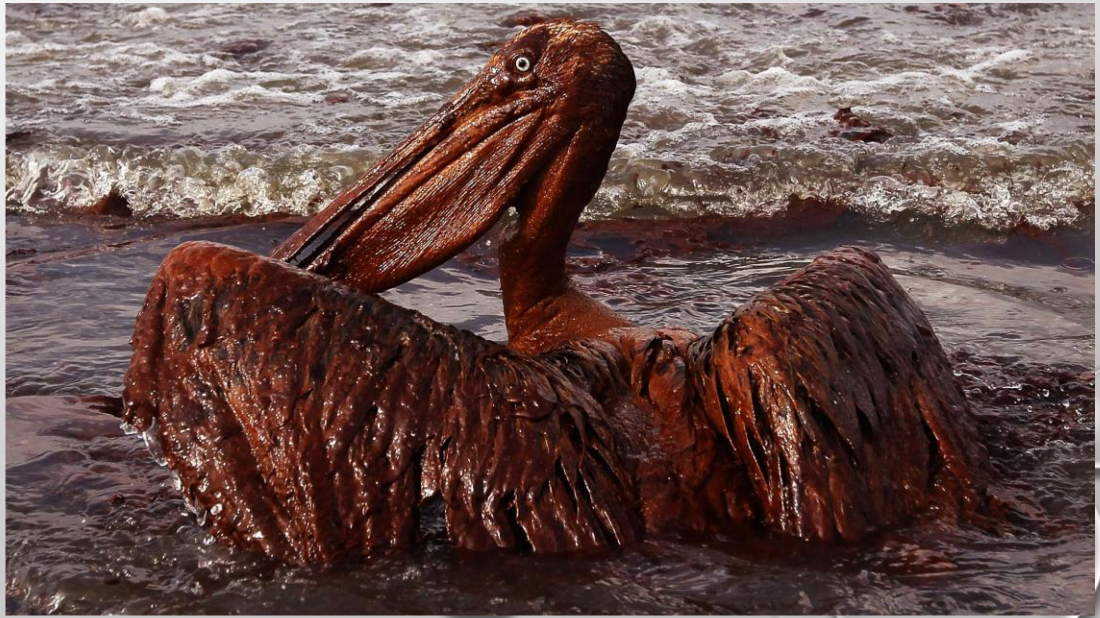
- Sources:
  - ➢Effluents released from **sewage treatment facilities** into water bodies
  - ➢Discharges occurring during **heavy rainfall**, when **stormwater** and **untreated sewage** mix and overflow into waterways
  - ➢**Leaks, breaks, or blockages** in municipal sewer lines leading to untreated sewage entering water sources

Ill effects of released effluents from sewage treatment plants

Oil spills

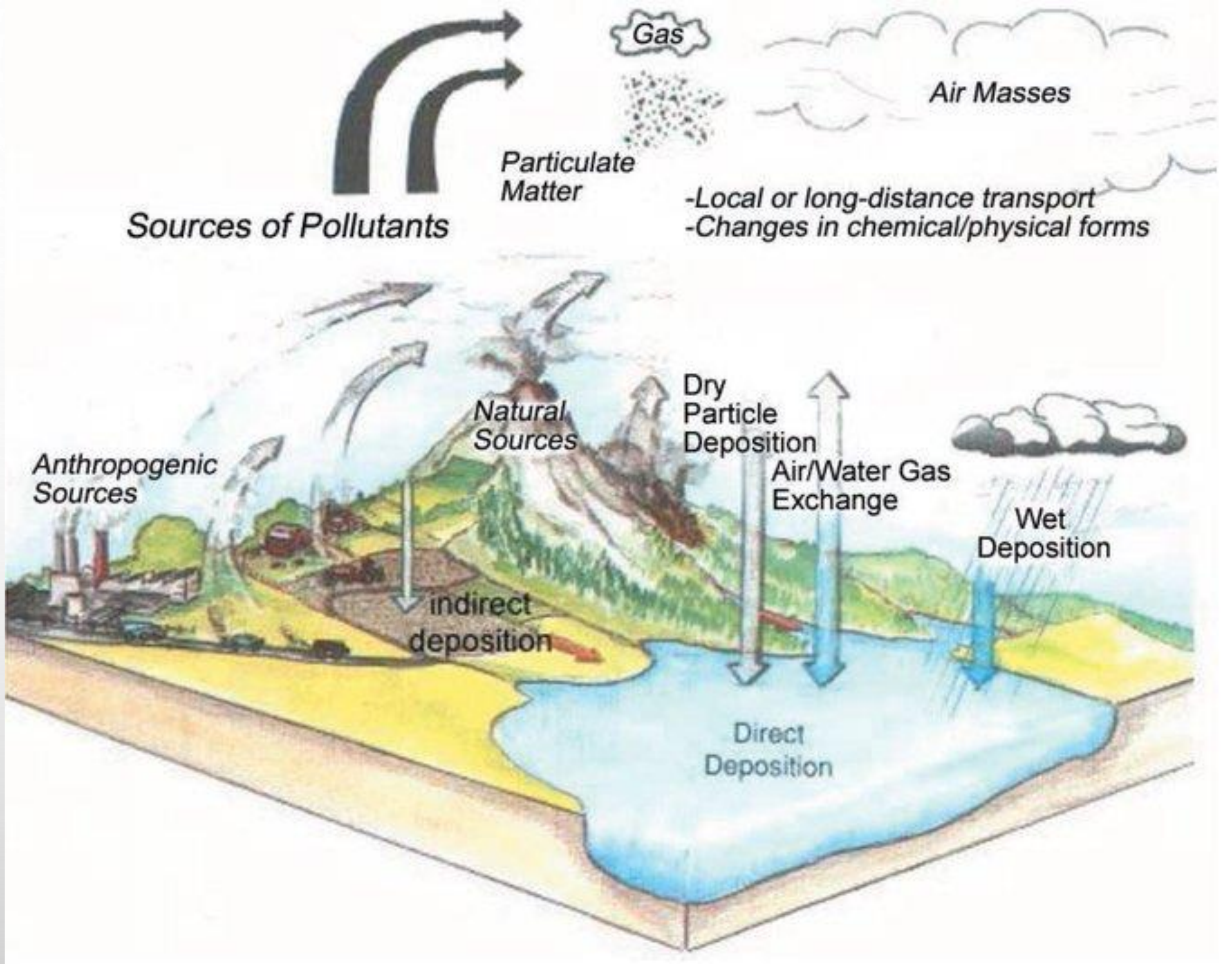
- **Sources** - Shipping Accidents, Offshore Drilling, Pipeline Ruptures, Well Blowouts, Natural Seepage, Industrial Activities, etc.

- Here are some ways in which oil spills can cause water pollution:
  - Oil spills release **toxic substances**, such as polycyclic aromatic hydrocarbons (PAHs), which are harmful to aquatic life and can contaminate water.
  - Oil coats the surfaces of marine organisms, disrupting their natural functions, **affecting respiration, and impairing their ability to feed**.
  - Microbes that break down oil consume oxygen, leading to **reduced oxygen levels** in the water, which can harm fish and other aquatic life.
  - Oil from spills can wash ashore, **affecting beaches and shorelines**, and causing harm to coastal ecosystems.



Atmospheric deposition

- Sources:
  - ➢Airborne pollutants **released by industries** settling on water surfaces
  - ➢Pollutants from **vehicle emissions** depositing into water bodies through air
  - ➢**Pesticides and fertilizers** transported by air settling into rivers and lakes



Schematic diagram of diffuse sources, distribution and atmospheric deposition of pollutants

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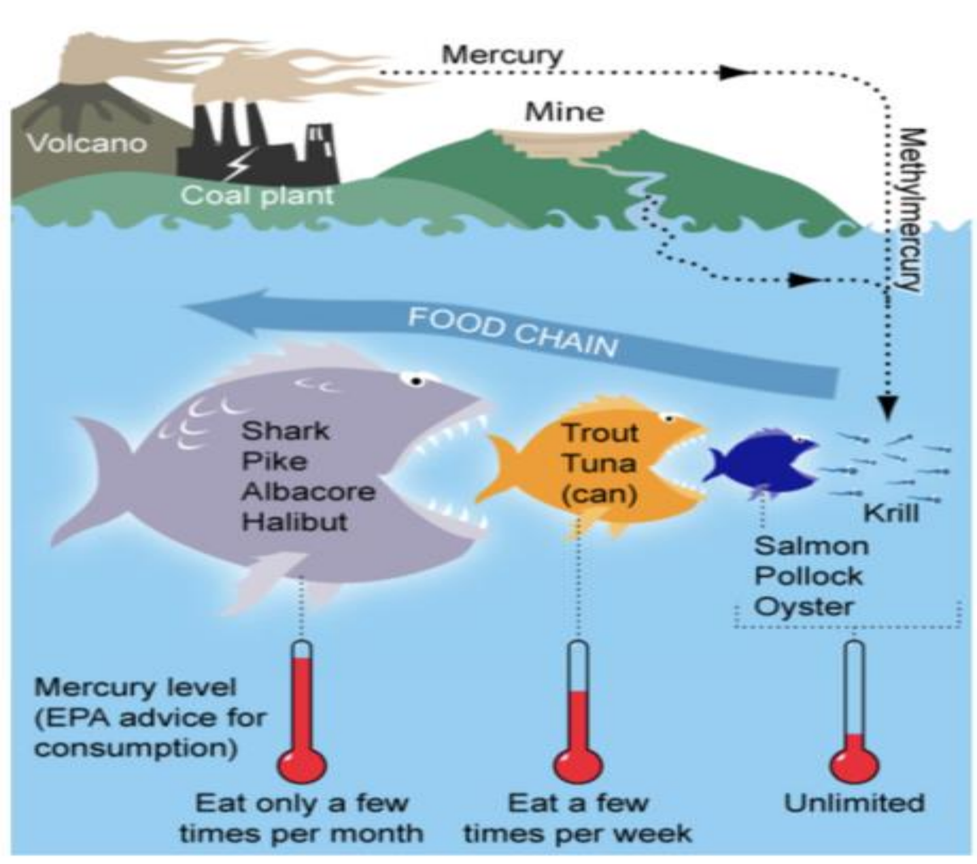
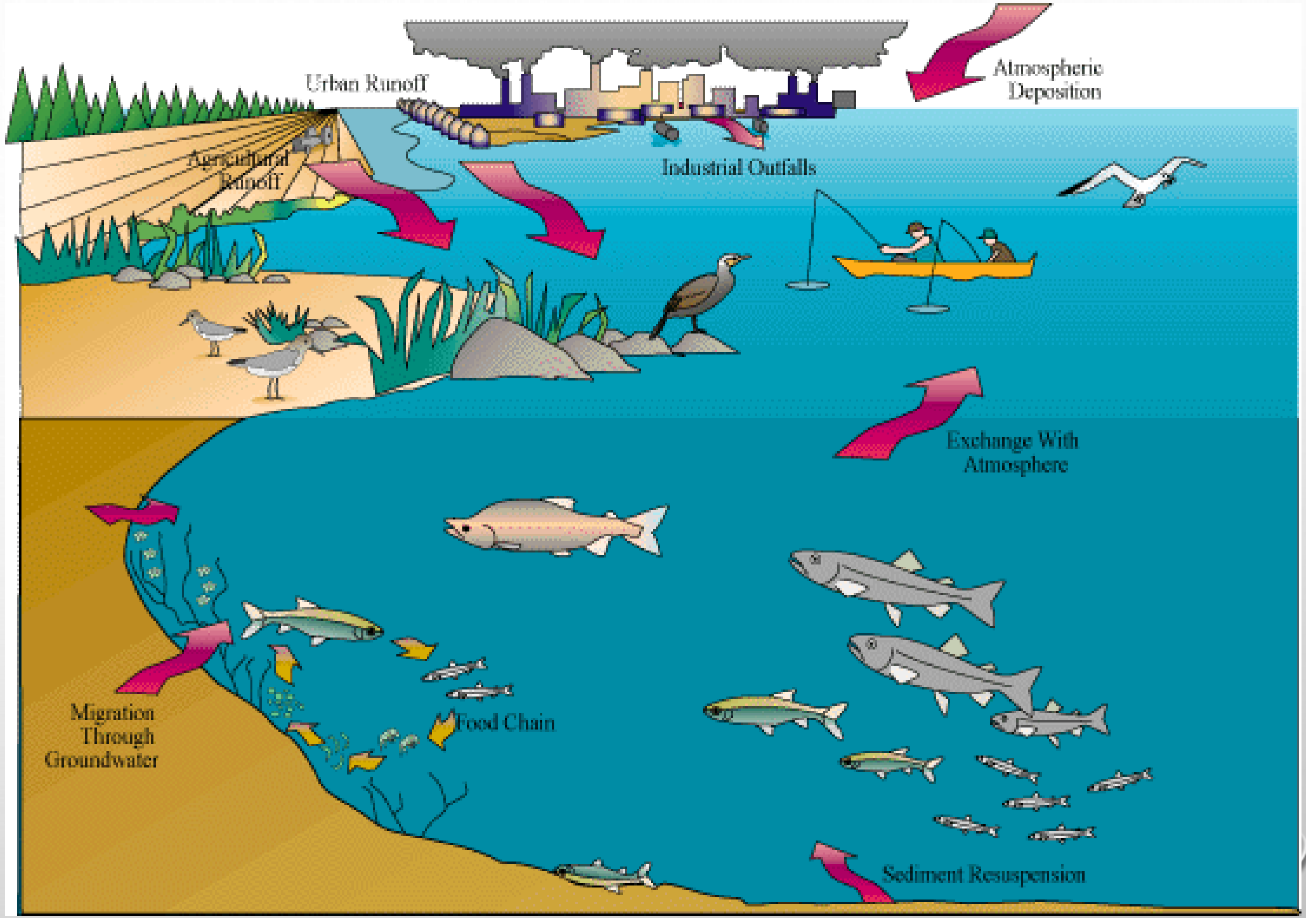
Environmental impacts

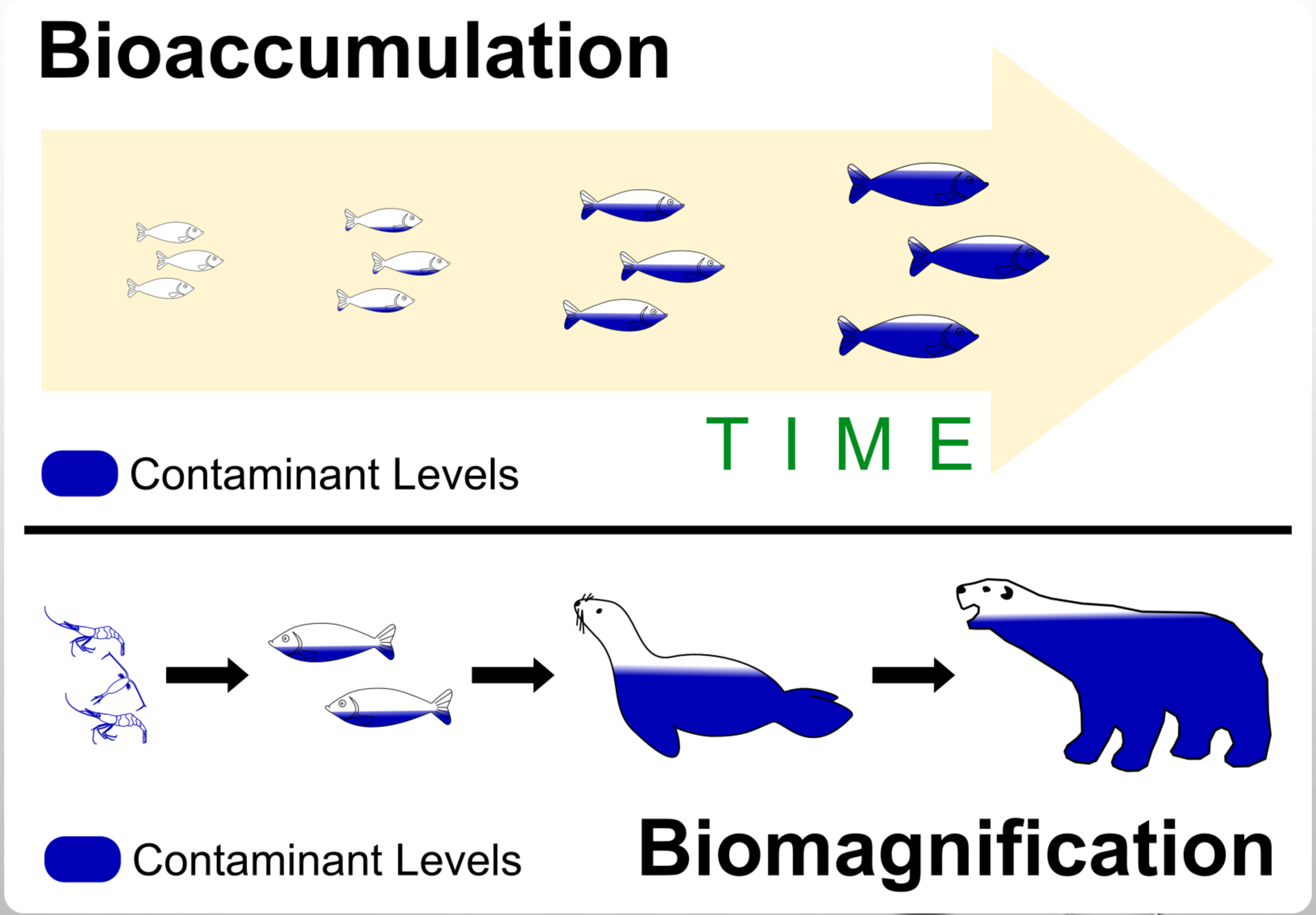


Bioaccumulation and Biomagnification



Disruption of the food chain leading to loss of habitat, loss of biodiversity, altered habitats, effects on aquatic life, etc.,

Biomagnification & Bioaccumulation



Effects on Aquatic Life

- High levels of pollution can lead to the **decline or extinction of various aquatic species**, disrupting the balance of ecosystems
- Pollutants such as organic matter or nutrients can stimulate the growth of microorganisms, leading to increased microbial activity that consumes oxygen. This **depletes oxygen levels** in the water, causing **"dead zones"** where aquatic life cannot survive.
- Toxic chemicals, heavy metals, or excessive nutrients can lead to **fish kills, harming populations and affecting the food chain.**
- Pollutants like heavy metals and certain chemicals can accumulate in the tissues of aquatic organisms, **gradually reaching higher concentrations** as they move up the food chain. This poses risks to predators, including humans.
- Sedimentation and pollution can degrade or destroy aquatic habitats, affecting the **reproduction and survival** of various species.
- Hormone-disrupting pollutants can interfere with the reproductive systems of aquatic organisms, leading to **altered reproductive patterns and reduced reproductive success**.

Effects on aquatic life (cont..)

- Exposure to certain pollutants may cause **genetic mutations** and **physical abnormalities** in aquatic organisms, affecting their health and viability.
- Changes in nutrient levels and the presence of pollutants can disrupt the **intricate web of relationships within ecosystems**, affecting the availability of food for various species.
- Pollutants can hinder the growth and development of aquatic organisms, particularly **larvae and juveniles**, leading to population declines.
- Aquatic organisms may exhibit altered behavior in response to pollution, **affecting feeding habits, migration patterns, and overall ecosystem dynamics**.

Effect of water pollution on aquatic life

Human Health Implications

- Some of the chemicals present in water affecting human health are the presence of **heavy metals such as Fluoride, Arsenic, Lead, Cadmium, Mercury, petrochemicals, chlorinated solvents, pesticides, and nitrates**
- Fluoride in water is essential for protection against dental carries and weakening of the bones. Concentration below **0.5 mg/L** causes **dental carries and mottling of teeth** but exposure to higher levels **above 1 mg/L** for 5-6 years may lead to adverse effects on human health leading to a condition called **fluorosis**.
- **Arsenic** is a **very toxic** chemical that reaches the water naturally or from wastewater of tanneries, the ceramic industry, chemical factories, and from insecticides such as lead arsenate, **effluents from fertilizers factories**, and from fumes coming out from burning of coal and petroleum.
- **Arsenic** is **highly dangerous** for human health causing **respiratory cancer, and arsenic skin lesions** from contaminated drinking water. Long exposure leads to **bladder and lung cancer**.
- Lead is contaminated in the drinking water source from pipes, fittings, solder, and household plumbing systems. In human beings, it affects the **blood, central nervous system, and the kidneys**.
- **Child and pregnant** women are **mostly prone** to lead exposure.

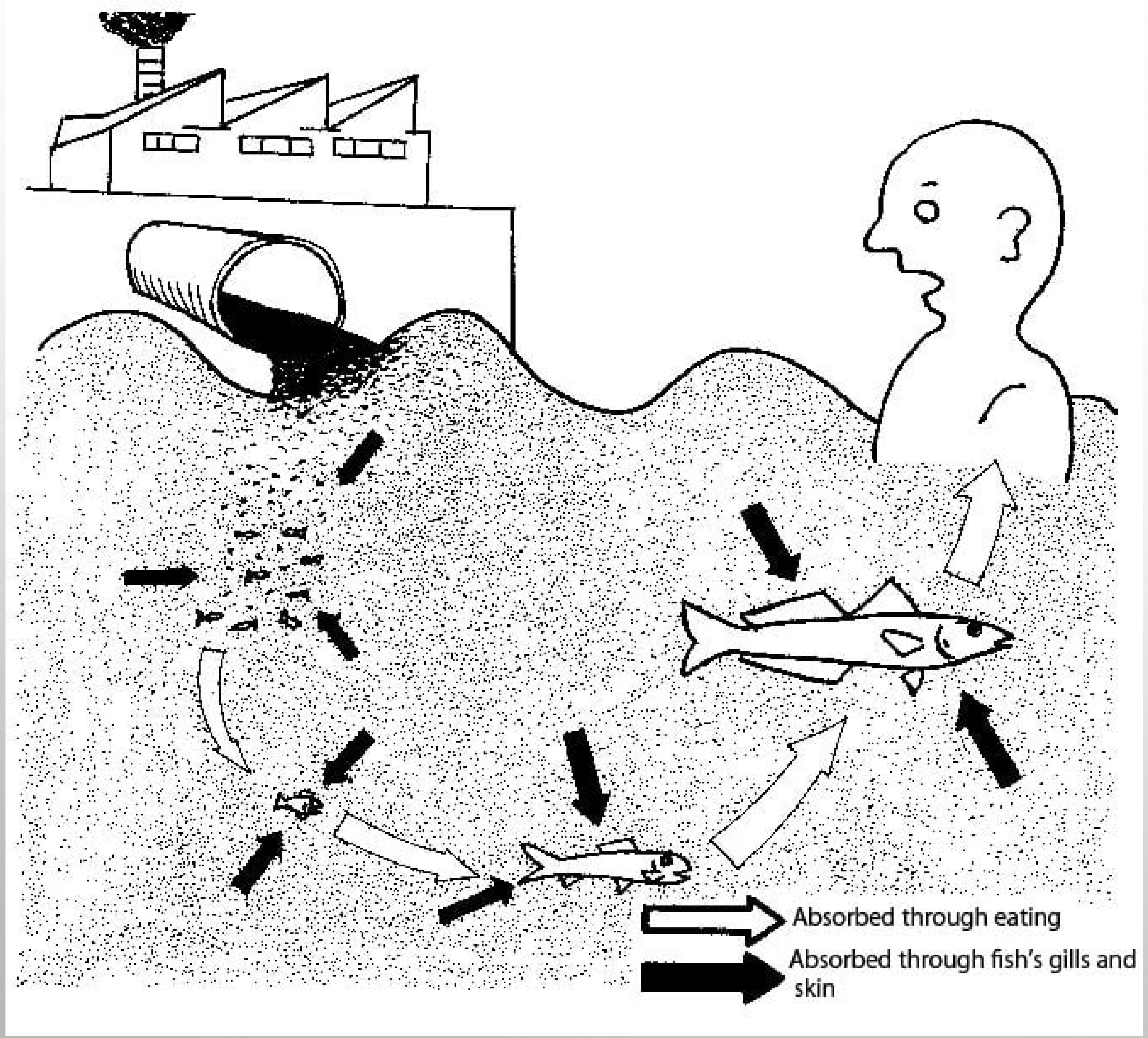
Human Health Implications (cont..)

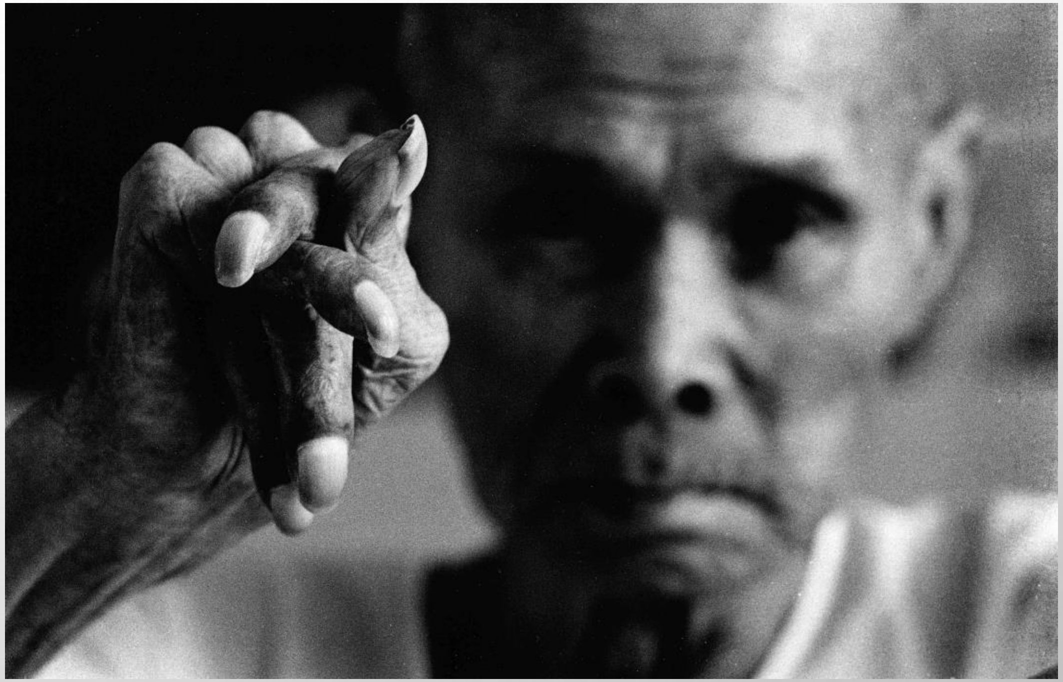
- **Mercury** is used in industries such as **smelters, manufacturers of batteries, thermometers, pesticides, fungicides** etc.
- The best-known example of Mercury pollution in the oceans took place in 1938 when a **Japanese factory** discharged a significant amount of **mercury into Minamata Bay**, by contaminating the fish stocks there. It took several years to show its effects.
- By that time, many local people had eaten the fish and around 2000 were poisoned, hundreds of people were left dead and disabled and the cause for death was named **“Minamata disease”** due to **consumption of fish containing methyl mercury**.
- It causes **chromosomal changes and neurological damage** to humans. Mercury shows **biological magnification** in aquatic ecosystems.

Effects of mercury in drinking water

Effects of arsenic in drinking water

Minamata disease

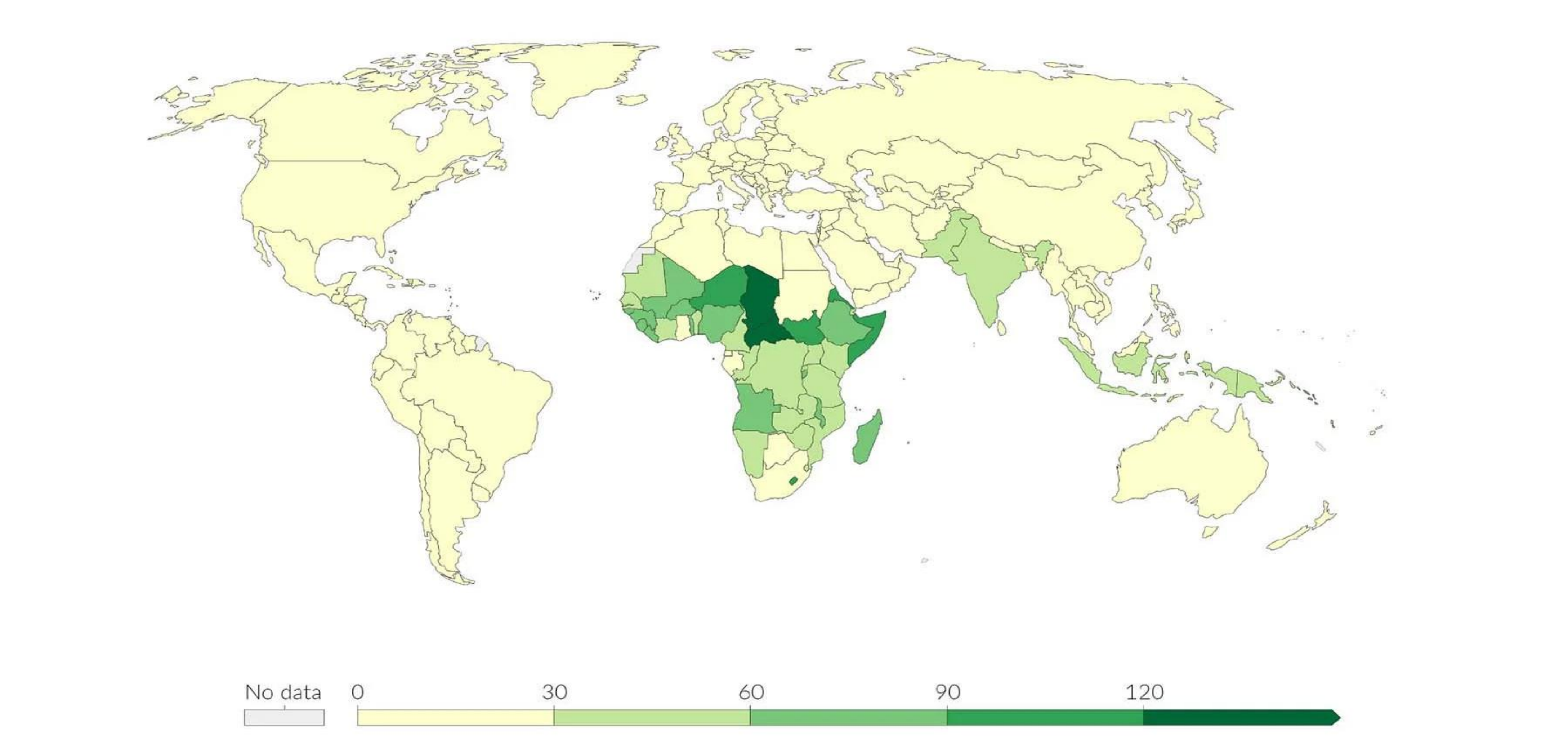




Water-related disease

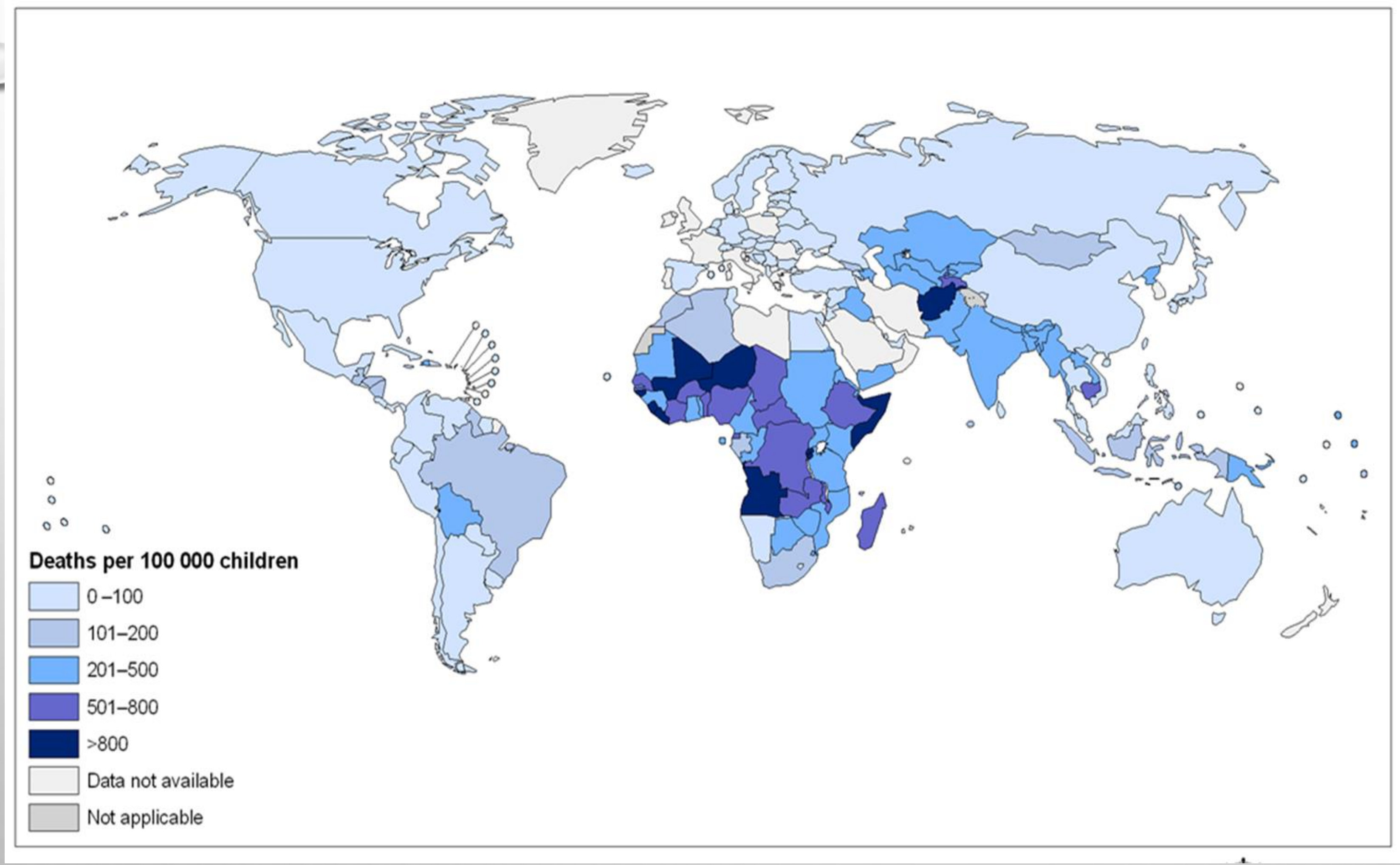
Category	Transmission	Disease examples
Water-borne	Ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria, viruses or parasites	Gastroenteritis, enteric hepatitis, amoebic & bacillary dysentery, cholera, leptospirosis, poliomyelitis, typhoid/paratyphoid fever
Water-washed	Skin, ear or eye contact with contaminated water & poor personal hygiene	Conjunctivitis, trachoma, intestinal helminth infections, leprosy, scabies
Water-aerosol disease	Inhalation of water aerosol containing pathogen	Legionellosis, phiesteria
Water-based	Parasitical worm infections (parasites found in intermediate organisms living in water)	Dracunculiasis, schistosomiasis, (tricho) bilharziasis
Water-related arthropod vector	Insect vectors breeding in water or biting near water	Dengue, lymphatic filariasis, malaria, onchocerciacis, trypanosomiasis, yellow fever

Human health implication (cont..)



Death rates as the number of deaths per 100,000 individuals from unsafe water sources till 2019

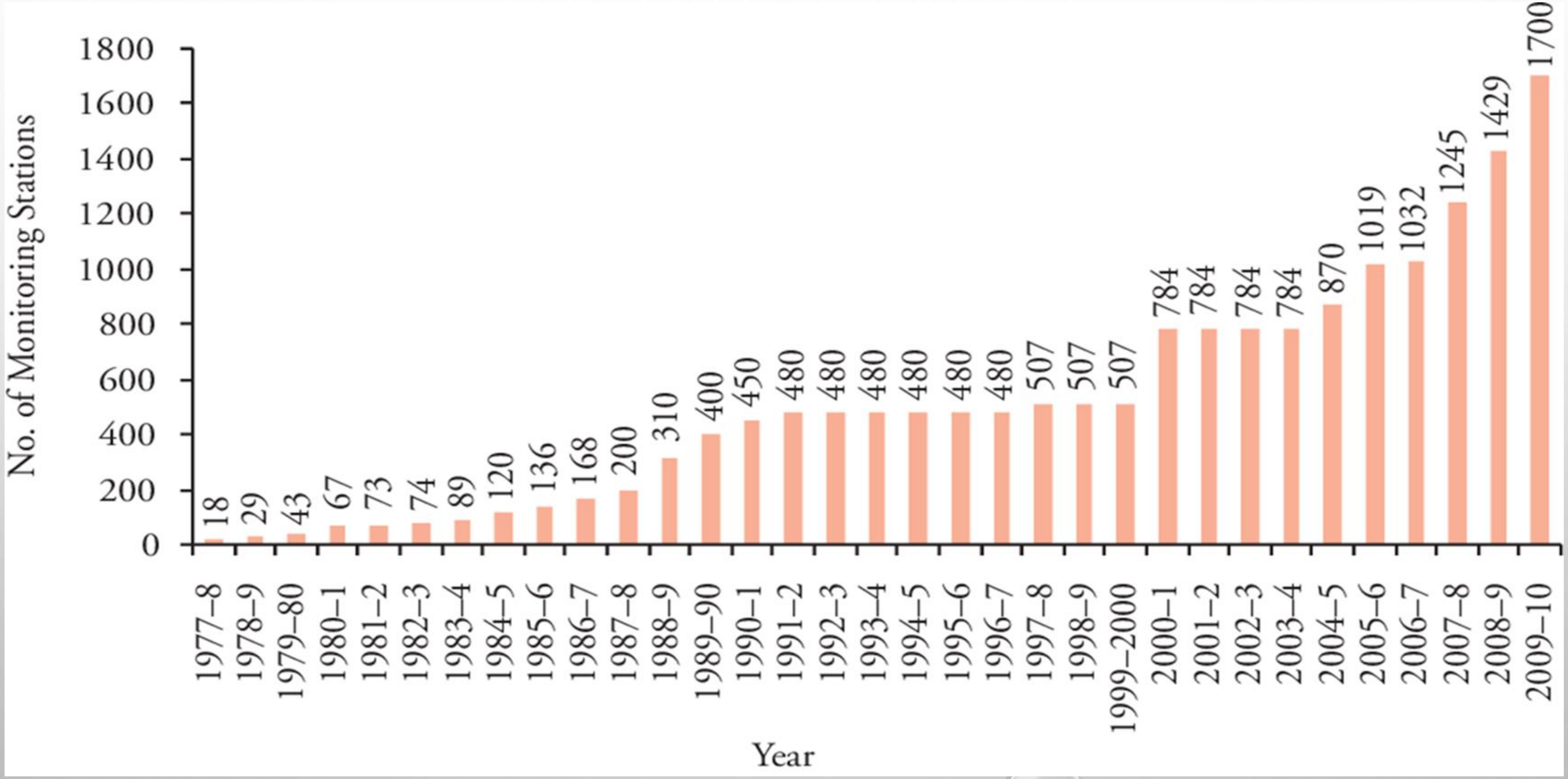
Human health implication (cont..)



Deaths attributed to water, sanitation and hygiene (diarrhoea) in children aged under 5 years till 2004

The WHO reports that nearly **2 billion people** around the world lack safe drinking water, of which **297 thousand** are children aged under **5 years**, are **estimated to die each year** from water pollution-related diseases, particularly infectious **diarrhea**.

Monitoring and Measurement



Growth of water pollution monitoring network in India – CPCB 2009

Water quality parameters

- Reflection of how clean/polluted the sample of water is
- There are three types of water quality parameters **physical, chemical and biological**

Physical parameters

- Solids
- Turbidity
- Color
- Temperature
- Taste and odor
- Electrical conductivity

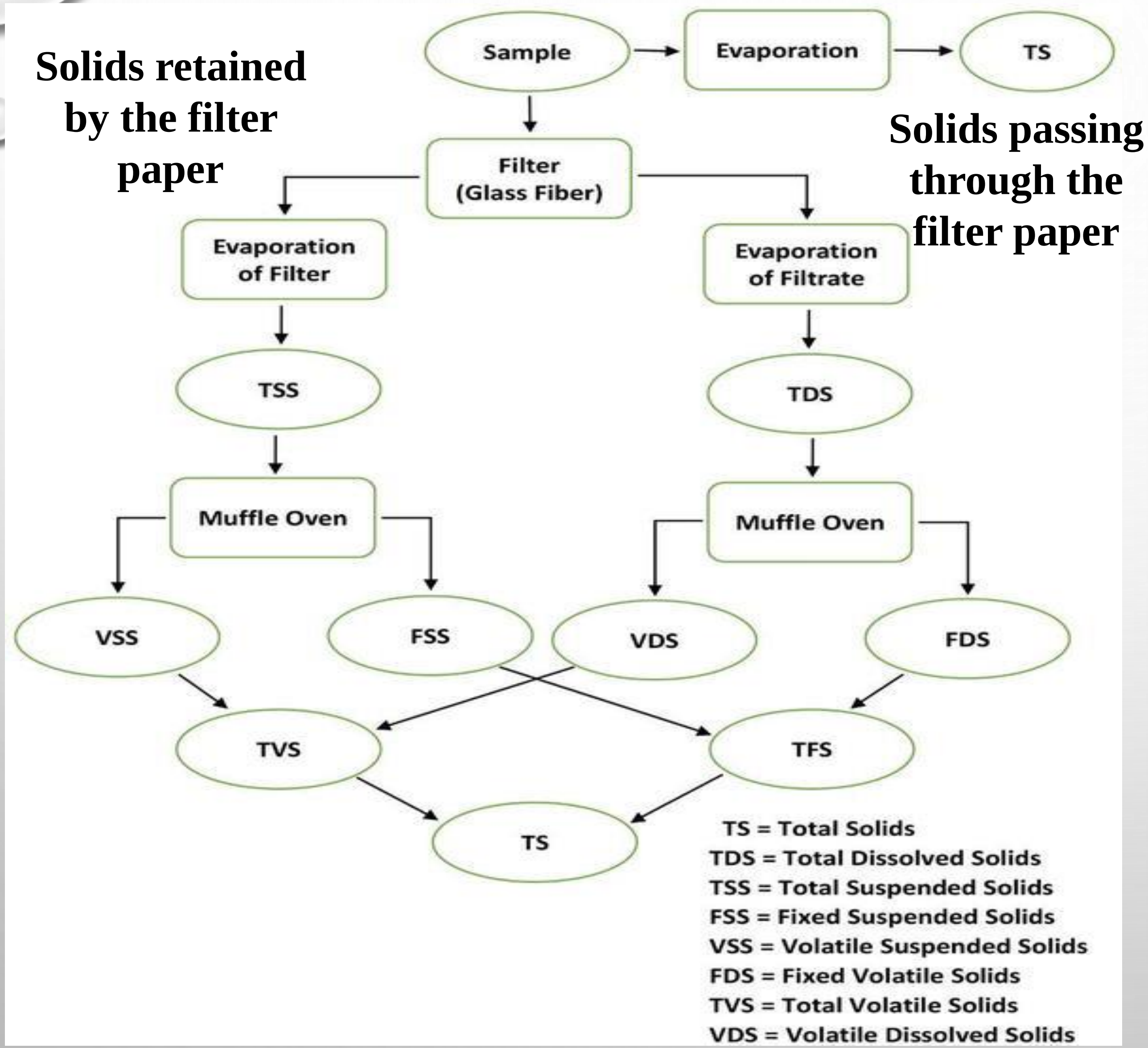
Chemical parameters

- pH
- Alkalinity
- Hardness
- Dissolved ion
- Heavy metals
- Refractory organics
- Nutrients

Biological parameters

- Bacteria
- Virus
- Protozoa
- Helminths

Solids



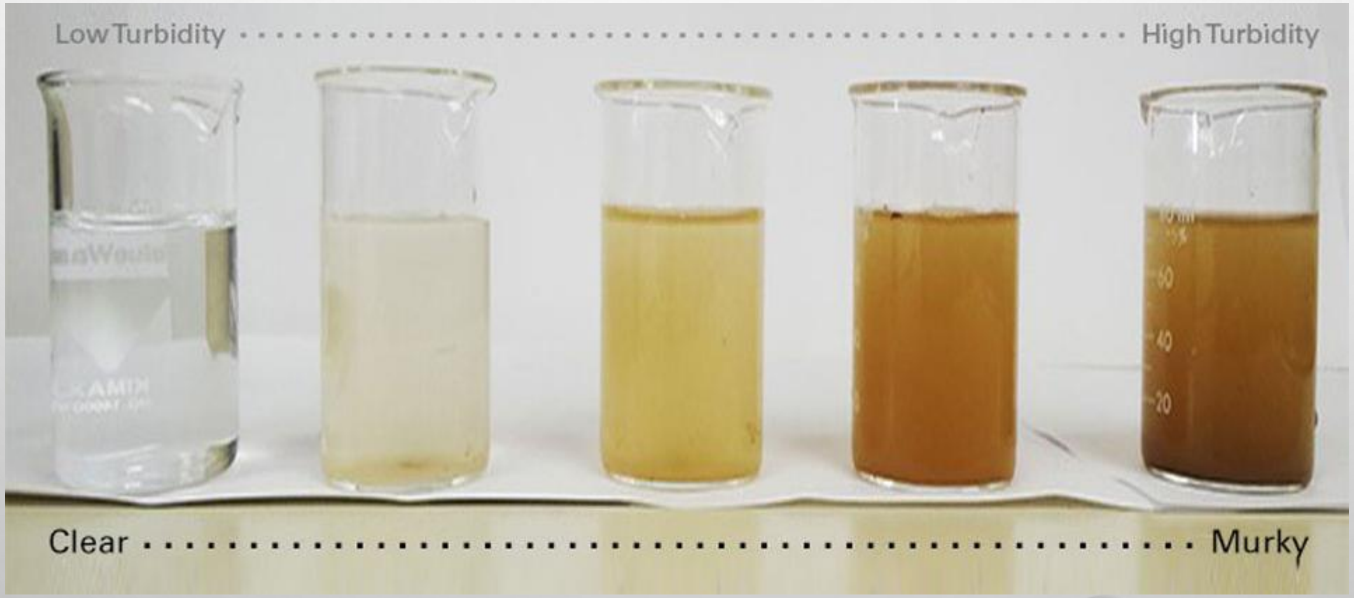
Interrelationships of solids found in water

Solids in water can be in suspended, colloidal or in dissolved form

Particle type	Size range, µm
Suspended	1 to 100
Colloidal	10^{-3}
Dissolved	10^{-5} to 10^{-3}

Turbidity

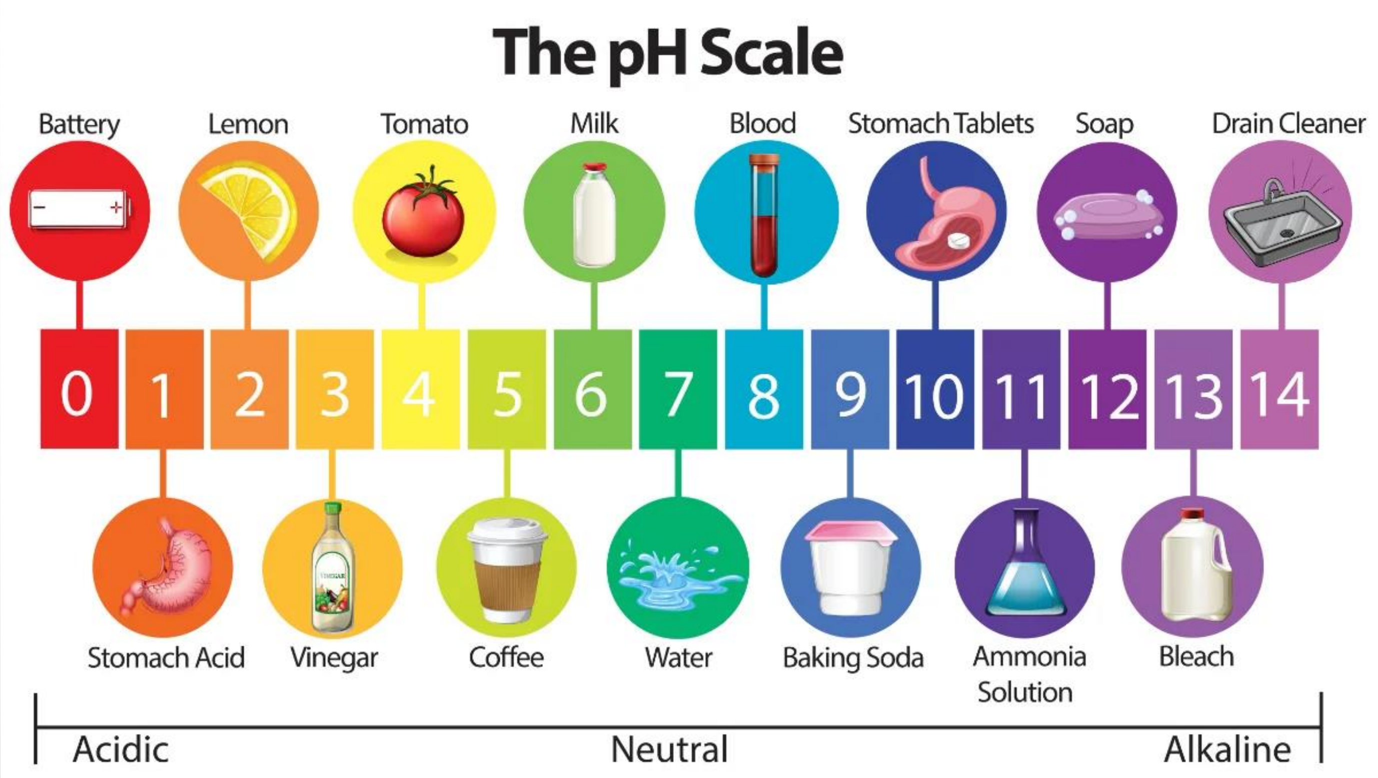
- Turbidity is a measure of the extent **to which light is either adsorbed or scattered** by the suspended material in water
- Indirect measure of **solids** in water
- Commonly used in water treatment plants (WTP) to measure the **quality of potable water**
- Turbidity in surface waters is **mostly** due to the presence of **colloidal particles**
- Measured using turbidimeter and expressed as NTU (Nephelometry turbidity unit)



Turbidity of different water samples

Alkalinity

- Measure of the **ability of water to neutralize acids**
- Most common constituents of alkalinity are bicarbonate (HCO_3^-), carbonate(CO_3^{2-}) and hydroxide (OH^-)
- Alkalinity is **pH** dependent
- Measured by titration
- Used as a process control variable in water and wastewater treatment



The pH scale showing alkalinity of water

pH

- pH is a measure of **how acidic or basic** (alkaline) the water is.
- The term pH comes from the French: "**puissance d'Hydrogène**”, which means strength of the hydrogen.
- It is defined as the **negative log of the hydrogen ion concentration**.
- The pH scale is logarithmic and goes from **0 to 14**.
- For each **whole number increase** (i.e. 1 to 2) the hydrogen ion concentration decreases **ten fold** and the water becomes less acidic.
- As the pH **decreases**, water becomes more **acidic**.
- As water becomes more **basic**, the pH **increases**.
- Many chemical reactions inside aquatic organisms (cellular metabolism) that are necessary for survival and growth of organisms **require a narrow pH range**.
- Changes in pH may alter the concentrations of other substances in water to a **more toxic form**

Hardness

- Defined as the **concentration of multivalent metallic cations** in solution
- In natural waters, hardness is caused by **calcium and magnesium ions**
- Hardness is classified as **carbonate hardness and noncarbonate hardness** depending on the anion with which it associates
- Carbonate hardness is equivalent to **alkalinity**
- Carbonate hardness precipitates readily as **upon boiling**
- Measured by titration and expressed as **mg/L as $CaCO_3$**

Effect of hard water

Conductivity

- The conductivity of water is a **measure of the ability of a solution to carry or conduct an electrical current**.
- Since the electrical current is carried by ions in solution, the **conductivity increases** as the **concentration of ions increases**.
- The major positively charged ions are **sodium, (Na^{+}) calcium (Ca^{+2}), potassium (K^{+}) and magnesium (Mg^{+2}).**
- The major negatively charged ions are **chloride (Cl^{-}), sulfate (SO_4^{-2}), carbonate (CO_3^{-2}), and bicarbonate (HCO^{3-}).**
- **Nitrates (NO^{-2}) and phosphates (PO_4^{-3})** are **minor contributors** to conductivity, although they are very important biologically.
- The conductivity can be used to **estimate the TDS** value of water

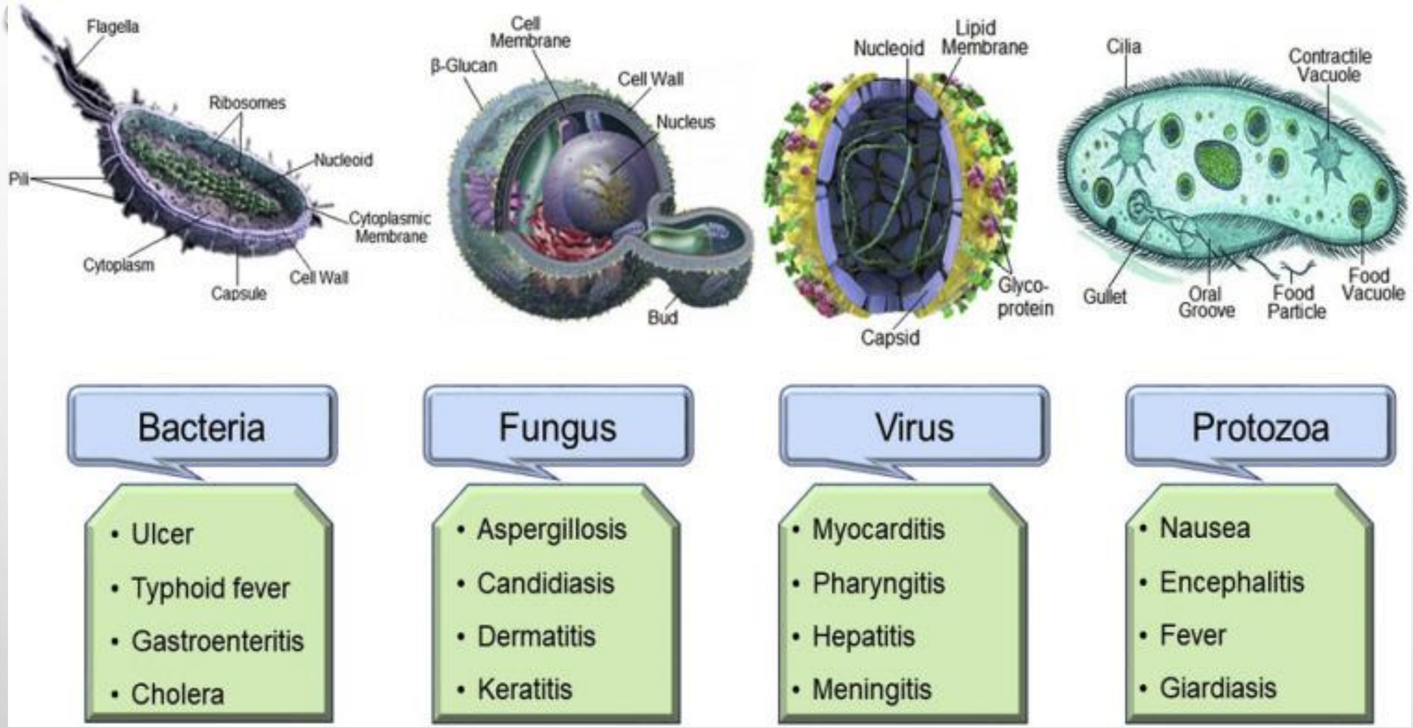
Nutrients

- Nitrogen and phosphorus are the **limiting nutrients** in aquatic plant growth
- High amounts of nutrients in surface water leads to the excessive growth of algae which is known as **eutrophication**
- Nitrate contamination leads to **methemoglobinemia or blue baby syndrome**

Eutrophication

Blue baby syndrome

Pathogens



Different types of pathogens and water-borne diseases associated with them

- Organisms capable of **infecting or transmitting** diseases to humans
- Bacteria, viruses, protozoa, helminths
- **Most critical parameter** in drinking water quality

1. **BACTERIA**
- Typhoid fever – salmonella typhi
- Paratyphoid fever – salmonella Paratyphi
- Cholera – vibrio cholerae
- Bacillary dysentery – shigella Dysentrial

2. PROTOZOA
- Amoebiasis
- Amoebic dysentery – entamoeba Histolytica

3. VIRUS
- Polio
- Infectious hepatitis

4. HELMINTHS
- Swimmer’s itch

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Organic content estimation

Estimation of organic content of the wastewater

- The organic matter present in the water body can be analyzed in laboratory by determining **Biochemical Oxygen Demand (BOD)**, **Chemical Oxygen Demand (COD)**, and by determination of **Total Organic Carbon (TOC)**.
- The Total Organic Carbon (TOC) analyzer utilizes a catalytic oxidation **combustion technique** at **high temperature** (the temperature raises up to **720 ºC**), to **convert organic carbon into CO_2**.
- The **CO_2 generated** by oxidation is measured with a **sensor**.

Biochemical Oxygen Demand (BOD)

- The BOD can be defined as the **oxygen required for biochemical oxidation of organic matter** present in the water under **aerobic conditions**.
- This test is based on the premise that all the **biodegradable organic** matter contained in a water sample will be **oxidized to CO_2 and H_2O** by **microorganisms** using **molecular oxygen**.
- The **actual BOD will be less than theoretical oxygen demand** due to incorporation of some of the carbon into **newly synthesized bacterial cells**.

Biochemical Oxygen Demand (BOD)

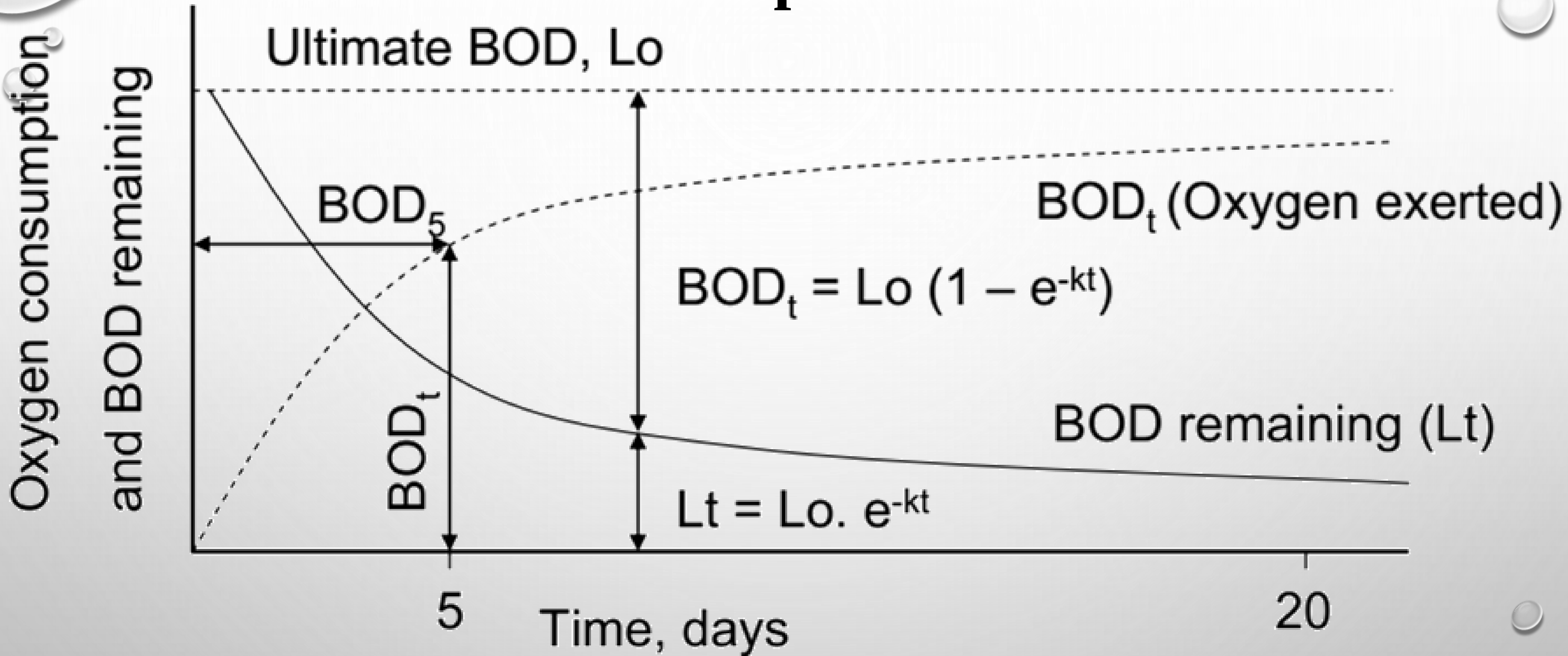
- During the BOD test the organic matter will be converted into **stable end product** such as **CO_2, sulphate (SO_4), orthophosphate (PO_4) and nitrate (NO_3)**. The simple representation of **carbonaceous BOD** can be explained as below:

$$\text{Organic matter} + O_2 \xrightarrow{\text{microorganisms}} CO_2 + H_2O + \text{New Cells} + \text{Stable products}$$

- This reaction continues till **sufficient DO is available** in the water. When DO is not available, **anaerobic decomposition** takes place (**fermentative reduction**). The reaction under **anaerobic conditions** is as under:

$$\text{Organic matter} \xrightarrow{\text{microorganisms}} CO_2 + CH_4 + \text{New Cells} + \text{Other products } (NH_3,\ H_2S)$$

BOD profile



For polluted water and wastewater, a typical value of **K (base e, 20°C) is 0.23 per day and K (base 10, 20°C) is 0.10 per day**. These values vary widely for the wastewater in the range from **0.05 to 0.3 per day for K (base 10) and 0.23 to 0.7 for K (base e)**.

BOD profile

- The **ultimate BOD (Lo)** is defined as the **maximum BOD exerted** by the wastewater.
- It is difficult to assign **exact time to achieve ultimate BOD**, and theoretically it takes **infinite time**.
- From the practical point of view, it can be said that **when the BOD curve is approximately horizontal the ultimate BOD** has been achieved.
- The **time required** to achieve the ultimate BOD depends upon the characteristics of the wastewater, i.e., **chemical composition of the organic matter** present in the wastewater and **its biodegradable properties** and **temperature** of incubation.
- The ultimate BOD best expresses the **total concentration of degradable organic** matter based on the **total oxygen required** to oxidize it.
- However, it **does not indicate how rapidly oxygen** will be depleted in the receiving water.

Formula for BOD estimation

For non-seeded samples

$$\text{The 5 day BOD of sample} = \frac{DO_i - DO_f}{p}$$

Where, DO_i and DO_f are initial and final DO of diluted wastewater sample

$$p \text{ is the dilution fraction} = \frac{\text{Volume of wastewater}}{\text{Volume of wastewater + volume dilution water}}.$$

Note: The total volume is generally 300 mL for a BOD sample bottle

For seeded samples

$$BOD_5 = \frac{(DO_i - DO_f) - (B_i - B_f)(1 - p)}{p}$$

Where,

DO_i an DO_f = DO of mixture, initial and final values, respectively,

B_i and B_f = DO of blank, initial and final values, respectively,

p = V_w/V_m = Volume of wastewater in mixture / Total volume of mixture.

Numerical

- A test bottle containing only seeded dilution water has its DO level drop by 1.0 mg/L in a 5-day incubation. A 300 mL BOD bottle filled with 10 mL of wastewater and the rest seeded dilution water experiences a DO drop of 6.2 mg/L in the same time period. What would be five day BOD of the wastewater?

Solution

Solution:

Dilution factor p = 10/300

Therefore, BOD_5 = [6.2 – 1.0 (1 – (10/300))] / (10/300) = 157 mg/L

Temperature correction

- The biochemical reactions are **temperature dependent** and the activity of the **microorganism increases with the increase in temperature** up to certain value, **and drop with decrease in temperature**.
- Since, the **oxygen utilization** in BOD test is caused by **microbial metabolism**, the rate of utilization is **similarly affected by the temperature**.
- The standard temperature at which BOD is determined is usually **20°C; however, BOD can be converted to different temperatures.**
- However, the **water temperature** may vary from **place to place** for the same river; hence, the BOD rate constant is adjusted to the **temperature of receiving water** using following relationship:

Temperature correction

$$K_T = K_{20}\,\theta^{(T-20)}$$

Where

T = temperature of interest, ^oC

K_T = BOD rate constant at the temperature of interest, day^{-1}

K_{20} = BOD rate constant determined at 20^oC, day^{-1}

θ = temperature coefficient. This has a value of 1.056 in general and 1.047 for higher temperature greater than 20^oC. This is because increase in reaction rate is higher when temperature increases from 10 to 20^oC as compared to when temperature is increased from 20 to 30^oC.

Numerical

- The BOD of a sewage incubated for one day at 30°C has been found to be 100 mg/L. What will be the five day 20°C BOD? Assume K = 0.12 (base 10) at 20°C, and $\theta = 1.056$.

Solution

BOD at 30^oC = 100 mg/L

$K_{20} = 0.12$

Now $K_{30} = K_{20}\ \theta^{(T-20)}$

$K_{30} = 0.12\ (1.056)^{30-20} = 0.207$ per day

$BOD_t = Lo\ (1 - 10^{-kt})$

$100 = Lo\ (1 - 10^{-0.207 \times 1})$

Lo = 263.8 mg/L

This is ultimate BOD, the value of which is independent of incubation temperature.

Now BOD_5 at 20^oC can be calculated as:

BOD_5 at 20^oC $= Lo\ (1 - 10^{-kt}) = 263.8\ (1 - 10^{-0.12 \times 5}) = 197.5$ mg/L

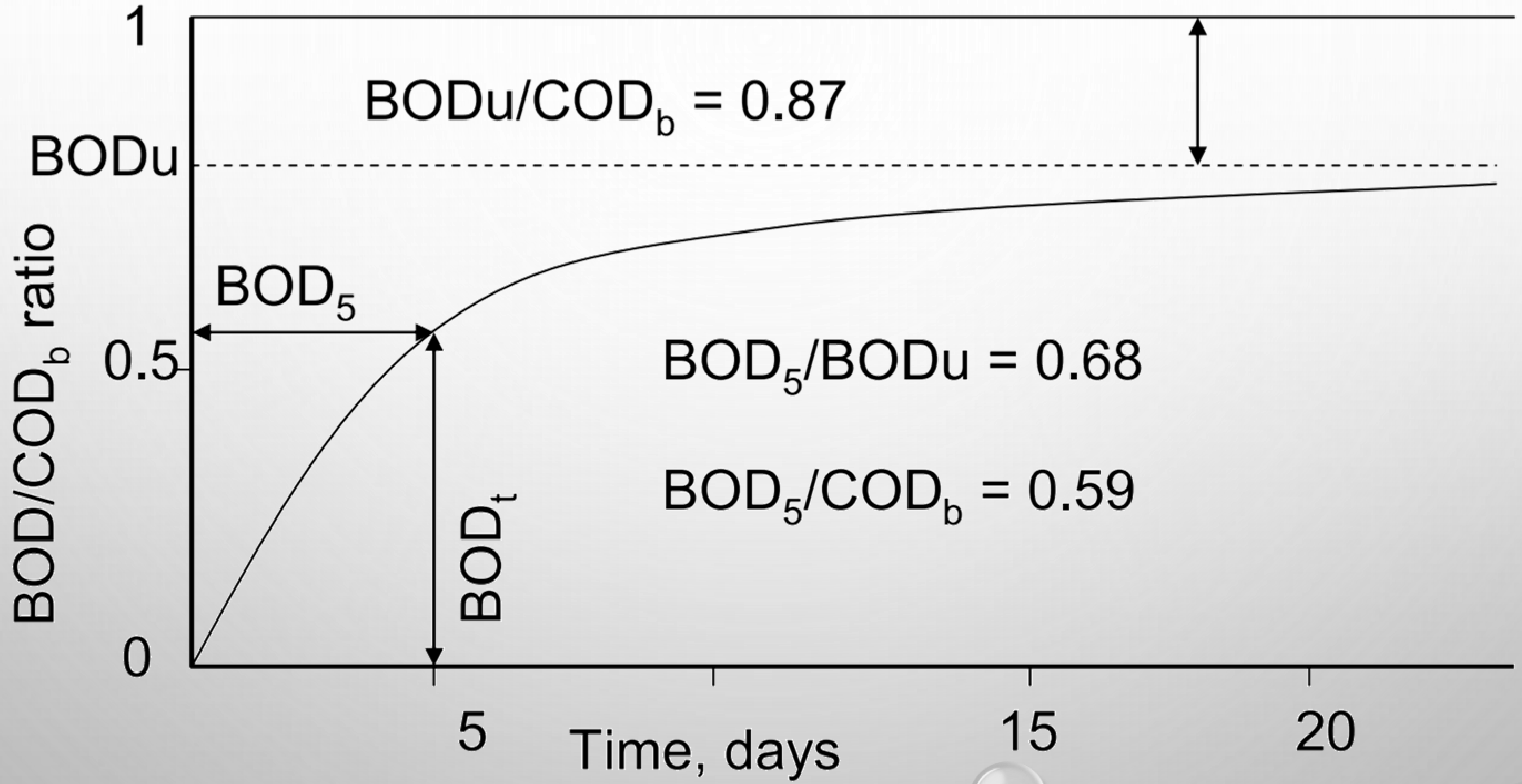
Chemical Oxygen Demand (COD)

- In this test to determine the **oxygen requirement** of the wastewater, strong oxidizing agent '**potassium dichromate**' is used.
- **Acidic environment** is provided to **accelerate the reactions** by addition of **sulphuric acid**.
- The reflux flasks (or closed reflux vials), used for the test, are heated to **150°C for two hours** with silver sulphate as catalyst.
- When **silver sulphate catalyst** is used, the recovery of **most organic compounds** is greater than **92 percent**.
- COD test measures virtually **all oxidizable organic compounds** whether biodegradable or not, **except some aromatic compounds** which **resists dichromate oxidation**.

Chemical Oxygen Demand (COD)

- The **COD is proportional to BOD** only for **readily soluble organic** matter in dissolved form **e.g. sugars**.
- **No correlation** between BOD and COD exists when:
  - Organic matter is present in **suspended form**; under such situation **filtered samples** should be used.
  - Complex wastewater containing **refractory** substances.
- For readily biodegradable waste, such as dairy **COD = BODu/0.92**

Correlation between BOD and COD



Chemical Oxygen Demand (COD)

- The **COD is faster** determination but does not give idea about th**e nature of organic matter** whether **biodegradable or biorefractory** organic matter.

- Hence, determination of BOD is necessary for the wastewater to know the fraction of **biodegradable organic matter**.

- The BOD is not very useful test for routine plant control due to the requirement of **long incubation period**, hence requiring **long time (5 days)** to obtain results.

Theoretical Oxygen Demand (ThOD)

- Theoretical oxygen demand for the wastewater is calculated as **oxygen required for oxidizing the organic matter** to end products.

- For example, for glucose, the theoretical oxygen demand can be worked out as below:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$ThOD = (6\ M_{o2}) / (M_{C_6H_{12}O_6}) = (6 \times 16 \times 2) / (12 \times 6 + 1 \times 12 + 6 \times 16) = 1.07$$

- For most of the organic compounds (except aromatics resisting dichromate oxidation) **COD is equal to ThOD**.

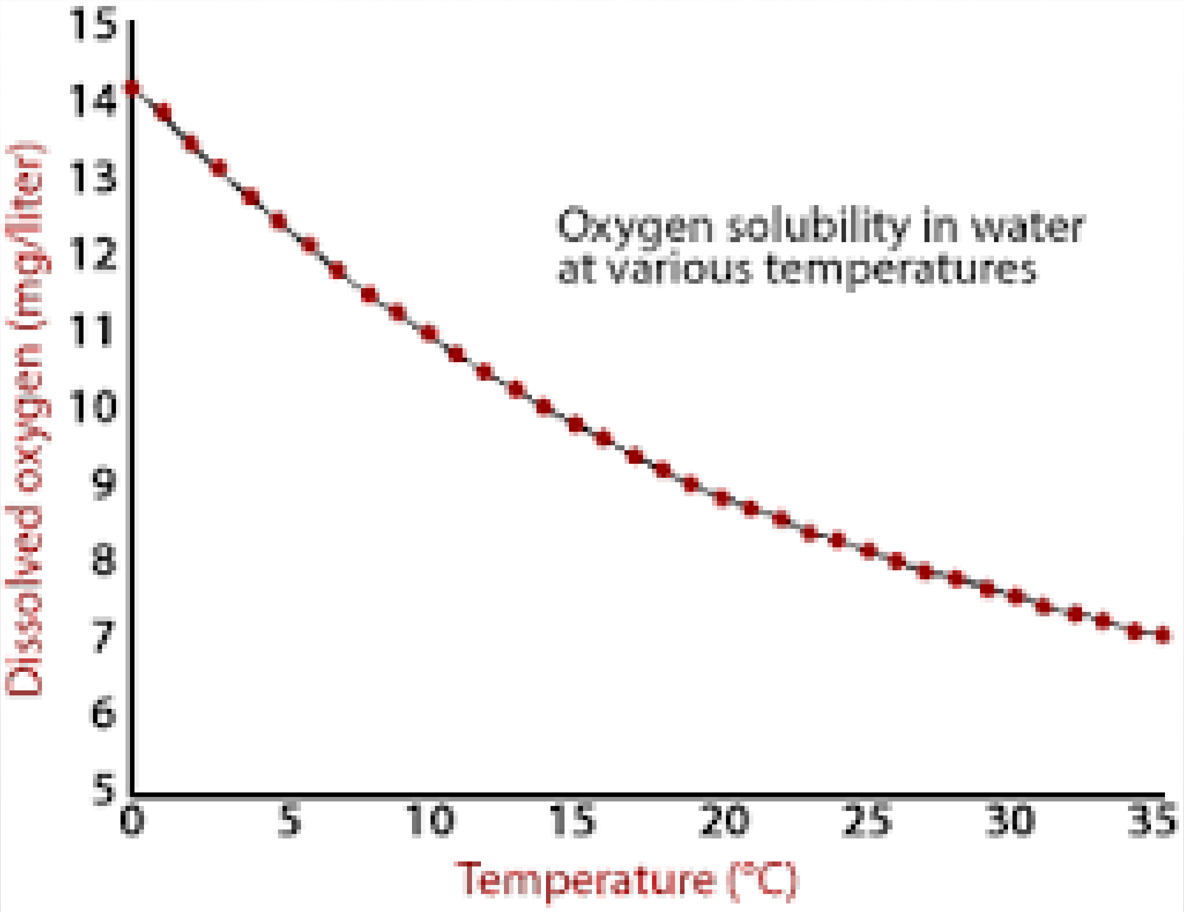
4th class

Self Purification of Natural Streams

Self Purification of Natural Streams

- The **self purification** of natural water systems is a **complex process** that often involves **physical, chemical, and biological** processes working **simultaneously**.
- The amount of Dissolved Oxygen (DO) in water is one of the most commonly used **indicators of a river health**.
- As DO drops below **4 or 5 mg/L** the forms of life that can survive begin to be **reduced**.
- A **minimum of about 2.0 mg/L** of DO is required to maintain **higher life forms**.
- **Oxygen demanding wastes** remove **DO**; **plants add DO** during day but **remove it at night**; **respiration of organisms removes oxygen**.
- In summer, **rising temperature reduces solubility of oxygen**, while **lower flows reduce** the rate at which **oxygen enters the water from atmosphere**.

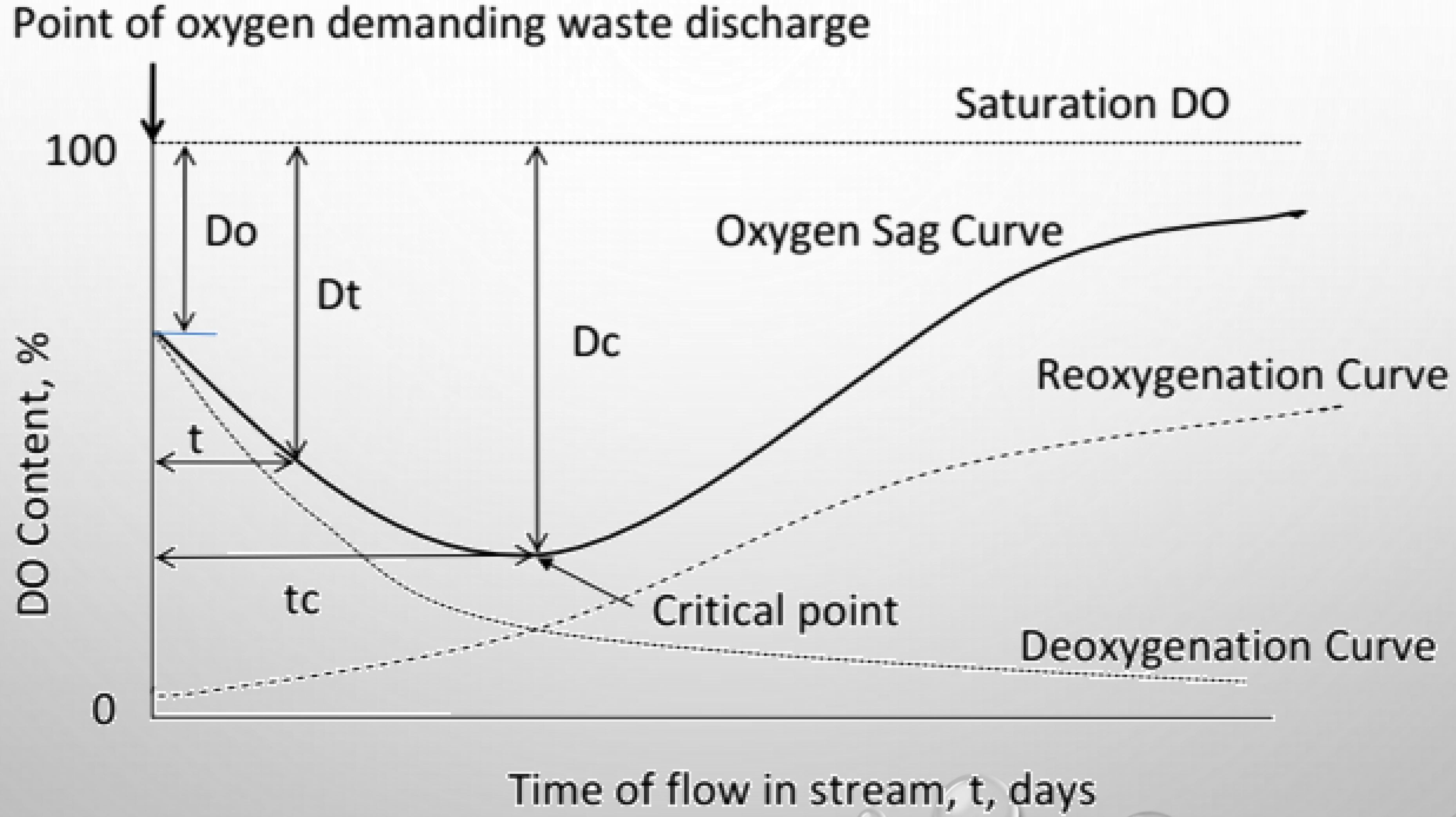
DO vs temperature



Factors Affecting Self Purification

- Dilution
- Current
- Temperature
- Sunlight
- Rate of oxidation

Oxygen sag curve



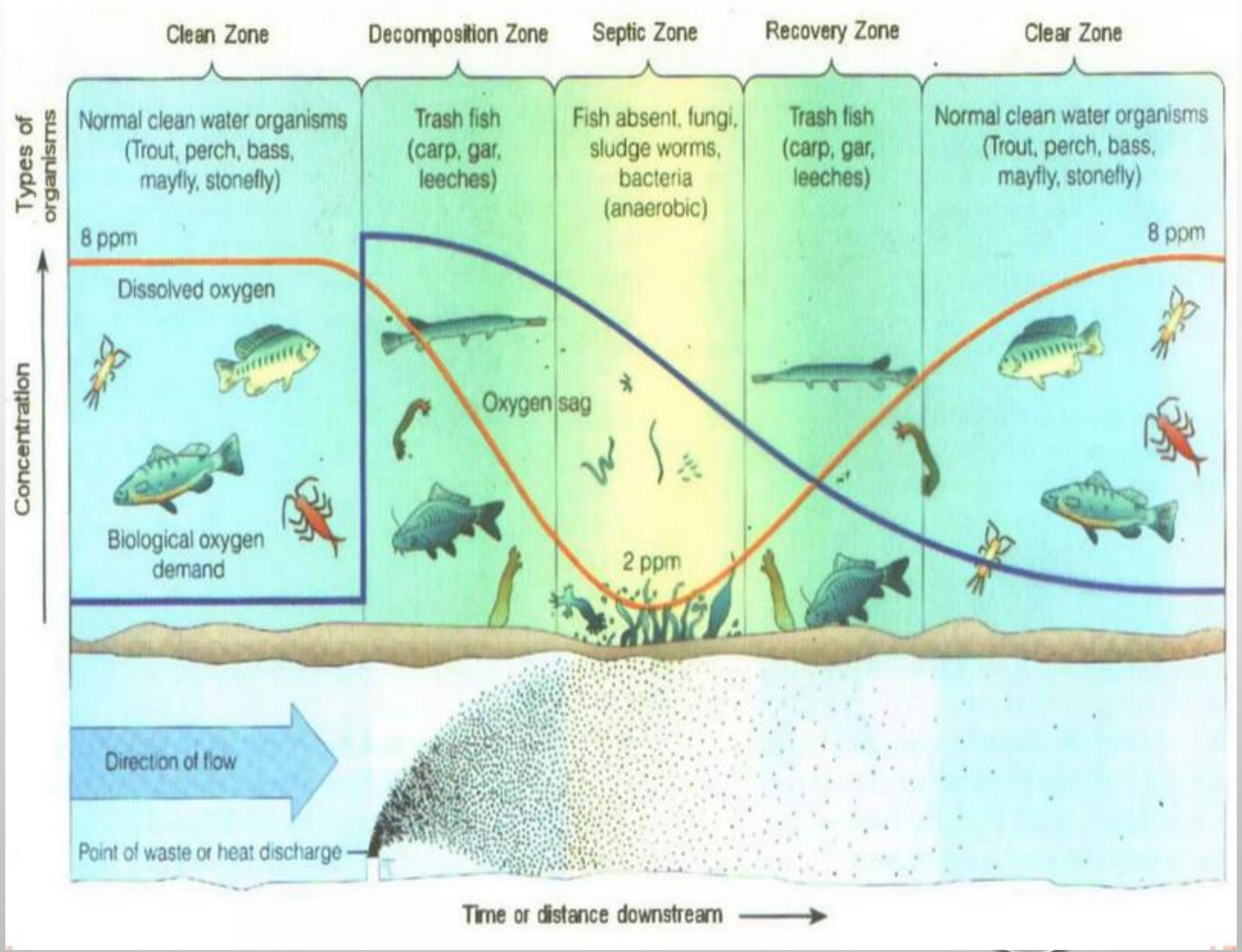
Oxygen Sag Analysis

- The oxygen sag or oxygen deficit in the stream at any point of time during self purification process is the **difference between the saturation DO content and actual DO content** at that time.

  Oxygen deficit, D = Saturation DO – Actual DO

- The saturation DO value for fresh water **depends upon the temperature and total dissolved salts** present in it.
- The DO in the stream may not be at saturation level and there may be **initial oxygen deficit 'D_o'**.
- At this stage, when the effluent with **initial BOD load L_o**, is discharged in to stream, the DO content of the stream starts depleting and the **oxygen deficit (D)** increases.
- The **variation of oxygen deficit (D)** with the distance along the stream, and hence with the time of flow from the point of pollution is depicted by the **'Oxygen Sag Curve'**.
- The major point in sag analysis is **point of minimum DO**, i.e., **maximum deficit.**
- The **maximum or critical deficit (D_c)** occurs at the inflexion points of the oxygen sag curve.

Oxygen sag curve



Rate of reoxygenation

- **Depth of water** in the stream: more for shallow depth.
- **Velocity of flow** in the stream: less for stagnant water.
- **Oxygen deficit** below saturation DO: since solubility rate depends on difference between saturation concentration and existing concentration of DO.
- **Temperature of water**: solubility of oxygen is lower at higher temperature and also saturation concentration is less at higher temperature.

Streeter – Phelps analysis

- The analysis of oxygen sag curve can be easily done by superimposing the rates of deoxygenation and reoxygenation as suggested by the Streeter – Phelps analysis.

$$Dt = \frac{K'Lo}{R'-K'}\left[e^{-K't} - e^{-R't}\right] + Do.e^{-R't}$$

Changing base of natural log to 10 the equation can be expressed as:

$$Dt = \frac{KLo}{R-K}\left[10^{-K.t} - 10^{-R.t}\right] + Do.10^{-R.t}$$

$$tc = \frac{1}{R'-K'}\log_e \frac{R'}{K'}\left[1 - \frac{Do(R'-K')}{K'Lo}\right]$$

OR

$$tc = \frac{1}{R-K}\log_{10} \frac{R}{K}\left[1 - \frac{Do(R-K)}{K.Lo}\right]$$

Where,
K or K' = BOD reaction rate constant,
D_t = DO deficit at any time t,
R or R' = Reoxygenation constant
D_o = Initial oxygen deficit at the point of waste discharge at time t = 0
t = time of travel in the stream from the point of discharge
L_o = Ultimate BOD
t_c = time required to reach the critical point
D_c =critical DO

$$Dc = \frac{K'}{R'} Lo.e^{-K'tc}$$

OR

$$Dc = \frac{K}{R} Lo.10^{-K.tc}$$

Numerical

A river is having discharge of 20 m^3/s receives wastewater discharge of 6 m^3/s. The initial DO of the river water is 6.2 mg/L, and DO content in the wastewater is 0.7 mg/L. The five day BOD in the river is 2 mg/L, and the wastewater added to river has five day BOD of 100 mg/L. Consider saturation DO of 8.22 mg/L and deoxygenation and reoxygenation constant values of 0.1 and 0.3 per day (base 10), respectively. Find critical DO deficit, distance at which critical DO occurs and DO in the river water after one day. The average velocity of flow in the stream after mixing the wastewater is 0.18 m/s.

Solution

River		
Q =	20	m^3/s
DO =	6.2	mg/l
BOD =	2	mg/l

Wastewater		
Q =	6	m^3/s
DO =	0.7	mg/l
BOD =	100	mg/l

Finally		
DO =	4.93	mg/l
BOD =	24.62	mg/l

$$DO_m = \frac{Q_1 \times DO_1 + Q_2 \times DO_2}{Q_1 + Q_2}$$

Similarly BOD should be calculated

Saturation DO =	8.22	mg/l	
K' =	0.1	d^{-1}	
R' =	0.3	d^{-1}	
u (velocity) =	0.18	m/s	
L_o =	36	mg/l	
Initial DO =	3.29	mg/l	
t_c =	1.95	days	$tc = \frac{1}{R-K}\log_{10}\frac{R}{K}\left[1-\frac{Do(R-K)}{K.Lo}\right]$
D_c =	7.66	mg/l	$Dc = \frac{K}{R}Lo.10^{-K.tc}$
L (distance) =	30.29	km	Distance = velocity X time
t =	1	day	(given)
Distance =	15.55	km	Distance = velocity X time (1 day)
D_t =	6.92	mg/l	$Dt = \frac{KLo}{R-K}\left[10^{-K.t} - 10^{-R.t}\right] + Do.10^{-R.t}$

How to tackle water pollution

Tackling water pollution is a complex task that requires coordinated efforts from individuals, communities, governments, and industries. Here are some strategies to address water pollution:

- **Raise Awareness:**
  - Educate the public about the sources and impacts of water pollution.
  - Promote water conservation practices to reduce overall water usage.
- **Proper Waste Disposal:**
  - Encourage proper disposal of household and industrial waste.
  - Implement and enforce strict regulations regarding the disposal of hazardous substances.
- **Wastewater Treatment:**
  - Improve and upgrade wastewater treatment facilities to ensure they meet environmental standards.
  - Implement advanced treatment technologies to remove pollutants from industrial and municipal wastewater.

How to tackle water pollution (cont..)

- **Regulations and Enforcement:**
  - Strengthen and enforce water quality regulations.
  - Implement penalties for individuals or industries that violate pollution control laws.
- **Monitoring and Testing:**
  - Regularly monitor water quality in rivers, lakes, and other water bodies.
  - Implement early warning systems to detect and respond to pollution incidents promptly.
- **Protect Watersheds:**
  - Implement measures to protect and restore natural ecosystems, such as wetlands and forests, which play a crucial role in maintaining water quality.
  - Establish buffer zones along water bodies to reduce runoff of pollutants.
- **Promote Sustainable Agriculture:**
  - Encourage the use of environmentally friendly agricultural practices.
  - Implement measures to reduce the runoff of pesticides and fertilizers into water bodies.

How to tackle water pollution (cont..)

- **Community Involvement:**
  - Involve local communities in water pollution prevention efforts.
  - Establish community-based monitoring programs.
- **Research and Innovation:**
  - Invest in research and development of innovative technologies for pollution prevention and remediation.
  - Support initiatives that focus on sustainable water management practices.
- **International Cooperation:**
  - Collaborate with neighboring countries to address transboundary water pollution issues.
  - Share knowledge and best practices on water pollution prevention and management.
- **Corporate Responsibility:**
  - Encourage industries to adopt environmentally friendly production methods.
  - Promote corporate responsibility and accountability for water pollution.
- **Plastic Pollution Reduction:**
  - Implement measures to reduce plastic usage and improve waste management to prevent plastic pollution in water bodies.

Doubts or questions?