IMPACT OF EXCESSIVE AND DEFICIENT ENVIRONMENTAL NUTRIENT LOADING FROM UPSTREAM TO DOWNSTREAM

By

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ABSTRACT

An adequate and balanced supply of elements necessary for life, provided through the ecological processes of nutrient cycling, underpins all other ecosystem services. The organic cycle provides the essential ecosystem services we all depend on - clean air, clean water and clean soil. Nutrients are a potent biological fuel. They are essential to natural cycles and for the growth of living organisms. Human activities often lead to increase inputs of nutrients and organic matter (as point and non point sources) into the coastal environment. The excessive nutrients input into coastal waters may cause increase in eutrophication of coastal regions and food web alterations in oligotrophic pelagic regions. Excessive nutrient loading is expected to become a growing threat to rivers, lakes, marshes, coastal zones and coral reefs.

The waterways that connect land and sea, transport the nutrients essential to maintaining a healthy environment and economy. Nutrients flow around in an organic cycle at natural (normal) levels. Without nutrients plants and animals cannot grow or remain healthy. When nutrients are increased beyond natural levels, there are ecological side effects, either locally or downstream. This paper generally covers the issues related to the impact of nutrient loading from upstream to downstream considering its type, excessive and deficient load. Issues like ;

i) Effect of nutrient load on water quality at upstream and downstream water bodies and conveying systems;
ii) Eroded sediment and its contribution to eutrophication of lakes and streams;
iii) Ecosystem nutrient balance;
iv) Sustainable aquatic life considering marine animal life, fisheries, and tourism;
v) Interrelationship between Dam and water reservoir and excessive and deficient nutrient loading;
vi) Eutrophication;
vii) Plankton, and
viii) Impact of nutrient loading on agricultural soils.

1 Introduction

Water is vital for all known forms of life and it covers 71% of the Earth's surface. The total water on earth is 97% saline and 3% fresh[1]. In 3% of fresh water, 2% of fresh water is capped in glaciers and icebergs. Out of remaining 1%, 20% cannot be captured and is inaccessible. Remaining fresh water globally available is only 0.8% and is finite.

The principal supply of renewable fresh water for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers. During its course many environmental factors influence its quality and quantity. Water takes up nutrient enriched sediment load with its flow due to erosive action of flowing water and deposits them on downstream side.

Information on water resources of a basin is a prerequisite to the orderly development and management of the resources for socio-economic advancement. Among the most important requirements in water resources development, management and conservation are information on sediment and nutrient loads of rivers. Fluvial sediment affects not only the quality of water for domestic and other purposes, but also the operation and integrity of hydraulic structures such

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as Dams, canals and bridges. Therefore, in the design of such structures, knowledge of both the quantity and characteristics of fluvial sediment is essential.

Human activities in watershed areas can increase nutrient loads carried into surface waters by runoff and enhance primary production (Sharpley & Menzel, 1987). Eroded sediment can carry nutrient particularly phosphates to water-ways and contribute to eutrophication of lakes and streams. Absorbed pesticides are also carried with eroded sediments, adversely affecting surface water quality (FAO, 1996; Webster & Wilson, 1980).

Sediment load may take up nutrient rich sediments and deposit it on water bodies and water conveying systems causing aquatic ecosystem problems. Pakistan has three major water reservoirs Tarbela, Mangla and Chashma, Table-1 shows the reduction of live storage capacity of reservoirs due to sediment loading and shows the importance of sediment input to reservoirs.

Table 1. Reservoir sedimentation

Reservoir	**Live Storage Capacity (MAF)**		**Live Storage Loss (MAF)**		
	Original	Year 2010	Year 2010	Year 2015	Year 2025
Tarbela 1974	9.69	6.67	3.02	3.54	4.43
Mangla 1967	5.34	4.50	0.84	1.00	1.32
Chashma 1972	0.72	0.22	0.50	0.50	0.50
Total	15.75	11.39	4.36	5.04	6.25

2 Environmental nutrient loading

Nutrient loading is a quantity of nutrients entering an ecosystem in a given period of time. Nutrients are the natural chemical elements and compounds that plants and animals need to grow and survive. They are the ‘fuel’ of the natural engine in all ecosystems. Nutrient loading is projected to become an increasingly severe problem, particularly in developing countries. Nutrient loading has adverse effects on freshwater ecosystems and coastal regions in both industrial and developing countries.

2.1 Nutrient cycle

Nutrient cycling describes the movement within and between the various biotic or abiotic entities in which nutrients occur in the global environment. These elements can be extracted from their mineral or atmospheric sources or recycled from their organic forms by converting them to the ionic form, enabling uptake to occur and ultimately returning them to the atmosphere or soil. Nitrogen and phosphorus have the key role in nutrient cycle of ecosystem.

2.2 Nutrient input and output processes

Ecosystem nutrient balance is the net result of inputs minus outputs. Negative and positive balances are ultimately unsustainable. The magnitude and duration of nutrient imbalance that can be tolerated is determined by an ecosystem’s buffering capacity. This is roughly indexed to the size of the nutrient stocks, divided by the normal net flux, which gives the turnover time.

2.2.1 Input processes

Input of nutrients to ecosystems occurs through five processes.

- Weathering of geological sources
- Atmospheric wet or dry deposition of elements
- Biological processes
- Biomass of mobile organisms
- Anthropogenic inputs

2.2.2 Output processes

The output of nutrients from ecosystems also involves five processes.

- Soil erosion
- Nutrient leaching from agricultural soils
- Gaseous emissions
- Emigration of fauna or the harvest of crop, forest, fish or livestock
- Permanent removal

2.3 Source of nutrient loading

The three most common sources are bottom silt and dead vegetation in the lake, runoff water from surrounding turf areas, and the sources of incoming water.

3 Excessive and deficient environmental nutrient loading from upstream to downstream

Water flows in lakes, rivers, swamps, and shallow groundwater aquifers due to gravity. The direction of water flow determines its upstream and downstream side. Generally upstream and downstream sides are relative to each other for a given body. But on global scale water which is coming out of glaciers is at upstream side and that water ends up its journey at oceans and seas which is at downstream side.

Excess nitrogen (N) and phosphorus (P) loading from point and non-point sources is considered one of the main factors damaging the ecological quality of streams, lakes and estuaries and the deteriorating quality of ground water (Meybeck, 1982; Iserman, 1990; Sabater et al., 1990; European Environment Agency, 1995, 1999; Jordan et al., 1997).

Nutrient and sediment loading occurs in flowing water from various reasons. Nutrients flow around in an organic cycle at natural (normal) levels. When nutrients are increased beyond natural levels there are ecological side effects, either locally or downstream. These side effects can exclude species, change ecosystems and even impact on human industries that depend on a healthy environment, such as tourism and fishing.

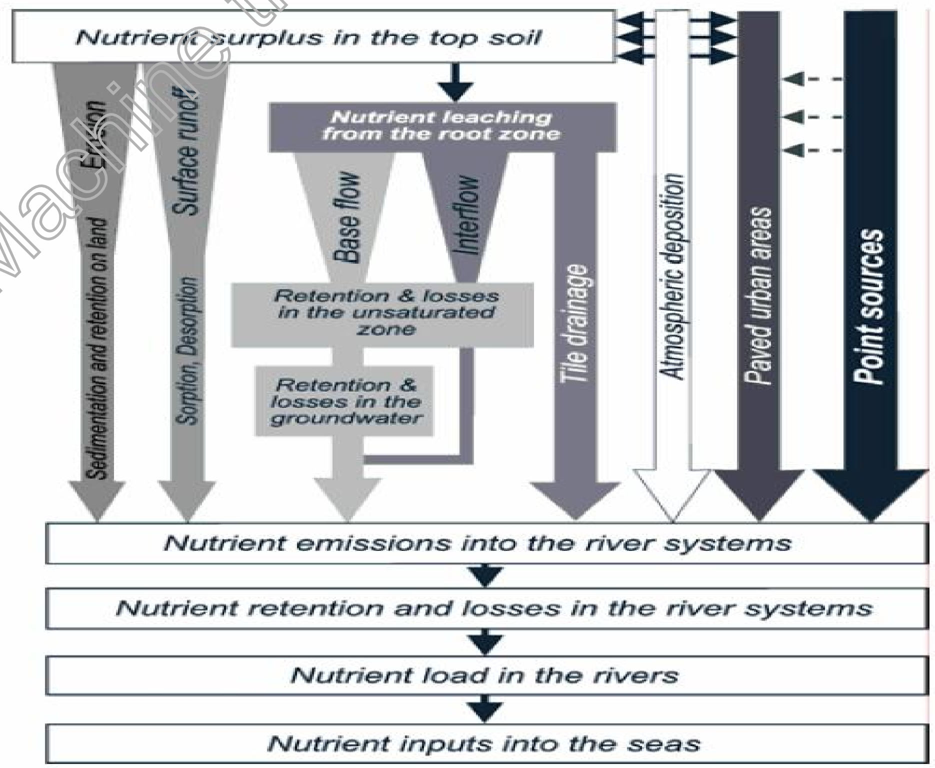
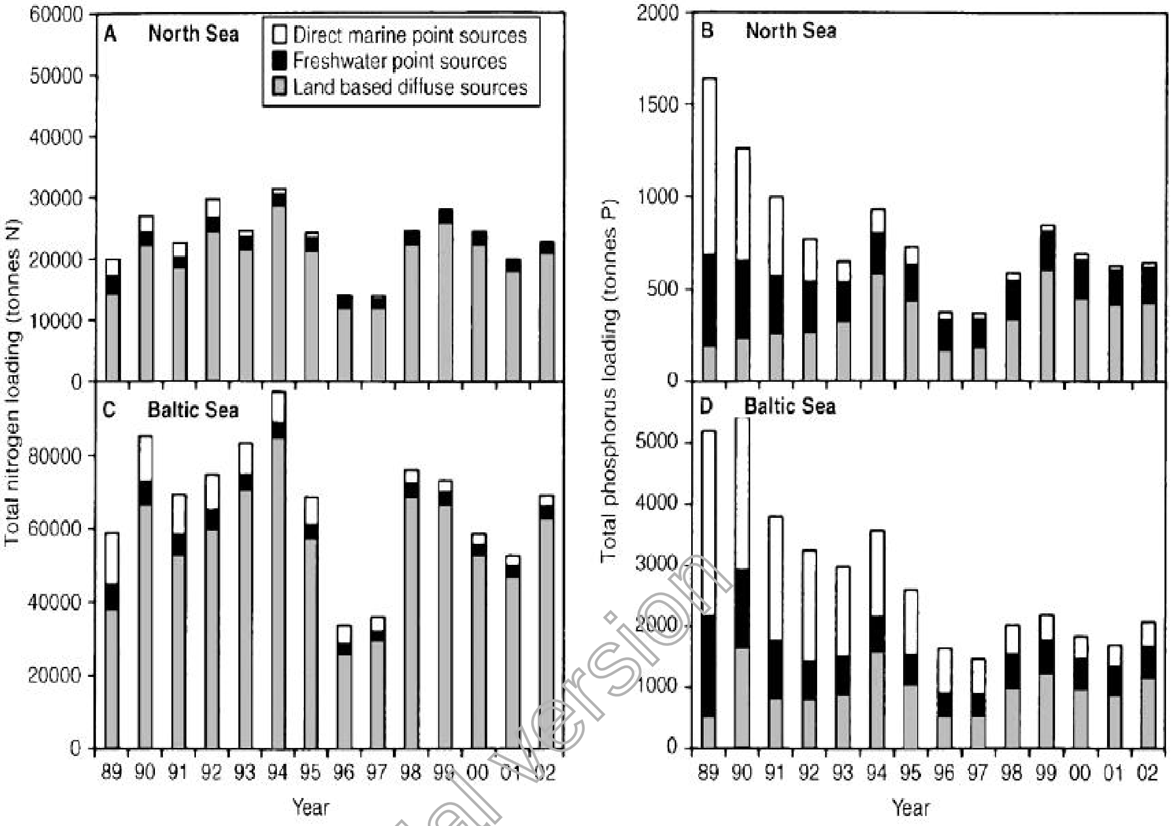


Figure 3: Pathways and processes of nutrients

3.1 Nutrient excess in fresh and marine waters

Major consequence of fertilizer inputs and atmospheric deposits, and of impairment of buffers and regulatory mechanisms at all scales, is eutrophication of aquatic system both fresh and saline waters.



3.1.1 Eutrophication of aquatic ecosystems

Eutrophication means excessive nutrients in a lake or other body of water, usually caused by runoff of nutrients (animal waste, fertilizers, sewage) from the land, which causes a dense growth of plant life; the decomposition of the plants depletes the supply of oxygen, leading to the death of animal life. It is the fertilization of surface waters by nutrients that were previously scarce (Carpenter et al. 1999). In the 1960s it became obvious that a change was occurring in many lakes and reservoirs, especially in industrial countries, resulting from an increase in their nutrient load. This was a consequence of human activity, with increased inputs of urban and industrial waste water and agricultural runoff containing mainly Carbon (C), Nitrogen (N), and Phosphorus (P). The problem is now apparent in many coastal areas as well. Eutrophication is regarded as the most widespread water quality problem in many countries (OECD 1982; NRC 1992; Nixon 1995; Carpenter et al. 1998; Howarth et al. 2000).

Eutrophication leads to many changes in the structure and function of aquatic ecosystems and thus the services they provide. Such characteristics are detrimental to many water uses, including for drinking, fisheries, and recreation. Although possible, remediation measures are costly, and mostly consist of reducing the inputs of nutrients to tolerable levels.

A debate took place during the 1970s on the possible reduction or ban of P in detergents as a means of reducing the Eutrophication of lakes. The pro-P argument relied on the small fraction of P load resulting from the detergents as compared with other urban or agricultural sources (Lee and Jones 1986). While phosphorus use has been totally banned in some countries (in Switzerland and some states of the United States), and partial restrictions occur in others, the use of high-P detergents is unrestricted in a number of other countries.

3.1.2 Marine dead zones

Low oxygen conditions in coastal marine waters are primarily the result of enrichment in nitrogen with consequent enhanced growth of phytoplankton. This nitrogen-fed phytoplankton sinks to the sea floor when they die, and the organic matter is regenerated by bacterial activity, consuming oxygen. At low oxygen concentrations, most marine life is unable to survive, leading to the designation of marine dead zones. The size of these reaches up to 70,000 square kilometers (Brian et al. 2004), and they have been reported off South America, Japan, China, Australia, New Zealand, and the west coast of North America.

3.2 Nutrient load deficiencies

A significant proportion of agricultural soils, mainly located in developing countries, are suffering nutrient deficiencies. Similar situations may occur in coastal and marine systems as a result of shortage of water flow from terrestrial systems, or naturally in the high nutrient, low chlorophyll zones, where deficiencies in Silicon (Si) and Ferrous (Fe) limit primary production.

3.2.1 Agricultural soils

The fertility of any soil will decline if the nutrient content of the harvest removed from the system (as grain, timber, livestock, and so on) exceeds the nutrient input from natural and anthropogenic sources. In general, the nutrient balances in the industrial world are positive, especially for N, as crops use less than half of the applied fertilizer, leading to the eutrophication problem just described. In large areas of South America (Wood et al. 2000) and Africa (Smaling et al. 1997; Sanchez 2002), on the other hand, the nutrient balance is negative, leading to declining soil fertility. In the case of South America, the magnitude of the imbalance appears to be decreasing as incomes rise and farmers can afford more fertilizer. In Africa, the cost of fertilizer to low-income farmers is usually prohibitive.

3.2.2 High nutrient, low chlorophyll regions of the ocean

Large parts of the ocean are characterized by the presence of adequate N and P in the euphotic zone but low phytoplankton biomass and low primary and new production (Minas et al. 1986). The best known of these regions are between the coast of Ecuador out to the Galapagos Islands, the equatorial Pacific out to the dateline, the Northeast Pacific, and portions of the Southern Ocean.

The interest in high nutrient, low chlorophyll regions has been sparked by the possibility of increasing their productivity through fertilization, with relatively small quantities of Fe and/or Si. This has been suggested as an option for slowing the increase in atmospheric CO_2. However, the scientific understanding of the consequences of full scale implementation of such an action remains insufficient for adequate assessment.

3.3 Definition of nutrient loads versus nutrient concentrations

The **nutrient load** refers to the total amount of nitrogen or phosphorus entering the water during a given time, such as "tons of nitrogen per year." Nutrients may enter the water from runoff, groundwater, or the air (in the form of wet deposition such as rain or snow as well as dry deposition). The **nutrient concentration** refers to the amount of nitrogen or phosphorus in a defined volume of water (such as milligrams of nitrogen per litre of water). Total nitrogen concentration is the total amount of nitrogen in one litre of water; total nitrogen includes both dissolved nitrogen in the water column and particulate nitrogen contained in algal cells and in organic detritus such as degrading leaves from trees. The relationship between nutrient concentration and nutrient load can vary and depends on the flow, the volume of water in the river, and watershed characteristics.

4 Inter-Relationship between Dams and excessive and deficient nutrient loading

The increase in nutrient concentrations in many aquatic systems over the past several decades is now well established (Carpenter et al. 1998, NRC 2000). Typically, N and P inputs to aquatic ecosystems are dominated by diffuse nonpoint sources from the surrounding landscape, often in association with agricultural and urban land uses. In many areas, including Wisconsin, fertilizer and manure application on farm fields represents a major input of both N and P to lakes and streams. But the paths that these two nutrients take from terrestrial to aquatic environments are distinct. In enriched systems, nitrate (NO_3 –) represents the dominant form of N, often accounting for more than 50% of the total N budget (Hedin et al. 1995, Goolsby et al. 1999). This form of N is highly soluble and thus travels easily in water from soil to groundwater and into surface water systems. It is also readily taken up by algae and bacteria, which can lead to excess growth of these microorganisms in aquatic systems. Fortuitously, NO_3 can be removed from water and returned to the atmosphere via the process of denitrification.

Dams can alter the water chemistry in the reservoir and downstream of the Dam compared with the original free flowing river. The turbulent water immediately below the Dam spillway may be supersaturated with dissolved oxygen and nitrogen, which can cause gas bubble disease in fishes. Temperature, turbidity, nutrients, and suspended solids are all altered by the residence time of water in reservoirs compared with the natural river flow.

The transport and deposition of silt and sediment by a river is as ecologically important as the movement of water. Dams profoundly alter the movement of sediment, which settles in the reservoir, often at rates much greater than predicted, causing premature loss of holding capacity. This sediment is no longer available to replenish soil and nutrients in downstream flooded areas, or in the Mekong Delta, or to provide habitat for aquatic species in the river.

4.1 Impacts of trapping sediments and nutrients behind Dam

In case of Tarbela reservoir in Pakistan, high temperature during the months of May and June accelerate the snowmelt, causing the river channel to widen in the upper reaches of reservoir resulting in considerable increase of sediment in the water flowing downstream. The sediments so eroded and the new sediments brought by the inflows are deposited in the main reservoir causing the development and advancement of delta towards the main Dam. A 61 m (200ft) high sedimentation delta at Tarbela is approaching the Dam at a pace of approximately 0.8 Km (0.5 mile) per year. It is presently located at about 10.6 km upstream of the Dam.

The average contribution of sediment from Monsoon areas is 5.18 MST/year (2.71%) and that from the snowmelt area is 186.22 MST/year (97.29%) which makes a total of 191.40 MST/year.

The reduction in sediment and nutrient transport in rivers downstream of Dams has impacts on channel, floodplain and coastal delta morphology and causes the loss of aquatic habitat for fish and other species. Changes in river water turbidity may affect biota directly. Reduction in sediment moving downstream from the Dam leads to degradation of the river channel below the facility. This can lead to the elimination of beaches and backwaters that provided native fish habitat and the reduction or elimination of riparian vegetation that provides nutrients and habitat for aquatic and waterfowl species, among others.

4.2 Upstream impacts

The construction of a Dam results in post-impoundment phenomena that are specific to reservoirs and do not occur in natural lakes. One difference is that with first reservoir filling terrestrial habitats are submerged and destroyed. Another difference is that level fluctuations may be much larger than those normally found in a natural lake. Non-earth storage Dams often have a bottom outlet. This may allow both sediment flushing and water releases from deep below the surface. Both management measures cannot be carried out with most natural lakes. Nevertheless some older reservoirs can be considered as lakes and the challenges presented in managing them are often the same (Dinar et al., 1995), such as the management of the riparian wetland habitats and fisheries.

4.2.1 Changes in water quality

Water storage in reservoirs induces physical, chemical and biological changes in the stored water and in the underlying soils and rocks, all of which affect water quality. The chemical composition of water within a reservoir can be significantly different from that of the inflows. The size of the reservoir, its location in the river system, its geographical location with respect to altitude and latitude, the storage retention time of the water and the source(s) of the water all influence the way that storage detention modifies water quality.

Major biologically-driven changes occur within thermally stratified reservoirs. In the surface layer, phytoplankton often proliferate and release oxygen thereby maintaining concentrations at near saturation levels for most of the year. In contrast, the lack of mixing and sunlight for photosynthesis in conjunction with the oxygen used in decomposition of submerged biomass can result in anoxic conditions in the bottom layer. Natural lakes, can act as nutrient sinks particularly for nutrients associated with sediments. Eutrophication of reservoirs may occur as a consequence of large influxes of organic loading and/or nutrients. In many cases these are a consequence of anthropogenic influences in the catchment (e.g. application of fertilizers) rather than a direct consequence of the presence of the reservoir.

Water quality changes due to the reservoir will be reflected throughout the downstream watercourse, affecting primary productivity and the invertebrate fauna that provides the basis for the food web.

4.2.2 Plankton and periphyton

Within natural fast-running river (lotic) systems, phytoplankton production is often negligible, only derived from lakes, low velocity backwaters and benthic algal communities. Natural rivers, particularly clean, slow-moving lowland rivers, do contain free-floating micro-organisms, but the plankton populations are inherently unstable and dependent upon the frequency of high discharges. The introduction of a reservoir into a river system, particularly in headwater areas, can markedly alter its primary productivity. The hydrological characteristics and thermal and chemical regimes of reservoirs are unique, so the character of primary production within reservoirs is highly site and catchment-specific. Upon Dam closure, the river (lentic) system resets itself as the reservoir fills. Often, a microbial population explosion releases nutrients as the newly submerged organic matter begins to decompose. This stimulates the rapid development of the phytoplankton. The enrichment of reservoir water by large amounts of nitrogen and phosphorous, as a result of the decay and mineralisation of organic matter flooded by the reservoir, may lead to a multiplication of blue-green algae. This in turn drives invertebrate productivity and fisheries production. In many reservoirs, fisheries thrive for 4-5 years after closure and then decline as primary productivity drops. The occurrence of lacustrine plankton assemblages varies seasonally and with individual reservoirs, depending upon their geographical location and catchment inputs. In temperate and high latitude climates plankton populations are lowest in the cold winters and greatest during the warm summers. Tropical reservoirs have no seasonal check to plankton growth comparable to winter in temperate regions.

4.3 Downstream impact

Rivers are part of the hydrological cycle and it is the variable nature of runoff processes that give rivers their dynamic characteristics. The ecological integrity of river ecosystems is dependent on the variation in flow regime to which they are adapted. Floods cause hydraulic disturbance that determines the composition of biotic communities within the channel, the riparian zone and the floodplain (Junk et al., 1989; Webb et al., 1999). The spatio-temporal heterogeneity of river systems is responsible for a diverse array of dynamic aquatic habitats and hence ecological diversity, all of which is maintained by the natural flow regime. Dams constitute obstacles for longitudinal exchanges along fluvial systems. Dams not only alter the pattern of downstream flow (i.e. intensity, timing and frequency) they also change sediment and nutrient regimes and alter water temperature and chemistry. These changes and others directly and indirectly influence a myriad of dynamic factors that affect habitat heterogeneity and successional trajectories and, ultimately the ecological integrity of river ecosystems. The changes induced by large Dams may affect ecosystems and the people who depend on them for tens to thousands of kilometers downstream.

4.3.1 Quality of water

The quality of water released from a stratified reservoir is determined by the elevation of the outflow structure relative to the different layers within the reservoir. Water released from near the surface of a stratified reservoir is often well-oxygenated, warm, nutrient depleted water. In contrast water released from near the bottom of a stratified reservoir is often cold, oxygen-depleted, nutrient-rich water which may be high in hydrogen sulphide, iron and/or manganese. Water depleted of dissolved oxygen is not only a pollution problem in itself, affecting many aquatic organisms (e.g. salmonid, fish that require high levels of oxygen for their survival), but one that may be exacerbated because such water has a reduced assimilation capacity and so a reduced flushing capacity for domestic and industrial effluents (ICOLD, 1994). The problem of low dissolved oxygen levels is sometimes mitigated by the turbulence generated when water passes through turbines. Water passing over steep spillways may become supersaturated in nitrogen and oxygen and this may also be fatal to fish immediately below a Dam (ICOLD, 1994; Fidler and Miller 1997: Bouck, G. R. 1980). This is known as the gas bubble disease. It is for example a problem on the Columbia river (USA), where very high Dams in the upper catchment generate high total dissolved gases that are not dissipated downstream (Bell and DeLacy 1967 in Bizer 2000).

4.3.2 Nutrient load deficiency

Reduction in sediment supply from upstream could lead to channel bed erosion and deepening of the channel cross-section, which in turn would reduce the frequency and duration of overbank flooding and limit sediment flux to the floodplain. Floodplain ecosystems would then experience a reduction in the supply of vital nutrients carried by fine-grained suspended sediments. This process has been documented by Ligon et al (1995) on the Oconee River in the southern United States. For example, cold water releases from a high Dam combined with a large reduction in suspended sediment flux downstream of a large volume storage Dam on the same river, may result in water too nutrient poor and cold to allow the spring bloom of algae, which form the base of the aquatic food chain. The effects of either Dam, taken individually, may not produce this result.

4.3.3.1 Downriver hydrological change

Major changes in downriver flows can destroy riparian ecosystems dependent on periodic natural flooding, exacerbate water pollution during low-flow periods, and increase saltwater intrusion near river mouths. Reduced sediment and nutrient loads downriver of Dams can increase river-edge and coastal erosion and damage the biological and economic productivity of rivers and estuaries. Induced desiccation of rivers below Dams (when the water is diverted to another portion of the river or to a different river) kills fish and other fauna and flora dependent on the river; it can also damage agriculture and human water supplies.

5) Nutrient loading and agricultural system

A rapidly growing global human population, and, therefore, a rapidly growing world demand for food, coupled with changing production and consumption patterns have stimulated the evolution of agriculture from traditional to modern, intensive systems. However, while modern agriculture has enabled food production to increase, contributing much to improving food security and reducing poverty, it has also been responsible for considerable damage to biodiversity, primarily through land-use conversion which is expected to remain the largest driver of biodiversity loss beyond 2010 and at least to 2050, but also through overexploitation, intensification of agricultural production systems, excessive chemical and water use, nutrient loading, pollution and introduction of alien species. Pollution is another important cause of biodiversity loss, particularly in aquatic ecosystems.

Excess nutrient loading as a result of the increasing use of nitrogen and phosphorous fertilizers in agriculture causes eutrophication and oxygen depletion. Toxic chemical pollution often arises from pesticide use in farming or aquaculture, from industry and from mining wastes. The increasing carbon dioxide concentration in the atmosphere is causing acidification of the oceans, which is likely to have widespread effects, particularly on shell- and reef building organisms. Excess of nutrients released into the environment from humans originate from different processes. Emissions from agriculture, industries, and municipal activities all add to the eutrophication. Large amounts of nitrogen and phosphorus applied on agricultural fields through fertilizers increase the risk of polluting groundwater through leaching and add to the nutrient load in the surface water when washed away by flush floods. Cultivated areas are more exposed to erosion, leading to a loss of nutrients to surrounding waters through overland flow. Another major source of phosphorus is domestic sewage, as phosphate is a component in faeces and is also commonly used as a water softener in detergent.

Conclusions

- Nutrient loading has adverse effects on freshwater ecosystems and coastal regions in both industrial and developing countries.

- Eroded sediment can carry nutrient particularly phosphates to water-ways and contribute to eutrophication of lakes and streams. Absorbed pesticides are also carried with eroded sediments, adversely affecting surface water quality.

- Ecosystem nutrient balance is the net result of inputs minus outputs. Negative and positive balances are ultimately unsustainable. The magnitude and duration of nutrient imbalance that can be tolerated is determined by an ecosystem's buffering capacity.

- Excess nitrogen (N) and phosphorus (P) loading from point and non-point sources is considered one of the main factors damaging the ecological quality of streams, lakes and estuaries and the deteriorating quality of ground water.

- When nutrients are increased beyond natural levels there are ecological side effects, either locally or downstream. These side effects can exclude species, change ecosystems and even impact on human industries that depend on a healthy environment, such as tourism and fishing.

- Major consequence of fertilizer inputs and atmospheric deposits, and of impairment of buffers and regulatory mechanisms at all scales, is eutrophication of aquatic system both fresh and saline waters.

- Eutrophication is regarded as the most widespread water quality problem in many countries.

- Eutrophication leads to many changes in the structure and function of aquatic ecosystems and thus the services they provide. Such characteristics are detrimental to many water uses, including for drinking, fisheries, and recreation.

- Low oxygen conditions in coastal marine waters are primarily the result of enrichment in nitrogen with consequent enhanced growth of phytoplankton.

- The turbulent water immediately below the Dam spillway may be supersaturated with dissolved oxygen and nitrogen, which can cause gas bubble disease in fishes. Temperature, turbidity, nutrients, and suspended solids are all altered by the residence time of water in reservoirs compared with the natural river flow.

- The reduction in sediment and nutrient transport in rivers downstream of Dams has impacts on channel, floodplain and coastal delta morphology and causes the loss of aquatic habitat for fish and other species.

- The enrichment of reservoir water by large amounts of nitrogen and phosphorous, as a result of the decay and mineralization of organic matter flooded by the reservoir, may lead to a multiplication of blue-green algae.

- Cold water releases from a high Dam combined with a large reduction in suspended sediment flux downstream of a large volume storage Dam on the same river, may result in water too nutrient poor and cold to allow the spring bloom of algae, which form the base of the aquatic food chain.

- Reduced sediment and nutrient loads down river of Dams can increase river-edge and coastal erosion and damage the biological and economic productivity of rivers and estuaries. Induced desiccation of rivers below Dams (when the water is diverted to another portion of the river or to a different river) kills fish and other fauna and flora dependent on the river, it can also damage agriculture and human water supplies.

- Excess nutrient loading as a result of the increasing use of nitrogen and phosphorous fertilizers in agriculture causes eutrophication and oxygen depletion.

- Large amounts of nitrogen and phosphorus applied on agricultural fields through fertilizers increase the risk of polluting groundwater through leaching and add to the nutrient load in the surface water when washed away by flush floods.

- The relationship between nutrient concentration and nutrient load can vary and depends on the flow, the volume of water in the river, and watershed characteristics.

Recommendations

- Comprehensive watershed area management program should be launched in the catchments of rivers as well as of their tributaries.

- Awareness among the farmers should be enhanced for the efficient use of fertilizers.

- Spillways and other hydraulic structures should be efficiently designed, so that turbulence is minimized.

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