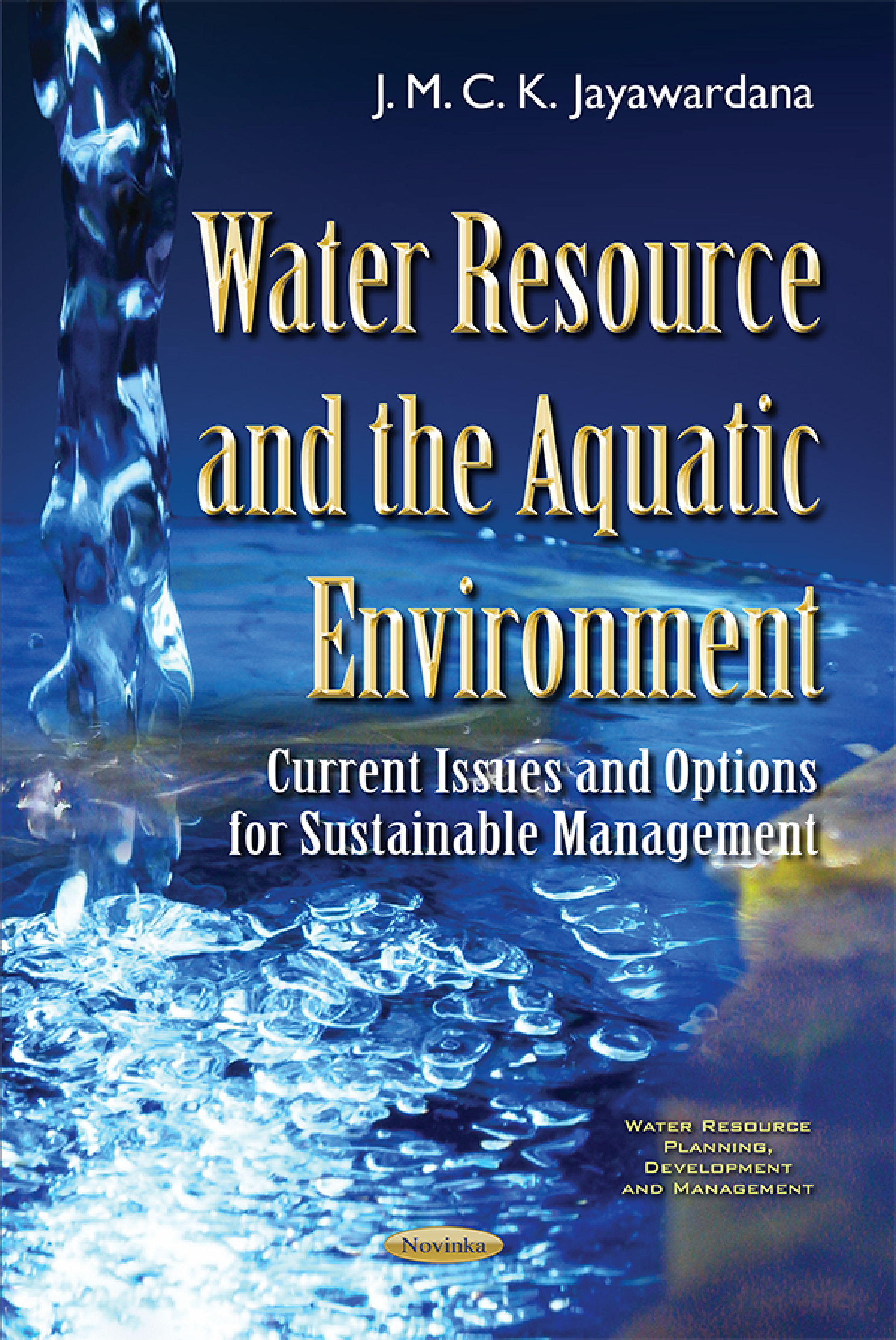

J. M. C. K. Jayawardana

Water Resource and the Aquatic Environment

Current Issues and Options for Sustainable Management

Water Resource Planning, Development and Management

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PREFACE

One of the main challenges faced by humans today is the finding balance between economic development of respective countries and sustainable utilization of the earth resources. With the increase of human population demand for the water resource is increasing globally. One of the challenges for our water resource conservation in the future is the sustainability of the current and future water resource allocation and its usage. Finding a balance between what is needed by humans and what is needed in the environment is an important step in the sustainability of water resources. With the growing uncertainties of global climate and the long term impacts of climate change on freshwater ecosystems management actions, the decision-making will be even more difficult. In such sustainable utilization of water resource and conservation and management of freshwater aquatic ecosystems on the earth is essential step towards the sustainable management of water resource of the world. The present book aimed to elaborate the current status of water resource on earth, challenges to water resource conservation, water quality and monitoring, lentic and lotic systems and associated environmental problems. Further it also elaborate the possible management strategies for conservation of aquatic environment and the water resource.

This book is recommended for undergraduates who are following courses modules of Limnology, aquatic ecology and Environmental sciences.

Chapter 1

WATER RESOURCE AND AQUATIC ENVIRONMENT: NEED FOR SUSTAINABLE MANAGEMENT

1.1. INTRODUCTION

Water is of vital importance for all life forms existing on the earth and to sustain life supporting systems. Water accounts for more than half of the body weight of an average human and the daily water need of a person may range between 1.8 liters and 2.1 liters per day depending on their physiological status. Apart from the individual's water need, the world's ecosystems and food production basically depend on the availability of quantity and quality of the water in the respective regions. Therefore, water has become the key element for economic and social development of many nations. This vitality of water has also given rise to conflicting situations among nations who share common water sources in the world. Nevertheless, the global water resources are not infinite, as a result of a range of human activities, the water resource on the earth has become limited. Scientific predictions suggest that there would be a severe water crisis in near future threatening the existence of life on the earth, unless the proper water conservation and efficient management are practiced. Therefore, further understanding of the present status of global water resource, demand, quantity, quality and issues in management is pivotal in properly managing this vital resource.

Estimates of global water distribution on earth show that 70% of the earth's surface is covered by water. However, out of the available water quantity, 97.5% remains as salt water and only 2.5% as fresh water. Out of the available freshwater, only about 1% are available in surface water bodies such as rivers, lakes and reservoirs and the rest is found frozen in ice caps in Polar Regions, in deep underground aquifers as groundwater and in the soil as moisture. This suggests that from the total water available on the planet earth only about 0.007% is readily available for human needs. Nevertheless, this small available fraction of freshwater is not evenly distributed on the earth. In some regions of the earth, water is adequately distributed and readily available, while some areas such as sub-Saharan African regions have a very limited amount of surface water sources. Ironically, the areas which are battered by water scarcity are the areas with very high human population densities. The lack of access to clean drinking water and sanitation has given rise to numerous health related issues in communities and has imposed a very high health burden to the economies of respective countries.

In addition to the justifiable use of global freshwater resource, modern human beings exploits this resource for number of lavish and lucrative purposes such as sanitation, agriculture, industries, hydropower, recreation, etc. With the expanding of human population, the demand on water resources all over the globe is relentlessly increasing. Despite the population growth available water on planet earth remains constant, hence making the per-capita water availability declining. According to the estimations by the United Nations, the water usage has been increased twice faster at the rate of population growth in the last century. By 2025 about 1.8 billion people will have to live in areas with severe water scarcity and two third of the world population may eventually live in water scarce areas. There is a proven association between the availability of clean water and human health. According to WHO, waterborne diseases are the leading causes of human mortalities in the developing world. Over 783 million people in the world do not have a proper access to improved water sources. WHO figures show that 1. 8 million children die each year from diarrhea and almost half of the population in developing countries is suffering at any given time from a health problem caused by water and sanitation deficits. Many epidemiological and demographic studies show that the public health issues linked with water deficiency, putting a huge public health burden in the economies of these countries and impairing the due economic and social development.

Water is not only needed for the essential functions of the human body, but also vital for agriculture, food industry, waste management, and for maintaining ecosystem services. Particularly, water usage in agricultural practices, industries and urbanization has also contributed much to the water crisis of the earth. Among them agriculture is the largest user of the world's freshwater resources, consuming 70 percent. Many traditional agricultural practices throughout the world consume a large fraction of available surface and groundwater. Specifically irrigated agricultural practices are the primary consumers of the global water. With the ever-expanding human population, the demand for food is increasing, and consequently world food production has to be increased to supply the demand. As a result of this association, it has been estimated that the water need for world food production would be doubled by 2050. One-fourth of the world's food is grown using groundwater, which makes it difficult to estimate or quantify the use. In the long run, climate change threatens to alter the rate of aquifer recharge, making availability even less predictable. Water scarcity is triggered not only by depletion of available water volume, but also by the deteriorated water quality, especially unplanned agricultural practices increasingly contribute to deteriorate water quality. There are numerous ways that agriculture practices contribute to water pollution by fertilizers, pesticides and weedicides. Many of these are being used with the intension of increasing the production and to protecting the produce from pests and diseases. Ultimately, tons of such fertilizer and other chemicals used worldwide, may not be fully utilized or become available for the intended purpose, and thereby the rest will end up in water sources through leaching and runoff. Needled to say, it causes environmental harm and negative impact on the systems.

The world is embracing the most significant technological era of the civilization and many countries of the world are now moving towards technological advancement. Water is a critical constituent for the production in a number of economic sectors. Many industries use water as an ingredient, solvent, cleaning solution and as a mode of conveying raw materials. With the rapid industrialization in many countries water is being severely polluted as a result of intentional or unintentional disposed industrial waste to the environment. Even though there are regulatory bodies, regulations, rules and emission standards are in place for industrial effluent discharge into the environment, in many instances, waste may discharge into water sources without a proper water-treatment because of the high treatment costs involved. Sometimes, this may cause scarring and irreparable damage to the environment and to the species living in such environments. Incidences of human non-communicable diseases such as cancer, kidney failure and various public health issues related to the environmental pollutants are also growing as a consequence of industrial water-pollutants.

Urbanization, and the continued expansion of urban populations that contribute to water pollution, are also major issues faced by many countries, particularly developing countries in the world today. In the last two decades, cities in Africa and Asia are faster converting to mega cities with over 10 million inhabitants. It is predictable that there would be approximately 50 such mega cities by 2025. The urbanization and water pollution are closely linked since in many developing countries, improper planning of cities and lack of facilities to cater to higher population densities have contributed to numerous social and environmental issues. Wastewater arising from urban areas usually contains excessive levels of nutrients and a range of pathogens. Especially urban wastewater need to be carefully managed to avoid possible environmental contamination and to avoid subsequent public health issues caused by such pollutants.

In the big picture, not only the agriculture, industrialization and urbanization but also human negligence may also contribute to aggravate water scarcity issue in many countries. Humans are mostly inefficient users of fresh water. The change of lifestyle of people in the modern society has also contributed much to the increased water usage. An average person needs 50L of water daily for all basic activities but modern lifestyle has increased this amount by four folds. Especially for the production of certain luxury goods consumed by the modern society, a large volume of water is spent. Production of water consuming goods in many parts of the world has put a tremendous burden on water resources in many parts of the world. In such water footprint accounting is a good option for the proper estimation of actual water use in the production of commodities and industrial water usage.

Climate change is also affecting the water availability and quality, hence considered as one of the main causes for freshwater limitation on the planet earth. Shifts in precipitation patterns and snow cover, the increase in the frequency of flooding and droughts can have many secondary impacts on freshwater resources, altering both the demand and supply of water, and changing its quality. In the long run, climate change threatens to alter the rate of aquifer recharge, making water availability even less predictable.

Freshwater ecosystems of the earth, which include Lotic and Lentic systems are very important in providing needed fresh water for drinking, bathing, agriculture, irrigation hydropower to humans and water requirements for ecosystem processes. However, increasing human population, agriculture, urbanization and industrialization has exerted a tremendous pressure on these valuable ecosystems. Most of the pollutants resulting from agricultural activities, industrialized areas and urban sewage often end up in surface water bodies causing changes of water quality and putting pressure on available water quantity. Many of the rivers and lakes on earth are extensively polluted and the water in such water bodies no longer fit for human consumption. This most frequently happens in industrialized countries, however developing countries are also experiencing similar problems due to poor implementation of regulations and laws pertaining to pollution control in these countries.

Water allocation for environmental needs is essential for keeping the balance between the human activities and healthy ecosystems, but this issue is often neglected or less prioritized. Due to the increased water demand for agriculture, hydropower generation and for various other activities many of the major rivers of the world are impounded and flow is severely altered. Especially in such freshwater ecosystems, alteration of flow regimes and reduced environmental flow can severely affect the fauna and flora associated with such systems. There are many direct and indirect impacts affecting the freshwater ecosystem health by such diverse schemes. If the current rate of impacts on these ecosystems continues sustainability of freshwater ecosystems is drastically under an alarming threat. Therefore, measures to control and keep the health and well-being of such ecosystems are of prime concern.

1.2. FUTURE OF WATER RESOURCE

One of the biggest concerns for our water resource is sustain the current and future water resource allocation, and its usage. As water becomes scarce, the importance of how it's being managed would become crucial. Finding a balance between what is needed by humans and what is needed in the environment is an initiative, but important step in the sustainable management of water resources. The growing uncertainties of global climate change and the long-term impacts of climate change on freshwater-ecosystems-management-actions will make the decision-making for water sustainability more difficult. Thereby, sustainable utilization of water resource and conservation and management of freshwater aquatic ecosystems on the earth are essential steps towards the sustainable management of water resource on earth.

This book is written with the aim of elaborating 1) the current status and the importance of water resource, 2) the quality aspects of freshwater, 3) functioning of lentic and lotic systems, and 4) environmental issues associated with the management of these systems and to suggest possible management strategies.

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Chapter 2

WATER QUALITY

2.1. INTRODUCTION

Water quality generally describes the chemical, physical, and biological status of water, usually with respect to its suitability for a particular purpose. The quality changes of water initiates when it passes through the atmosphere during precipitation. The water is mainly received by the earth's surface through precipitation. A significant fraction of water received by the earth's surface drains through the land into surface water bodies as surface runoff and ends up in the ocean. A portion of water infiltrates through the soils to the underground stores. During this process different substances are added to the water naturally-or it occurs from various anthropogenic activities. Various gasses and dust particles derived from natural or anthropogenic sources may contaminate the water when it passes through the atmosphere. Further contamination of water may take place when it flows through the earth's surface or underground. The water quality is affected by a wide range of natural factors as well as human activities. The most important natural influences are geological, hydrological and climatic, since these factors affect both the quantity and the quality of available water. The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and/or restrict water use. The rapid rate of advancement in industrialization, urbanization and expansion of agriculture in many countries are significantly contributing to the pollution of water. Industries produces a huge amount of waste contained toxic chemicals and pollutants which can cause water pollution. Wastewater discharges with high nutrient loads from diffuse sources such as run-off from livestock feedlots or agricultural land fertilized with organic and/or inorganic fertilizers have become common sources of water pollution.

Population growth and urbanization is closely linked with the water pollution as well. Especially in developing countries, untreated-urban waste is a prime source of water pollution. Due to those reasons, water quality rarely remains static; it varies at spatial and temporal scales. Further, the quality of the water basically determines its suitability for different uses. For example the quality of water in a lake may be considered suitable for swimming, but may not be suitable for drinking or cooking purposes (consumption). Conversely drinking water can be used for irrigation, but vice versa is not. Therefore, water quality monitoring has become an essential step in many situations such as for effluent description, when monitoring the health of aquatic environments and to develop management programs and action plans to protect water resource. Such knowledge of general water quality parameters, their relationships with ecosystem functions and human health are essential for better management of water resource on the earth. Such knowledge is important for multiple groups; institutions dealing with water, industries using water and those who are in the water related decision making bodies. Therefore, this chapter focuses mainly on describing general water quality parameters and their associations with ecosystem components and human health.

2.2. PROPERTIES OF WATER

The water molecule has a remarkable tendency to dissolve substances due to its unique physical and chemical properties; being a fluid in atmospheric temperatures (0 - 100ºC), molecular arrangement and the presence of hydrogen bonds in the molecule. These properties allow water to become a universal solvent. Depending on the temperature, water exists as liquid, solid (below 0ºC) and gas (above 100ºC) phases allowing it to circulate in different environmental compartments. It also has a high specific heat capacity, which allows it to absorb heat with very little change in water temperature. Further, the water density increases with declining temperatures. However, when the temperature falls below 0ºC and water freezes, the water density reduces. This phenomena has a significant biological importance for life on earth, and allows most life forms to survive in the aquatic environment during the winter or low temperature seasons because the low density ice may float on the water surface. These properties of water make it a universal solvent, and allow life forms to exist on the earth being the medium of life. One of the prime reasons for life forms to form, survive and thrive on the planet earth may have been contributed by the abundance of water on earth.

2.3. WATER QUALITY

Basically, physical, chemical and biological characteristics of water may determine its quality or its suitability for a particular purpose. Generally, physical properties such as taste, color and odor of water provide superficial information about the water quality. However, in-depth analysis of water for its constituents, particularly contaminants is indispensable for a better estimation of water quality. In this respect, proper sampling and water quality analyses using suitable equipment are required. Some of the general physical properties of water, which can be used for testing the status of water quality include color, turbidity, odor and taste. Different odors may arise from water under various situations or conditions. Rotten-egg smell or Hydrogen sulfide smell from the water may arise due to the presence of sulfate-reducing bacteria and algal products which usually occur under anaerobic conditions. This indicates that the water has turned into anaerobic condition and anaerobic bacterial actions have become predominant. In particular, this smell is very common in lakes or reservoirs which are undergoing a process of eutrophication. Decomposition of the large amount of algal cells and resulting anaerobic conditions prevailing in such water bodies provide ideal conditions for anaerobic bacteria to thrive and release these odors through anaerobic decomposition of algae. Similarly, oily smell can result from water when it is contaminated with gasoline or oil due to large scale oil spills. High levels of organic matter decomposition associated with sediments of a waterbody or presence of gas in the aquifer may contribute to the release of methane gas and subsequent methane gas smell. The phenolic smell of water is an indication of the contamination of water with industrial waste or gasoline contamination. Therefore, the smell of the water is an indicator of water contamination.

Generally, pure water does not have a taste. Certain substances dissolved in water can add taste to the water. There are many different solutes found in water naturally and as a result of pollution. Presence of salts such as sodium chloride in water can give salty taste. Presence of alkaline compounds in water will give an alkali taste. Metallic taste of water is found when water pH levels go down (acidic) hence dissolving of metals. Specific metallic taste can be resulted from water when excessive levels of inorganic chemicals such as iron (at levels over 0.004 mg/l), copper (2-5 mg/l), and zinc (4-9 mg/l) are present in water.

The pure water is colorless and contaminants in water may indicate different colors depending on their makeup. Generally, large quantities of dissolved organic matter in water give yellow brown color. Presence of phytoplankton in water indicates green color while the presence of large amounts of zooplanktons provides reddish brown color. The presence of certain inorganic compounds such as iron either dissolved or precipitated, also can give reddish color to water. Especially the dissolved or precipitated iron present in the water can even give reddish tint. Sometimes, the activities of iron Reduction Bacteria would also contribute to color variation of water due to bacterial metabolites. Normally black color of water is given by certain bacterial actions such as Ion Reduction with manganese and possibly iron compound in water. Presence of high levels of humic substances in water may generally give yellowish color.

2.3.1. Turbidity

Turbidity is a measure of the degree of water clarity (The degree of materials suspended in water). Suspended materials in natural water may include soil particles (clay, silt, sand), plankton, microbes and other substances. Various land based activities can contribute to the turbidity changes in the aquatic environment. Especially soil erosion of catchments can deliver higher loads of suspended soil particles into surface water bodies. In addition to that, waste water discharge from industries and urban areas can bring large amounts of suspended particles to water. In many developing countries illegal dumping of untreated effluent from industries has become a significant problem. Especially untreated effluent discharged illegally to the natural water sources can bring significant loads of suspended materials and cause-water turbidity. Nevertheless, the presence of bottom feeding fish species is also capable of disturbing the bottom sediments and contributing to high turbidity.

Higher turbidity is generally recorded in eutrophic water bodies resulting from the excessive growth of algal cells. Turbidity may have direct and indirect impact on physical water properties and aquatic life. Higher water turbidity can lead to the elevation of water temperature due to the increased heat absorption by the particles. Subsequently, this can lead to reduced oxygen levels dissolved in -water. Increased turbidity can also lead to reduced light penetration through the water column and limited primary production. In addition to such direct and indirect effects on water quality parameters, increased turbidity in water can have a detrimental impact on aquatic communities. Increased levels of suspended materials in the water may clog the gills of filter feeding species (both fish and invertebrates). Such stressful situations would reduce their immunity and disease resistance. Further, high loads of suspended particles in slow flowing rivers can have many adverse effects on benthic communities. In slow flowing rivers, the suspended particles gradually settle in the stream bottom and cover the bottom substrate which are used by various aquatic species for laying eggs, hatching and larval development. Eventually, this can lead to a reduced benthic production in those streams.

2.3.2. Temperature

Temperature can influence many physical and chemical properties of water and subsequently change aquatic communities. Among physical properties, temperature is cardinal and capable of directly affecting the density of water. When the water temperature rises, water density reduces. However, the highest density of the water prevails when the water temperature becomes $4^{\circ}C$. But the lowest water density is recorded when water becomes ice or freezes. Generally, ice crystals may float on water as a result of the above phenomenon. In addition to that, the temperature can also influence chemical properties such as solubility of ions in water. At higher temperature solids (metals) easily dissolve in water, but gases tend to be less dissolved. Water being the main media of biological matrices, the significance of temperature change can be observed in complex biological systems in various means; growth, development, reproduction, spawning and embryonic development. Thereby, every organism has an optimum temperature requirement for them to survive and then to thrive. Beyond these temperature ranges aquatic organisms undergo stress adversely affecting or threatening their survival, growth and reproduction.

2.3.3. Dissolved Oxygen

Oxygen is essential for most aquatic species and therefore the concentration of dissolved oxygen in water is critical for the function of the healthy system. In addition, the natural purification process of water requires adequate levels of oxygen, in order to enrich aerobic life forms. Oxygen levels in the water will determine the distribution, behavior and growth of aquatic species. Oxygen level also affects solubilities of other chemicals in water. The saturation level of oxygen dissolved in water depends on water temperature, salinity and atmospheric pressure. Oxygen level in water slightly decreases when the water salinity increases. Similarly with the increase of water temperature, dissolved oxygen level declines.

A number of processes may increase or deplete the dissolving of oxygen in water. There are two ways of adding oxygen to water; diffusion of atmospheric oxygen or photosynthesis of plants. On the other hand, oxygen is removed from water for other processes; oxidation of organic matter in water, ammonia, organic matter in sediments and respiration of aquatic life. Despite the fact that oxygen is not a limiting factor for running water, in running water, oxygen levels may depend on some other factors; current velocity, contaminants, water temperature and biological activities within the stream. In fast flowing water, generally the dissolved oxygen level is higher because of the increased and consistent aeration of water during its flow. Generally, water originating from springs has low oxygen level due to the limited exposure of ground water to atmospheric air. Rivers with sewage pollution have low oxygen levels because decomposition of organic loads in large volumes may consume the dissolved oxygen. Similarly the presence of life forms (fish, macrophytes and other species) in higher densities may consume available oxygen in the water, giving rise to low oxygen levels at during the night.

2.3.4. Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD_5) is generally measured to assess the levels of organic pollution of water. It measures the amount of oxygen consumed for biodegradation of organic matter in water and therefore widely used test in the analysis of sewage, wastewater quality and water pollution levels. Usually BOD_5 is performed over a 5 days of the incubated period of water at 20^0C and measures the oxygen utilized for biodegradation of organic matter in the sample during the incubated period. BOD_5 levels of water will be increased with the presence of higher levels of decomposing organic matter. Organic matter enters into water bodies in the form of organic debris, dead plants and animals, organic manure, effluent from various industries such as pulp and paper mills, waste water treatment plants, food processing plants and also effluents coming from failing septic systems and urban runoff generally contribute to increased BOD_5 levels in water.

Table 1. BOD_5 levels in water and pollution status

BOD in mg/L	Water quality
1 – 2	Very good. Very low organic matter content
3 – 5	Moderately clean
6 – 9	Polluted. Higher levels of organic matter present and microbial activities take place.
100 and more	Very polluted. Very high levels of organic matter and microbial activities are taking place.

2.3.5. Chemical Oxygen Demand (COD)

COD test is commonly used to indirectly measure the amount of organic compounds in water. The basis for the COD test is that nearly all organic compounds can be fully oxidized to CO_2 with a strong oxidizing agent (Potassium dichromate) under acidic conditions. In the COD test, both biologically oxidizable matter and biologically inert matter are oxidized and hence the COD value of a sample is generally higher than BOD_5 value.

2.3.6. pH

pH is the negative log of hydrogen ion concentration in a water-based solution. Normally the pH of pure water is 7. However, natural water exhibits a pH range, because it contains various dissolved minerals and gases.

In surface water, pH ranges from 6.5 to 8.5 while in groundwater it ranges between 6 and 8.5. When the water pH becomes less than 6, it is considered acidic. In places such as swamps and bogs, mostly the water pH may range between 4 and 6 and is considered acidic. The water pH between 8 and 12 is considered Alkaline. In natural water, pH and CO_2 levels are closely associated and therefore pH level fluctuates daily.

pH affects many biological and chemical processes in water. Aquatic animals prefer a pH range of 6.5 and 8. pH values exceeding this range, may increase physiological stress and decrease reproductive capacity of freshwater organisms. This can contribute to reduction of species diversity in freshwater ecosystems. At low pH levels, toxic elements such as heavy metals in the sediments may get dissolved in water and become available for aquatic flora and fauna. As a consequence of the increased toxic metal levels in water many sensitive aquatic organisms, may negatively affect and disappear from the ecosystem. The fluctuation of water pH may occur due to many reasons. Low pH or increased acidity in water can be caused mainly by dissolving of atmospheric CO_2, and also by acid rains in certain parts of the world. In addition to that, sedimentary rocks with soluble carbonates also contribute to lowering of pH in surface water. Mainlywastewater containing acidic or alkaline compounds, discharged into natural water bodies may significantly contribute to the fluctuation of pH of the water depending on their makeup present.

2.3.7. Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current. It depends on the amount of ions dissolved in the water, their valence, mobility and water temperature. Therefore, conductivity is an indirect measure of the presence of dissolved ions in the water. The presence of ions such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron may contribute to the increase of water conductivity. Since water conductivity is a measure of ion content in -water, it can also be considered as an indicator of water pollution.

Freshly distilled water has very little amount of ions dissolved in the solution and hence conductivity can range between 0.5 and 2.0 $\mu S\ cm^{-1}$. In normal potable water fare amounts of ions are present and hence conductivity may range between 50 and 1500 $\mu S\ cm^{-1}$. The water contaminated with industrial waste may have a conductivity of more than 10,000 μScm^{-1} since industrial waste may contain compounds which may dissociate into cations and anions when they dissolve in water. The conductivity of the water in streams and rivers in the upcountry region in Sri Lanka is generally lower than that of the lowland rivers. When the river flows over a long distance over various geological formations, various substances derived from such geological formations can naturally add into the water. Similarly, a wide range of anthropogenic activities may also contribute to the addition of various ions to the water thus increasing the water conductivity. Water runs through areas with clay soil also tends to have higher conductivity. This is mainly due to the presence of materials that ionize when washed into water. In areas where ground water discharged into rivers and lakes also may have varying conductivity values depending on the bedrock through which they flow. In addition to that, various contaminants of stream water which originate from failing sewage systems connected to surface or ground water can increase conductivity due to the presence of Cl^-, PO_4^- and NO_3^-. Generally the presence of oils in water reduces the conductivity since oils are not good conductors of electricity.

2.3.8. Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids**.** Alkaline compounds in water may include HCO_3^-, $CO_3^{--}$and OH^-. These alkaline compounds in the water contribute to the removal of H^+ ions and avoid drastic changes of pH in the water. Measuring alkalinity is important in determining a streams or lakes ability to neutralize acid pollution from rainfall or wastewater. Therefore, alkalinity is one of the best measures of the sensitivity of a water body to acid inputs.

There are many factors which contribute to the alkalinity of water. Increased alkalinity of water may result due to contamination of the water with certain industrial waste which contains alkaline compounds. Certain rocks, soils and certain plant activities may also contribute to the alkaline nature of water. Especially, surface water and groundwater in areas with rock/aquifers containing $CaCO_3$ or $MgCO_3$ may have higher alkalinity levels.

2.3.9. Hardness

Hardness to -water is given by various ions present in water. Among them, the main ions responsible for water hardness are Ca^{+2} and Mg^{+2}. In addition, iron (Fe^{2+}) and manganese (Mn^{2+}) may also contribute to the hardness of water, but generally these are present in much lower concentrations. Based on the levels of such ions present in water, the water hardness can be categorized into four different levels.

Soft	0 **-** 60 mg /l $CaCO_3$
Moderately hard	61 – 120 mg/l
Hard	121-180mg/l
Very hard	≥ 181 mg/l

In water, these $Ca^{2+}$and Mg^{2+}ions are associated with various anions. When the $Ca^{2+}$and Mg^{2+} are associated with bicarbonates (HCO_3^-) water hardness is referred to as "carbonate hardness" or "temporary hardness." Water hardness can be reduced by heating the water because of higher temperatures, the insoluble carbonates precipitate out of water.

Sometimes, $Ca^{2+}$and Mg^{2+} ions are associated with other ions (Cl^-, NO_3^-, SO_4^{--}) and the hardness is called permanent hardness or non-carbonate hardness. These ion complexes are difficult to remove through heating because precipitates may not be formed by heating. Since non-carbonate hardness is difficult to remove through simple treatments such as heating, much more complex and expensive treatments would be necessary.

Natural water acquires $Ca^{2+}$and Mg^{2+} ions from various sources. Calcium can enter -water through the dissolving of ions from calcium bearing rocks such as Calcite. Magnesium also can enter the water from Mg bearing rocks such as dolomite. Some organisms that live in water may also contribute to the addition of Ca and Mg into the water. Some green algae such as *Chara* and *Cladophora*, macrophytes (*Elodea* and *Potamogeton*), *s*ome blue green algae and bacteria may also secrete Ca to the water. Sometimes decomposition of calcium bearing shells of molluscs also adds Ca to water. Mg also contributes to -water hardness and it is an important component in the Chlorophyll molecule. Excess levels of Mg are toxic to animals. $MgCl_2$ can produce neuropathies (or anaesthetic effect) on animals.

2.3.10. Nitrogen

Nitrogen is an essential nutrient for plants and a basic component in protoplasm. It is present in the aquatic environment in multiple oxidation states such as NO_2^-, NO_3^- or reduced form such as NH_4^+. Even though nitrogen is an essential nutrient for plant growth, excess amounts can cause significant problems to water quality. Together with phosphorus and NO_3^- can accelerate eutrophication causing dramatic increase in aquatic plant growth and change in type of plant and animal that live in aquatic habitats. Eutrophication also triggers the development of anoxic conditions in aquatic environment causing loss of sensitive species and making the water unusable. Excess nitrogen levels in the drinking water can also cause various health issues to humans. Intake of water containing excessive levels of nitrates can lead to develop a condition called Methemoglobinemia in infants younger than six months of age. When excess levels of Nitrate are taken up, they are converted into nitrites in the body. Increasing levels of nitrites would convert hemoglobin to methemoglobin hence decrease the oxygen supply to the vital organs. Infants lack the enzymes which are responsible for reversing methemoglobin to hemoglobin and therefore, the infants are more vulnerable to Methemoglobinemia. Excess N levels in drinking water also lead to the formation of carcinogenic Nitrosamines in the stomach leading to a risk of developing cancers. In addition to the health hazards, higher nitrogen levels in surface water may lead to contamination of ground water bodies with nitrogen through seepage. Reactive nitrogen (NO_3^- and NH_4^+) present in surface waters and soils, can also enter the atmosphere as the smog-nitric oxide (NO) causing acid rains.

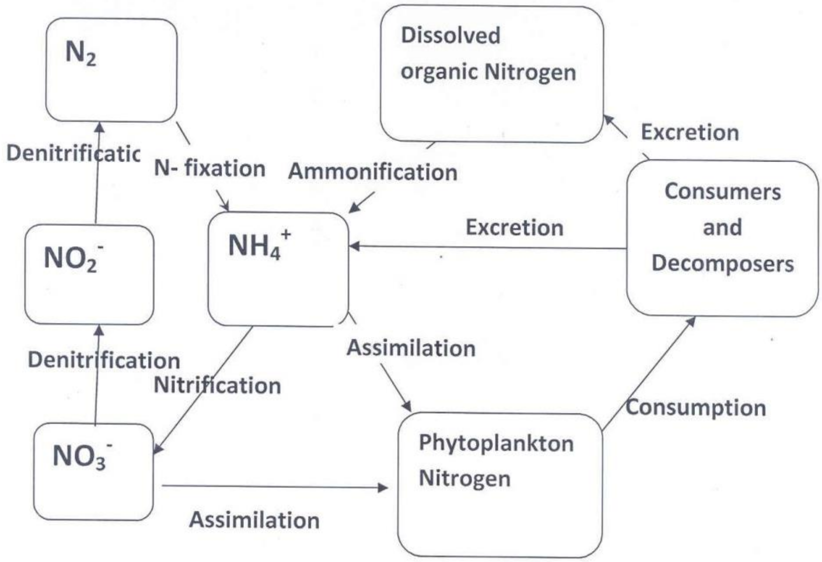

Figure 1. Aquatic Nitrogen cycle.

Fixation

The largest pool of N is available as atmospheric N_2 which is biologically unavailable. This biologically unavailable form has to be converted into a biologically available form of N in order to nurture organisms. There are two natural processes that transfer N_2 to biologically available forms; lightning and biological N fixation. Various microorganisms are responsible in biological fixation of N. In the aquatic environment, mostly N_2 fixation is carried out by

Cyanobacteria or blue green algae. During this process, N_2 is converted to ammonia and later to other organic N such as amino acids.

Ammonification

Ammonification means conversion of organic N such as protein into ammonia by the action of ammonifying bacteria. When planktons and other animals die or when they excrete their waste, these are decomposed by ammonifying bacteria into NH_4^+.

Nitrification

This process involves conversion of ammonia into nitrates by bacterial action. Nitrification takes place in two steps in the nitrogen cycle.

Stage i.

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 4H^+ + 2\,H_2O$$

Stage ii.

$$NO_2^- + O_2 \longrightarrow 2NO_3$$

The conversion of NH_4^+ to NO_2^- is carried out by *Nitrosomonas* bacteria. Conversion of NO_2^- to NO_3^- is carried out by *Nitrobacter* bacteria.

NO_3^- is highly oxidized, easily dissolving and biologically most reactive. For the nitrification reactions a large amount of O_2 is needed and this may lead to the development of anoxic conditions in water. The oxygen demand for nitrification process is also known as “Nitrifying oxygen demand (NOD)”. Under anaerobic conditions, these reactions are reversed and more NH_4^+ is produced.

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + H_2O + 2H^+$$

Assimilation

Assimilation involves the conversion of nitrates and ammonia into protein by plants. Most plants can assimilate atmospheric N_2.

In the aquatic environment, some algae such as *Chlorella and Microcystis* can readily assimilate atmospheric N_2.

Denitrification

Denitrification involves the conversion of nitrates into nitrogen gas by anaerobic denitrifying bacteria.

$$NO_3^- \text{ or } NO_2^- \longrightarrow N_2/N_2O$$

Mostly this reaction takes place under anaerobic conditions, most close to sediments or in soils which are water logged.

Human Induced Alteration to N Cycle

Changes induced by humans to N cycle have resulted numerous problems to terrestrial and aquatic ecosystems. A largest inert pool of N_2 exists in the atmosphere in a biologically unavailable inert form. However, human activities have currently accelerated the conversion of this inert N into more biologically available form in an accelerated manner subsequently affecting the balance of the N cycle. Extensive growth of nitrogen fixing legume crops, increased production of N containing fertilizer, which are produced using artificial fixation of atmospheric Nitrogen through technologies such as "Haber - Bosch process" (a process which uses high temperatures and pressures to convert nitrogen gas and a hydrogen source, i.e., natural gas or petroleum into ammonia) and increased fossil fuel burning has increased the bioavailable fraction of N in the environment affecting the balance of the N cycle. Human induced changes of N cycle have increased-N in the aquatic environment. In many parts of the world, there are reports of increased levels of N in rivers and in other lentic water bodies. Examples include increasing trends of Nitrate levels in rivers such as the Mississippi River and many European rivers. It has also been reported that nitrate fluxes and concentrations in the large rivers correlated with the demography (human population densities) in the watersheds. Analyses of recent data suggest that N in streams and rivers draining relatively undisturbed forests is largely organic N. With increasing human disturbance, total N fluxes in rivers increase and a higher proportion is composed of nitrate. Anthropogenic N inputs to aquatic environment basically include1) fertilizer, through N fixation by agricultural crops, 2) deposition of oxidized N from the atmosphere, and 3) the net import or export of N in food and feed stocks.

2.3.11. Phosphorus

Phosphorus (P) makes up around 0.1% of the earth's crust by weight and is an important element for all living organisms to synthesize ATP, ADP, DNA and phospholipids (membranes). In combination with N compounds, P is an essential nutrient for plants, therefore, higher concentrations can contribute to increased algal growth. P also serves as a limiting nutrient for plankton growth. P can present in different forms in the aquatic environments. These include Dissolved Inorganic Phosphorus (DIP), Dissolved Organic Phosphorus (DOP) and Particulate Phosphorus (PP).

Total P = DIP + DOP + PP

i. DIP – normally present at low levels (<5%) as PO_4^{3-} and polyphosphates
ii. DOP – dissolved organic phosphorus is organic colloids and they are not readily available for plant growth
iii. PP - often represent the largest percentage of P in lakes (>70%).

These include,

- P in the form of organic matter in the bodies of living or dead organisms
- Particulate P in minerals (not bio-available)
- Phosphate adsorbed onto clays

P can enter into the aquatic environment in different ways. One of the main ways of P entering into the aquatic environment is through rock weathering. Weathering of calcium phosphate containing minerals such as apatite [$Ca_5(PO_4)_3OH$] may release P into the aquatic environment. In addition to that, anthropogenic inputs of P are now greater than natural inputs of P in many watersheds i.e., urban runoff, agriculture (animal waste, fertilizers), sewage (treated or untreated), and industries. In lakes and reservoirs, the largest quantity of P is trapped in the sediments (50 – 500 times greater than that in the water column). There are many factors leading to P release into the water column from sediments. Water column chemistry/Redox reactions, bacterial activities, water currents and plant uptake are a few of the mechanisms leading to P release from sediments.

Development of anoxic conditions in the hypolimnion is one of the leading factors which trigger P release from sediments to the water column. When the hypolimnion remains well oxygenated, phosphate in sediments is trapped by metal ions such as iron, aluminum and calcium. In oxygenated waters, iron is present in the form of Fe^{3+} and it is converted to Fe^{2+} under anaerobic conditions. Fe^{3+} ions readily bind with phosphates and make it binding to sediments. Lack of oxygen due to decomposition, converts the available Fe^{3+} into Fe^{2+} and release the sediment bound phosphates back into the water.

In addition to that, bacterial actions also contribute to the release or precipitation of phosphates in the aquatic environment. Bacterial actions are mainly responsible for the mineralization of living and dead matter in the aquatic environment and thus release of P. They are responsible for the conversion of organically bound phosphates in dead animals and plant membranes into inorganic phosphates. Similarly, in shallow lakes rooted and floating aquatic plants can readily absorb phosphates in sediments and assimilate phosphates into living biomass. Underwater currents occurring in lakes and reservoirs also contribute to the re-suspension of phosphates from the sediments into the water column. Therefore, management of sediments is very important in the control of eutrophication in lakes because sediments are one of the largest sources of P reserves in the lentic environment.

2.3.12. Chloride

Chloride is normally present in natural waters. The chloride levels in water can be influenced by different factors; 1) geological material which is in contact with water, 2) chloride containing contaminants such as industrial waste or sewage or 3) the intrusion of sea water into freshwater bodies. Higher levels of chloride in water may have a corrosive effect on metals. A salty taste is detectable when Cl^{-} is in combination with sodium ions.

2.3.13. Fluoride

Fluoride may enter into water mainly through geological materials in the area concerned. Areas with F^{-} bearing rocks such as Granit and Apatite containing rocks may have higher Fluoride levels in water. Fluoride ion in the rocks can easily exchange with OH^{-} ions in the water. According to the WHO guidelines the Fluoride levels in drinking water should be 1.5 mg l^{-1}. However, excess or very low levels of fluoride in drinking water can cause health impacts. Very low levels of fluoride (<0.5 mg/l) in drinking water are found to cause dental caries, limited growth and fertility in humans. In contrast, fluoride levels higher than 1.5 mg/l in drinking water can cause dental fluorosis (mottling of teeth) and skeletal fluorosis.

Fluoride is widely used in certain industrial processes and consequently occurs in the resulting wastewaters. Industrial sources of fluoride are: 1) production of glass and ceramics, 2) electronics, steel and aluminum processing, 3) pesticides and fertilizers, and 4) electroplating operations. The fluoride levels resulting from such operations may range from several hundred to several thousand milligrams per liter in untreated wastewaters

2.3.14. Metals

Metals in the environment can be originated from different sources such as the natural weathering process of rocks, soil erosion and through volcanic eruption etc. There are many anthropogenic activities also contributing to release of metals, especially heavy metals to the environment. These include industrial discharge, urban runoff, sewage effluent, air contaminant fallouts, Agrochemicals and pesticides. With the industrial revolution in many countries, use of metals has been expanded and their release into the environment has become exponential and widespread.

Heavy metals are high density metals which are naturally present in the environment. These include Lead, Mercury, Cadmium, Chromium, Iron, Copper, Zinc, Aluminum, Beryllium, Cobalt, Manganese and Arsenic. Many of these elements are essential to the body in very low concentrations (trace elements). For example, iron is an essential metal for the formation of hemoglobin. Copper is essential for the hemocyanin formation in invertebrates. Cobalt is essential for the formation of vitamin B_{12} and Zinc is an essential component of many enzymes. However, excess levels of these metals entering into bodies can be harmful and cause various health problems. Some heavy metals have no essential function in the body (i.e., Mercury, Lead) and even very low levels can trigger a harm.

Contamination of the aquatic environment with heavy metals can occur through soil-leaching; atmosphere-raining and through the direct discharge of industrial waste to the waterways. Once enter into the aquatic environment, these can transform into different physical-chemical forms which are highly toxic and promote bioaccumulation. Toxicity of metals can vary according to their valence and their amalgamation with other elements.

Pollutants like heavy metals are also considered conservative pollutants since they are not broken down by biological activities or through other mechanisms such as photo degradation. Most plants and animals can regulate their metal content to a certain point, but metals that can't be excreted accumulate in an organism over its lifetime. Some of the heavy metals commonly found in the environment and their impacts on biota are summarized below.

Iron

Iron is an abundant element in the earth's crust. However, in natural water, iron can be present in very low concentrations. Iron is found in natural water in the forms of +2 and +3 oxidation states. The form and solubility of iron in natural waters are strongly governed by pH and oxidation- reduction potential of -water. In a reducing environment, ferrous (+2) iron is relatively soluble. In oxygenated water, ferrous ions are converted to ferric (+3) and hydrolyzed to precipitate as hydrated ferric oxide. The precipitate is highly insoluble and found in solution only at a pH of less than 3. The presence of inorganic or organic complex-forming ions in the natural water also can enhance the solubility of ferrous and ferric iron subsequently increasing the ion levels in the water. However, surface waters in a normal pH range of 6 to 9 rarely carry more than 1 mg of dissolved iron per liter. The formation of hydrated ferric oxide can give objectionable odor, taste and reddish color to the water. This can make the water undesirable for domestic use when levels exceed 0.3 mg l^{-1}

Mercury (Hg)

Mercury (Hg) is a metal which is liquid at room temperature and has a low boiling point. It is extensively used by various industries such as the manufacture of Hg batteries, electrical apparatus, laboratory equipment, paints and pesticides.

Hg contamination of the soil and water is caused by both natural and anthropogenic sources. Volcanic actions, erosion of Hg containing sediments, and gaseous emissions from the earth's crust are the natural sources of Hg. Hgs or metallic state embedded in igneous rocks (basalt and granite) is released to the environment through rock weathering process. The majority of Hg comes from anthropogenic emissions. These include mining, combustion of fossil fuels, processing of pulp and paper, incineration, use of Hg compounds as seed dressings in agriculture, and emissions from smelters.

Hg can present in the environment in various forms. Conversion of Hg from one form to another occurs in sediment, water and air, and is catalyzed by various biological activities. In the aquatic environment, microorganisms convert the elemental Hg into methyl mercury (MeHg) through a process called methylation. The MeHg thus formed easily move up the aquatic food chain and bio-accumulate. Freshwater and marine organisms and their predators, normally accumulate more Hg than that of terrestrial animals, with the levels being highest in top predatory fish. Hg can enter into top predators in the aquatic environment such as fish in numerous ways; by absorption from the water across the gill or through the food chain.

There are many factors that govern the rate of bioaccumulation of Hg in the aquatic environment. At higher temperatures bioaccumulation of Hg can be increased due to the elevated temperature enhances metabolic rate of fish and thus enhancing the accumulation of Hg. MeHg can get into the human body through contaminated seafood and possibly from red meat.

Health hazard of Hg is also well known. Generally Hg has no known biological role in the human body and in other organisms. Hg is fat soluble and hence can readily get into the bodies of living organisms through the bio accumulative process. Once enter into the body, it tends to inhibit the action of many enzymes in the body. Some of the health impacts of Hg include interference of the metabolism of mineral elements, such as sodium (Na) and potassium (K), cellular dysfunction, Liver dysfunction, Neurological disorder, Erithism- psychic disorder and Teratogenic effects.

Cadmium (Cd)

Cadmium is a nonessential trace element and is present in air, water, and food. It is widely used in many industries and therefore contamination of fresh water with Cd is common. Cd is widely used in the production of Nickel/Cadmium batteries. Cadmium coatings are widely used in high stress environments such as marine and aerospace applications where high safety or reliability is required since it is highly resistant to corrosion. Cadmium is also widely used in alloys, electronic compounds and as a stabilizer for PVC (polyvinyl chloride). It is also present as an impurity in several products, including phosphate fertilizers, detergents and refined petroleum products.

Cadmium occurs naturally in aquatic systems at very low concentrations (<10 mg/l). However, Cd enters into water through environmental pollution because many Cd containing wastes ends up in the aquatic environment. The amount of Cd suspended in water is determined by several factors including pH, carbonate alkalinity, and concentrations of Ca and Mg. There is a distinct difference between the forms of Cd in marine waters and fresh waters. In seawater, over 90% of the Cd is in the form of chloride salt ($CdCl_2$), while in fresh water Cd is present mostly as $CdCO_3$.In the aquatic environment uptake of Cd by aquatic organisms are influenced by many factors. In seawater, various Cd binding ligands occur, and these ligands prevent Cd absorption by organisms to an appreciable extent. Other factors affecting Cd uptake into the tissues of aquatic organisms are salinity and temperature, however, their effects are diverse and opposite. Salinity has a negative effect; a decrease in salinity causes an increase in the rate of Cd uptake. Temperature has a positive effect and when temperature increases, the Cd uptake increases.

Cadmium derives its toxicological properties from its chemical similarity to zinc an essential micronutrient for plants, animals and humans. Under this context, Cd is readily taken up in places where the Zn is required. It is bio-persistent and, once absorbed by an organism, remains resident for many years (over decades for humans) although it is eventually excreted. High cadmium levels can lead to depressed growth, kidney damage, cardiac enlargement, hypertension, fetal deformity and cancer in humans.

Lead (Pb)

Pb is naturally entered into the environment through weathering of rocks, windblown dust, forest fires and through volcanic eruptions. Modern industrial engagement in terms of rapid development, largely contributes to the release of Pb into the environment since it is widely used in industrial applications. Some of the applications of Pb in the industrial processes include the production of glass, paint, pipes, building materials, art sculptures, print type face, weapons, and even money. Wider application of Pb in these processes has resulted the release of Pb into the environment and the consequent elevation of Pb concentrations in the ecosystem. Combustion of leaded gasoline, acid storage batteries, lead containing paints and PVC products are some of the other sources of Pb released into the environment.

Once emitted into the atmosphere or soil, Pb can find its way into the aquatic systems. Both surface water and groundwater may contain significant amounts of Pb derived from these sources. In aquatic systems, acidification of waters may lead to Pb toxicity. The influence of Pb on freshwater fish also varies, depending on the species exposed. Pb inhibits hematopoiesis (formation of blood or blood cells) because it interferes with heme synthesis, and thereby Pb poisoning may cause anemia. Pb also affects the kidneys by triggering renal tubular dysfunction. Pb poisoning is also manifested indirectly by muscle aches and joint pain, lung damage, difficulty in breathing, and diseases such as asthma, bronchitis, and pneumonia. It may lead to suppress the immune function, and to interfere the cell maturation and skeletal growth. Pb can pass the placental barrier and may reach the fetus, causing miscarriages, abortions and stillbirths. The primary target organ for Pb in the fetus is the central nervous system (CNS) and it can cause permanent damage to the brain and nervous system, resulting in problems as growth retardation and behavioral changes.

Nickel (Ni)

Ni is quite mobile element in the air, water and soil. It is used in a wide range of industrial applications such as in iron processing, nickel plating, and nickel–cadmium batteries. Nickel has a known industrial use as an amalgam: 1) Nickel-iron is also used for electrical equipment, 2) copper-nickel is used as an anticorrosive for marine vessels and equipment, and 3) nickel-titanate is used as a pigment in paints.

Environmental contamination by Ni can occur through natural processes such as volcanoes, ocean spray, soil dust, and forest fires. Anthropogenic sources include mining, smelting, and refining of Ni. Nickel sulfate is released to the environment through the burning of fossil fuels and sewage incineration. Nickel–cadmium batteries are also a potential source of water pollution by Ni, which may result as a leaching from waste sites. An elevated Ni concentration is often found in the water bodies near industrial areas due to the above reasons.

Ni also can trigger many health issues once absorbed into the body because the ionic form of Ni can compete with Ca, cobalt (Co), Cu, Fe, and Zn. There is a possibility of interference with processes such as Fe absorption. Ni may inhibit a number of enzymes in the human body, including urease and carbon monoxide dehydrogenase.

Arsenic (As)

Arsenic (As) is an element which can be found in the earth’s crust. Arsenic can be released into the environment from several natural sources, including volcanic eruptions, weathering and the processes of sedimentation. Methylation by microorganisms mobilizes organoarsenic compounds in groundwater. Some microorganisms such as strains of Bacillus and Pseudomonas can oxidize or reduce As. *Penicillin brevicaule*, called the arsenic fungi, can produce toxic and highly volatile arsines. Fungi, yeasts, and bacteria can methylate As into monomethylarsonate, dimethyl arsinate, and gaseous derivatives of arsine, which are widely distributed in soils.

The use of arsenical compounds is widely practiced in 18th and 19th centuries for the control of agricultural pests. Paris Green ($[CH_3COO]_2Cu$. $3Cu[AsO_2]_2$) and lead arsenate ($PbHAsO_4$) were widely used as insecticides. White arsenic (As_2O_3) was used as a rodenticide. Sodium arsenite (a solution of NaOH and As_2O_3) was used as an insecticide and herbicide, and methylarsenic sulfide (CH_3AsS) as a fungicide. Other miscellaneous uses of arsenic include pigments and dyes, pharmaceutical substances, preservatives of animal hides, glass manufacture, and wood preservatives.

The main exposure to As can occur through ingestion, since it can present in varying amounts in food. Especially fish may, contains relatively high concentrations of organic arsenic. After absorption, inorganic arsenic is transported by blood to other organs. The toxicity of As to mammals relates to its absorption and retention in the body, and varies with chemical form. The inorganic arsenites and organic trivalent compounds (arsenoxides) are more toxic forms of arsenic in comparison to elemental arsenic. An association between environmental exposure to As from drinking water and a higher incidence of skin cancer has been observed and proved. Epidemiological studies in areas where drinking water contained As at levels of 0.35 to 1.14 mg/l showed increased risks of cancers of the bladder, kidney, skin, liver, lung, and colon, in both men and women.

2.4. Biological Indicators of Water Quality

Biological agents are widely used as indicators of water quality worldwide. Physical and chemical parameters of water provide quantitative and qualitative information on the water at sampling locations and the surrounding catchment. Therefore, chemical water quality is widely used in stream health monitoring programs worldwide. However, long-term impacts to lotic or lentic systems by pollution events and physical habitat modifications are not fully reflected through the water quality analysis alone. Such aquatic organisms are widely used in stream/health assessment programs worldwide as they respond to the long term impacts to the aquatic systems.

Biological indicators (bioindicators) may be defined as a particular species or communities, which, by their presence, provide information on the surrounding physical and/or chemical environment. Some biological agents in water can be used as indicators of pathogens because the presence of these organisms indicates that the water is contaminated with disease causing agents. Some biological agents in water can be considered as ecological indicators since their abundance, species composition may respond to changes in water quality, stream habitat quality, riparian vegetation composition and for catchment characters etc.

2.4.1. Pathogen Indicators

Worldwide it is estimated that 10,000 people die every day from waterborne diseases due to lack of safe drinking water. The water may be contaminated with various infectious agents that enter through human and animal wastes. With credit to the danger and gravity of infectious disease transmission, most important biological organisms in water and wastewater are pathogens. Therefore, viruses, bacteria, protozoa, and parasitic worms in the water are widely used as indicators of water quality. Most of these organisms are not native to aquatic systems and usually require an animal host or a vector for growth and reproduction or other changes (i.e., Metamorphosis). Many of them can maintain their infectious status for some period in the water.

Drinking water devoid of infectious agents is considered safe and essential to prevent many waterborne diseases. However, analysis of water for all known pathogens is very time consuming and expensive. Usually specific pathogens are not tested unless there is a real need and suspicious activity or anecdotal data. In most cases indicator organisms are used to test the presence of pathogens. Indicator organisms suggest the incidence of contamination and the level of contamination.

Most waterborne pathogens are introduced into water bodies through fecal contamination. The most common bacteria found in the intestine, feces or sewage is Coliforms. They are also present outside the intestines of warm-blooded animals, including humans and places like soil or decaying vegetation. Therefore, the presence of Coliforms is an indicator of the presence of pathogenic organisms.

Virus

There are many viruses passing to drinking water and cause human health issues when an opportunity for an infection occurs (i.e., When drinking water is contaminated with human enteric viruses from an infected person). For example, Hepatitis is a well-known water borne viral disease which transmitted by the contamination of drinking water with virus containing feces from infested persons or such sewage. Standard sanitation and disinfecting/sterilization practices of water can eliminate viruses, but quick conclusive tests are not available similar to that of bacteria, makes monitoring of treatment methods expensive. Uncertainty in viral disinfection is a major obstacle in direct recycling of wastewater and a concern for land application of wastewater.

Bacteria

Bacteria can be classified based on their oxygen requirement. Generally in water, which is polluted and not sufficient oxygenated, anaerobic bacterial groups predominate. Some of such groups of bacteria which can be commonly found in the environment under different or low oxygenated conditions are listed below.

- **Obligatory anaerobic**

These strains of bacteria can survive in the absence of oxygen. Examples: *Clostridium, Desulfovibria*

- **Obligate aerobes**

Obligate aerobic groups of bacteria can survive only in the presence of oxygen. Example. Bacillus groups.

- **Facultative forms**

Facultative forms generally can survive in the presence or absence of oxygen. Example: *E-coli.*

There are many bacterial groups which cause human health problems through water contamination. These include;

Salmonella typhi (Typhoid fever)
Vibrio cholera (Cholera)
Shigelladysenteriae (Bacterial dysentery)
Salmonella schottmulleri (Salmonella seoticemias)

Gastrointestinal (GI) disorders are commonly caused by waterborne pathogenic bacteria.

Fungi

Fungi are anaerobic multicellular, nonphotosynthetic, heterotrophic group. Most of them are saprophytes, obtaining food from dead organic matter.

Similar to bacteria, fungi are responsible for decomposing of organic matter. Most aquatic fungi belong to the class: Phycomycetes (Example: Saprolegnia).

Protozoans

Protozoans are found in all aquatic habitats and found abundantly in water polluted with organic matter. They can be pathogenic or non-pathogenic, microscopic or macroscopic and are highly adaptable and distributed in natural water. However, only a few species of protozoans become pathogenic. Some of the nonpathogenic groups include *Vorticella* and *Paramecium.*

Protozoal infections are usually characterized by gastrointestinal disorders, but they are milder than bacterial infections. Sewage contaminated water is the common source of protozoan infections. Some of the water borne diseases caused by protozoans are:

Giadiasis diarrhea (Giadia *lamblia*)
Amoebic dysentery (*Entamoeba hystolitica*)
Cryptosporidiosis (*Cyclosporacayetanensis*)

Helminths

Helminths life cycle involves two or more animal hosts, of which one may be human. Water contamination may result from human or animal waste that contains helminths. Few of the diseases caused by helminths include:

Echinococcosis - *Echinococcus* (dog tapeworm)
Schistosomiasis (blood fluke disease) –*Schistosoma*

2.4.2. Indicators of Water Quality or Habitat Quality

Plankton

Planktons are microscopic organisms with limited power of locomotion and hence they drift with the water current. They are an ecologically important group in most aquatic ecosystems and are ideally suited for water quality assessment because they have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. Among planktons, phytoplankton are primary producers and they are affected by many physical and chemical parameters of water. Most phytoplankton are found in lentic systems such as lakes and reservoirs and hence they can be used as biological indicators for predicting the trophic status of such systems. In general, green algae tends to occur mainly in low nutrient waters while colonial blue-green algae is more typical of eutrophic waters.

Zooplanktons are the primary consumers of the aquatic food web and they feed on phytoplankton. Cell size of zooplanktons is quite larger than the phytoplankton. Eutrophication of freshwaters can trigger great changes in the structure of zooplankton communities. It is reported that in nutrient poor oligotrophic lakes nanophytoplankton (2-20 µm) and large herbivores such as Copepoda, Calanoida and large Cladocera predominate among zooplankton, consuming a large fraction of the phytoplankton. Conversely, in eutrophic systems, microphytoplankton (20-200 µm), bacteria and colonial algae dominate, and small sized consumers such as Rotifera, small Cladocera and Copepoda, Cyclopoida may become abundant, indicating a detritic food-chain. In eutrophic water bodies, some bloom forming blue green algae produce toxins. As a consequence, many species disappear due to algal toxins or the clogging of filter-feeding apparatus during algal blooms. However, some species of zooplanktons such as *Brachionus calyciflorus* and *Bosmina longirostris*, having a great ability to utilize colonial Cyanophyceae as food, exhibit a greater tolerance to their blooms, so that they become abundant in such conditions and may be considered bioindicators of eutrophication. It is also reported that the zooplankton composition in lentic systems may also vary regionally. In non-eutrophic lakes in temperate regions the zooplankton are usually dominated by Cladocera species belonging to the Daphnidae family. In tropical regions the Rotifera has been observed to be dominant irrespective of the level of eutrophication thus suggesting that other factors and particularly the zooplanktonic interactions (competition and predation) may be more important.

Macroinvertebrates

Macroinvertebrates represent the secondary production level in the aquatic ecosystem. They also have an important influence on nutrient cycles, primary productivity, decomposition and translocation of material in aquatic systems. Thereby aquatic macroinvertebrates form an important link between secondary producers and higher levels of the food chain in aquatic environments. They respond to water quality changes as well as to habitat changes in lotic and lentic ecosystems mediated by anthropogenic activities. Some of the environmental changes that macroinvertebrates may respond are oxygen depletion, toxic substances in the water and sediments, loss of microhabitats due to modification of channels of streams and dredging and disturbance of the lake bottom, siltation of habitats, food availability changes and competition from other species. Some groups of macroinvertebrates are very sensitive to oxygen depletion and poor water quality resulting from organic enrichment. These include species belonging to orders: Ephemeropter, Trichoptera and Plecoptera. Some species belonging to the class: Oligocheta, order: Diptera (Chironomidae) and Phylum: Mollusca is tolerant of polluted water conditions. Therefore, these groups of macroinvertebrates are widely used as macroinvertebrate indicators of water quality.

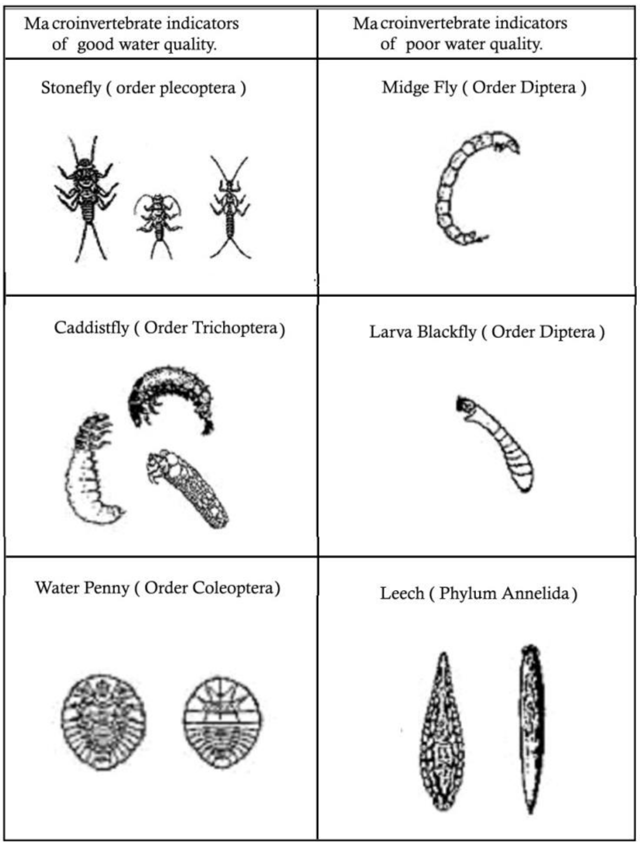

Figure 2. Macroinvertebrate indicators of water quality.

Use of macroinvertebrates as bioindicators has several advantages over other groups of aquatic species. Macroinvertebrates are relatively sedentary and therefore their movement is mostly restricted. Any environmental change that occurs, immediate vicinity of their presence may affect their species composition. Similarly, they have very short life cycle of 06 months or longer which also aid in providing an overview of prevailing physical/chemical conditions. They respond to environmental stress and integrate the effects of short-term perturbations. Their restricted movements also aid in easy sampling using simple equipment. Therefore, macroinvertebrates have been widely used to monitor the accumulation of heavy metals and insecticides in streams. They also can be used to predict stream health resulting from riparian vegetation changes and energy dynamics, etc. Therefore, various indices have been developed to measure stream health based on macroinvertebrates. Some common biotic indices developed using macroinvertebrates are listed below:

i. Ephemeroptera (Mayfly) Taxa Richness

Mayflies are a sensitive group of macroinveretebrates which are affected by river disturbances by chemical pollutants. They are algal grazers and particularly sensitive to chemicals added into the water. Especially the chemical pollutants which interfere with their food sources may affect their abundance. Mayflies are highly sensitive to heavy metal pollution in comparison to caddis flies and stone flies. Therefore, in contaminated sites their number is drastically reduced. Sometimes nutrient enrichment in streams may increase mayfly numbers possibly due to the increase of their food resources. However, nutrient enrichment negatively affects the species richness of stoneflies and caddis flies.

ii. Plecoptera (Stonefly) Taxa Richness

Plecoptera is a group of macroinvertebrates which are very sensitive to water quality changes. They normally live in cold, highly oxygenated and clear water. With the increase of water temperature, this group disappears. In addition to that, human interferences also affect their abundance. Especially sediment input to streams and subsequent filling of the interstitial spaces of stream bottom can negatively affect stoneflies since they occupy these spaces in the stream bottom. Many stoneflies are predators that stalk their prey and hide around and between rocks.

iii. Trichoptera (Caddisfly) Taxa Richness

Caddisflies have different modes of feeding. Some species spin nets to trap food and others collect or scrape food on top of exposed rocks. Some may build gravel or wood cases to protect themselves from predators. Some species act as predators. Even though they are very diverse in habit, taxa richness of caddisflies declines steadily as humans eliminate the variety and complexity of their stream habitat.

iv. EPT Taxa Index

The EPT taxa index represents the number of Ephimeroptera, Plecoptera and Trichoptera. The index is calculated summing up the taxa represented by these three families. This category of benthic invertebrates decreases in abundance as a response to disturbance. Therefore, EPT taxa index is useful in measuring the level of disturbance of a site.

v. Percent Predator

Predator taxa represents the upper levels of the food web, and they depend on a reliable source of other invertebrates that they can prey upon. The percentage of obligate predators provide a measure of the trophic complexity supported by a site. Less disturbed sites support a greater diversity of prey items and a variety of habitats in which to find them.

vi. Percent Dominance

As diversity declines, a few taxa comes to dominate the assemblage. Especially those dominant species are opportunistic and they do not require special foods or particular types of physical habitat. Dominance is calculated by adding the number of individuals in the three most abundant taxa and dividing by the total number individuals in the sample.

Vertebrates

Fish and aquatic vertebrate assemblages can also be used as ecological indicators. Fish/Amphibians generally have a long life span and integrate pollution effects over a longer time period and large spatial scales. They often reflect the responses of the entire trophic structure to environmental stress. Therefore, they are good indicators of stream and riparian quality. The responses shown by vertebrates such as fish to pollution trends contain:

- Decline in the number of species
- Decline in the number of trophic specialists (those who have specific food habits.) i.e., Top carnivores/insectivores.
- Increase in the trophic generalists (omnivores)
- Decline in fish requiring specific habitats for reproduction

- Increase in the incidence of externally evident diseases, parasites and morphological abnormalities

2.4.3. Tissue Contaminants, Physiological and Behavioral Changes of Aquatic Communities in Response to Pollution

Similar to individual and community response of aquatic species such as fish to water quality/environmental variations, their tissue contaminants also provide information about the potential exposure of aquatic systems to toxic compounds and thereby environmental changes. Some of the tissues of the fish's body that can be used in those tests include, the whole fish, fillets and liver. Similarly physiological and behavioral changes of fish also can be used as a tool to evaluate environmental stress. Some of these physiological and behavioral indicators in response to environmental pollution events include;

i. Protein and Lipid Profile

When the water is contaminated with various pollutants, the fish living on those sites is also exposed to such contaminants. When such pollutants get into the fish's body, they are detoxified to a certain extent by body metabolic processes. As a result, elevated levels of specific proteins involved in detoxification process can be detected in the fish living in polluted water. (i.e., Elevated levels of Cytochrome P-450 can be observed in fish body exposed to water contaminated with hydrocarbons).

ii. Peroxidation of Unsaturated Lipids in Biological Membranes Due to Polluted Water

A wide range of agricultural and industrial chemicals which are entering the aquatic environment are being taken up into tissues of the aquatic organisms living in those sites. Transition metals, polycyclic aromatic hydrocarbons, organochlorine and organophosphate pesticides, poly-chlorinated biphenyls, dioxins, and other xenobiotics play important roles in the mechanistic aspects of oxidative damage. Such a diverse array of pollutants stimulates a variety of toxicity mechanisms, such as oxidative damage to membrane lipids, DNA, proteins and changes to antioxidant enzymes. Therefore, the measure of peroxidation level of lipids in biological membranes of aquatic organisms is an indication of their exposure to such pollutants.

iii. Loss of Homeostasis (Decreased Blood Electrolytes/Anemia)

Hematological parameters are also affected by exposure to chemical pollutants and therefore they are considered useful indicators of sub lethal environmental stress in fish. Exposure of fish to chemical pollutants in the water can lead to interference of certain enzyme activities related to blood cell formation. This is most often reflected through the development of anemic conditions in exposed fish.

iv. Compensatory Response Due to Excitement Due to Fear or Pain (Elevated Blood Glucose Levels)

Stress caused by polluted water induces the well-known fight-or-flight response in fish, in which body increases its levels of certain stress hormones. These, in turn, causes a rise in the amount of sugar in the blood. Therefore, sustaining elevated glucose levels in blood in fish is an indication of the environmental stress factors such as pollutants.

v. Altered Immune Function (Depressed Macrophage Active Index)

Under stress conditions fish immune function is also compromised and thereby they become vulnerable to diseases. The altered immune function can be assessed by calculating the macrophage active index.

Similarly, externally evident wounds and diseases are also common in fish living in polluted water.

vi. Hepatosomatic Index (HSI)

Hepatosomatic Index (HSI) is defined as the ratio of liver weight to body weight.

$$\text{Hepatosomatic Index} = \frac{\text{Liver weight}}{\text{Body weight}} \times 100$$

HSI is an indication of the status of energy reserved in an animal. In a poor environment, fish usually have a smaller liver (with less energy reserved in the liver). HSI has been reported to decrease in fish exposed to high concentrations of cadmium and zinc.

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Chapter 3

WATER POLLUTION

3.1. INTRODUCTION

Pollution of water can be defined as an undesirable change in the physical, chemical or biological characteristics of water that may or will harmfully affect human life or other desirable species. Health issues due to lack of access to clean water in some regions of the world are increasing and it is reported that approximately 50 million human deaths annually occur due to water related diseases worldwide. It has a tremendous burden on the public health cost in many countries. It affects not only human health but also ecosystems by causing species mortality (perhaps driving to extinction), reducing biodiversity and losing ecosystem services.

Water pollution occurs mainly through the contaminants entering into the aquatic environment. Pollutants may enter the aquatic environment in many ways.

Point source pollution represents those activities where wastewater is routed directly into receiving water bodies, where they can be easily measured and controlled (i.e., Discharge pipes of wastewater to streams or lakes or sea).

Non-point source water pollution arises from a broad range of human activities in which the pollutants have no obvious point of entry into receiving watercourses. Due to those reasons non-point source pollution is much more difficult to identify, measure and control than point sources. Generally, these pollution sources do not respond to hydrological conditions and are not easily measured or controlled directly (and therefore are difficult to regulate). They in turn, focus on land and related management practices. Examples include agricultural runoff, which contaminates ground and surface water bodies respectively by water through leaching and surface runoff.

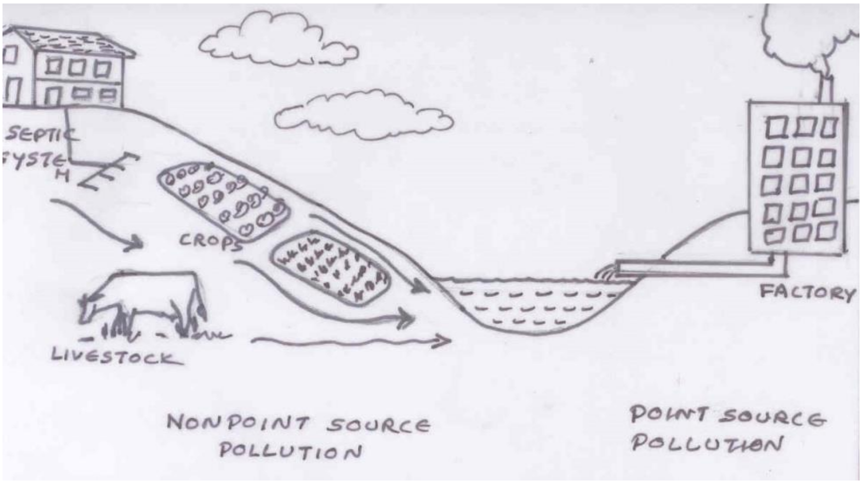

Figure 3. Point source and nonpoint source pollution.

3.2. TYPES OF WATER POLLUTANTS

Pollutants that may enter the waterways are of wide range. These include radioactive wastes, sediments, detergents, fertilizer, pathogenic microorganisms, sewage and domestic waste, industrial wastes, heavy metals, mineral oils, herbicides, pesticides and fungicides, acids and alkaline compounds. These can be broadly classified into:

- Organic pollutants
- Inorganic pollutants
- Radioactive compounds
- Thermal pollutants

3.2.1. Organic Pollutants

The most common form of organic pollutants that contaminate water sources are generally compounds such as proteins, fat, carbohydrates, and synthetic compounds (i.e., Dyes, pesticides, herbicides, etc). Organic wastes are predominantly discharged into the environment from various sources such as domestic sewage, urban runoff, industrial effluents and waste from livestock farms. Industrial waste discharged from food processing industries, tannery industry, slaughter houses, paper and pulp industry, and textile industry predominantly discharge organic compounds in their waste streams. Wastewater emitting from food processing industries includes starch, cellulose, gelatin, keratin, casein, fat, etc. Domestic wastewater contains substances such as detergents and they contain compounds such as sodium palmitate, potassium stearate and sodium lauryl sulfate. Starch and organic dyes such as Fluoresein and Magenta are predominantly discharged into the environment from the textile industry. Most Agrochemicals from agricultural activities also release organic substances to the waterways which include chemical compounds such as DDT, 2, 4-D.

Organic substances which enter waterways are readily degraded by aerobic bacteria while utilizing available dissolved oxygen in the water. Higher loads of organic waste entering water may result in higher bacterial activity leading to higher BOD levels in water. By the bacterial action complex organic substances are converted into simple compounds.

C $\longrightarrow$ CO_2 - carbonates and bicarbonates
H $\longrightarrow$ H_2O
N $\longrightarrow$ NH_3
S $\longrightarrow$ sulphates
P $\longrightarrow$ phosphates

This can lead to limitation of oxygen in the water and initiation of anaerobic bacterial activities. Oxygen is essential for the maintenance of self-purification ability of water bodies from the wastes naturally enter the water bodies. Low oxygen may reduce the self-purification ability of the water and further deteriorate the water quality. Low oxygen levels in water provide ideal conditions for anaerobic bacterial strains to multiply. As a result of bacterial activities, organic substances undergo anaerobic decomposition and the following end products may result.

C $\longrightarrow$ organic acids
N $\longrightarrow$ organic amines
S $\longrightarrow$ H_2S^+ organic sulfur compounds
P $\longrightarrow$ PH_3^+ organic phosphorus compounds

3.2.2. Inorganic Pollutants

Inorganic pollutants entering waterways may originate from different sources such as mining activities, industrial activities, tanneries, metallurgical operations and chemical manufacturing industries. The inorganic waste originating from such sources includes acids and alkaline compounds, metals such as heavy metals, sulfides, cyanides, caustic soda, lime, etc. Once they enter aquatic environment they can alter the pH of water and may change physical and chemical properties of the water, particularly, the natural buffering capacity of water. The Acids generate H_2S gas from sludge deposits and destroy bacteria, and so inhibit self-purification processes. The heavy metals entering the aquatic habitats may get deposited in sediments and can bio accumulate in aquatic food chains at higher trophic levels leading to many ecological impacts.

3.2.3. Radioactive Waste

There are several radioactive elements that are naturally occurring in the earth's crust. Some naturally occurring radioactive elements are uranium, thorium and actinium. However, contamination of water with such naturally occurring elements in the earth's crust is very rare. The main mode of water contamination with radioactive materials is due to human activities; from industry, mine sites, abandoned hazardous waste sites and from hospital waste containing radioactive elements used in therapeutic purposes.

The radioactive elements in the aquatic environment are taken up by aquatic organisms. The uptake mostly happens when the radioactive elements present in the organisms exchange with chemically similar elements present or added to the water body. Mostly radium and strontium are traded with Ca because of their chemical similarity and deposited in the bones and scales of the aquatic species such as fish. Once these radioactive elements are deposited in the body, they start to emit radiation. A multitude of health impacts can occur due to the exposure of body tissues of an organism to the radiation. Consequently, these radioactive elements which may bioaccumulate through the aquatic food web and can trigger severe health hazards to humans when such aquatic species are consumed by humans.

3.2.4. Heat

Thermal pollution can occur when water is used as a coolant in industrial operations and once heated water is returned to the aquatic environment. Thermal pollution may affect aquatic environment directly and indirectly. Increased water temperature can affect aquatic species directly through variation of water temperature. Most aquatic species cannot tolerate sudden changes of water temperature. The fluctuation of water temperature can change their metabolic processes. Increased water temperature can lead to a decrease in the dissolved oxygen level in the water and increase the biological demand of aquatic organisms for oxygen. Sensitive fish species and other aquatic organisms may be most affected by such temperature variations and species diversity in such locations would be lowered. Some of the impacts caused by thermal pollution on aquatic organisms include;

1) Early hatching of eggs of the fish or the failure to hatch eggs
2) Change of diurnal and seasonal behavior and metabolic responses of organisms
3) Change in algal composition towards more heat tolerant forms
4) Decrease in solubility of gasses
5) Changes in macrophyte composition, and
6) Changes in migration behavior of aquatic species.

3.3. Fate of Pollutants in the Aquatic Environment

Pollutants entering into the aquatic environment can behave in different ways based on their chemical characteristics. Degradable pollutants are substances which undergo biological decay by microorganisms. Upon entering the aquatic environment, these substances easily undergo degradation and their impact on ecosystem processes is less marked. Non-biodegradable substances are referred to as conservative pollutants and they do no degrade readily through biological or physical processes. Both degradable and non-biodegradable pollutants can enter into the bodies of aquatic organisms and can bioaccumulate in various tissues. Each organism in the aquatic food chain feeds upon the organisms of the lower trophic level. The food they intake is metabolized and excreted while the persistent pollutants are retained. This leads to the buildup of greater concentration of pollutants higher at the food chains as the organisms at the highest levels of the food chain may feed upon lower trophic levels to a large extent. This can lead to the successive increase of the non-biodegradable pollutants in the higher trophic levels of the food chain leading to bio magnification.

3.4. Agriculture and Water Pollution

Agriculture is an important contributor to the global economy. Despite the contribution it makes to the economy, agriculture is the largest user of freshwater on a global basis and considered as a major contributor of degradation of surface and groundwater resources through erosion and chemical runoff. With the increase of human population worldwide, the pressure to produce sufficient food has had a worldwide impact on agricultural practices. In many countries, this pressure has led to changes of traditional agricultural practices focusing more on the increase of production. The use of chemical fertilizer in crop production and the application of pesticides for the control of a wide variety of agricultural pests has been common practices adopted to increase yield from crops. Regarding the benefits of the increased crop production through the use of Agrochemicals, there were dangers posed to the long-term survival of major ecosystems by disruption of predator-prey relationships and loss of biodiversity. In addition to these ecological impacts, these chemicals pose a wide range hazards on human health worldwide.

Agricultural practices release a wide range of chemicals into the environment. These predominantly include phosphorus, nitrogen, metals, pathogens, sediment, pesticides, salt and trace elements (i.e., Selenium) and etc. The runoff from agriculture containing such substances leads surface and groundwater pollution. Agriculture related industries such as Agro food processing also contribute significantly to the water pollution through the waste discharged into the environment. These wastes predominantly consist of organic pollutants such as sugars, starch, pesticide residues and pathogenic bacteria. Aquaculture is also has become a major source of water resource, pollution in many regions of the world. Even though aquaculture is important in providing readily available protein source to rural communities in many developing regions of the world, it is also considered one of the main industries which cause water pollution in the world. Mostly wastewater released from aquaculture farms contains a wide range of organic pollutants such as feed residues, excreta, antibiotics and growth hormones applied in the operations. Specifically, medium and small scale shrimp farms operating in many tropical regions have a significant impact on water resources. Similarly, in many arid regions of the world, agriculture is conducted using irrigated water. Irrigated water is stored in reservoirs and diverted to the lands of crop cultivation through concrete canals. Evaporation loss of water is more intense from bulk water storages as reservoirs and also when the water flows through concrete canals in the arid regions. This will contribute to the concentration of salts in the water and contribute to soil salinization once applied to soils in crop lands. The water applied to croplands can enter into groundwater stores or can enter into surface water bodies are called irrigation return flow. Irrigation return flows also carry salts, nutrients and pesticides and often contaminate surface and groundwater bodies.

Agricultural pollution is both a direct and an indirect cause of human health impacts. The WHO reports that “intensification of farming practice” has resulted in elevated nitrogen levels in groundwater in many parts of the world. Nitrate levels have grown in some countries to the point where more than 10% of the population has exposed to nitrate levels in drinking water that exceeds the 10 mg/l guideline. According to various surveys in India and Africa, 20-50% of wells contain nitrate levels greater than 50 mg/1 and in some cases, as high as several hundred milligrams per liter.

There is -overwhelming evidence that agricultural use of pesticides has a major impact on water quality leading to serious environmental consequences. Pesticides can be classified in different ways; by their target, chemical nature, physical state, and mode of action. Major groups of pesticides and herbicides widely used in the world can be categorized into the following groups based on their chemical composition:

- Organochlorines
- Organophosphates
- Carbamates
- Pyrethroids
- Fungicides and herbicides.

Organochlorines

Chlorinated hydrocarbons, or organochlorines, were the first commercial organic insecticides developed and widely used pesticide in the early days. DDT, aldrin, chlordane, dieldrin, endrin, lindane, heptachlor DDT and other chlorinated hydrocarbons are a few of the examples which come under this category. The residues of this group of pesticides persist in the environment for long periods since they are not readily degraded by the action of water, heat, sunlight, or microorganisms. The organochlorines have broad-spectrum characteristics, enabling them to affect many different species of insects. They are fat soluble and readily enter into the living bodies and bio accumulate in food chains. It has been observed that DDT interferes with the reproduction of wild species due to their impact on endocrine systems. It has also been observed that the top predators of the aquatic food web such as birds are mostly affected by these chemicals through changes in their reproduction. Older chlorinated agricultural pesticides have been implicated in a variety of human health issues and causing significant and widespread ecosystem dysfunction through their toxic effects on organisms.

Organophosphates

Organophosphorus insecticides are the most toxic among the insecticides and they affect not only insects but also mammals. Some examples of compounds coming under this category include parathion, paraoxon, timet, and tetram. Even though organophosphates are usually more toxic to humans and mammals than chlorinated hydrocarbons, they are more easily biodegraded than the organochlorines. Since they do not persist in the environment or accumulate in fatty tissue, they have virtually replaced the organochlorines for most uses. Their mode of action both in vertebrates and invertebrates is initiated through the inhibition of acetylcholinesterase (AChE), the enzyme responsible for the breakdown of the neurotransmitter acetylcholine (ACh). Inhibition of the enzyme results in accumulation of ACh at the nerve endings, leading to disruption of the signal transmission process in the nervous system.

Carbamates

The carbamates are esters of carbamic acid and structurally more complex. The carbamate insecticides also act similar to the organophosphates by inhibiting acetylcholinesterase (AChE) at nerve synapses and neuromuscular junctions. However, presently the volume of carbamates used exceeds that of organophosphates, because carbamates are considered to be safer than organophosphates.

Pyrethroids

Pyrethrins are botanical insecticides derived from chrysanthemum flowers most commonly found in Australia and Africa. Pyrethroids are synthetic chemical insecticides whose chemical structures are adapted from the chemical structures of the pyrethrins and act in a similar manner to pyrethrins. This chemical compound affect target insect by altering nerve function causing paralysis, eventually resulting in death. Pyrethroids are also modified from their original form to increase their stability in sunlight.

3.5. URBANIZATION AND INDUSTRIALIZATION EFFECTS OF WATER POLLUTION

Rising urban populations and expansion of industrialized area are causing many environmental issues in many countries of the world. With the increase of urban population and rapid expansion of industries, proper planning of cities and industrial zones is essential to avoid any adverse environmental impacts. Even though many developed countries were able to cater to the demands of rising urban populations and expanding industries through proper city planning and effective implementation of environmental regulations, most of the underdeveloped and developing countries are facing severe economic, social and environmental adversities due to the lack of proper plans for the growing demands of urban populations and industries. Especially lack of proper disposal of urban and industrial waste has become a major environmental problem faced by these countries. Urbanization and industrialization are closely linked with the water pollution issue in many countries. Due to lack of facilities to treat urban and industrial waste in many developing countries, partially or fully treated municipal wastewater effluents, sewage sludge, industrial effluents, wastewater from home septic systems are often dumped into watercourses. In addition, urban runoff from roofs, streets, parking lots, overloading of sewage plants from combined sewers, or polluted runoff routed directly to receiving waters. Similarly, local industries and businesses may discharge wastes to street gutters and storm drains; street cleaning, road salting contributes to surface and groundwater pollution. In many developing countries poor enforcement of laws pertaining to the environment management may result in dumping untreated municipal, domestic and industrial waste into the waterways. As a result of it, contamination of waterways with pathogens, nutrients, metals, organic compounds and various other pollutants are ubiquitous. Contamination of water with sewage can lead to the spread of epidemic diseases such as cholera, typhoid, dysentery and many other water borne diseases. The major impact of water pollution by sewage is that it can reduce large amounts of dissolved oxygen in the water. This also can lead to the increased BOD levels in water. Due to the higher demand for oxygen the system can convert into anaerobic conditions favoring anaerobic bacterial activities. Domestic and municipal waste may also contain higher levels of nitrates and phosphates often leading to the eutrophication of the water through nutrient enrichment.

Industrial waste often contains many toxic compounds which are dangerous to aquatic life and mostly kill aquatic microorganisms who are contributing to the self-purification process of natural water. Industrial effluents may contain toxic chemicals, organic or inorganic or both, depending on the industrial process. These contaminants include trihalomethanes, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, hydrocarbons, phenols, benzene, cyanide, chromium, copper, arsenic, cadmium, lead, iron, manganese, mercury, nickel, selenium and zinc etc.

3.6. Atmospheric Deposition

With the rapid rate of industrialization pollution of atmosphere with toxic gasses has become a common problem. Pathetically atmospheric pollutants do not follow the land boundaries and their impacts may be evident in more pristine areas as well. Long-range transport of atmospheric pollutants and deposition in land and water surfaces regarded as a significant source of pesticides, nutrients and metals in pristine environments. There have been reports of finding residues of DDT, a persistent chemical widely used in the control of mosquitoes in tropics in the early days, in arctic regions where they have never been used, as a consequence of long range transport of stable chemicals through atmospheric circulation. Acid precipitation is also a common phenomenon which is caused when the burning of fossil fuels emits sulfur dioxide into the atmosphere. The sulfur dioxide discharged to the atmosphere reacts with atmospheric water and forms sulfuric acid. These acids may reach the earth through precipitation and can lower the pH level in surface water affecting aquatic plants and animals, thereby affecting the whole food chain. Lowered pH can also trigger leaching of heavy metals from the soil into the water, affecting fish and other aquatic organisms.

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Chapter 4

WATER QUALITY MONITORING

4.1. INTRODUCTION

Water quality monitoring programs are the key to forecasting possible threats to the future sustainability of the aquatic systems. In many situations water quality monitoring programs are conducted routinely to assess the status of water quality, to identify specific pollutants, sources of pollutants and to determine trends of pollution. Water quality data gathered through such monitoring programs usually provide important information of the relative healthiness of an aquatic system.

Design of water quality monitoring program is an important priority step in implementing a good monitoring program. A good design of the monitoring program facilitates better implementation of the program and capture all information targeted to collect during the program. As a first step in the program, defining the purpose of the monitoring will enable in selecting parameters to be monitored. Parameter selection is pivotal for minimizing the unnecessary waste of resources, time and effort. Generally, analyzing all or too many water quality parameters is costly as well as practically difficult. Therefore, the selection of the most appropriate parameters which would reflect the condition of the water is important. Such known, or suspected, water pollution events may be the basis for deciding to analyze for specific water quality variables. Another possible reason for selecting the variables for monitoring water quality is to determine the suitability of water for a planned use. In situations like this parameters which are selected should be based on the purpose of planned use of water. Table 2 represents the water quality variables that can be tested to evaluate possible impacts of different pollution sources.

Table 2. Pollution condition/sources and associated pollutants

Pollution condition/ source	Associated pollutants and necessary water quality parameters to be tested
Impacts from agricultural land	Turbidity, phosphorus, nitrates, temperature, total solids, pesticide residues, BOD
Eutrophication trends of a reservoir	Nitrate, nitrite, ammonia, total phosphorus, reactive silica, transparency and chlorophyll *a*.
Impacts caused by forestry harvest	Turbidity, temperature, total solids, total dissolved solids
Industrial discharges into a water body	Effluent from industries may contain many toxic chemicals, depending on the industrial process. Some knowledge of industrial processes is, therefore, necessary before selecting variables for testing. Some parameters that can be tested for industrial discharges are: Temperature, conductivity, total solids, toxins, pH, total solids, BOD, COD, trihalomethanes, polynuclear aromatic hydrocarbons, total hydrocarbons, phenols, polychlorinated biphenyls, benzene, cyanide, arsenic, cadmium, chromium, copper, lead, iron, manganese, mercury, nickel, selenium and zinc.
Contamination from septic systems	Fecal bacteria, nitrates, phosphorus, dissolved oxygen, BOD, conductivity, temperature
Sewage treatment plants	Dissolved oxygen, BOD, turbidity, conductivity, phosphorus, nitrates, fecal bacteria, temperature, total solids, pH
Urban runoff and food-processing and similar agriculture related industries	Turbidity, phosphorus, nitrates, temperature, conductivity, dissolved oxygen, BOD

4.2. Site Selection for Water Quality Monitoring

Sites for the water sampling might be chosen considering a number of factors such as accessibility, proximity and objective of the monitoring program. If the water quality analysis is providing the baseline data to characterize a stream or screen for problems, it is necessary to monitor a number of sites representing a range of conditions in the stream watershed or lake. To determine the effects of land use activities or potential point source of pollution impact, it is necessary to monitor upstream and downstream of the area where the source is suspected. To evaluate the effectiveness of catchment restoration impacts on stream water quality, a paired watershed approach might be chosen. In such situations sampling two similar small watersheds, one with controls in place and one without controls can be implemented.

When planning the monitoring program, it is also necessary to evaluate the accessibility of sites to be sampled. Safe and convenient access to the site during the sampling period are essential for better implementation of the monitoring program and otherwise practical problems of sampling may arise during the sampling phase. Once the monitoring sites are selected it is necessary to decide on the time and frequency of monitoring which often depend on the purpose of monitoring. Generally, monthly chemical sampling and biological sampling are considered adequate to identify water quality changes over time in rivers and reservoirs. Monitoring at the same time of the day and at regular intervals also helps to ensure comparability of data over time.

4.3. Sampling in Rivers

When doing baseline water quality monitoring of the streams and rivers, site selection should ensure the representation of the whole watershed. Otherwise, the collected data may not provide information related to the watershed. When sampling streams and rivers, samples should represent the entire flow. Sampling stations should not be established at locations where mixing is incomplete or where significant differences in water composition exist. Factors which affect the homogeneity of the sample in streams and rivers include; inflow from tributaries, turbulence, in slow flowing rivers poor vertical and lateral mixing. In places where a tributary meets the main channel, complete mixing of tributary and mainstream waters may not take place for a considerable distance, sometimes many kilometers, downstream of the confluence. If there are rapids or waterfalls in the river, the mixing will be speeded up and representative samples may be obtained downstream. In such a case, several samples should be taken across the width of the river to allow for the possibility of incomplete mixing. Immediately downstream of a waterfall, the water would be well aerated and oxygen saturated. Therefore, when taking oxygen levels downstream of a waterfall should be avoided and samples should be taken upstream of a rapid or a waterfall. A bridge is an excellent place where a sampling station can be established (provided that it is located at a sampling site on the river). It is easily accessible and clearly identifiable, and the station can be precisely described.

4.4. Lakes and Reservoirs

In lakes and reservoirs sampling has to be done at different depths along with the selected cross sections in the water body. Factors which affect the homogeneity of water composition in lakes and reservoirs include water circulation, thermal stratification, shore line characteristics, activities of aquatic plants and animals, etc. These factors can cause water quality to vary from place to place and from time to time. In areas where feeder streams bring water to the reservoir there maybe local variations of water quality. Isolated bays and narrow inlets of lakes are frequently poorly mixed and may contain water of a different quality from that of the rest of the lake. Wind action and the shape of a lake may lead to a lack of homogeneity. Sometimes due to wind action (direction) surface algae may be concentrated at one end of the reservoir.

When a reservoir becomes larger in size and contains many narrow bays or several deep basins, a selection of a number of sampling stations is needed for the accurate assessment of water quality. To allow for the size of a lake, it is suggested that a number of sampling stations should be the nearest whole number to the $\log_{10}$ of the area of the lake in km^2. Lakes and reservoirs, are vertically stratified resulting in differences in water quality at different depths. Stratification at a sampling station can be detected by taking a temperature measurements at 1 m intervals along the water column. A significant difference (more than 3°C) between the surface and the bottom water temperature, indicates the existence of a “thermocline” (a layer where the temperature changes rapidly with depth) or the lake or reservoir is stratified. If the thermocline is formed in the reservoir or in the lake it is likely that there will be important differences in some water quality variables exist in the above and below the thermocline.

4.5. Sample Collection and Preservation

When collecting water samples, the containers should be properly cleaned to avoid the contamination of samples with impurities. In sampling events in which natural water is of interest, immersing the sampling container in the water and taking a sample without trapping air are sufficient. In deep water sampling events in reservoirs, special samplers have to be used. These devices are useful in taking samples at desired depths.

The selection of containers for sampling is also a crucial factor in water sampling. Depending on the type of water quality variables to be measured, containers made up of different materials needed to be selected. Polyethylene or glass containers are widely used in sample collection. However, glass containers are commonly used to collect water for general analysis of water quality. However, polyethylene containers are widely used to collect samples which are to be analyzed for Si or sodium, etc., because similar elements of glass which is composed of can leach into the sample during storage.

Sometimes the collected samples are needed to be stabilized until further analysis is done. There may be some post collection changes occur in the sample; chemical and biological reactions which can alter the parameters to be tested. Especially, chemical parameters such as pH, alkalinity and hardness may change over time due to reactions taking place in the sample. In some situations, biological activities can contribute to change certain parameters. Particularly, algae and certain bacteria may utilize the available N, P and Si in the water sample for their growth and multiplication. In order to reduce biological activities, the water samples can be stored at cooler temperature of $4^{\circ}C$ (refrigerated). Algal and bacterial actions can also be minimized by filtering the samples using 0.45 µm filter paper and then being refrigerated. If the trace metals are to be analyzed, the samples needed to be acidified using inorganic acids such as nitric, sulfuric or HCl, aiming to decrease the pH of the samples to 1-2. This will prevent the conversion of certain metals to their hydroxide forms and become attached to container wall.

4.6. Analysis and Quality of Data

The collected water samples are analyzed in the field or at a laboratory using a wide range of analytical techniques. For analyzing inorganic anions, calorimetry, titrimetry and High Performance Liquid Chromatography with an ion exchange column (HPLC) methods are widely used. For determining metals, titrimetry, Molecular absorption spectrophotometry, Atomic absorption and emission spectroscopy, X ray fluorescence analysis and flame photometry can be used. To determine the organic pollutants of the water, chromatography techniques are widely used. BOD test can also be used to quantify the levels of organic pollution in the water sample.

The quality of the data derived from monitoring programs is crucial for the better implementation of management plans related to aquatic systems. Specifically, reliable and accurate data derived from monitoring programs are useful in proper assessment of the pollution status of water bodies, predicting trends and for the implementation of management plans with the use of this data output. Therefore, quality data is essential for the implementation of management strategies for future sustainability and conservation of aquatic systems.

There are many criteria which can be used to assess the quality of data. Accuracy of data is essential to reflect the true condition of the sampling location and it is a reflection of accurate sampling and analysis. Accuracy is defined as the degree of agreement between the sampling results and the true value of the parameter or the condition being measured. Accuracy of data mostly depends on the sampling procedures and equipment used to measure the parameter.

Another important criterion to be considered in the process of sample analysis is the precision of the data. Precision refers to the reproducibility of the result of the same sample, regardless of accuracy. Human error in sampling techniques plays an important role in reducing the precision.

Another important criterion that has to be ensured to maintain the quality of data is representativeness; valid representation of sampling location of the water body. Further, representativeness is the degree of representation to which the collected data actually represent the stream or lake condition under scrutiny. Samples have to be collected representing the actual condition of the sampling location and encompassed all the variability within the sampling location. Most of the time, the representativeness of the samples is ardently affected by the site selection protocol, and therefore, it needs attention.

Generally in most water quality monitoring programs, all the planed sampling events are difficult to be successfully completed. Sometimes, due to unexpected situations such as bad weather conditions or floods, sampling at some locations may have to be abandoned during the scheduled time period. Completeness is a measure of the amount of valid data actually obtained verses the amount expected to be obtained as specified in the original sampling design (experimentation). Generally the success of sampling could be presented as a rate; as a percentage of successful sampling events after the scheduled events of the initial plan. For example, if 50 samples were scheduled, but sampled only 45 times due to deleterious weather or broken equipment, the complete record would be 90 percent.

Comparability is also an important criterion for which the collected data can be compared with the data gathered from a similar study or studies elsewhere. Comparability represents how well data from one stream or lake site could be compared to data from another. It allows visualizing the broader spatial and temporal variations of variables outside the areas where monitoring has been conducted. In order to maintain the comparability of data, it needed to be assured that sampling methods should be the same from site to site.

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Chapter 5

LENTIC SYSTEMS

5.1. INTRODUCTION

Aquatic systems are important ecosystem components of earth, which provide numerous ecosystem services and support diverse life forms contributing to earth's biodiversity. They provide water for drinking, irrigating crops, and running industrial processes in the production of food, medicines and many other economically valuable commodities to the society. Among ecosystem services they provide wetlands, rivers and lakes serve as natural filters of pollutants, control floods, and act as nurseries for many aquatic species. In addition to that, they also provide important services such as transportation, recreation, and purification of human and industrial wastes, habitat for plants and animals, and fisheries. There is growing recognition that despite the numerous benefits that these ecosystems provide to mankind and its contribution to ecosystem processes these, functionally intact and biologically complex freshwater ecosystems are being severely altered or destroyed at a greater rate due to human activities. There are also numerous evidences to suggest that freshwater ecosystems of the earth are becoming vulnerable to long-term environmental changes triggered by climate change. It is well known that ecological services are costly and often impossible to replace when these systems are degraded and therefore proper management of such valuable ecosystem components is an urgent need.

Freshwater ecosystems on the earth can be broadly categorized into two basic types. These are lentic systems and lotic systems. Lentic systems include lakes and reservoirs in which water remains static and lotic systems are those in which water flows such as in rivers and streams. Both systems are increasingly becoming vulnerable to anthropogenic impacts worldwide. The inherent differences of structure and function of these systems require different approaches of management. Among them lakes and reservoirs are used by mankind for various purposes such as for obtaining water for drinking, agriculture, industries, fisheries and various other purposes for centuries. Therefore, a better understanding of their ecological processes, services, threats and management needs of these systems are essential for their sustainable management.

5.2. ORIGIN OF LAKES

Lakes on the earth are originated as a consequence of various natural processes on earth as well as by anthropogenic activities. Some of the natural processes responsible for the formation of natural lakes include tectonic movements, volcanic activities, glacial action, stream activities and rock erosion.

The largest lakes on the earth are formed as a result of tectonic movements. As a consequence of movements of the earth's crust, depressions are being formed on the earth's surface and subsequent filling of these depressions with water gives rise to a lake.

Volcanic activities are also contributing to the formation of lakes. When the volcano erupts, middle of the mountain may collapse leaving a crater. Filling of crater with water may eventually lead to the formation of a lake.

Most lakes in North America and Europe, are being formed as a result of glacier action. Most of these lake origin, run back to Pleistocene period. The global climatic variation which has been taking place during that period has led to the onset of cold and warm episodes in those regions. Due to the alternate freezing and thawing of ice on mountains during that period, has led to the formation of depressions on mountains. Eventually, those depressions were filled up with water, leading to the formation of lakes. Similarly, flow of glaciers may also lead to the erosion of the earth's surface, because the glaciers have various materials such as rocks and boulders entrapped in them during their formation, which gives them high erosive power when it is in contact with the ground in its flow path. Some lakes on the earth are formed due to the erosion caused by such glacier flow.

Erosion of rocks made up of soluble minerals such as $CaCo_3$ and $CaSo_4$ may also contributing to the lake formation. Such lakes are commonly found in regions such as in the Balkan peninsula (Yugoslavia: limestone erosion), Florida and in North America.

Stream or river activities are also contributing to the formation of lakes. A stream, blocked by rocks and soil falling from a slope of a valley, may also give rise to the formation of a lake. These water bodies are often short lived.

Similarly a large stream builds its banks with sediments at a faster rate than a tributary isolating it from the main stream and forming an oxbow shape depression filled with water. The lakes which are having this shape are called Oxbow lakes. Floodplain lakes also originate as a consequence of river activity. Floodplain lakes are water filled depressions that can be found in the flood plains of major rivers. Often these lakes are filled with the flooding events of a river. Sometimes lakes are formed due to sand spits formed parallel to the shoreline of a water body and completely cutting it off from the main water body.

The impact of meteors on the surface of the earth occasionally creates depressions which later may be filled with water creating a lake.

Sometimes animals such as beavers construct dams using woody debris and water plants and separate an area of a main body of water such as a river or a stream. Similarly, human are responsible for the construction of reservoirs, making dams across rivers for various purposes from very ancient time. These types of lakes are considered biogenic in origin.

5.3. LAKE CLASSIFICATION

In lakes, particularly, the absorption of solar energy and its dissipation as heat are critical to development of temperature gradients between the surface and deeper water layers and also to water circulation patterns. Circulation patterns and temperature gradients in turn influence nutrient cycling, distribution of dissolved oxygen, and both the distribution and behavior of organisms. Onset of water circulation and stratification of lakes are mostly triggered by the seasonal temperature differences. Heat is absorbed by the surface layers of the water and penetrated to deeper layers by conduction and mixing. When water does not mix thermal stratification begins in the deep lake/reservoir. In thermally stratified lakes uppermost layers of water remains warm and have low density. In the bottom regions, colder high density water can be found. Due to density differences of water, upper warmer low density water floats on high density colder water in the bottom layers. In between the zone of rapid temperature drop from shallow to deep water is called a thermocline or the metalimnion. The warmer upper zone of water is called epilimnion and the cooler bottom layer is called the hypolimnion. In tropical deep lakes, thermal stratification prevails throughout the year and in temperate lake stratification occur during a particular season of the year. Thermocline acts as a physicochemical barrier to the diffusion of dissolved substances. Therefore, water in the epilimnion and hypolimnion does not mix. This situation often leads to the development of deoxygenated condition in the hypolimnion. Lakes experiencing permanent thermocline often lead to the permanent nutrient storage in the hypolimnion region making the lake less productive.

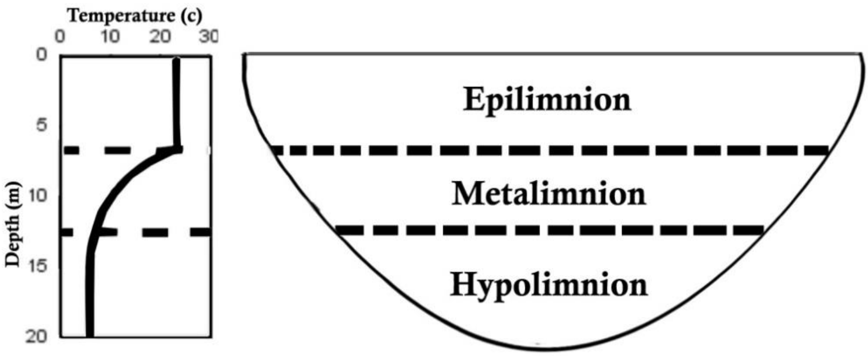

Figure 4. Thermal stratification of a lake.

In temperate and polar regions marked seasonal temperature differences prevail. A marked temperature differences may also exist with altitude changes. Based on the latitude and altitude changes different climatic patterns may prevail in different geographic regions of earth. The temperature changes triggered by such altitude and latitudinal changes have a great impact on lake circulation and stratification processes. Depending on the degree of thermal stratification and de-stratification process world lakes are classified.

Amictic Lakes

Amictic lakes are generally found in Arctic, Antarctic and Alpine areas of the world. These lakes are covered with an ice cover throughout the year and never stratify or mix due to extreme weather conditions prevailing in those regions.

Monomictic Lakes

Monomictic lakes stratify once a year and mixes once a year. Monomictic lakes can be further classified into two groups depending on the temperature differences.

i. Cold Monomictic

Cold monomictic lakes can be found in regions where the atmospheric temperature doesn’t exceed 4^0C. In cold monomictic lakes temperature will not exceed 4^0C. Water in these lakes mixes once during the year when temperature reaches 4^0C.

ii. Warm Monomictic

In these lakes always the temperature remains above 4^0C. There is only one annual overturn in winter and generally stratified during summer

Dimictic Lakes

In temperate lakes the thermal stratification and mixing process take place several times during a year in parallel to the seasonal temperature differences in the region. During winter air temperature drops and an ice cover is formed on the water surface. The high density water (4^0C) sinks to the bottom.

During spring air temperature increases and water absorb more heat. In upper layers temperature increases (about 4^0C) and temperature at hypolimnion become equal to that of the epilimnion (4^0C). Since the water temperature at epilimnion and hypolimnion regions become equal water density also becomes equal. As a result thermocline disappears and water in both layers well mixes due to lack of density differences in both layers.

During summer, the day length is longer and therefore more solar radiation is absorbed by water. As a result a temperature gradient is formed from surface to bottom layers forming a thermocline. Thermocline acts as a barrier to mix water in the epilimnion and hypolimnion regions. Therefore, water in the surface layers of the lake and bottom layers remains as separate units.

During autumn atmospheric temperature drops and heat is lost from epilimnion to the atmosphere. Temperature at hypolimnion become equal to the epilimnion (4^0C) and high density water at 4^0C sink to the bottom. As a result entire lake mix from top to bottom (overturn) making nutrients well mixed throughout the lake.

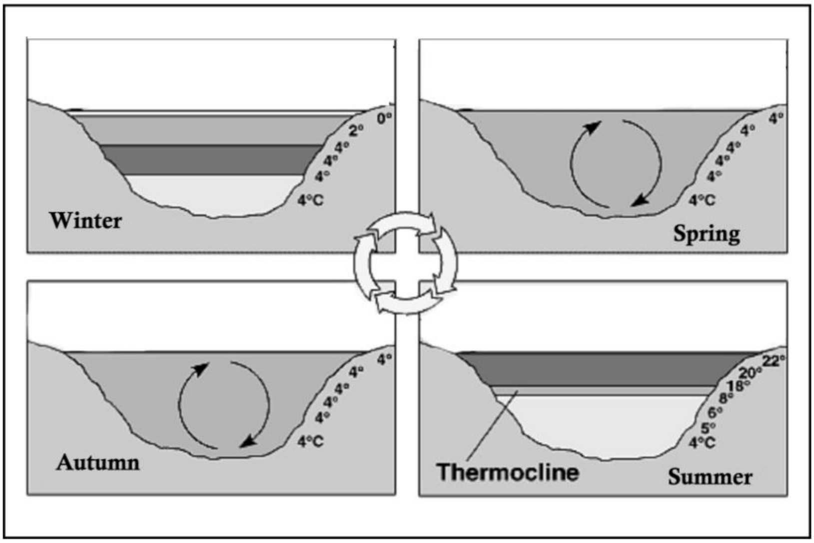

Figure 5. Seasonal temperature variation and thermal stratification process in temperate lakes.

Polymictic Lakes

Polymictic lakes are found in tropical regions of the earth. These lakes show limited thermal gradients that they stratify and mix more or less every day. No long-term stable stratification occurs.

Oligomictic Lakes

Oligomictic lakes are also found in tropical countries. Generally temperature of these lakes always higher than 4^0C. They are deep and stable with continuous stratification

5.4. Zonation of Lakes and Communities

A typical lake has distinct zones of biological communities linked to the physical structure of the lake. Depending on the depth of the water column and light availability three distinct zones can be identified in a lake.

- Littoral zone
- Limnetic zone
- Profundal zone

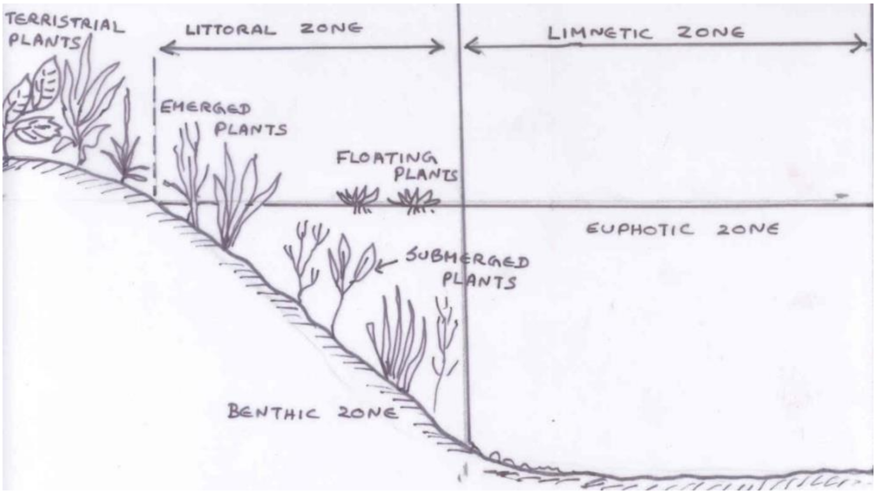

Figure 6. A cross section of a lake showing different zones and associated communities.

Littoral Zone

A shallow area of the lake closes to the periphery where many rooted vegetation grows. Due to wind action water movement is also high and nutrients are well mixed in the water. Due to shallowness sunlight penetrate through the entire water column and favors photosynthesis and primary production. Mainly rooted vegetation is responsible for primary production in the littoral zone. Many aquatic species find refuge in this zone because of the shallowness and high productive nature in this zone.

Limnetic Zone

The limnetic zone is the open water area where light does not generally penetrate all the way to the bottom. However, in the photic zone many planktons live. Mostly planktons are responsible for the primary productivity in this zone. Productivity in the limnetic zone is mostly limited by the availability of light and supply of nutrients from the profundal zone.

Profundal/Benthic Zone

Covered by fine layers of mud in which animals live. Most of the dead plant and animal matter may deposit in the profundal zone giving rise to a detrital food chain of the lake. The inhabitants of this zone are mostly worms, the larvae of Chironomid flies, and molluscs.

Communities in Lakes

Aquatic organisms can be divided into different groups based on their micro-habitat requirements.

Planktons

Planktons are a very important group of biota in the lake environment which is primarily governed by the level of light and nutrient availability. They significantly contribute to the lake productivity. Planktons can be classified based on their size.

Ultra nanoplankton <2 µ (bacteria)
Nanoplankton 2- 20 µ (Phytoplankton)
Microplankton 20-200 µ (Phytoplankton and Zooplankton)
Mesoplankton 200-2000 µ (Zooplankton)
Megaplankton >2000 µ (Large zooplankton)

The main group of planktons responsible for the primary production is phytoplanktons. Main groups of phytoplanktons that can be found in the lentic environments include;

i. Diatomaceae
ii. Myxophyceae
iii. Dinophyceae
iv. Euglenoceae
v. Chlorophyceae

Zooplanktons feed on phytoplanktons and their abundance is mainly governed by the availability of phytoplanktons. Main groups of zooplanktons generally found in the stagnant water bodies include;

i. Rotifera
ii. Cladocera
iii. Copepoda
iv. Coelenterata
v. Protozoa

Nekton

Nekton are organisms in the aquatic environment which have the ability to move or swim freely in the water. These groups include bony fish, decapod crustaceans and many other aquatic species such as reptiles.

Benthos

Benthos are the organisms living in soil/water interface. They can be classified based on their size.

Macro benthos (> 1mm)
Meio benthos (0.1-1mm)
Micro benthos (<0.1mm)

They are an important group of the aquatic environment because they are the second and third link in the trophic sequence of aquatic communities. They are also important in mineralization and recycling of organic matter and a major food source for fish.

5.5. Trophic Classification of Lakes/Reservoirs and Eutrophication

Lakes and reservoirs can be broadly classified as oligotrophic, mesotrophic, eutrophic or hypereutrophic depending on concentration of nutrients in the water body and/or based on the nutrient loading. Strict boundaries for these groupings are often difficult to apply because of regional variations in ranges of limnological parameters. In general terms, oligotrophic lakes and reservoirs are characterized by low nutrient inputs and primary productivity, high transparency and a diverse biota. Their natural nutrient and chemical conditions, often reflect local climate, bedrock, soil, vegetation type, and topography in the area. In contrast, eutrophic waters have high nutrient inputs and primary productivity, low transparency, and high biomass of fewer species with a greater proportion of cyanobacteria than in oligotrophic waters.

Nitrogen and phosphorus are nutrients that often limit the concentrations of algae in a lake; the higher the concentration of these nutrients, the more eutrophic a lake. In large quantities, they can encourage the growth of nuisance aquatic plants such as algal blooms. High levels of nitrogen and phosphorus in the water most often come from agricultural runoff and urban wastewater, but can also come from geothermal inputs and deep springs where leaching of phosphorus has occurred as a result of the rock geology.

Eutrophication occurs naturally over centuries as lakes age and fill in with sediments. However, human activities may accelerate the rate and extent of eutrophication through both point-source discharges and non-point loadings.

The eutrophication of water bodies leads to significant changes in the structure and function of the aquatic ecosystem. A large number of lakes in many regions of the world such as the United States, Europe, and Asia have recently been found to be highly eutrophic. Some of the common parameters which are being used to demarcate trophic state of lakes or reservoirs are Chlorophyll levels, phosphorus levels and Secchi depth. The trophic category of a lake and respective levels of phosphorus, Chlorophyll levels and Secchi depth are represented in the Table 3.

Table 3. Chlorophyll (Chl), phosphorus (P) (both micrograms per liter), Sechchi depth (SD meters) and trophic category (after Carlson 1996)

Trophic Class	Chl	P	SD
Oligotrophic	0 -2.6	0 -12	>8 - 4
Mesotrophic	2.6 -20	12 - 24	4 - 2
Eutrophic	20 - 56	24 -96	2 - 0.5
Hypereutrophic	56 -155+	96 - 384+	0.5 - <0.25

5.6. Consequences of Eutrophication

5.6.1. Eutrophication and Problems Related to Public Water Supply

Nutrient pollution is one of the most common problems associated with surface water bodies on the earth. Eutrophication of water bodies may cause numerous ecological and social issues to water users. Most surface water bodies are being used for public water supply and when such water bodies become eutrophic, problems related to water treatment may arise. The excess growth of algae, interfere the treatment processes of water and increase the cost of water purification due to the necessity of frequent cleaning of filters which are blocked by algal cells. Similarly, small algal cells can pass through filters producing turbid final water. Subsequently, these algal cells start to decompose in the distribution pipes, forming breakdown products such as Mucopolysacharides. These Mucopolysacharides may chelate with metals in distributing pipes and can leach into water, increasing the metal levels in drinking water. The Growth of bacteria on decomposing algae also give rise to unpleasant appearance, taste and odors in drinking water.

Increased nitrate levels in drinking water may also contribute to various health issues in water consumers. "Methaemoglobinaemia" or Blue baby syndrome is a condition commonly reported in infants who are fed with drinking water having high levels of nitrates. Nitrates are taken into the body with water are being converted into nitrites (NO_2^-) and absorbed into the bloodstream. Increased nitrite levels in the bloodstream may convert hemoglobin into methemoglobin. Even though methemoglobin has higher affinity to oxygen, it hardly release oxygen bound to the molecule, and subsequently lead to reduced oxygen supply to vital tissues. Thus severe methemoglobinaemia can result in brain damage and even death. Especially infants lack enzymes, which are responsible for the conversion of Methemoglobin into hemoglobin and therefore they are highly susceptible to this condition. Pregnant women, adults with reduced stomach acidity, and people deficient in the enzyme that changes methemoglobin back to normal hemoglobin are all susceptible to nitrite-induced methemoglobinaemia.

5.6.2. Algal Toxins

Eutrophic water bodies are often associated with very high densities of algae. Among the divers algae present in the water, cyanobacteria or blue green algae become the dominant group in eutrophic water bodies. Such algae may increase their cell densities to very high levels, causing 'Algal blooms.' Certain blue green algae are known to release toxins, especially during a blooming event. Algal toxins are of various types depending on the algae species producing them and health impacts caused by them are also different. Some forms of algal toxins produced by the algae are Hepatotoxins which cause liver damage and gastrointestinal problems. Some blue green algae produce Neurotoxins which they release to water. Ingestion of water containing these toxins may cause muscle tremor, paralysis, and respiratory arrest in animals. Endotoxins are also released to water by certain blue green algae. They are contact irritants and they cause, skin rashes, eye irritation, allergic reactions and gastroenteritis.

5.6.3. By Products of Algal Blooms

In eutrophic water, a large number of algal cells prevail. When these algal cells die and decompose increased amounts of Dissolved Organic Carbon

(DOC) is released to the water. Problems may arise in situations where this water is used for drinking purposes after disinfection. The chlorine, which is commonly used for water disinfection, may interact with DOC in water may lead to the formation of potentially carcinogenic and mutagenic trihalomethanes. Ingestion of these mutagenic compounds in drinking water can cause numerous public health issues.

5.6.4. Other Impacts

In eutrophic water bodies excess growth of algae and the decomposition of the large number of algal cells often lead to the development of deoxygenated conditions in the lake bottom. As a consequence the species living in such water bodies may get a limited supply of oxygen for their survival. In addition to the reduced oxygen levels, development of anaerobic conditions in the lake may lead to production of gasses such as hydrogen sulfides and methane which are having offensive odors. Especially sensitive species are mostly affected by such conditions and their population gradually declines. Only the species tolerant to harsh conditions and low oxygen levels can survive in such water bodies. As a result, aquatic species community changes can take place along with the other changes occurring in such water bodies. Mostly economically important fish species may be replaced by low valued species. In addition to that public health hazard, reduction of aesthetic and recreational value, the development of unfavorable conditions for fishing, sailing, swimming and smell of decaying algae are the other problems associated with eutrophic water bodies.

5.7. Natural Factors Leading to Eutrophication of Aquatic Systems

There are several factors leading to the eutrophication of water bodies. Among these not only the anthropogenic activities, but also natural factors are also contributing to the onset of eutrophication.

5.7.1. Morphology of the Catchment Area

Morphological features of the catchment where the lake is situated has a great impact on the rate of eutrophication. Especially larger catchment areas with steep slopes favor higher input of nutrients to the lakes than smaller catchments. Increased input of nutrients to the lakes often triggering eutrophication.

5.7.2. Hydraulic Renewal Time

Hydraulic renewal time is the time required to completely replace all the water in a lake or a reservoir. It is a useful parameter for estimating the loading rates of nutrients and other substances into the lake. Water inflow into the lake is the sum of water runoff from the catchment, seepage of ground water through the lake bottom and direct precipitation on the lake surface. Water outflow from the lake is slightly lower than the water input due to evaporation loss of water from the lake surface. Reservoirs and flood plain lakes can experience strong riverine flushing in certain seasons. Lakes that exchange water via seepage or those with large volumes of water have much longer residence time, allowing more time for biological uptake of nutrients and causing eutrophication.

5.7.3. Climatic Conditions

Regional climatic factors such as temperature and rainfall may determine, many phenomena of lakes. These include nutrient loading from surrounding catchments, thermal stratification, mixing, residence time and flushing. These may ultimately determine the eutrophication tendencies.

5.7.4. Soil Chemistry and Physical Conditions

Soils or geological materials naturally containing higher levels of phosphorus or apatite may also enhance the eutrophication process. Hence underline geological material in which the lake is situated also has a great impact on eutrophication tendencies.

5.7.5. Characteristics of the Retained Body of Water (Surface Area, Depth, Volume)

The shape of the basin and the surface area also has a relationship with the rate of eutrophication. Lakes with higher surface area with irregular shoe lines has a high land, water interface and hence has a greater potential for eutrophication than circular lakes because of the high input of land based nutrients.

5.8. ANTHROPOGENIC IMPACTS

Human induced eutrophication of aquatic systems is a common problem often faced by water or catchment management authorities throughout the world. Point sources of pollutants and Non point sources/ diffuse source pollutants contribute significantly to nutrient pollution of the aquatic environment. Excessive use of fertilizer in agriculture, soil erosion due to unplanned agricultural practices, release of industrial effluents from industrialized areas, domestic waste and sewage from urban areas are some of the examples of diffuse sources of pollutants which affect the aquatic environment leading to eutrophication.

Clearing of vegetation cover in catchments may also increase the soil erosion rates and soil loss by several folds. Especially clearing of vegetation cover in steep lands for agricultural purposes is one of the main causes for sediment input to rivers. Similarly planting of agricultural crops which enhance soil disturbance will also accelerate the soil erosion rates. For example, potatoes, tobacco and seasonal vegetables such as cabbage, carrot will lead to disturbance of soils during the harvesting season. Further cultivation of crops on steep lands requires continuous application of fertilizer and Agrochemicals to maintain soil fertility and to enhance crop production because much of the applied chemicals are lost to runoff giving limited supply to crop growth. This may lead to contamination of river water with higher loads of chemical pollutants and sediments. In addition, frequent application of nitrogen containing fertilizer may lead to infiltration of the excess nitrate to ground water and increase the level of nitrates in well water which are used for drinking purposes. The increased sediment loads entering the rivers may deposit in river beds and also in reservoirs built across the rivers leading to the reduction of water holding capacity of reservoirs. This has become a severe environmental issue faced by many of the catchment management authorities in developing countries.

5.9. Eutrophication Control and Management

A successful eutrophication control strategy will require several approaches. Similarly an effective management will require the application of a combination of technologies. It is widely accepted that ecosystem restoration is often costly and therefore preventative measures are often more desirable than the corrective measures. In order to carry out preventive measures, sound knowledge on the ecological behavior and function of these ecosystems is a prerequisite. For successful management strategy a management plan should be established at an early stage. In order to implement eutrophication management strategy following aspects also need to be considered.

Baseline water quality monitoring programs are essential to assess the trophic status of water bodies. The regular baseline monitoring programs are useful in determining the trends in water quality changes over time and to identify specific pollution events of the reservoir or lake. Water quality monitoring programs of the reservoir or lake alone is not sufficient to estimate the pollution trends of the target water body. It is also essential to carry out a watershed assessment to have a holistic view of the problem and to implement a better control strategy. Watershed assessment includes land uses and soil types to identify active or potential sources of pollution that need to be addressed to protect and improve lake water quality.

The results of the diagnostic study and watershed assessment are used to evaluate most appropriate methods to remediate undesirable lake conditions and to manage pollution sources in the lake watershed. The plan identifies the most cost effective ways to achieve water quality objectives.

Implementation of the management plan includes two phases

- **Remediation of undesirable lake conditions** (i.e., Sediment dredging, weed harvesting, artificial aeration, and aquatic herbicide treatments etc.)
- **Watershed management** involves the implementation of best management practices for non-point sources of pollution. A detailed description of watershed management for pollution control is discussed in detail in the chapter 07.

5.10. REMEDIATION OF UNDESIRABLE LAKE CONDITION

There are a number of methods adopted to restore already eutrophic lakes. In eutrophication management strategies, this step is considered least favorable since ecosystem restoration is often costly. Therefore, it is advisable to prevent eutrophication at prior stages through better catchment management attempts.

5.10.1. Sludge Removal/Sediment Skimming (Dredging)

Sludge removal or sediment dredging is a common approach to restore eutrophic water bodies. In this method top nutrient rich layer of sediments is removed by mechanical means. Generally sludge removal is most effective in eutrophication control since nutrient rich top sediment layer is removed mechanically. Since sediments contain high amount of nutrients reentering of nutrients to the water column is prevented.

5.10.2. Lake Restoration by Chemical Precipitation

In this method, chemicals are added to water in order to inactivate phosphorus through precipitating and binding into sediments. Most commonly alums of Iron, calcium and aluminium may be used to remove phosphorus. After reacting with alums inorganic phosphorus or phosphorus-containing particulate matter is precipitated out from the water column as a floc.

It has been reported that phosphorus inactivation has been highly effective and long-lasting in thermally stratified natural lakes. However, there are several disadvantages are also associated with this method. Some of the phosphorus precipitated is not bound permanently to the sediments and thus it could contribute to later internal loading of phosphorus. Similarly, under acidic conditions, Aluminium may become readily bioavailable and become toxic. Similarly the precipitation of phosphate containing floc may lead to a temporary reduction of benthic assemblages of the reservoir due to blanketing of bottom substrate with floc.

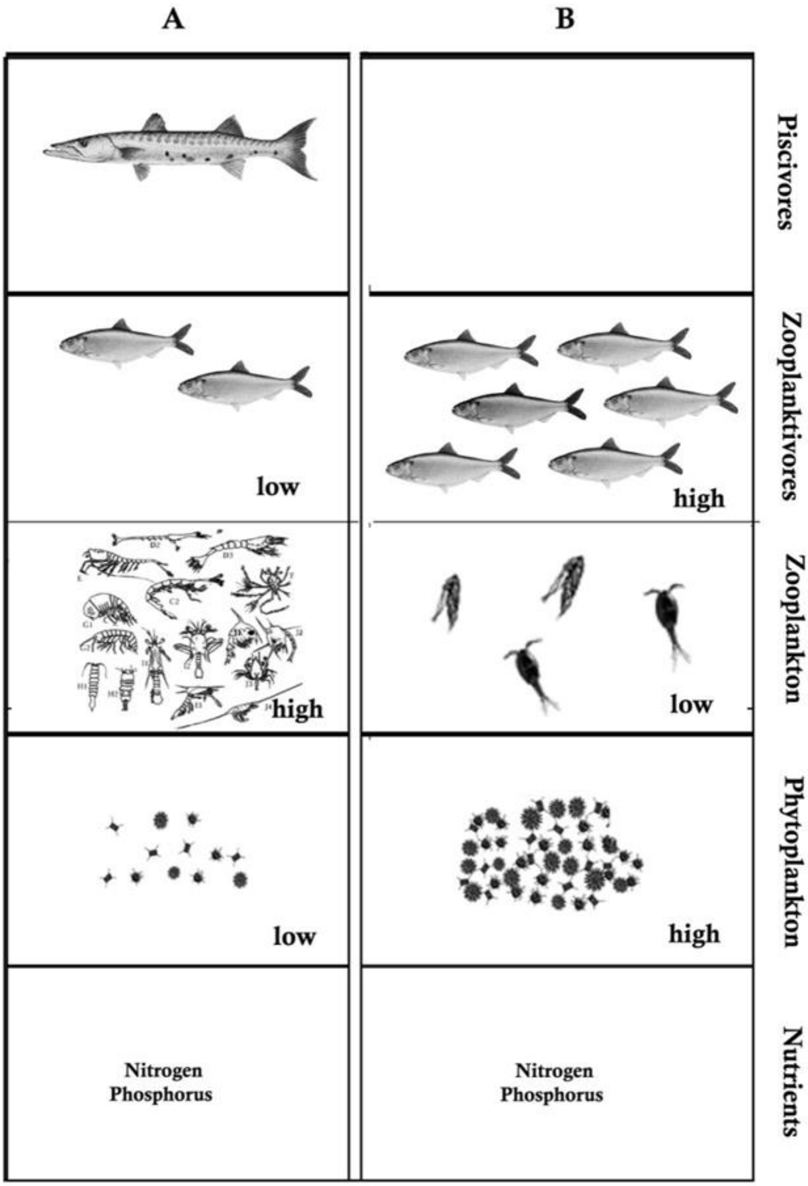

Figure 7. Biomanipulation of lakes. A - represents the phytoplankton reduction through the introduction of piscivorous fish. B- represents the condition of natural lake with only planktivorous fish.

5.10.3. Deep Water Aeration

The deep water of the lake is aerated in order to oxygenate the bottom water and also to break thermal stratification. Through the oxygenation of the hypolimnion zone of the reservoir, release of sediment- bound phosphates to the water column can be prevented.

5.10.4. Deep Water Discharge

In this method, nutrient rich, deep water is discharged from hypolimnion. However translocation of this nutrient rich water into streams may pose other ecological problems.

5.10.5. Biomanipulation

Biomanipulation includes lake improvement procedures through alteration of the aquatic food web. In this method excessive algal growth is controlled through the manipulation of the density of algal grazers. Biomanipulation.

Eliminates fish species that recycle nutrients and favor those that assist algal management. For instance, grazing of algae by zooplankton can be achieved through the removal of planktonivorous fish that prey upon zooplanktons. Number of planktonivorus fish can be reduced by increasing the number of piscivorus predatory fish. Similarly for the management of aquatic plants or weeds, plant eating grass carps can be introduced. Despite the effectiveness of the biomanipulation process it has its own limitations. Biomanipulation is most effective for controlling planktons or weeds in small reservoirs. It has been also observed that biomanipulation may not be effective on its own, particularly in larger lakes where changes in fish population have less of an impact. It has been also reported that biomanipulation used in conjunction with other nutrient reduction and control mechanisms can be fully effective.

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Chapter 6

LOTIC SYSTEMS

6.1. INTRODUCTION

Lotic systems which include rivers and streams are characterized by its unidirectional flow, which differentiate them from lentic systems. They are also important in linking terrestrial landscape, freshwater and coastal marine systems. River flow generally results from the differences in altitude in the landscape. Due to the flow characteristics, retention time of the water in rivers is relatively shorter in comparison to lentic systems. The continuous inflow of water to rivers through runoff or ground water sources, makes short turnover times of river water. The movement of water through the river channel also dissipates energy, contribute to the channel formation and its morphological features, sedimentation and erosion, water quality and distribution of biota. Unlike lentic systems, rivers are longitudinally connected and any change made in upstream can affect downstream areas.

6.2. WATER QUALITY

Generally variation of water quality can be observed along the course of a river. In head water streams/rivers the water is well oxygenated due to the fast turbulent flow. In lower parts of the river water quality also changes in parallel to physical changes. Lower reaches of rivers are characterized by low flow and therefore oxygenation of water is markedly reduced. Similarly nutrients spiraling from the upstream areas and dissolving of ions from the geological materials along its course and input of nutrients through runoff contribute to higher nutrient levels in water in the lower reaches.

6.3. BIOTIC COMMUNITIES

Flow, erosion, deposition processes result substrate closely linked with biota. Habitat diversity, water chemistry, nutrients, stream flow, predation are some of the important variables which govern the distribution of biota in streams. Development of biota in the aquatic environment is also governed by the retention time of water in the system. In flowing water, such as in rivers and stream water retention time is less and therefore development of phytoplankton in streams is limited. However, in stream reaches in which water flow is less and with sufficient light, plankton development may occur. Smaller zooplanktons are also present in streams where water flow is low. They are more frequent in the periphery of stream reaches and depositional zones of streams/rivers where water flow is very low. In nutrient rich stream reaches with sufficient light levels, promote algae development in substrates. Especially filamentous algae attached to the substrates such as cobbles and gravel beds in stream reaches is possible and provide a plentiful food supply to grazers.

In addition to the phytoplankton, macrophytes also contribute to streams and rivers primary production. In fast flowing streams and rivers macrophyte development is limited because nutrient retention in such streams is limited. However, in the depositional zones of the rivers where water velocities are very low, macrohyte development is more frequent.

Water chemistry and substrate characteristics of streams/rivers are also closely linked with the biota. Especially headwaters are well oxygenated and nutrients dissolved in the water is comparatively less. In such areas, mostly species who adapt to high oxygen levels may thrive. Most these species are sensitive species to pollutants. In depositional zones of the streams/rivers the water flow is reduced, water is less oxygenated, colloidal and dissolved substances in the water are high. In such areas, mostly the pollution tolerant species are more abundant.

River flow and substrate characteristics are also closely linked with biota. In flowing water most species develop mechanisms to cope with flow by developing physiological and morphological adaptations. Species such as benthic invertebrates who live in fast flowing areas of streams generally develop morphological adaptations to cope up fast flow and some get flow refuge from undercut banks, gravel or cobble where they can avoid fast flowing water.

6.4. Threatening Processes of Stream/River Health

Until recent decades, rivers and streams have often been regarded as simply a resource to be exploited, viewed as convenient channels from which water can be extracted, wastes transported away. The way the aquatic ecosystems function and their ecological, social and aesthetic values were never taken into consideration when exploiting such resources. The scientific knowledge of the river ecosystems function and their values were given very little attention when taking management decisions with regard to such aquatic systems.

More recently the perception of rivers and streams have changed significantly and management is oriented towards incorporating previously neglected ecological, social and aesthetic values. The understanding of how river ecosystems function and their ecology is pivotal in understanding and management of lotic environment. The following section describes some of the common factors contributing to affect river health.

6.4.1. Alteration to the Natural Flow Regimes

Natural flow regimes of streams/rivers are important for maintaining natural river processes and communities who depend on them. Basically, in lotic systems, erosion, deposition, water quality variation and communities are structured based on flow regimes. Mostly at its natural state river biota have developed evolutionary mechanisms and adaptations to face predictable flow regimes of these systems. Among natural processes triggered by natural flow regimes, the occurrence of natural flooding events in rivers is important for sustaining floodplain ecosystems. These floodplain ecosystems are closely linked with the river’s flooding cycle. Seasonal or periodic flooding is important for the maintenance of the lateral connectivity between aquatic environment and the terrestrial environment. It aids in deposit of nutrients on the land, flush out backwater channels, and replenish wetlands. Many of the sediments and organic matter which is received from the terrestrial environment through these lateral connections are important for the stream energy dynamics since allochthonous organic matter is a vital food source for aquatic communities. Similarly, these flooding events would be beneficial for some aquatic species to reproduce, hatching, migration and other important lifecycle stages, since flooding is the signal for the onset of certain physiological mechanisms in them. Reduced flooding also contributes to the accumulation of sediments, pools of nutrients, chemicals or saline water, changes of water temperature, composition of the river bed and channel size.

However, many factors are contributing to interrupt the natural flow regimes of rivers causing hydro morphological alterations of the river. The natural flow regimes of rivers are often altered by damming or construction of weirs across rivers and streams and subsequent extraction of water for mainly irrigation purposes. It has been reported that about 40,000 large dams- now obstruct the world’s rivers. Consequences of the alteration to the natural flow regimes of rivers include, elimination of natural flooding; reversal of seasonal flows; lower than normal flows during dry periods; daily variation of flows.

Estuaries are very productive ecosystems where the freshwater meets the sea. Some 80% of the world’s fish catch are collected from estuarine environment and their production mainly depend on the volume and timing of nutrients and fresh water flowing from the terrestrial environment through the rivers. Some fish species in those systems depend on the fluctuation of salinity levels of the estuary for the migration or the completion of their life cycle. Through damming freshwater flow to the estuaries is interrupted and fish species and other species who depend on these salinity regimes would be affected due to the variation of the salinity of the estuary. Many of the fish species which contribute to sea fisheries also find estuaries as their breeding grounds. The change of salinity levels in such environments can affect sea fisheries production due to the reduction of fish recruitment from altered estuarine ecosystems. In addition, dam also acts as a barrier between the upstream and downstream movement of migratory river animals, threatening to decrease reproduction numbers and reduce the species population.

Not only the environmental services provided by the natural flow regimes of rivers, many agricultural operations in arid regions also depend on flow regimes of rivers. In arid regions of the world, soil moisture retained after a flooding event in the river flood plains is important for crop cultivation. Many of the farmers in those regions depend on the flood recession cropping after a flooding event. In these practices the land is cultivated, taking advantage of the residual soil moisture after floods recede.

6.4.2. Alteration to Temperature Regimes of Rivers and Streams

Under natural conditions the temperature of water in an aquatic ecosystem is the product of local climatic conditions and the temperature of the ground water. Many factors may contribute to the changes in water temperature in streams and rivers. Some of these activities that contribute to changing water temperature include the release of water from dams with off takes low in the water column; the disposal of industrial cooling water; reduction in flow during dry periods; removal of riparian vegetation.

The impacts of changes of water temperature are lethal to adult or larval fish. These impacts may include reduced breeding due to cold water, delayed or premature emergence and migration. Among these impacts sub-lethal effects on metabolic rates can affect feeding, growth rates and disease resistance.

6.4.3. Removal of Riparian Vegetation

The riparian zone is the interface between aquatic and terrestrial ecosystem. It plays a crucial role in linking stream ecosystems and their catchments. The contributions of riparian vegetation to the process of energy flow through the lotic systems are well explained by concepts such as the river continuum concept, riverine productivity model and the telescopic ecosystem model. The river continuum concept provided a framework to explain biological changes along the length of a river within the context of changes in the terrestrial setting. This further describes the energy budgets of the riparian zone and the lotic environment and its link with aquatic biota. Riverine productivity model stresses the importance of local autochthonous production and allochthonous inputs to food webs of large rivers. It states that carbon from local autochthonous sources is more easily assimilated than refractory carbon arising from the flood plains and tributaries. All these ecological models indicate the link between terrestrial vegetation structure and in stream carbon sources in energy dynamics in the lotic ecosystems. In addition to this riparian zone fulfills various other important ecological processes such as regulation of water temperature through shade, filtering sediments and nutrients, stabilization of stream banks and ground water retention. It has been found that rivers streamside vegetation support many species of aquatic organisms and hence increased benthic invertebrate production than a monoculture of riparian vegetation. Direct organic matter input is one of the major ways riparian vegetation influences aquatic systems. Leaf litter and other organic debris such as logs and branches from riparian vegetation are major sources of allochthonous organic matter input to the streams and river ecosystems. Differences have been observed globally in the pattern of invertebrate production in streams with different organic matter budget patterns.

Shade by riparian vegetation also has a significant influence on aquatic species composition and distribution. Influence is due to a combination of indirect factors, which depend on the degree of incident radiation falling on the channel bed. Shading reduces energy inputs to streams and reduces primary production. It can also reduce diurnal temperature ranges and maximum stream temperature. In addition to the direct influence of the riparian zone of carbon and nutrient flux in stream and river ecosystems, riparian vegetation is also important in providing habitat structures for aquatic communities. One way by which organisms survive natural disturbances is by the use of refugia. Therefore, habitats created by riparian vegetation are important for the maintenance of aquatic communities. These habitats include natural debris dams, which delay downstream transport of organic matter, allowing sufficient time for it to be colonized by the stream biota. Logs and other woody debris provide habitat for fish and macroinvertebrates. Tree roots are also important habitats, which provide an excellent microhabitat and food resource for aquatic organisms living within the littoral zone. They provide ideal cover for many aquatic organisms to escape from predation. The roots of the streamside vegetation stabilize stream banks, allowing them to withstand natural forces. With the degradation of riparian habitats, many of these refugia are disappearing. Thus restoring refugia may therefore critical to the survival of aquatic communities, particularly in facilitating resilience to ongoing anthropogenic disturbance regimes.

Disturbance and removal of riparian vegetation along the rivers are a common phenomena associated with agricultural practices. Removal of riparian vegetation may lead to direct input of nutrients and pollutants to river water. Similarly, it will affect many water quality parameters such as temperature and sediment input to streams. Lack of shade due to the removal of riparian vegetation along the river may lead to increased water temperature due to removal of shade. Riparian vegetation of rivers is also subjected to colonization and spread by non-native species in riparian zones. They can influence stream ecosystem through modification of the physical environment, floristic and faunistic composition through food web effects. They may also have significant influence on the dynamics of riverine carbon cycle and food web structure and function. Many countries around the world are experiencing the problem of removing of problematic non-native species in riparian zones of their rivers and restoring native habitats.

Livestock grazing is also contributing to degradation of riparian and stream habitats throughout the world. Riparian areas tend to be more heavily impacted from grazing because they are more heavily utilized by livestock owing to their proximity to water and high quality forage. Livestock grazing can negatively impact riparian and stream environment by changing and reducing vegetation, destabilizing banks, increasing sediment and changing hydrology.

6.4.4. Sedimentation

Sedimentation of river beds has significant ecological impacts. In particular, sediments enter into streams and rivers mainly deposit in riverbed and transported with the flow and ultimately fill the reservoirs built across the rivers reducing the reservoir capacity. River substrate is home to an array of the invertebrates and fish species as grounds of feeding, breeding and for attachment. Sedimentation of riverbed make these habitats unavailable for species and reducing the species diversity and the ecological integrity. Sediments also bring toxic materials attached to them and also change the water quality and physical properties of the stream habitats. Reduced visibility and light transparency through water, increased particles suspended in the water also pose threat to aquatic species.

Sedimentation of rivers may occur due to various land based activities. Among them agricultural activities are prominent. Especially unplanned agricultural activities in the catchments may significantly contribute to soil erosion. Cultivation in steep slopes without proper soil conservation measures are contributing causes of stream sedimentation. Grazing of river banks by livestock, timber harvesting in the catchment and in riparian zones, construction activities, sewage treatment plants, mining and dredging activities also contribute to sedimentation of rivers. Especially in Sri Lanka, sand mining operations in rivers may contribute to increase the turbidity of water and lower the river bed below the sea level making the river vulnerable to salt water intrusion.

6.4.5. Input of Nutrients and Toxic Materials into Rivers and Streams

Illegal dumping of solid and liquid waste into rivers is one of the sources of water contamination with toxic pollutants. Especially agricultural, urban and industrial wastewater often contaminates the surface water bodies with such toxic pollutants. Some of the pollutant categories having impacts on surface water are Biocides (herbicides and insecticides), Heavy metals (mercury, cadmium, Arsenic, zinc), Petroleum by products (oils), organic chemicals (formaldehyde, cyanide, phenols), inorganic substances (sulphides and chlorides) and radioactive substance. These can enter the aquatic environment through different modes such as via surface runoff, through leaching and transport via ground water, via spray drift and through direct disposal. These may exert acute effects which occur rapidly, and usually leads to death or serious disease due to a high dose of the toxins over a short duration. Some chemicals may exert chronic effects or persistent effects, which occur following prolonged exposure to a toxin at low concentrations. Chronic effects, reduce the fitness of an organism at the biochemical, physiological, behavioral or life-cycle level. Some chemicals which are persistent are easily bio accumulate, i.e., mercury, methyl -mercury, tetra ethyl lead, DDT, heavy metals. These metals may deposit in- fat tissues, bones, teeth of consumers. These chemicals can interfere biological process of the body by interfering brain activity and nerve transmission, muscle activity, enzyme function, oxygen uptake, Ionic balance, organ function, biochemistry, photosynthesis and behaviors. These also trigger indirect effects by affecting habitat or food source as well.

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Chapter 7

WATERSHED MANAGEMENT AND WATER POLLUTION CONTROL

7.1. INTRODUCTION

Natural landscapes in river catchments encompass forests, wetlands, grasslands and many other ecologically important vegetation types. The surface and subsurface flow of these natural landscapes carry low levels of pollutants which result from dissolution of natural geological material, atmospheric deposits and nutrients entering from natural vegetation. The vegetation types in river catchments also serve as sinks of potential pollutants. Conversion of these landscapes into agricultural lands or urban centers may lead to large scale clearing of natural vegetation. In addition to construction work, irrigation, filling of wetlands, mining and excavation, will enhance the runoff rates and pollutant loads entering streams to many times the background load.

Wetlands in river catchments are important ecotones which link terrestrial and aquatic environments and also act as filters of the pollutants which enter into the aquatic environment. They also provide important habitat for biota which use both aquatic and terrestrial environments for completing their life cycle. Wetlands support unique vegetation due to their unique soil properties. However the expansion of agriculture and urban development activities in catchments may lead to filling and destroying of such important wetlands. Many of the environmental services provided by such wetlands are altered and hampered by such activities and increase the contamination of water with terrestrial sources of pollutants. Draining of wetlands may also lead to changes in soil chemistry. Most wetland soils are chemically reduced form and draining wetlands can lead to conversion of the soils into chemically oxidized form. Many of the chemicals such as nitrogen and metals can be present in precipitated and in more immobilized form in the saturated wetland soils. Draining of wetlands can trigger nitrification of immobilized N and oxidation of metals leading to their release in large quantities to groundwater and to subsurface flow causing health issues to water consumers.

Reduction of external sources of pollutants is essential for the long term management of river catchments and associated aquatic environment. Pollution control involves both point and diffuse sources of pollution control. Control of point sources is relatively less complex in comparison to the control of non-point or diffuse sources. There are regulations and provisions pertaining to point source pollution control in many countries, however diffuse or non-point source pollution control is complex and requires a combination of approaches for their control. Diffuse source control is an essential step in large-scale catchment management efforts. Some of the approaches to control diffuse sources of pollutants include, following measures;

Source Reduction/Control

Source reduction includes measures to reduce, control or eliminate possible sources of pollution. Examples include banning of harmful chemicals such as DDT, PCBs or reducing emissions through re-use of wastewater and application of soil conservation measures in agriculture.

Hydrological Modification of Sources

In most urban settings surface runoff rate is related to impervious surfaces in the area. Through the adoption of hydrological modifications in the catchment, surface runoff rates can be controlled. Adoption of soil conservation measures and best management practices can reduce the surface erosion and runoff. Increasing the pervious surface in urban areas can also reduce surface runoff and consequent pollution of water bodies.

Prevention of Input of Pollutants to Water Bodies

Input of pollutants to water bodies can be prevented through adopting mechanisms such as establishment of buffer zones between farmland/urban areas and water sources. A key measure to prevent pollutant contamination of water bodies is the establishment of artificial and natural wetlands and buffer zones along the rivers.

End of Pipe Treatment

This includes methods to treat waste after it is generated and prevent contamination of natural water bodies. Crop residues and livestock waste can be used to produce compost. In urban settings, urban waste can be treated before discharge into the environment.

7.2. AGRICULTURAL WATER POLLUTION CONTROL

Farming operations can contribute to nutrient pollution when not properly managed. Excess nutrients can adversely affect the water quality when fertilizers containing nitrogen and phosphorus wash into nearby waters or leach into ground waters. Not only synthetic fertilizers, but also animal manure, which is also rich in nitrogen and phosphorus. Fertilized soils and livestock also produce gaseous, nitrogen-based compounds such as ammonia and nitrogen oxides. Ammonia can be harmful to aquatic life if disposed into surface waters. Nitrous oxide is a potent greenhouse gas which contributes to global warming. Therefore, control and management of fertilizer used in agriculture are fundamental to solving many environmental issues.

Recognizing the importance of controlling chemical fertilizer usage in agriculture, world leaders meeting at the (Rio + 20) conference passed a resolution to reduce the annual use of chemical fertilizer by 20% by 2020. It was estimated that this could save US$ 50 – 400 billion per year in terms of improvement of human health, climate and biodiversity. Therefore, both economic and ecological considerations have become imperative for agriculture and food production in order to minimize adverse environmental impacts.

Several measures can be adopted in order to manage nutrients in agricultural lands in order to control nutrient pollution of the aquatic environment. Some of these approaches involve holistic approaches and others are through sustainable agricultural practices aimed at reducing nutrient pollution. Some of the practical applications in agriculture which can be used to manage nutrients are described below.

7.2.1. Holistic Approaches in Watershed Management

Nutrient pollution control and water quality management need holistic approaches. A collaboration of all stakeholders of the watershed need to be incorporated in watershed management attempts. State governments, farm organizations, conservation groups, educational institutions, non-profit organizations, and community groups all play a part in successful efforts to improve water quality.

7.2.2. Fertilizer and Soil Fertility Management

Modern agricultural practices depend heavily on inorganic fertilizer usage in crop production. Applying fertilizers at the correct rates, at the right time of year and with the right method can significantly reduce the potential for pollution. However, excess and indiscriminate use of inorganic fertilizer on crop lands may lead to contamination of surface water bodies through leaching and runoff. Such organic fertilizer usage is very important in soil fertility management and is more environmentally friendly in preventing nutrient pollution. Soil fertility can be enhanced through applications green manure and composting to incorporate organic matter in the soil. Application of organic manure enhances the natural soil microflora. A wide range of bacteria and fungi in soil is responsible for breaking down chemicals, plant matter and animal waste into productive soil nutrients. In turn, they produce benefits of healthier yields and more productive soil for future crops. Further, to improve soil fertility, crop rotation, cover cropping and reduced tillage can also be adopted. By reducing tillage, soil is not inverted and exposed to air; less carbon is lost to the atmosphere resulting in more soil organic carbon. This has an added benefit of carbon sequestration, which can reduce greenhouse gases and help reverse climate change.

Therefore, farmers need to be encouraged to use organic fertilizer in place of inorganic fertilizers. Governments should implement policies to decrease inorganic fertilizer used by farmers, through adopting mechanisms such as removal of fertilizer subsidies and providing incentives for organic fertilizer users. Other options to reduce the excess use of fertilizer during agriculture are to change to crops requiring less fertilizer. New crop varieties which need less fertilizer to grow need to be developed using biotechnology.

Organic farming should be encouraged, to reduce adverse effects of agro-chemicals and inorganic fertilizer on the environment and human health by expanding the organic farming sector. This may involve increasing public awareness of consumption of organic products, generating new technology and certifying products, processing and packaging to earn foreign exchange and gain high price to the farmers.

7.2.3. Management of Livestock Waste through Integrated Farming Practices

Livestock waste management is important in livestock farming practices. Animal excreta and farm waste have high levels of nitrogen and phosphorus which, has a high potential of contamination of water if disposed without treatment. In most cases partially or non treated animal waste ends up in water bodies leading to eutrophication. Therefore, the development of methods to deal with animal waste is essential.

Integrated farming practices are a solution to minimize waste generation from farming practices and to utilize waste for enhancing agricultural production. In an integrated system, livestock and crops are produced within a coordinated framework. The waste products of one component serve as a resource for the other. For example, livestock manure is used to enhance crop production; crop residues and by-products are used to feed the animals, thus contributing to improved animal nutrition and productivity while preserving the environment through minimum waste production. Knowing the benefits of such integrated agricultural practices, in many Southeast Asian countries such as Vietnam, China and Thailand integrated farming systems are widely practiced at small scale household farming systems and thus has contributed to more sustainable economies and environmental sustainability in those regions.

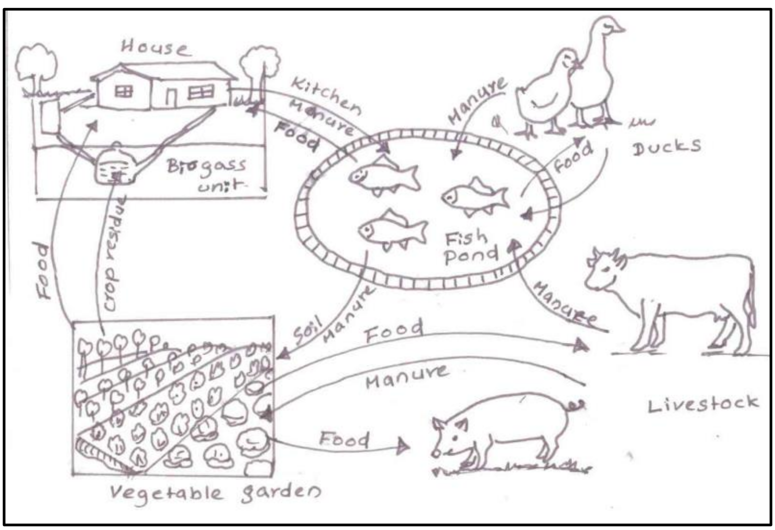

Figure 8. Integrated farming system.

Figure 8 illustrates the components of an integrated farming system. The house is constructed close to the pond so that the domestic and kitchen wastes are drained into the fish pond to increase fish production. The livestock pens and garden are also situated near the pond. The garden includes a variety of vegetables, and fruits. Livestock manure is used for fertilising the trees, vegetables and fish pond. Pond sludge is removed after the harvesting season and used as a fertilizer for crops. In this system waste produced from one component of the farm is used for enhancing production of livestock and agricultural crops and thereby waste generation is minimized.

7.2.4. Soil Conservation and Erosion Control

Soil erosion is a major factor leading to loss of soil fertility and water pollution by sedimentation. Erosion control and better soil management practices are essential when agricultural practices are conducted in surrounding catchments. Soil erosion is often enhanced by farming in slopes that are too steep, absence of rotation of different crops, inadequate input of organic materials, soil compaction due to footpaths or heavy machinery used for tillage and removal of harvest products. Soil erosion during agricultural practices can be prevented by adopting agronomic and soil management practices and through adopting runoff control measures.

a. Agronomic Practices

Agronomic measures utilize vegetation to minimize the erosion by increasing soil surface cover, surface roughness and soil infiltration. Some examples are:

Establishment of Contour Hedgerows

Contour hedgerows of nitrogen fixing trees/shrubs have been widely used to minimize soil erosion, restore soil fertility, and improve crop productivity. Trees or shrubs used as hedgerows are grown at intervals of 4-6 m along the contours to minimize runoff and soil erosion. The strips of land between the hedgerows are planted with food crops. The hedgerow trees have to be pruned periodically in order to minimize shading of food crops. The pruned biomass can be used as green manure, as mulch *in situ*, or as fodder.

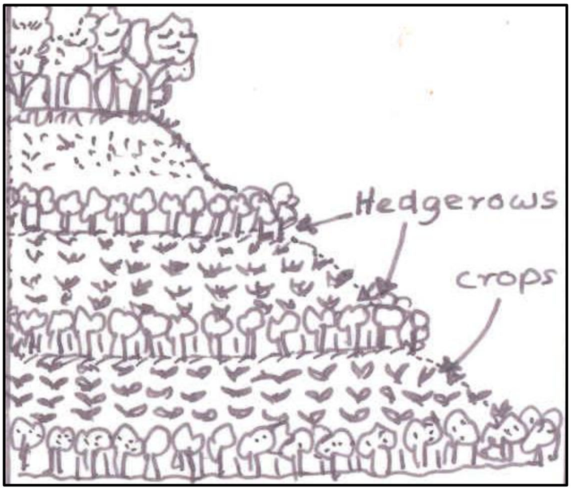

Figure 9. Contour hedgerows with pruned trees.

Natural Vegetative Strips

Natural vegetative strips are also used to minimize soil erosion in crop fields and these can be considered as an attractive alternative because they are simple to establish and maintain. Normally these natural vegetation containing buffer strips are spaced at every one meter drop in elevation. The natural vegetation of the strips, filters the eroded soils, slows down the rate of water flow, and enhances water infiltration, making them very effective for soil and water conservation.

Improved Fallow Systems

When arable lands in upland areas are cultivated with food crops for some years the land needs to be fallowed for some time to allow the soil to rejuvenate. The soil can be enriched during the fallow period by cultivating leguminous trees because they have the ability to fix atmospheric N and reduce the amount of nitrogen needed as fertilizer during crop cultivation. Once the soil has been rejuvenated, the trees are cleared for crops. The pruned leaves and branches can be used as fodder.

Crop Rotation

Crop rotation is the sequential cultivation of different crop species on the same plot during a year. One species of crop is grown during a particular season of the year, followed by another crop species during the other season. For example, rice would be grown during the rainy season followed by vegetable cultivation during the dry season in the same plot. The different rooting pattern of different crop species planted may help in the soil structure formation and improve water percolation. It also improves soil structure and nutrient condition and interrupts life cycle of weeds/pests/plant disease.

b. Soil Management

Soil management measures include improving the soil structure so that it is more resistant to erosion.

Conservation tillage: This involves reducing frequency of soil tillage during the farming period. Reduced tillage can reduce soil erosion and compaction, build soil organic matter, and reduce runoff.

Terrace farming: Terrace farming is practiced when farming practices are conducted on steep lands. In terrace farming the topography of the land is modified to slow water flow through a series of terraces. Terraces reduce the water flow rate and soil erosion from farmlands.

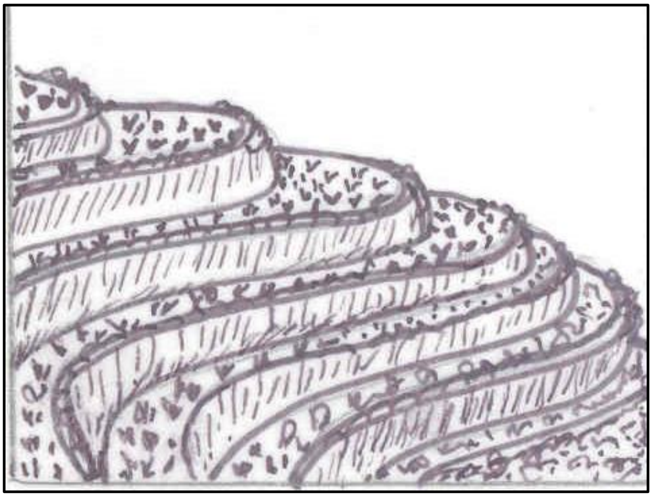

Figure 10. Terrace farming.

Contour farming. In this farming system crops are planted following the contours of the landscape. Crops planted parallel to the land slow the flow of water that prevents soil erosion and enhance water infiltration.

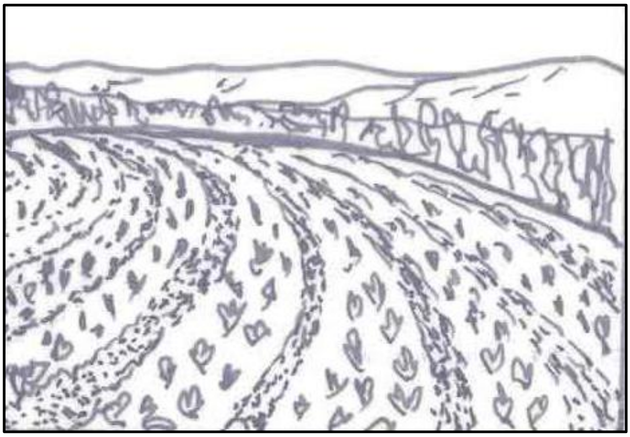

Figure 11. Contour farming.

Contour Ditches (Drainage and Infiltration Ditches)

Contour ditches prevent down slope water movement as the water falls into the ditch. These also diverts excess water to protect drainage channels, reducing soil erosion and leaching of nutrients.

Figure 12. Contour drainage ditch.

Contour infiltration ditches enhance water infiltrate through the soil. To retain water, earthen dikes can be constructed in the ditches or the ditches can be constructed on a 0% slope so that water infiltrates into the soil and is not diverted outside the field.

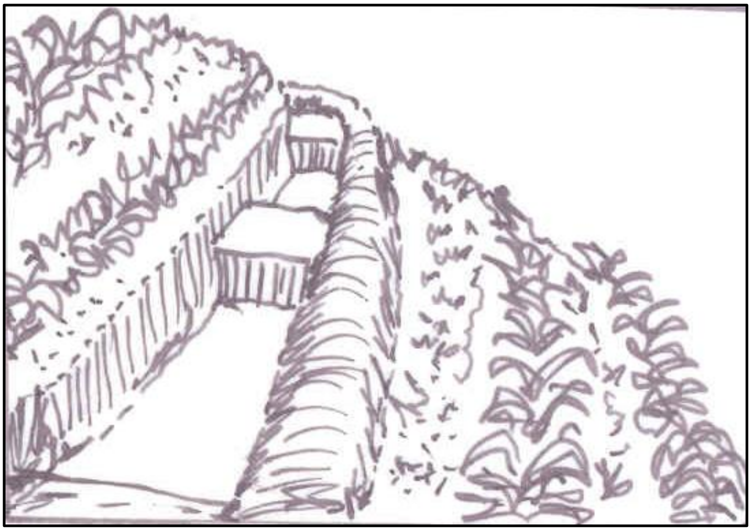

Figure 13. Contour infiltration ditch.

c. Irrigation Management

Irrigation management can be used to minimize runoff, improve water efficiency, and prevent soil erosion from the catchment. For example, farmers can reduce erosion and sedimentation by 20-90% by applying better irrigation techniques to control the volume and flow rate of runoff water. For example, adoption of irrigation techniques such as micro irrigation (i.e., drip and sprinkler irrigation), the precise quantities of water and fertilizer can be applied to the crops and thereby reduce the volume and flow of runoff. Drip irrigation involves dripping water onto the plants at very low rates (2-20 liters/hour) from a system of plastic pipes fitted with emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted and water usage efficiency is improved. Sprinkler irrigation is a method of applying irrigation water through a system of pipes by pumping. Water is sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground.

7.2.5. Establishment of Buffer Zones

The riparian zone is important in the stabilization of channels, filtering sediments and preventing entry of toxic pollutants, nutrients from land base activities. Activities which may impact riparian areas include agriculture, grazing, logging, building of roads and transportation, residential, urban, and industrial developments. Loss of riparian vegetation due to such activities can have significant impact on aquatic ecosystems including water quality degradation. Thus, establishment and management of riparian buffer zones are essential in stream restoration and water quality restoration efforts in river catchments. Yet many restoration projects have focused only on replanting vegetation while ignoring underlying hydrologic, geomorphic, biological, and chemical processes. Therefore, the goal of restoration should be to reinstate natural variations in the fundamental environmental factors within this particular zone. A review of riparian zone ecology by Naiman and Decamps (1997) has described many models of riparian zone establishment. Among them, the most commonly adopted riparian model uses three interactive zones to provide a stream with protection from agricultural impacts. The zone closest to the waterway consists of a strip of forest trees and serves to influence the stream temperature, light and channel morphology, etc.. The middle zone comprises of shrubs and trees, and aims to control pollutants in subsurface flow and surface runoff. The outermost strip, bordering on the agricultural land, is a strip of herbaceous vegetation, which facilitates deposition of sediments.

In addition to the three zone forest buffer system, there are other types of riparian buffer establishment methods are also available. A two-zone forest buffer is used in many situations to protect streams from terrestrial pollutants. Two zone buffer systems consist only of managed and unmanaged forest zones, the grass zone is not established.

Buffers consisting of only grass species are also used along small streams that flow through crop fields and pastures. Grasses are most effective at filtering sediment and provide valuable wildlife habitats. In most cases native grasses are preferable in grass buffer zones, but they are often invaded by exotic species. Therefore, periodic maintenance of grass buffers is essential to control invasion by unwanted plant species and to re-establish grasses.

Buffers in urban areas are important for intercepting runoff and pollutants from urban areas. These buffers are designed to withstand human impacts and mostly consist of more stable woody trees and shrubs. The vegetation selected for such buffer zones provides a more visual impact and are also resistant to human impacts. Urban buffers can also function as Greenways along streams and may include recreational trails.

In the establishment of riparian zones a good understanding of vegetation ecology, particularly succession sequences in different situations, and weed ecology is important. Some weeds are serious threats to the ecological sustainability of riparian buffers. Continuous disturbance of riparian zones by human activities may lead to create unoccupied patches along riparian zones, which are relatively susceptible to colonization by exotic species. Establishment of a closed canopy from an early stage may help minimize the risk of weed invasion. Close plantings of trees, at spacing of one meter ensure rapid canopy closure and minimize the risk of weed invasion. Monitoring and follow-up maintenance are also essential for the better establishment of riparian buffers.

7.2.6. Integrated Pest Management (IPM) - to Reduce Agrochemical Use

Dependence on Agrochemicals to control agricultural pests is very common in recent agricultural practices. Excess use of Agrochemicals in crop production has become a major issue in the agriculture sector and ecological and public health issues created by such practices are well known. Contamination of food, water, soil and atmosphere with such chemicals has contributed to increasing the incidence of public health problems worldwide. The ecosystem damage cause by such chemicals is also significant. Therefore, minimization of agrochemical usage for pest control is essential for maintaining healthy ecosystems and to minimize public health problems.

Integrated pest management is an effective and environmentally sensitive approach to pest management that relies on a combination of pest control practices. It uses current, comprehensive information on the life cycle of pests and their interaction with the environment to control their populations. These aspects in combination with available pest control methods are used to manage pest damage by the most economical means and with the least possible hazard to people and the environment. The IPM approaches in pest management involve biological control, cultural control, mechanical and physical control and chemical control methods of pests. Mostly biological control methods involve the use of natural enemies of pests such as predators, parasites, pathogens and competitors to control pest populations. Cultural control methods are mainly aimed at reducing pest establishment, their dispersal and reproduction. For example, irrigation management techniques can be used to control water levels in the field in order to control the emergence of larval stages of pests in rice fields. Selecting crop varieties best suited to local growing conditions and crop sanitation such as removal of diseased plants, and cleaning, pruning shears to prevent spread of infections are cultural practices adopted for pest control. Mechanical and physical control methods are used to control pests through mechanical barriers or through making their environment unfavorable for pests. Techniques such as mulches for weed management, traps, sterilization of soil for weed management are examples of mechanical control methods. Chemical control is also applied in IPM techniques however, in a very controlled manner. Pesticides are used in combination with other techniques for pest control and they used only when necessary. Synthetic pesticides are used as required and often only at specific times in a pest's life cycle. Many newer pesticides are derived from plants or naturally occurring substances. Application of those control measures are implemented after careful evaluation of the pest life cycle, their interaction with the environment and damages they cause to crops through close monitoring programs. All these measures are useful to substantially reduce Agrochemical usage to control agricultural pests and thereby reduce adverse impacts to the environment.

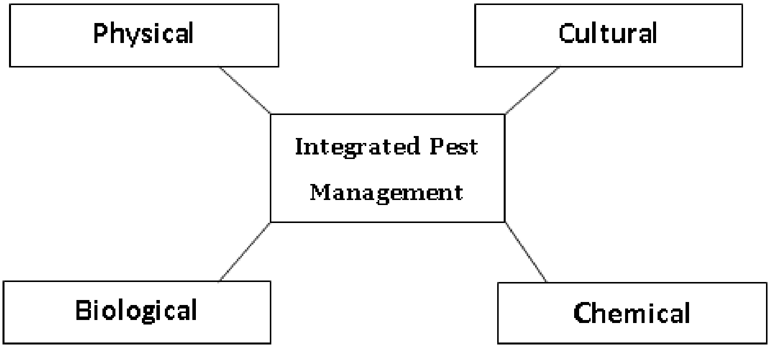

Figure 14. Components of integrated pest management.

7.3. MITIGATION OF URBAN AND RURAL IMPACTS

Human population expansion, migration of populations and economic development activities have led to the expansion of urban populations in many regions of the world. Unplanned urban settings in river catchments can cause a wide range of environmental issues. Urban and industrial wastes, increased impervious surfaces leading to higher runoff volumes, coupled with high exploitation rates of water for urban and industrial processes may accelerate the pollution tendencies of the aquatic environment.

7.3.1. Construction Activities

Construction activities in urban and rural landforms can have a number of negative impacts on aquatic ecosystems. Increased impervious surfaces in urban settings can increase the volume of surface runoff and reduce the infiltration of water to groundwater stores. Construction activities in urban areas may alter hydrologic regimes and sediment delivery to streams, influencing channel morphology and habitats used by aquatic biota.

In urban areas several measures can be adopted to control increased runoff and increase storm-water infiltration. Those include establishment of porous pavings, removing hard surfaces where possible and planting with vegetation, establishment of a variety of retention, or seepage basins or ponds, overflow wetlands and alternative drainage systems.

A number of rehabilitation actions can be initiated to mitigate for the negative impacts that construction activities have on aquatic ecosystems. Some of these mechanisms aim to reduce sediment delivery by such construction activities include resurfacing roads, stabilizing cut and fill slopes and replacing stream crossings to improve the natural transport of sediment and biota. Construction activities also may interrupt the connectivity of streams and rivers, affecting aquatic species dependent on these interconnected aquatic systems for completing their life cycles. In river systems, the movement of sediments and influxes of organic matter are important components of habitat structures for river communities. Especially in smaller rivers and streams, the organic matter that arrives from the land is a particularly important source of energy and nutrients, and woody materials that fall into the water provide important substrates and habitats for aquatic organisms. Culverts, bridges, and fish migration ladders can be used to restore connectivity among stream reaches and channels at road crossings. New construction activities needed to be designed to maintain connectivity among aquatic systems to ensure the efficient passage of natural materials and biota.

7.3.2. Urban and Industrial Waste

Urbanization directly contributes to waste generation, and improper waste disposal contributes to health hazards and urban environmental degradation. In developing countries financial constraints, institutional weaknesses and poor technology are the leading causes for poor waste management. Disposal of urban and industrial waste into aquatic environments is a leading factor which contributing to degradation of aquatic environments. In most urban settings in developing countries, sewer systems used for transporting urban wastewater are malfunctioning or overloaded. Some areas are devoid of sewer systems and wastewater is directly routed to nearby waterways. During rainy seasons, these sewer systems or drainage canals are often flooded and the wastewater may contaminate natural water bodies. Similarly, urban communities living under poverty and with poor housing conditions such as in community gardens do not have proper waste disposal facilities. Most household waste generated is disposed of by dumping into nearby water. . Most waste arising from such sources, including fecal matter, ultimately contaminates natural water bodies. Industrial waste discharged into the aquatic environment also poses significant environmental problems. Despite the regulatory measures available for industrial pollution control, in many developing countries poor law enforcement has contributed to, haphazard dumping of industrial waste into the environment without proper treatment.

Sound waste management is one of the options to minimize environmental impacts caused by the waste generated through industrial and urban sources. Waste management generally focuses on processing waste after it is created, concentrating on re-use, recycling and waste treatment rather than eliminating the creation of waste in the initial phases of production. Recycling involves reuse of raw materials during production, recovery or reclamation of material from the waste stream for different purposes during production.

Waste treatment involves application of physical, chemical, biological and other technologies to minimize volume, mass and toxicity of waste. In many countries it is mandatory that industries comply with the regulations pertaining to the waste disposal and treating their waste before emitting to the environment.

Waste minimization involves efforts to minimize resource and energy use during manufacture. It involves in activities to reduce or eliminate the generation of waste at production sites. It includes energy use efficiency, reduction of water consumption and an optimal use of raw materials. Waste minimization usually requires knowledge of the production process, cradle - to grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

7.4. Strategies to Reduce Waste Generation and Pollution Control

A wide range of strategies can be adopted to control pollution of aquatic environments. These approaches may range from direct regulatory measures to the application of economic tools. All these approaches alone or in combination have been used as effective solutions to control pollution in different countries. Depending on the social and economic status in respective countries, these strategies can be adopted to control pollution of the aquatic environment.

7.4.1. Direct Regulatory Instruments (Command and Control Instruments)

Regulatory tools influence environmental outcomes by regulating processes or products, limiting the discharge of specified pollutants, and by restricting certain polluting activities to specific times or areas. These categories include measures such as the implementation of Emission standards in situations where industries discharge their pollutants to the environment and EIA (Environmental Impact Assessment) procedure prior to the implementing major projects. For example, in Sri Lanka all industries which discharge or deposit effluents or emissions into the environment are required to obtain an Environmental Protection License (EPL) from the Central Environmental Authority (CEA) of Sri Lanka. The License issued to an industry will stipulate the standards and criteria under which the industry is allowed to discharge its waste. Such command and control approaches aimed at reducing pollution caused by industries through the implementation of rules and regulations, imposed on them by a regulatory body.

7.4.2. Economic Tools

In contrast to regulatory instruments or command and control instruments, economic instruments have the potential to make pollution control economically viable to commercial organizations and to lower pollution prevention costs. The principal types of economic instruments used for controlling pollution are:

Taxes and User Fees

This involves an emission fee, which involves charging polluters a fee per unit of pollutants generated. For example charge for a unit volume of residential solid waste generated and put into municipal waste treatment plants. This process will motivate householders to reduce the quantities of waste generated through changing their purchasing patterns, reuse of products and containers and composting of yard waste.

User fees are also a kind of fee charged for using a common facility for disposing waste. For example the users of the municipal wastewater collection and treatment system can be charged according to the load they place on the system (not a fixed monthly charge).

The deposit-refund system is another approach, where consumers pay a surcharge when purchasing a potentially polluting product. When the consumers or users of the product, return it to an approved center for recycling or proper disposal, their deposit is refunded.

Similarly the introduction of taxes for socially undesirable sectors such as pollution in place of socially desirable sectors such as investment, labor also can be categorized as an economic tool to reduce pollution.

Subsidies

In developing countries, promotion of industrial and agricultural sectors is considered to be primarily important for the development process. With the existing financial constraints in industrial sectors in those countries, implementation of systems such as "pollution charges" is practically difficult and industries are mostly discouraged by the implementation of such action. In such cases, implementation of subsidy schemes for pollution prevention efforts would be a better solution. For instance, excess use of inorganic fertilizers in agriculture is one of the main factors contributing to nutrient pollution of the aquatic environment. In many developing countries inorganic fertilizer is provided for subsidized prices to farmers with the aim of promoting the agricultural sector. This has often contributed to indiscriminate use of inorganic fertilizer in the agricultural sector and subsequent impacts to aquatic environment Government intervention in the removal of subsidies for the purchase of inorganic fertilizer and provision of subsidy schemes for the promotion of organic fertilizer users is important in combating nutrient pollution of water bodies.

Tradable Permits

Market instruments are also useful in pollution reduction. One such approach is the use of “Tradable permits” to use aquatic system, lake or reservoir for discharging effluents. In this approach a regulatory authority determines the total amounts of emissions or nutrients which can be discharged into a water body while maintaining its health. The carrying capacity is calculated based on lake water retention time, local climatic conditions and many other related parameters which affect the nutrient retention time of the lake.

Secondly the agency allocates the total allowed nutrient load among various emitters in the region based on the carrying capacity of the water body. In the execution phase emitters are allowed to emit only allowable nutrient loads which are being strictly controlled/monitored. In this way the receiving water body would be protected because it receives only the pollutants up to its carrying capacity. However, depending on the nature of the industry some emitters may require higher loads of effluent emissions and some may require lesser volumes of emissions. In situations such as this one user can sell his permit to another who requires higher emissions (tradable permits). In this way excess emissions can be controlled and the water body receives effluent loads only up to its carrying capacity. The natural purification ability of the water body would be sufficient to purify pollutant loads emitted from industries located in the surrounding catchment.

7.5. Problems Associated with Water Pollution Control and Possible Solutions

There are many issues associated with the implementation of water pollution control strategies in the developing world. Many of such issues are common to developing countries and in the following section some of the issues experienced in Sri Lanka are summarized.

7.5.1. Weak Environmental Regulations and No Enforcement

The legal support system of the country reflects societie’s obligation to the maintenance of a sustainable environment for economic and social well-being. In many developing countries weak environmental regulations or lack of enforcement of laws pertaining to environmental pollution control has become a limiting factor to the sustainable development of those countries. With the poor enforcement of laws, none of the pollution control measures become effective or conducive. In parallel to the development activities of countries new threats to the environment may also emerge. Therefore, pollution control also needs a periodic review of the legal system to ensure that it keeps up with new developments in the country. Most commonly, rules and regulations pertaining to pollution control in developing countries are not up to date. Therefore, a periodic review of the legal system and updates are required to cope with new challenges arising from development activities of the country.

7.5.2. Poor Political Support

The environmental policies of a country should be embodied in the economic policies of government. Without a clear perception of the role of the environment, economic gains are liable to be short lived. In developing countries, environmental policies and economic policies are divergent and hinder the sustainable development process of the country. Most often the implementation of environmental policies are given less priority and political will leading to poor implementation of environmental policies and pollution control measures.

7.5.3. Lack of Institutional Cooperation and Overlapping Responsibilities

The traditional approach adopted by many developing countries, including Sri Lanka is that the various governmental agencies administrate independently. A large number of government agencies that are active and have responsibilities in water related sectors in Sri Lanka are working in isolation. Most often, many of the responsibilities of these institutions overlap, often leading to confusion when initiating pollution prevention efforts. In such cases, mechanisms for strengthening institutional co-ordination and the review of organizational structures to trace overlapping responsibilities are essential for better implementation of pollution prevention mechanisms by responsible institutions.

7.5.4. Lack of Information and Monitoring

Monitoring programs are essential for tracking pollution sources and pollution tendencies of the aquatic environment. However, updated information related to most aquatic systems of the country is lacking because monitoring is not systematically done even for point sources. Lack of facilities or weak technical support systems within institutions are often the cause of such problems. In some situations, data are collected and held by different agencies with different responsibilities and not shared among institutions working in the same sector.

Therefore, the establishment of well-maintained research and monitoring facilities in the institutions working in water related sectors is essential. Similarly, establishment of central or regional data and information management systems which are responsible for maintaining water related data bases within the country and information system to meet the needs of water management need to be established. Such information and databases related to water related sectors should be freely accessible to various institutions in the sector and thereby huge costs involved in individual monitoring programs by individual institutions can be reduced and directed for other development activities within the sector.

7.5.5. Technical Support System

Many water related institutions in developing countries has limited technical capacity to solve environmental issues and they mostly rely on traditional technology for solving such problems. However, given the development goals of the country, new environmental threats may arise from economic development activities. In this case new technological solutions to solve the arising problems is needed. For example a large number of synthetic chemical compounds from industrial sectors are discharged into the environment daily. However, long-term impacts of these compounds in the biological systems and mechanisms of their degradation are poorly known. Traditional water treatment systems, are not capable of monitoring the presence of these compounds and treating such compounds. Therefore, pollution control systems require constant review of technological capacity for efficient pollution management. Therefore, innovative technology to cope with new threats that arise from economic activities must be developed.

7.5.6. Facilitating Public Awareness and Participating in Water Management Strategies

No environmental program can succeed without the full support and corporation of the public, stakeholders and land users. The support can only be achieved through an effective information and public awareness support system. Therefore, all water management and pollution control attempts in rural and urban settings should be implemented with awareness raising programmes among the community and with the participation of all stakeholders. In addition to the above recommendations, the following recommendations also are suggested to control water pollution and effective management of freshwater and associated aquatic environment.

7.5.7. Prevention of Water Pollution and Improving Water Use Efficiency in Agriculture and Industrial Sector

Water wastage is one of the main problems associated with agriculture, domestic and industrial sectors of the country. Therefore, it is essential to develop water conservation strategies in each sector. In irrigated agriculture, water losses from reservoirs and canals should be minimized, efficient field water management has to be promoted for increasing the water productivity through crop diversification and with new water saving techniques. Eutrophication seriously affects stagnant waters and proper catchment management practices should be introduced to avoid costly restoration of water bodies. All land users for agriculture should be encouraged to sustainable use of natural resources by awareness creation, making resource conservation compulsory, generation of improved technologies, safe and efficient management of rainwater, river, tank and groundwater.

In the industrial sector, the development of low water consuming technologies is essential. Adoption of water saving criteria in industries such as reuse or recycling of water to reduce water consumption, cleaner production technologies to prevent water usage are some of the actions to be taken. In addition, close monitoring of industrial sector to curb effluent discharged into water bodies should be conducted and effective preventive measures of water pollution should be implemented. Similarly, increased institutional capabilities of municipalities and other local bodies to prevent water wastage is needed. Ground water is heavily exploited by agriculture and industrial sectors. Therefore, better monitoring of use of ground and surface water by the industrial and agricultural sectors to curb the current exploitation of water resources is essential.

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