



# Environmental Analytical Chemistry

Humphrey T Samambgwa



# Introduction

---

- Industrialization and urbanization are exponentially on the rise, therefore release of pollutants into the environment has become a significant concern.
- These pollutants can adversely impact ecosystems, human health, and general environmental quality.
- Analytical chemistry provides the tools and methodologies necessary to identify, quantify, and characterize these pollutants in various environmental matrices.
- This includes a range of techniques, from traditional methods such as chromatography, spectroscopy, titration and gravimetry to modern approaches like mass spectrometry and sensor technology
- These tools can be invasive or non-invasive and detect constituents at macro to molecular levels. The choice of technique depends on the analyte of interest and the matrix being analyzed.

# Objectives of Environmental chemical analysis

- **Background monitoring**- to establish natural baseline concentrations of chemical constituents in various environmental matrices
- **Identifying threats**- to recognize potential hazards that could harm human health and ecosystems
- **Trend analysis**- To investigate the trend over time Chemistry, enabling identification of emerging environmental problems( pesticides , microplastics, cosmetics etc..)
- **Regulatory compliance**- To confirm adherence to environmental standards and legislation(EMA,WHO etc)
- **Policy development**- To supply data-driven input for policies related to pollution control
- **Efficacy of control measure**- To evaluate the success of pollution mitigation strategies

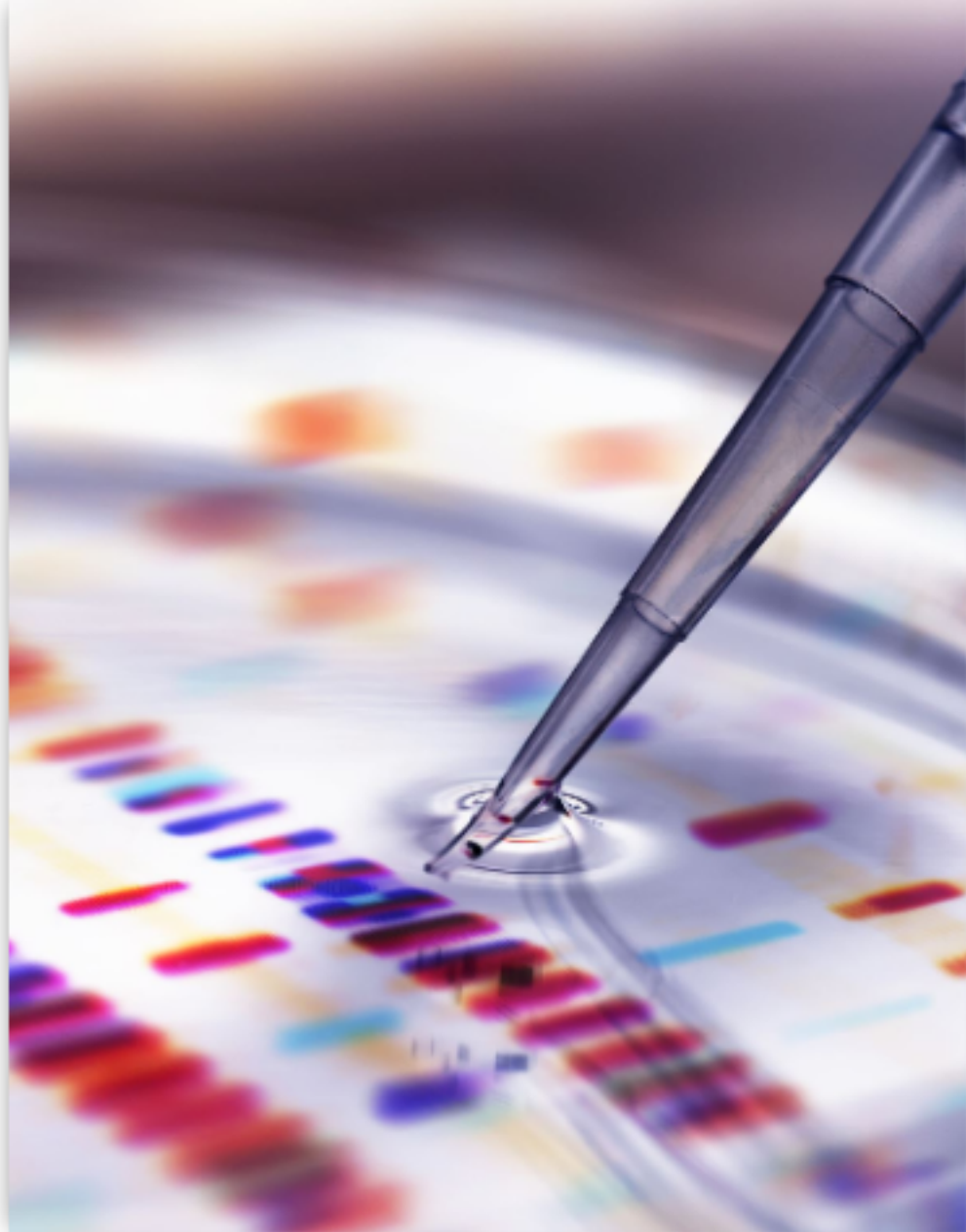


# Scope of environmental chemical analysis

- **Sampling-** This is the most crucial step; proper sampling ensures samples are representative of the environment being studied
- **Preservation-** Samples are preserved to prevent degradation or transformation of analytes.
  - Immediate cooling, pH adjustment, or adding of preservatives depending on the analyte of interest
- **Sample preparation-** Raw environmental samples are often complex mixtures. Samples need preparation to isolate the chemicals of interest and remove interference
  - These steps involve crushing ,digestion ,filtration, extraction, and concentration depending on the target analyte, sample matrix, analytical instrument, or technique

# Scope of environmental chemical analysis

- **Analysis and quantification-** The important part of environmental chemical analysis. Analytical instruments are used to identify the types and amounts of chemicals present.
- Techniques range from simple colorimetric tests to advanced instrumental methods like chromatography and spectroscopy.
- **Data interpretation and presentation-** Raw analytical data is useless without proper evaluation and interpretation.
- This stage involves comparing the results of standards, assessing data quality, and drawing conclusions.
- The environmental implications are then presented to key stakeholders and policy makers for data-driven decision-making





---

## Analytical techniques in environmental chemistry

- Environmental analytical chemistry employs a diverse array of analytical techniques to detect and quantify pollutants.
- These techniques can be broadly categorized into two groups: **classical methods** and **modern/advanced techniques**



# Classical methods

There are two main classical methods used in environmental analysis namely **titrimetry** and **gravimetry**

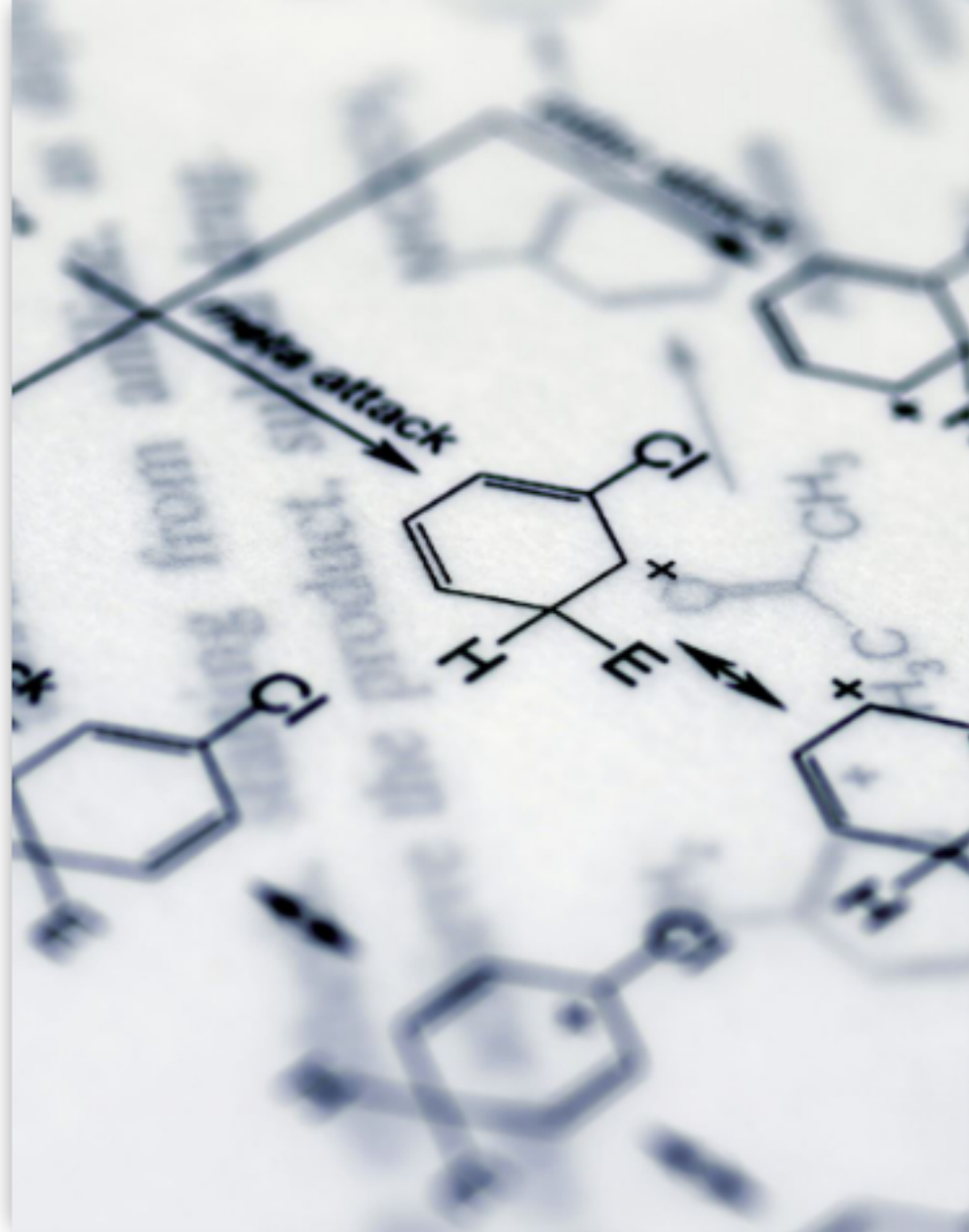


# Titrimetry

- Titrimetry involves determining the concentration of an analyte by reacting it with a reagent of known identity and concentration.
- **Acid-base titration-** Determination of acidity and alkalinity e.g rain water , industrial effluent , and concentration of dissolve carbon dioxide
- **Complexometric titration-** Determination of water hardness in water e.g  $Mg^{2+}$  and  $Ca^{2+}$
- **Redox titration-** Determination of COD(Chemical oxygen demand) and other reducible/oxidisable species(e.g  $Fe^{2+}$ )
- **Precipitation titration-** Determination of halogens , sulfides and sulfate ions

# Gravimetry

- Gravimetry determines the amount of an analyte by selectively converting it into a substance of known composition that can be accurately weighed
- **Precipitation gravimetry**-Determination of inorganic ion by converting them into weighable ppt. e.g sulfates, often precipitated as barium sulfate.
- **Volatilization gravimetry** –Determination of various solids in water or liquid samples, e.g TDS(Total dissolved solids), TSS(Total suspended solids) and TS(Total solids)



# Modern Techniques

- modern techniques often involve separation methods, spectroscopic techniques
- **Chromatography:** Techniques such as High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) are widely used for separating and analyzing environmental samples. HPLC is effective for polar and non-volatile compounds, while GC is preferred for volatile substances
- **Spectroscopy:** Spectroscopic methods, including Ultraviolet Visible (UV-Vis) spectroscopy, Infrared (IR) spectroscopy, and Atomic Absorption Spectroscopy (AAS), are fundamental in identifying and quantifying chemical substances. These techniques provide information on the molecular structure and concentration of pollutants



# Modern Techniques

- **Mass spectrometry (MS):** MS is a powerful analytical tool used for detecting and quantifying trace levels of pollutants. Coupled with chromatography (e.g., GC-MS, HPLC-MS), it offers high sensitivity and specificity, making it ideal for complex environmental samples.
- **Electrochemical sensors:** These sensors provide real-time monitoring of pollutants, offering advantages in terms of sensitivity, portability, and low-cost analysis. They are particularly useful for detecting heavy metals and organic contaminants in water
- **Nanotechnology:** The application of nanomaterials in analytical chemistry has led to the development of highly sensitive and selective sensors for detecting environmental pollutants, enhancing detection limits and response times.



# Modern Techniques

- **UV-Visible Spectroscopy (UV-Vis):** Measures the absorption of ultraviolet and visible light to analyze metal ions, organics, and chromophores in environmental samples, commonly used for monitoring water quality and detecting pollutants
- **Infrared Spectroscopy (IR/FT-IR):** Identifies functional groups in organic contaminants and atmospheric gases, widely applied for organic pollutant analysis in soils and water
- **Atomic Absorption/Emission Spectroscopy (AAS/AES):** Performs elemental analysis, quantifying metals such as lead, mercury, and cadmium in environmental samples
- **X-ray Fluorescence (XRF):** Non-destructive elemental analysis technique for solid samples to assess heavy metals and other elements in soils and sediments; also used for rapid screening of environmental contaminants



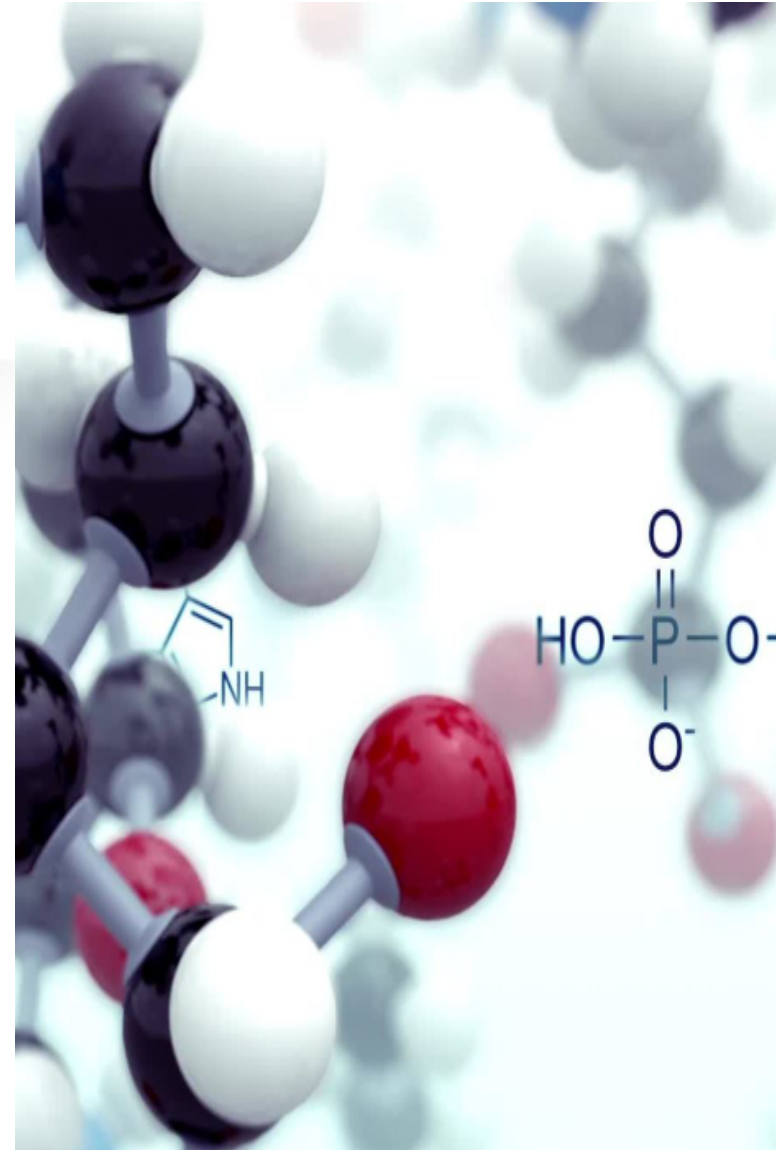
# Modern techniques

- **Gas Chromatography (GC):** Separates and analyzes volatile and semi-volatile organic compounds, such as VOCs, polycyclic aromatic hydrocarbons (PAHs), and pesticides in environmental samples. GC coupled with Mass Spectrometry (GC-MS) is extensively used for trace analysis and identification of complex mixtures in air, water, and soil.
- **High-Performance Liquid Chromatography (HPLC):** Ideal for non-volatile and thermally labile compounds. HPLC is widely employed for pharmaceuticals, personal care products, herbicides, and organic micropollutants in water and soil. Various stationary phases allow targeted separation of different chemical classes
- **Thin-Layer Chromatography (TLC):** Simple and rapid technique often used for qualitative screening of pollutants or separation of small molecules in field studies.



# Modern hypernated Techniques

- **(GC-MS/MS)**: Ideal for analyzing volatile and semi-volatile organic compounds (VOCs and SVOCs) like pesticides, PCBs, and persistent organic pollutants (POPs) in air, water, and soil. Tandem Mass Spectrometry (**MS/MS**) provides greater selectivity and lower detection limits.
- **Liquid Chromatography-Mass Spectrometry (LC-MS/MS or UPLC-MS/MS)**: Essential for non-volatile, polar, and thermally labile compounds, such as **pharmaceuticals and personal care products (PPCPs)**, hormones, and emerging contaminants in water. **Ultra-Performance Liquid Chromatography (UPLC)** offers faster separation and better resolution
- **Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)**: This is the gold standard for the **multi-elemental analysis** and quantification of **heavy metals** (e.g., lead, arsenic, mercury) and other trace elements in water, soil, and biological samples, offering extremely low detection limits (parts per trillion)



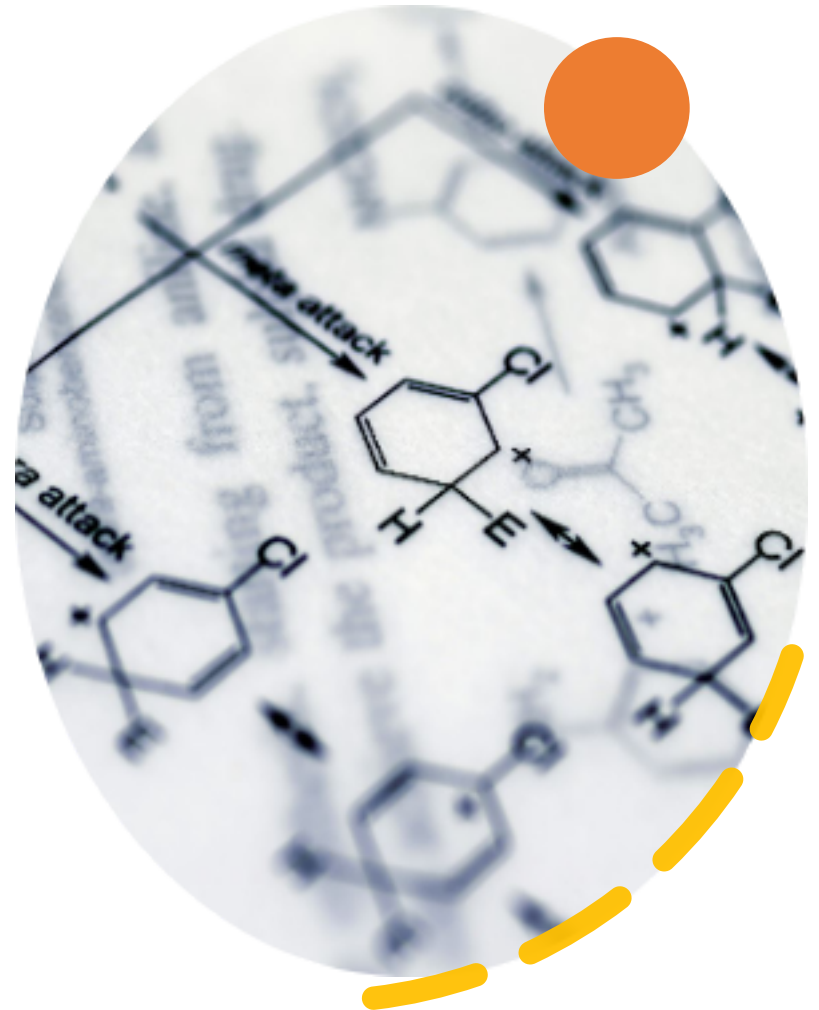
# BioChemical methods

- Biochemical analysis bridges chemistry and biology to monitor contamination and understand its biological impacts. Techniques include quantitative chemical assays, immunoassays, enzyme-linked immunosorbent assays (ELISA), bioassays
- Key Biochemical Methods in Environmental Chemistry
- **Bioassays:** These assess the toxicity of substances by observing biological effects on indicator organisms.
- **ELISA:** Used to detect and quantify proteins, hormones, and other biomarkers indicating environmental stress or contamination.
- **Biosensors:** Devices combining biological and chemical components to detect pollutants or pathogens in real time.



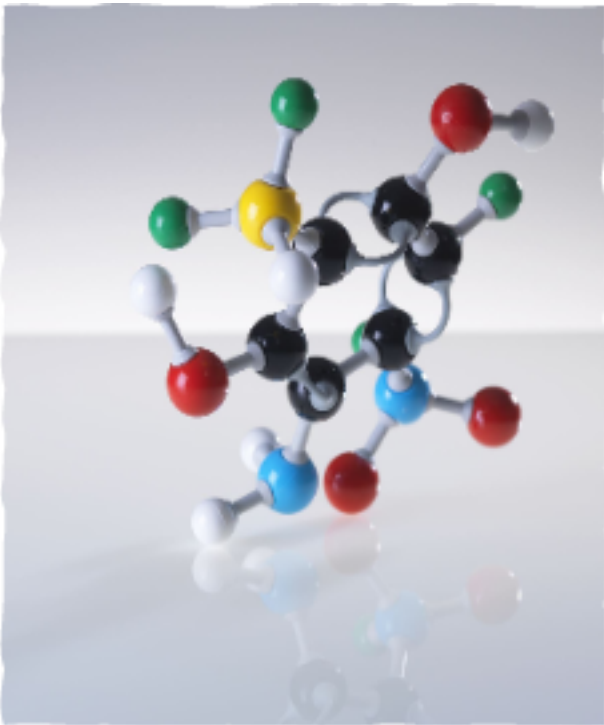
# Immunoassays

- Immunoassays are analytical tests that use the highly specific binding of an antibody to a target molecule (antigen) to detect and quantify contaminants. They are often used for high-throughput screening.
- **Enzyme-Linked Immunosorbent Assay (ELISA):** The most common format, where the antibody-antigen reaction is linked to an enzyme that produces a measurable color, fluorescent, or luminescent signal.
- **Applications:** Rapid, cost-effective screening and quantification of small organic molecules like pesticides (e.g., atrazine), PCBs, and pharmaceuticals in water and soil, especially for field testing.



# Biosensors

---



- A biosensor is a device that integrates a biological recognition element (like an enzyme, antibody, DNA, or microorganism) with a transducer (electrochemical, optical, mass-sensitive) to generate a measurable signal.
- **Enzyme Biosensors:** Use the specific interaction between a pollutant and an enzyme. For instance, pollutants like organophosphate pesticides can inhibit the activity of the enzyme acetylcholinesterase, with the degree of inhibition being proportional to the contaminant concentration.
- **Microbial Biosensors:** Utilize whole living microorganisms (often genetically engineered) that produce a detectable signal (e.g., light, current, color change) when they encounter a specific pollutant or exhibit a general stress response. For example, bioluminescent bacteria can dim when exposed to heavy metals, providing a measure of toxicity.
- **Applications:** Real-time, on-site monitoring of heavy metals, herbicides, and general ecotoxicity in water systems

# Bioassays and Ecotoxicity Testing

- Bioassays use living organisms (from cells and enzymes to whole fish or daphnia) to determine the overall toxicological effect of a sample.
- **Enzyme Activity Assays:** Measure the alteration in the activity of specific enzymes (biomarkers) within an organism exposed to a pollutant.
- **Microtox Assay:** A standard test that measures the decrease in light output (bioluminescence) of a specific bacterium (*Vibrio fischeri*) when exposed to a toxic sample. It provides a measure of acute toxicity.
- **In Vitro Toxicity Testing:** Use isolated cells or cell lines to assess the impact of environmental chemicals on human or ecological health, particularly for endocrine-disrupting chemicals (EDCs) and their effects on hormone receptors



# Current challenges

---

- **Emerging contaminants** The detection of emerging contaminants, such as pharmaceuticals, personal care products, and microplastics, poses significant challenges.
- These substances are often present at trace levels and require sensitive analytical methods for detection. Additionally, their diverse chemical nature complicates analysis and necessitates the development of new methodologies.
- **Regulatory compliance** Regulatory frameworks governing environmental monitoring can be complex and vary by region.
- Compliance with these regulations is essential for accurate reporting and public safety, necessitating rigorous method validation and adherence to standardized protocols.



# Current challenges

- **Resource limitations** Many environmental laboratories operate under limited resources, impacting their ability to invest in advanced analytical technologies. This limitation can hinder their capacity to monitor pollutants effectively and respond to emerging environmental issues