POLLUTION SOURCES

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Summary

There are two types of pollutants, those affecting the natural environment such as organic matter, nitrogen and phosphorus, and those that affect human health. High levels of organic matter in water bodies cause depletion of dissolved oxygen and damage to other ecological conditions needed by aquatic life, offensive odors and deterioration of landscape. High levels of nitrogen and phosphorus cause eutrophication, leading to many problems such as toxic algal blooms, problems in water treatment works, deterioration of landscape and depletion of dissolved oxygen in the bottom layer. Organic matter, nitrogen and phosphorus enter water bodies mainly as domestic wastewater, industrial wastewater, treated water from sewage treatment plants, wastewater from livestock farms, and wastewater from fish farms.

There are many kinds of harmful compounds in the environment encompassing human activities. Harmful compounds that damage human health include heavy metals, dioxins, endocrine disruptors, and agricultural chemicals—particularly organochlorine compounds. These are discharged from industry, landfills, agricultural fields and incinerators. To protect human health and satisfy water quality for utilization purpose, standards have been established for environmental quality and effluent standards in many countries.

Another form of water pollution is the thermal pollution caused by conventional and atomic power plants. This has various adverse effects on aquatic life. The global environmental problems relating to the aquatic environment include acid rain. This is caused by emission of SOx and NOx from industries and automobiles.

1. Introduction

The world's water is broadly classified into seawater, lake and marsh water, river water, groundwater, soil water, atmospheric water, glaciers and ice sheets, and the water in living organisms. Around 97% of it is seawater. The water on Earth is constantly being cycled under the driving force of evaporation of water from the sea and, to a lesser extent, the land surface, followed, of course by precipitation. Water flowing on the ground as a result of rainfall flows through forests and other land, runs over the surface, becomes groundwater, and eventually flows into rivers and hence to the ocean. It flows through rivers into lakes, marshes, and reservoirs, before reaching the ocean. This is the naturally occurring background circulation of water that puts carbon, nitrogen, and phosphorus loads onto water bodies. In addition to this, human actions create an artificial element in this circulation—we obtain and purify water from sources such as lakes and marshes, reservoirs, and rivers, and we use it as domestic, industrial, or agricultural water, then discharge it into water bodies, either directly or after treatment. Most of the pollution of lakes, marshes, rivers, and the ocean is a result of the circulation of water driven by human factors.

The main pollution sources that contaminate public water bodies, rivers, lakes, and oceans, are industrial wastewater, domestic wastewater, treated water from sewage treatment plants, wastewater from the livestock industry, and wastewater from fish farms. Others are runoff from cities, seepage from industrial waste material treatment plants, seepage from waste material that has been disposed of illegally, excrement from free-ranging animals, and runoff from forests, agricultural land, and golf courses. These latter cannot be specified as individual pollution sources. Pollutants common to many of these pollution sources are organic substances, nitrogen, and phosphorus. Other pollutants are heavy metals, organochlorine compounds, agricultural chemicals, dioxins and endocrine disruptors. Agricultural chemicals that are discharged from agricultural land and golf courses can pollute both groundwater and surface water bodies.

Pollutants in public waters can be classified as those that harm the wider environment and those that are a threat to human health. Major substances that harm the environment are organic matter, nitrogen, and phosphorus. Inflow of organic matter causes bacterial growth and reduces dissolved oxygen concentration, and inflow of nitrogen and phosphorus causes eutrophication that can lead to algal blooms. These are damaging to aesthetic and recreational values and can cause major problems in water treatment processes. As eutrophication advances, cyanobacteria (blue-green algae) propagate, and these can produce hazardous substances for animal and humans. Elevated concentrations of nitrogen and phosphorus not only damage aquatic ecosystem, but are also a threat to human health.

Typical pollutants that harm human health include heavy metals, toxic inorganic compounds, organochlorine compounds, agricultural chemicals, dioxins and endocrine disruptors. If people ingest these substances, they may suffer acute or chronic intoxication, according to the exposure condition and quantity ingested. Because such substances are extremely harmful, effluents from factories and business establishments are strictly regulated by effluent standards, but there are dangers of water resources being polluted by seepage of such substances from industrial waste material treatment plants or illegally dumped industrial waste. Because many new chemicals are now being used without adequate evaluation of their harmful effects on people, wastewater regulations have not kept up with actual risk. Pollution by these new chemicals is, therefore, an extremely serious problem. In addition to pollution caused by substances, thermal pollution caused by conventional thermal and atomic power plants also affects aquatic life, particularly in rivers and coastal areas. Global environmental problems include the NOx and SOx emitted from industries and automobiles, that cause the so-called acid rain. This decreases the pH of water bodies and affects aquatic life.

2. Pollution of organic matter, nitrogen and phosphorus

2.1. Adverse effects of organic matter, nitrogen and phosphorus

2.1.1. Organic matter

Waste water from domestic, industrial and business establishments contains organic matter such as carbohydrates, fat, protein and organic acid. When these wastewaters flow into water bodies without treatment, organic matter is assimilated by aerobic microorganism such as bacteria and fungi, and dissolved oxygen is consumed with their growth. If consumption of dissolved oxygen is greater than the supply of oxygen from air and photosynthesis, the concentration of dissolved oxygen decreases. Thus organic matter pollution causes a decrease of dissolved oxygen and, as the concentration approaches zero, production of hydrogen sulfide by anaerobic bacteria begins. The living conditions for aerobic aquatic life deteriorate and species that can survive without dissolved oxygen become dominant. Water bodies with low levels of dissolved oxygen and high levels of anaerobic bacteria decomposing organic matter, often have an unpleasant smell. Fish can only survive where the dissolved oxygen concentration is at least 3 mg/l. Organic matter pollution exacerbates the odor problem, giving the water an unpleasant smell and taste, which creates problems for public water supply. The growth of microorganisms is also stimulated, and water bodies with high levels of bacteria are not suitable for recreational use.

2.1.2. Nitrogen and phosphorus

Nitrogen and phosphorus are essential elements for algae, bacteria, protozoa and metazoa including fish, i.e. the whole hydrospheric ecosystem. Excessive inflow of these elements, however, eutrophicates lakes and coastal areas. Efforts to remedy the organic pollution of water bodies in Japan focused on reducing the biochemical oxygen demand (BOD) of household and industrial wastewaters. As a result, organic pollution was significantly reduced. At the same time, however, there was higher input of nitrogen and phosphate from sources independent from wastewater treatment processes. This raised their concentrations in public water bodies, triggering frequent outbreaks of algal blooms.

Algal blooms became commonplace in the summer in eutrophic lakes and reservoirs in Japan, such as Lakes Kasumigaura, Teganuma, Inbanuma, and Suwa. The major constituent of algal blooms is cyanobacteria, represented by *Microcystis*, *Anabaena*, and *Oscillatoria*. Under appropriate conditions, these algae propagate rapidly, absorbing nitrogen from nitrate and ammonium, and phosphorus from phosphate. Nitrogen and phosphorus are provided by influent rivers, recycling of material in the bottom layer (associated with bacterial decomposition of detritus and excreta of zooplankton), elution from the sediment, and rainfall. The growth rate of algae greatly depends on light intensity, water temperature, and nitrogen and phosphorus concentrations. In addition to cyanobacteria, green algae and diatoms multiply in eutrophic lakes and reservoirs, where the dominant species are subject to seasonal change. Such seasonal changeovers happen because each algal species has different growth characteristics as a result of variation in nitrogen and phosphorus concentrations, illumination, and temperature. These factors determine which algae dominate under changing environmental conditions. The cyanobacteria are generally not dominant in oligotrophic environments, because their growth rate is low or null in oligotrophic water. It was reported that *Microcystis*, a typical cyanobacteria, dominates lakes when the total nitrogen and total phosphorus are over 0.5 mg/l and over 0.08 mg/l, respectively.

Due to their shape, e.g. colonies of cells in *Microcystis* and filaments in *Oscillatoria*, the cyanobacteria are not susceptible to being eaten by zooplankton, which is also a contributing factor in algal domination. Furthermore, cyanobacteria can float due to their intracellular gas vacuole. When they dominate the lake, the cyanobacteria cluster on the surface, which greatly reduces sunlight penetration, reducing insolation to other algae. This tendency to float accelerates the domination of cyanobacteria, unless wind or other phenomena increasing mixing of the lake.

In waterworks, elimination of suspended solids (SS) from raw water taken from eutrophic lakes and reservoirs requires the coagulation-sedimentation process. Coagulants, such as aluminum sulfate, have to be increased in proportion to the SS proliferation. Growth of algae inhibits coagulation by raising the pH level. Proliferation of algae therefore requires not only coagulants in quantity, but also may hinder the coagulation-sedimentation process. In addition, the cyanobacteria that form the water bloom tend to float, which means that they may flow out rather than settle.

Pre-chlorination is sometimes practiced to ensure sufficient chlorine disinfection by averting the obstacles to coagulation and filtering. In this process, hypochlorous acid (HC1O) reacts with organic matters derived from algae to form trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform) that are suspected of being carcinogens. Animal tests have demonstrated that, among them, chloroform and bromodichloromethane are carcinogenic, which suggest that they are also likely to be so for humans. The Waterworks Law in Japan stipulates the Water Quality Standards for Drinking Water for all four substances as well as their total value (total trihalomethanes) as 0.1 mg/l.

Algal blooms triggered by eutrophication clog the filters. The clogging-causing algae are not limited to cyanobacteria; blooms of diatoms, such as *Synedra* and *Melosira*, are also found to cause clogging. Algal blooms can also impart musty odors to drinking water. Some are effused by algae directly, while others are produced through the decomposition of dead algae, affected by actinomycetes and bacteria. Musty odors are caused by 2-MIB (2-methylisoborneol) and geosmin, which are found to be effused by *Phormidium tenue*, *Oscillatoria* and *Anabaena*.

Massive amounts of algae, spawned by eutrophication, die and settle out on the bottom to undergo bacterial decomposition. As a result, the bottom layer becomes anaerobic, causing iron and manganese elution from the sediment. These metals in tap water can stain laundry and affect the taste of the water. Consequently, they need to be eliminated through a water purification process. Among the water-coloring metals, the Water Quality Standard of Drinking Water under the Waterworks Law in Japan regulates manganese and aluminum. The WHO Guidelines for Drinking Water Quality sets guideline values for aluminum, copper, iron, and manganese.

Growth of phytoplankton in eutrophic lakes reduces the transparency, coloring the lakes green in the case of cyanobacteria and brown with diatoms. This significantly reduces the quality of the aquatic environment. When the algal bloom forms a surface scum, the lake is unfit for recreation activities such as swimming, water-skiing, and boating. The opacity of the water is itself a danger, but it is also important to remember the toxins released by cyanobacteria. A case was reported from England involving soldiers who became ill after canoe-training in water with a heavy bloom of *Microcystis*. Water blooms can give off offensive odors, making the area less suitable for hiking and other forms of recreation, and any nearby residents may be distressed by foul odors from decomposing algae and hydrogen sulfide from the anaerobic bottom layer, caused by organic decomposition.

Water taken from eutrophic lakes and rivers for agricultural irrigation can have an adverse effect on crop production. Nitrogen in particular significantly reduces rice yield through overgrowth, lodging, poor maturation, and frequent pest outbreaks. It is normally considered that 1 mg/*l* of nitrogen is harmless, whereas a level exceeding 5 mg/*l* causes grave problems. When mostly-toxigenic cyanobacteria bloom in ponds or lakes to which livestock have access, they may develop health disorders as a result of drinking infested water. Cases of lethal cyanobacterial intoxication of livestock, including cattle, sheep, pigs, and fowl, have been reported from Australia and USA. Furthermore, an accident was reported from Brazil in which 54 people died after drinking tap water containing the toxic substance microcystin.

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Biographical Sketches

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