POLLUTION OF LITTORAL ZONE AND BOTTOM SEDIMENT

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Contents

Summary

Aquatic environments are complex ecosystems that maintain stability through buffering mechanisms. The dynamic balance and homeostasis of the aquatic ecosystem are often altered by various human activities that cause ecosystem perturbation and loss of biodiversity. Pollutants are of diverse origins, and some pollutants are highly persistent in nature and bioaccumulate in the food chain to levels harmful to aquatic ecosystems and human health.

Of different categories of pollutants, the synthetic organic compounds are most toxic and cause detrimental effects in natural waters. For example, the persistent organic pollutants (POPs) enter the hydrosphere and remain unchanged for a long time in the environment. Nonpersistent chemicals, such as organophosphorus compounds and carbamates, are not considered harmful to aquatic ecosystems. Conversely, DDT is persistent in the environment, and its breakdown products persist for many years.

Another important source of pollution is due to increasingly high rates of nitrogenous fertilizer input in agriculture that causes a high concentration of nitrate in drinking and surface waters. Nitrate is a potential threat to the environment through nitrate leaching or nitrate accumulation in surface water at pH > 8.0.

This chapter is an overview on the state of the art regarding general principles of ecotoxicology; the structure and functions of ecosystem, and movement of inorganic and organic toxic substances in inland waters with reference to their sources, storage, transportation, use, fate, properties, and prevention policies. This information may provide insight into the occurrence and distribution of pollutants in the aquatic system, enabling an assessment of existing environmental hazards or damage of the aquatic ecosystem and development of strategies for future planning and growth.

1. Introduction

Recently, concern has increased about environmental pollution because of fast deterioration of the world’s ecosystems and reported cases of human health hazards and death resulting from Minamata disease, Itai itai disease, etc. Lakes, reservoirs, and a large number of wetlands and inland water bodies constitute the world's most valuable resource, fulfilling key roles in the economy and overall well-being of humankind. Many large freshwater lakes and reservoirs are used for drinking water, recreation, fishing, irrigation, transportation, cooling water, waste assimilation, and aquaculture. Some large lakes such as Lake Maracaibo in Venezuela are important sources of minerals and petroleum, and thus most important economically. Inland water sources are also important for their ecology and rich biodiversity. Diverse water habitats support a large number of biota with great species diversity. For example, Lake Baikal—the world's deepest lake—supports approximately 1700 biological species, of which 1200 are endemic. Likewise, numerous wetlands in the tropics are considered as the kidney of ecosystems, serving as a buffer to control floods and as contributors to the economy.

Pollutants and many toxic substances can enter water bodies through manufacturing processes (industries), use (agriculture), and disposal practices (landfills). Discharge of industrial effluents, untreated domestic waste or raw sewage, unsustainable agriculture practice through indiscriminate application of insecticides and pesticides, unlimited population growth and ill-conceived development policies have led to mass-scale deterioration of inland aquatic resources and, therefore, pose ecotoxicological risk and health hazards. Many toxic substances are highly persistent and can bioaccumulate in the food chain to levels that threaten aquatic ecosystems and human health. To these serious concerns is added the conflict between the demand for large amounts of clean water and the pollution of many waters, which has become a major global concern to day.

Large lakes, because of their long residence and flushing times, are particularly susceptible to persistent toxic substances. The input of persistent toxic substances, such as persistent organic pollutants (POPs), polychlorinated biphenyls (PCBs) and DDT, results in long-term whole-lake problems at the level of ecosystem health. It is necessary to have an in-depth knowledge of the nature, extent, and impact of different pollutants in water and bottom sediments of lake systems for a better understanding of the global aquatic resource problems. The bottom sediment of lakes are of considerable importance because they act as a sink for many toxic agents and enter into the water phase through desorption process, and maintain the stability of the lake through buffering mechanisms. Such information is necessary for better management and conservation of inland water resources.

2. Freshwater Resources

Water is the essence of life; it is one of the integral components of the biosphere that is severely threatened by the heavy demands of modern civilization. It is estimated that nearly 0.013% of Earth's water is biospheric freshwater, and an additional of 1.97% is ice and 0.61% ground water, while the rest (97.40%) is saline waters. Although freshwater resources amount to only about 2.7% of the total area of the globe, their importance to humans is far greater than their actual area.

The availability of freshwater has declined by two thirds. It is estimated that 40–60% of water used by utilities is lost because of leakage, theft, and poor accounting. The health risk from inadequate sanitation is growing, especially in urban areas; it is projected that

62% of the world population will be city dwellers by 2025, which is a marked increase from the 45% in 2000.

Food production, which consumes about 70% of the world's freshwater, is at high risk. The 1997 Comprehensive Assessment of Freshwater Resources of the World predicts that one-third of the world's population already lives under water-stress conditions. Today, close to two billion people have access to clean drinking water and sanitation, and only 5% of the world's wastewater is treated or purified. As a consequence, global water crisis is fast increasing. As a consequence, the global water crisis is fast increasing, which results not only in a steady increase in water pollution, but also an increase in diversity of water quality problems in recent years (see Figure 1).

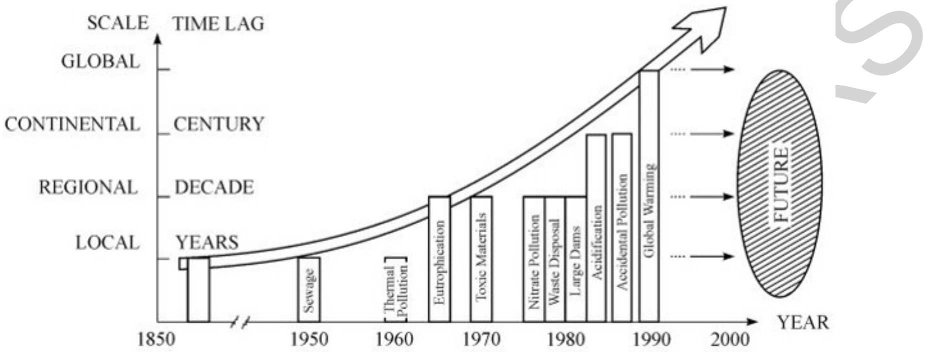

Figure 1. Time development of water quality problems

If the present trend of consumption continues, it is likely an estimated one-quarter of the world's population will suffer a from chronic problem of water shortages. This trend appears unsustainable.

There are two major issues of water crisis: (a) the diminishing quality of readily available freshwater resources, and (b) the continuing degradation of existing supplies. The United Nations General Assembly in the year 1997 identified freshwater as a first priority and called for urgent actions to avoid further degradation of the freshwater resources and to increase availability of freshwater. This calls for necessary measures to be made to prevent undesirable human-generated pollution in water bodies and to conserve these essential resources in a sustainable way for welfare of humankind.

3. The Aquatic Ecosystem

Aquatic environments are complex ecosystems resulting from the interactions among physical, chemical, biological, and anthropogenic factors. The dynamic balance and homeostasis of the aquatic ecosystem are often altered by various human activities, resulting in ecosystem perturbation and loss of biodiversity.

Inland water resources are of two categories: the lentic or open water system (lakes, reservoirs, and other standing water bodies) and lotic (rivers, streams, etc.) water system.

The zonation of lakes and reservoirs are typically vertically divided into littoral or surface and profundal or benthic zones and their subdivisions. The physical subsystem of a lake, reservoir, or large body of water consists of (a) open water or pelagic zone, which includes most of the water volume in the center, (b) the littoral zone located in the shallow area, and (c) the benthic zone located in the bottom of the lake (see Figure 2).

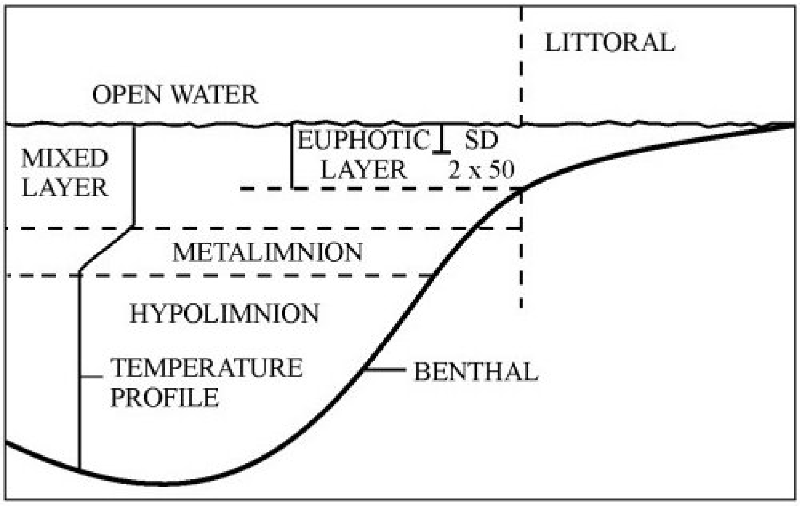

Figure 2. Major vertical regions in a reservoir with indication of the distinction between mixing zone and euphotic zone

The littoral zone may be considered either as an open-water or shallow-water zone. On the basis of waves, the bank region of lakes can be subdivided into uppermost zone, the epilittoral, which is not directly affected by the water level. This is followed by supralittoral, or the spray zone, affected by the breaking waves. The eulittoral is still not under the influence of wave and water-level fluctuations, whereas the infralittoral, the bank zone, is colonized by the higher aquatic plants.

The open water zone of deep lake or reservoir can be distinguished into three subzones: (a) the epilimnion or mixing zone, characterized by multiple water movement and mixing processes, reaches the depth of Z_{mix} and is with thermocline; (b) the hypolimnion or the dark zone, characterized by less vertical mixing and is where decomposition process takes place; and (c) metalimnion, a fairly narrow zone, is the intermediate zone between the two layers. In an ideal situation, the thermocline is located in the middle of the metalimnion.

The flora and fauna of the littoral zone are the macrophytes, periphyton, diverse invertebrate fauna such as rotifers, cladocerans, copepods, ostracods, turbellaria, nematodes, chironomid, and caddis-fly larvae, etc. High hemoglobin content of eight chironomid species living in the littoral zone of a lake is reported to be responsible for withstanding low oxygen concentrations, which determine vertical distribution of chironomids in the sediments. The benthic region of the lake is occupied by a diverse group of flora and fauna that live in bottom mud and collect organic particles originating from material produced or introduced in the open-water region, but eventually reach the bottom sediment of lakes and reservoirs.

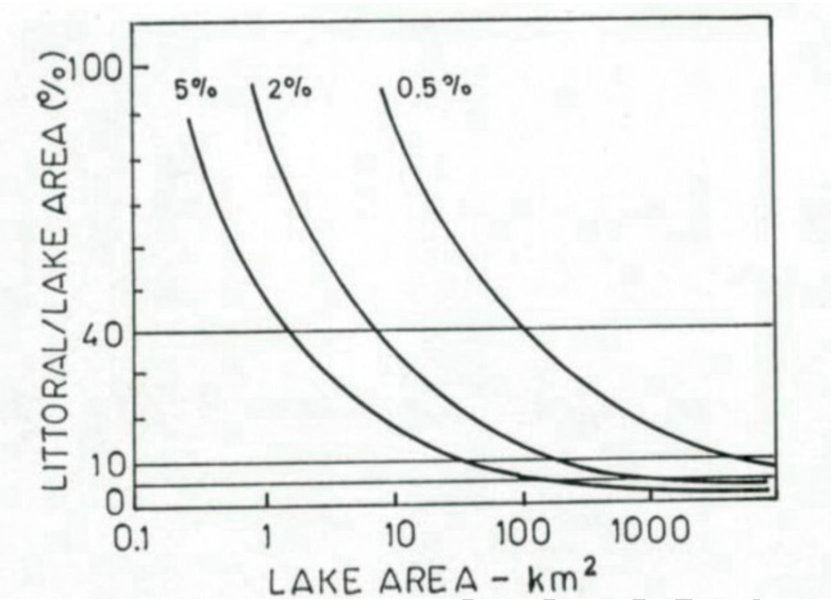

Figure 3. Proportion of the littoral zone in lakes with a shoreline development index of 1.0, as a function of lake size and of littoral slopes (%)

In small and wind-protected water bodies, mixing zones usually reach only 2 m, but may be up to 25 m in the large, deep lakes in temperate regions and up to 50 m in tropical regions. The littoral region is usually not well developed in deep reservoirs because of their short-term water level fluctuations, but inhabitants grow well in extensive shallow water bodies.

The decline in the portion occupied by the littoral zone with increasing lake size can simply by demonstrated by considering a theoretical situation of perfectly round lakes (shoreline development index of 1.0) with a certain littoral slope and depth (see Figure 3).

Figure 3 shows that the littoral slope strongly influences the relative proportion of the littoral zone in the ecosystem. Gradually shelving lakes (for example, slope = 0.5%) with an area smaller than 10 km^2 have practically no pelagic zone. The colonizable littoral area of lakes of similar size narrows with increasing littoral slope.

The availability of littoral resources and its demand by pelagic organisms may be assumed proportional to the respective relative size of the lakes. Beyond a certain lake size, the demand for littoral habitats may diminish as a result of large interhabitat distance, which reflects situations of very large bodies of water where the pelagic zone practically functions independently of the littoral zone (see Figure 4).

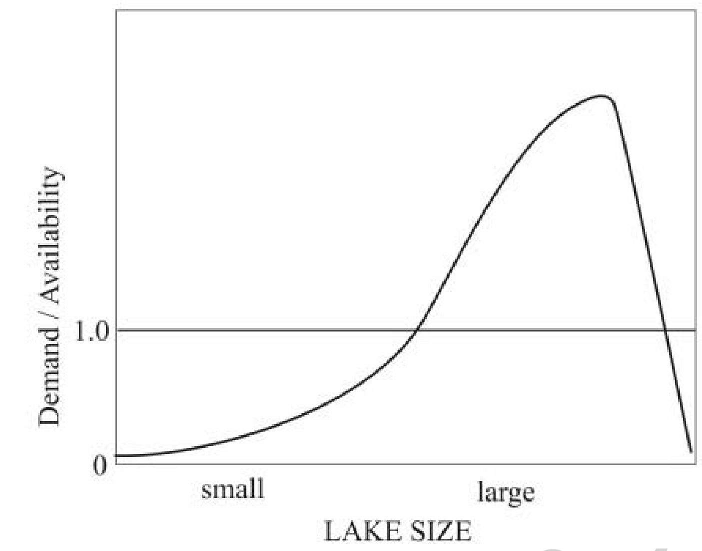

Figure 4. Conceptual trend of change of the ratio of the demand for a littoral resource by pelagic organism to the availability of this resource in the littoral zone, as a function of lake size

Benthic sediments of a lake can play an important role in regulating the bioavailability of hydrophobic organic chemicals in aquatic ecosystems. Depth of the lake is an important parameter in the mud water exchange process for nutrients. A shallow lake has a greater percentage of its water mass in direct contact with the bottom than does a deep lake. This contact usually helps to dissolve nutrients more effectively from the sediments into the overlying water. As tropical wetlands are shallow, they provide better ecological conditions for an effective mud–water exchange mechanisms.

3.1. Food Chain and Food Web

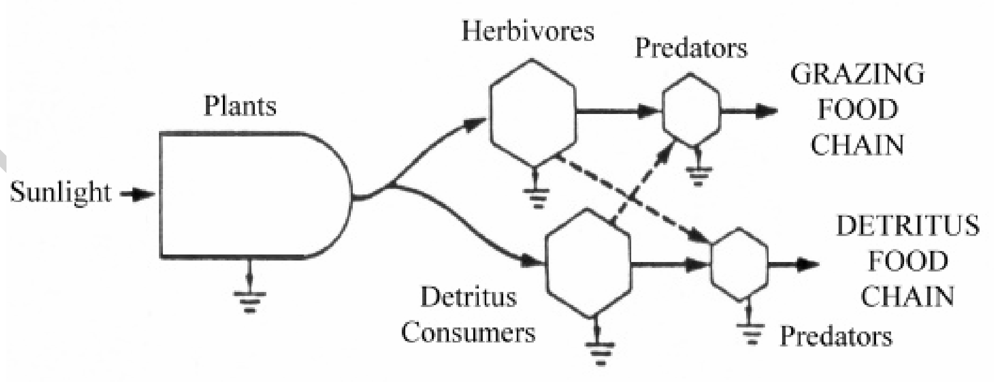

Figure 5. The Y-shaped energy flow model showing linkage between the grazing and detritus food chains

Organisms are mutually interrelated, not only through their feeding activities, but also by allelopathic reactions induced by chemical compounds released by organisms, by behaviour of organisms and recycling of nutrients and others. Two laws of thermodynamics are followed in the food chains and food webs of the aquatic system.

Energy inflows balance outflows according to first law of thermodynamics, and each energy transfer is accompanied by dispersion of energy into unavailable heat according to the second law. In fact, the grazing and detritus food chains are interconnected, and the Y-shaped or two-channel energy flow model (see Figure 5) is more appropriate than a single-channel model in aquatic ecosystems.

While 50% or more of the net production may pass through the grazing food chain in some shallow water bodies, approximately 90% or more of unconsumed autotrophic production accumulates as particulate and dissolved organic matter in water and sediments and this operates as the detrital system in deep lakes and oceans.

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Bibliography

Das S. (2000). *Biofilter Potential of Freshwater Mussel,* Lamellidens Marginalis*: An Approach Towards Cadmium Intoxicated Wastewater Management*, 324 pp. Doctoral thesis. University of Kalyani, India. [This is a doctoral thesis dealing with reclamation of cadmium-intoxicated water bodies using freshwater bivalves.]

Frantz A.M.T. and Artemenkova L.A. (1971). *Nuclear Techniques in Environmental Pollution*. Vienna: International Atomic Energy Agency. [These are the proceedings of a symposium on use of nuclear techniques in the measurement and control of environmental pollution.]

German Advisory Council on Global Change (1997). *World in Transition: Ways Towards Sustainable Management of Freshwater Resources*, 392 pp. Springer. [This is an Annual Report on water resource management, global freshwater crisis].

Gulati R.D., Lammens E.H.R.R., Meijer M.L. and van Donk E. (1990). *Biomanipulation Tool for Water Management*, Dordrecht: Kluwer Academic Publishers. [These are the proceedings of an international conference on biomanipulation dealing with reclamation through various biotic components.]

International Lake Environment Committee (1991). *Guidelines of Lake Management, Volume 4: Toxic Substances Management in Lakes and Reservoirs*, 170 pp. Shiga, Japan: International Lake Environment Committee Foundation and United Nations Environment Programme. [This manual deals with different aspects of reservoir water quality management].

International Lake Environment Committee (1997). *Guidelines of Lake Management, Volume 8: World's Lakes in Crisis*,. 184 pp. Shiga, Japan: International Lake Environment Committee Foundation and United Nations Environment Programme.. [This manual deals with different aspects of environmental problems of world's lakes.]

International Lake Environment Committee (1999). *Guidelines of Lake Management, Volume 9: Reservoir Water Quality Management*, 229 pp. Shiga, Japan: International Lake Environment Committee Foundation and United Nations Environment Programme. [This manual deals with different aspects of reservoir water quality management].

Jana B.B., Banerjee R.D., Guterstam B., and Heeb J. (2000). *Waste recycling and resource management in the developing world: ecological engineering approach* 722 pp. Kalyani: University of Kalyani and International Ecological Engineering Society. [These are the proceedings of international conference dealing with different aspects of wastewater and water management and environmentally sound technologies.]

Jorgenssen S.E. (1995). State-of the-art management models for lakes and reservoirs. *Lakes and Reservoirs Research and Management* **1**, 79–87. [This is a journal article dealing with eutrophication model.]

Kormondy E.J. (1978). *Concepts of Ecology*, 238 pp. New Delhi: Prentice Hall of India Private Ltd. [This is a widely used handbook of ecology.]

Odum E.P. (1983). *Basic Ecology*, 613 pp. New York: Saunders College Publishing. [This is widely used textbook dealing with the principles and different aspects of ecology.]

Saha S. (2000). *Reclamation of Eutrophic and Wastewater Resources for Aquaculture: Management Through Certain Macrophytes and Fishes*, 336 pp. University of Kalyani, India. [This is a doctoral thesis dealing with wastewater resource management using macrophytes and fishes.]

Schwoerbel J. (1987). *Hand Book of Limnology*, New York: John Wiley & Sons. [This a textbook of limnology that presents the structure and functions of inland water resources.]

Biographical Sketch

B. B. Jana is a senior professor of zoology, coordinator of microbiology, and coordinator and convener of the International Centre of Ecological Engineering in the University of Kalyani, West Bengal, India. He received his doctoral degree in 1970 and has since worked in various capacities at Visva Bharati, Vidyasagar, and Kalyani Universities. His research interests include a wide variety of projects concerning fisheries, aquaculture, aquatic microbiology, eco-reclamation, fish biology, etc. He has also devoted much time to developing the International Centre of Ecological Engineering. He is a fellow of the National Academy of Agricultural Sciences, India, and a member of the International Ecological Engineering Society, Switzerland. He has guest-edited a book on sustainable aquaculture: global perspectives. He has traveled extensively and chaired many scientific sessions in India and abroad. He is an author or coauthor of several books and more than 175 research papers.