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Aquatic pollution and its effects on fish population

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Abstract

It is clear that human-induced changes in the aquatic environment, in particularly pollution, are fundamentally altering the water chemistry from the shallowest waters to the darkest depths of the deep sea which in turn will have a great effect on the living communities inhabiting these waters. The aquatic pollution approaching conditions not seen in many millions of years, and the rate at which this is occurring is unprecedented. For instance Caldeira and Wickett (2003) stated "Unabated CO2 emissions over the coming centuries may produce changes in ocean pH that are greater than any experienced in the past 300 million years…..".

*Keywords***:** Aquatic pollution, toxicity, heavy metals, thermal pollution, acid rain, global warming and Fish.

Introduction

The wastes of any society can be placed on land, in the atmosphere or in the water. It is reasonable to consider the consequences of the wastes disposal in each of these receiving environments on scientific, economic and social bases. The disposal of wastes in the aquatic environments, even those produced by the best available technologies and after extensive treatment, may have an impact on the ecosystems, resources and human health.

The term "aquatic pollution" has different meanings for different people. To some, it only means the discharging of industrial wastewater or sediments from urban development while to others; it is the contamination of water bodies with pesticides and agricultural chemicals. Most people think of aquatic pollution in terms of massive fish killing.

Clark *et al.* (1997) in their book "Marine Pollution" stated that "most pollution scientists use different terms for the waste ('inputs'), the occurrence of them in the aquatic environment ('contamination') and their damaging effects ('pollution')". The authors also found that some of the wastes reaching the aquatic environment are man-made (not existing in nature) while the rest exist naturally in the environment. They also added that the contamination is caused when an input from human activities elevates the levels of a substance in the water, sediments or organisms above that natural background level for that area and for the organisms.

Ellis (1989) and Clark *et al.* (1997) defined the water pollution as any undesirable alteration in the natural (physical, chemical or biological) quality of the aquatic environment causing deleterious changes to this natural quality which in turn endanger human health and harm living resources and ecosystem. This undesirable alteration is mainly due to the direct or indirect activities of man.

Recently, it is becoming increasingly clear that, for many pollutants, no single level can be suggested as the crucial level between safe and harmful which is globally applicable on all aquatic situations. This could be attributed to the complexity of the natural surface waters chemistry that depends on the physical, chemical and biological characteristics of the surrounding environment (Svobodová *et al*,. 1993). However, the effects of the environment on both the toxicity of pollutant and the susceptibility of the fish, have to be considered when attempting to formulate criteria for safe levels (Alabaster and Lloyd, 1980).

Various terms are used to describe the extent to which the environment is able to accommodate waste without unacceptable effects. For example" The Environmental Capacity" which can be defined as the ability to accommodate a particular activity (e.g. volume of discharge per unit time, quantity of dredging dumped per unit time, quantity of minerals extracted per unit time) without unacceptable impact. Definition of this capacity must take into account such physical processes as dilution, dispersion, sedimentation and evaporation, as well as all chemical, biochemical and biological processes which lead to degradation or removal of pollutants from the impacted area by which a contaminant or an activity loses its potential for unacceptable impact.

Since the industrial revolution, the man-made pollutants, shown in figure (1) have often resulted in the transformation of lakes, rivers and coastal waters into sewage depots where the natural biological balance is severely upset and in some cases totally disrupted, in other words they cause adverse effects on the ecosystem. Many of these pollutants add unpleasant odor or taste to the water. Many others have direct and indirect influences on aquatic organisms and can cause serious damage as in the case of heavy metals that are not usually eliminated from the aquatic environment by natural processes, in contrast to most organic pollutant. Some heavy metals tend to accumulate in the bottom sediments; from which they may be released again to the system and move up through the food web where they may produce chronic and acute effects (Förstner and Wittmann, 1981). However, the increasing pollutant load in addition to the over exploitation of the water resources for potable supplies, irrigation, industries and thermal power plants to meet the requirements of the ever-increasing human population, significantly reduces the assimilative capacity of the aquatic media.

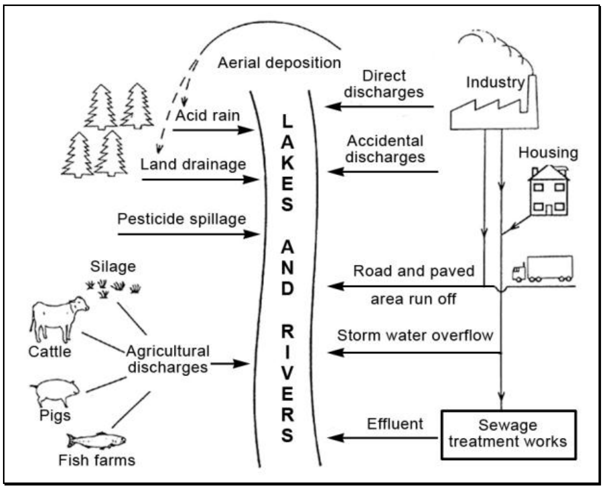

Figure 1. Sources of man-made inputs into the aquatic environment (cited from Lloyd, 1992).

The aquatic ecosystems have been subjected to various forms of anthropogenic environmental stress, mainly urban activities, during the past few decades. Some of such problems are pollution, siltation, river course modification, overfishing and introduction of exotic fish species.

The consequences of aquatic pollution on the biological communities inhabiting polluted areas have gained a major global concern lately. Of these communities, fish is the most important aquatic community concerning the man. The present article aims to highlight those consequences that might affect fish as well as fisheries potential of aquatic ecosystems. It describes the sources, features and effect of many different types of aquatic pollution in clear, straightforward way.

1. Pollutants' Types, Sources and Environmental Fate

1.1. Pollutants' types

Krenkel and Novotny (1980) categorized water pollutants according to their constitution properties into four main groups as follows:

1.1.1. Chemical pollutants (organic and inorganic materials)

The organic materials (i.e. organic chemicals, manure, plastics, sewage wastes,… etc.) in the aquatic environment are of great concern because of their potential for depleting dissolved oxygen (DO)which in turn affects the aquatic life. The presence of sufficient amounts of these organic materials, especially in lakes, increases the number of decomposers which use great deal of oxygen during their growth which in turn lower the DO-levels to unfavorable values for the living communities (Lloyd, 1992).

The discharge of inorganic materials may cause undesirable results like changes in water pH, caused by soluble salts, and toxicity caused by heavy metals or other toxic materials (i.e. chemo-toxicants). In addition to the previous effects of inorganic materials, insoluble inorganics, like barium-sulfate and aluminum-oxide, may result in sludge deposits on the bottom and inhibit benthic biological activity.

1.1.2. Physical pollutants

Physical pollutants like colour, turbidity, temperature, suspended solids and foam are mainly associated with chemical pollutants discharged into receiving water.

Although some of these physical pollutants are not necessarily harmful, they may cause some undesirable effects on the aquatic life. For example: (i) temperature significantly affects chemical, physical and biological processes, (ii) colour is obviously undesirable in aquatic media water, (iii) turbidity may cause a reduction in productivity as a result of the reduction of sunlight intensity in the water, and(iv) foam from various industrial waste may cause a reduction in the rate of atmospheric oxygen absorption, thus decreasing the self-purification capacity of the receiving water (Mostafa, 1994).

1.1.3. Biological pollutants

The biological pollutants are those waste materials that may be discharged into a receiving water bodies causing either diseases like in case of primary pollutants [pathogens] or biological growths like in case of secondary pollutants. Excessive growth of algae and fungi is often attributed to the waste discharges containing nutrients that may be considered as secondary biological pollutants (Mostafa, 1994).

1.1.4. Physiological pollutants

Physiological pollutants are those substances causing taste and odor problems. These substances are among those pollutants that are hard to manage for the water-pollution-control engineers. Extremely minute quantities of some substances can add objectionable taste to water (hydrogen sulfide can be smelled at a concentration of 0.0011 mg/L). Many taste and odor-producing materials possess the ability to eliminate the use of fish for food, because of the bad taste imparted to fish flesh by the chemicals discharged in the water (Abaza, 2004).

1.2. Pollutants' sources

In order to control any type of pollution, its source should be clearly classified as well as its causes. The sources of aquatic pollution can be classified to many categories. Of these categories:

1.2.1. Domestic sewage

It refers to the wastewater that is discarded from urban areas containing sewage and laundry detergents. (organic matter), to the watercourse nearby. Also referred to as sanitary sewage, such water contains a wide variety of dissolved and suspended impurities.

1.2.2. Agricultural wastes

Modern methods of agriculture have resulted in use of fertilizers and pesticides to increase the yield of the crops. Most of them are synthetic and chemicals-based known as "agro-chemicals". These chemicals enter the water bodies with the rain water flow and the irrigation water drains from cultivated lands that have been fertilized and treated with pesticides in addition to the ground water by seepage. These water flows are mainly loaded with pesticide residues and mineral fertilizers (major contributor of residual phosphates and nitrates).

1.2.3. Industrial effluents (organic and inorganic wastes)

This form of pollution is one of the leading causes of aquatic pollution worldwide. Industries are mostly situated along the riverbanks for easy availability of water and also disposal of the wastes. These Industries generate a significant quantity of wastewater; known as "industrial effluents". Such effluents generally include organic or/and inorganic substances and various acids. Some of these industries like paper, dairy and textile industries generate decayable organic waste, while others like those manufacturing organic-chemicals (i.e. pesticides, fertilizers), dyes, steel and chloroalkali generate hazardous and toxic inorganic waste (heavy metals or chemo-toxicants). All these wastes are mainly discharging their wastewater into the nearby lakes and rivers.

1.2.4. Thermal pollution

It is the changing of water quality by any process that changes ambient water temperature. It occurs when water is used as a coolant near a power or industrial plant and then is returned to the aquatic environment at a higher temperature than it was originally. It can also occur as a result of dumping heated gases or heated wastewater into the rivers and streams.

1.2.5. Global warming

Lately, global warming is one of the biggest challenges to the global environment. It mainly comes from vehicles (which burn gasoline or diesel fuel), electricity station (generated by burning coal and natural gas) and heating systems (mainly via electricity, natural gas and home heating oil).In terms of water pollution, there are two main threats from global warming: (i) ocean temperature, and(ii) ocean acidification.

1.2.6. Ocean acidification

The overwhelming cause of ocean acidification is the absorption of the anthropogenic carbon dioxide (CO_2), although in some coastal regions, nitrogen and sulfur are also important (Guinotte and Fabry, 2008; Doney*et al.*, 2007).

Since the industrial revolution, the oceans have been the major buffers of the human produced CO_2 emission as it has absorbed approximately half of the CO_2 emitted by human activities(burning fossils, deforestation, industrialization and cement production) through air-gas exchange(Fernand and Brewer, 2008; Guinotte and Fabry, 2009). Without this long-term storage, the greenhouse gas concentration in the atmosphere would have been much higher, and the planet much warmer.

On the other hand, CO_2 absorbed reacts with water forming carbonic acid leading to a perturbation of the aquatic environment; primarily in ocean surface waters (water becomes more acidic). Ocean surface water now has an average pH of ranging between 8.06 and 8.1 and is predicted to decrease rapidly with projected rises in atmospheric CO_2 (Guinotte and Fabry, 2009; MPA-

NEWS, 2009). For the last 200 years, the pH of surface oceans has dropped by 0.1 pH units, to reach its present level (8.06), and is expected to drop another 0.3-0.4 pH units by the year 2100 (Caldeira*et al.*, 2007; Feely *et al.,* 2008). This agrees with both Caldeira and Wickett (2003) and The Royal Society (2005) who found that the ocean pH levels will drop from 8.06 down to a level as low as 7.76 by the year 2100 if CO_2 emissions are not regulated. This would represent a 30% increase in acidity, as the pH scale is logarithmic (MPA-NEWS, 2009).

1.2.7. Acid rain

The term “Acid rain” is the popular term of “acid deposition”. It can have harmful effects on plants, aquatic life. Acid rain is caused by emissions of sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) which react with atmospheric water vapour forming acids like sulfuric acid and nitric acid. Places with significant impact by acid rain around the globe include most of Eastern Europe from Poland northward into Scandinavia (Hatier, 1993), the eastern third of the United States, and southeastern Canada (US-EPA 2008a).

1.2.8. Oil spillage

Oil spill is a major problem in the oceans and seas. Recently, oil pollution is considered as a serious global problem of the marine water. Oil tankers operations and accidents, offshore platform (oil rig), refineries, seepage of oil from underwater oil reservoir, accidental oil spills and the disposal of oil waste materials, are all causes of oil leakage into the water (Clark *et al.*, 1997).

1.2.9. Radioactive pollutants

Radioactive pollutants are these wastes containing radioactive material. This type of wastes can be divided into: (i) low-level waste with low levels of radioactivity generated from certain medical centers and industry (i.e. rags, tools, clothing, filters and other materials which contain small amounts of mostly short-lived radioactivity), and (ii) high level waste such as the material left in a nuclear reactor after the fuel has been consumed (i.e. fission products and transuranic elements generated in the reactor core)[1].

The Radioactive wastes found in the marine environment can be associated with various human activities. Such activities are: (i) the explosion of nuclear weapons either in the atmosphere or during underwater testing and (ii) the controlled release of low level radioactive liquid effluents from industries, hospitals and scientific research centers. However, other sources include the accidents at sea involving potential release of radioactive materials, for example the loss of a nuclear powered ships submarine or one carrying nuclear fuel (UNSCEAR, 1988).

[1] From Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Radioactive_waste.

1.3. Environmental fate of pollutants

Persistence in the environment of a given substance strongly depends on the characteristics of both the substance and the environment itself. Certain substances may be removed from the aquatic environment or rendered harmless; by chemical transformation while other substances, particularly some of the synthetically-produced organic substance may not be so readily removed and thus become a potential threat in view of their persistence. Such removal processes include, photolysis and photo-oxidation, dissipation, biodegradation and metabolization, sedimentation and sediment burial, transfer into the atmosphere,…etc.

Biological processes in various components of an ecosystem may hinder or enhance the mobility of contaminants, thus influencing the size of the impacted area. Metabolism in organisms plays a minor role in the transformation of environmental contaminants. In the water column, primary production or bacteriological oxidation-reduction may enhance the removal or degradation of contaminants. Also, concentrations in the field may slowly accumulate as the addition continues, with the consequence that the environmental concentrations can reach those known to cause effects if appropriate control measures are not applied.

Clark *et al.* (1997) categorized pollutants or wastes entering the marine ecosystem according to their fate as follows:

1.3.1. Degradable wastes

These are wastes subjected to bacterial attack (oxidative process) and ultimately breaks down to stable compounds such as carbon dioxide, water and ammonia (Clark *et al.*, 1997).

Wastes included under this heading are mainly organic wastes like: urban sewage, agricultural wastes, food processing wastes (from slaughterhouses), distillery wastes, paper pulp mill wastes, and chemical industry wastes. Such degradable wastes are not different from plant and animal remains which are subjected to bacterial decay.

If the input of these degradable wastes is within the capacity of the receiving waters; which is related to temperature, oxygen availability, water currents; it will result in enrichment of benefit chiefly to plants. If the capacity of the receiving waters is exceeded, the accumulation of organic material and the development of deoxygenating condition (anoxic condition) result in impoverishment of the fauna and flora (most plants and animals are excluded) (Clark *et al.*, 1997).

1.3.2. Leachable wastes

The agricultural fertilizers (i.e. nitrates and phosphates) are a good example of the leachable pollutants. They are leached from arable land to the rivers which in turn carry it to the sea. These fertilizers enhance phytoplankton production, sometimes to the extent that the accumulation of dead plant remains on the seabed produces anoxic conditions.

1.3.3. Dissipating wastes

These are the industrial discharges into the aquatic media that rapidly lose their damaging properties after they enter the water. Any effects these discharges may have on the ecosystem are therefore confined to the area around the point of discharge. The extent of that area depends on the rate of discharge and water cur-rents(Clark *et al.*, 1997).

Wastes included under this heading are: (i) acids and alkalis, (ii) cyanide (from metallurgical-industries) which rapidly dissociates in water and has little effect except in the immediate neighborhood of the out-fall, and (iii) heat (form cooling water of the coastal power stations). In temperate areas, heated discharges are generally of little consequence while in tropical areas where summer temperatures are already near to the thermal death point of many organisms, the increase in temperature can cause substantial loss of life.

1.3.4. Conservative wastes

Those are the waste materials that are not subjected to bacterial attack and are not dissipated. They are reactive in various ways with plants and animals causing harmful effects. Because of their persistence and harmful effects, they are regarded as a very serious threat.

The principal categories of such wastes are: (i) heavy metals (mercury, copper, lead, zinc,… etc.), (ii) halogenated hydrocarbons (DDT and other chlorinated hydrocarbon… etc.), and (iii) radioactive substances.

1.3.5. Solid wastes

Nearly all rivers and inland waters have some solid matter in suspension and in certain cases very high concentrations resulting from soil erosion as well as sewage and industrial effluents' discharge in the watercourse. It also results from deforestation, intensive agricultural practices, high rainfall, and construction of roads etc. and mining activities. Solids of many different kinds are therefore to be found in the water column. These solids may be of toxic properties (kill the fish) others may be organic solids which will lower the dissolved oxygen content in the water (due to their decomposition) to levels at which fish will suffer (Alabaster and Lloyd, 1980).

2. Heavy Metals Pollution and Toxicity in Aquatic Environment

In addition all these pollutants mentioned above, many others do have direct and indirect influences on aquatic organisms and can cause serious damage as in the case of heavy metals which are not usually eliminated from the aquatic environment by natural processes, in contrast to most organic pollutant. Some heavy metals tends to accumulate in the bottom sediments; from which they may be released again to the system and move up through the food web where they may produce chronic and acute effects (Förstner and Wittmann, 1981).

2.1. Sources of heavy metal in the aquatic environment

Metals are normally present in the aquatic environment in trace amounts represented by (µg/L) and exhibit some known biological function. The metals of biological concern may be divided into three groups: (i) light metals (sodium, potassium, calcium etc.) normally transported as mobile cations in aqueous solutions, (ii) transitional metals (e.g. iron, copper, cobalt, and manganese which are essential in low concentrations but may be toxic in high concentrations and (iii) heavy metals or metalloids (e.g. mercury, lead, cadmium, tin, and arsenic) which are generally not required for metabolic activity and are toxic to the cell at quite low concentrations (Wood, 1974). Shimp *et al*. (1971) showed that heavy metals in aquatic media can be divided to two groups according to their origin:

- **Anthropogenic metals (civilizational):** are the contaminants associated with urban runoff, domestic wastewater, industrial discharges, sewage treatment plant discharges, and atmospheric deposition of airborne metals (Nriagu, 1989; Irwin *et al.* 1997, Gregory and Terry, 1998).
- **Lithogenic metals (geochemical):** are the contaminants derived from rock material by natural weathering processes and soil erosion (Shimp *et al.*, 1971; (Förstner and Wittmann, 1981).

2.2. Heavy metals uptake by aquatic organisms

Organisms in contaminated aquatic environment are often exposed to toxicants for their entire life. In addition to the metal concentration accumulated in the organism organs the rate of accumulation is also of importance for survival (Michiel *et al.*, 1994).

The ecological significance of contamination of the natural environment by heavy metals can only be understood by examining and understanding the mechanisms and consequences of biological uptake. Of such mechanisms, Coombs (1980) mentioned: (***a***) ***Passive diffusion:*** the metal binds to ligands (forming a complex with central atom) on a cell membrane and diffusion occurs to the internal components of the cell (plankton and shellfish), (***b***) ***Facilitated diffusion:*** carriers are involved in the diffusion of the metal across the membrane (glycollic acid in Phytoplankton), (***c***) ***Active transport:*** uptake of metals such as Na and Ca across the gills, and (***d***) ***Endocytosis:*** uptake of particulate and colloidal metals. The author added that the epithelial cell membrane surrounds the metal and absorbs it, and then it pinches off to form a membrane-bound vesicle within the cell. This vesicle expels its content into the blood to be transported to the tissues and the kidneys to be stored or excreted.

2.2.1. Factors affecting the heavy metals uptake

The ecological significance of contamination of the natural environment by heavy metals can only be understood by understanding the mechanisms and consequences of biological uptake.

Marjorie (1999), mentioned that there are many factors controlling the heavy metal bioavailability and uptake by the aquatic organisms. These factors are:

- **Biological factors**

The dietary habits and feeding behavior

The feeding behavior of fish during the larval and adult stages is believed to play an important role that may affect the contaminant uptake (Marjorie, 1999).

Regulation of essential metals (balance between uptake and excretion)

Regulation is the mechanism by which organisms may control the concentration of contaminants within body tissues. The degree to which an organism is able to control these concentrations varies with the contaminant and the species of organism. It has even been shown to vary between individuals of the same population (Lobel, 1981). Regulation is more common for metals which are biologically essential e.g. copper and zinc (Förstner and Wittmann, 1981). Closely related species may differ markedly in the mechanisms and degree of regulation of a particular contaminant (Rainbow, 1997). If the copper and zinc concentrations in the environment become too high; regulatory mechanisms cease to function and the essential metals act in a toxic manner (Förstner and Wittmann, 1981). There is little evidences in the literatures for the regulation by marine organisms of non-essential metals such as lead (Ying *et al.*, 1993).

According to Marjorie (1999), subjecting a marine organism to heavy metal pollution may lead to at least three possible types of relation between the organism and its surrounding environment. Such relations are: (i) the organism excretes the metal at a rate proportional to the body burden and therefore the concentration in the body is proportional to environmental availability and usually remains fairly constant or tends to fall with increasing length which is related to its age; (ii) the organism has limited powers of excretion and tends to store the metals (the concentration in the organism may still be directly proportional to environmental availability but the level in the body tends to increase with length, and (iii) the organism is able to increase the efficiency of excretion in response to increase absorptions and therefore the concentration in the body does not increase in proportion to environmental availability.

Effects of sex and season sampled on body burdens

Many studies showed that heavy metals are not stored in equal concentrations in different organs of the animal (Presing *et al.*, 1993). In a few studies the metal concentration has been found to be partly dependent on the sex of the organism (Watling and Watling, 1976; Förstner and Wittmann, 1981). Differences in growth rate and size at a given age for the two sexes are important determinants of metal concentrations in the tissues (Mance, 1987). The faster growing sex can be expected to contain lower concentrations of metals, but not necessarily a smaller total body loads. Periods of fast growth are associated with reduced metal concentrations in the tissues and low growth results in increasing tissue concentrations (Mance, 1987; Pentreath, 1976). The growth rate determines the quantity of tissue through which the net gains or losses of metal is distributed (Mance, 1987). Body loads of heavy metals may be correlated with the age or size of the individual (Boyden, 1977). This may occur in species where uptake is not balanced by excretion.

Bioturbation

It is the displacement and mixing of sediment particles due to the burrowing and digging activities of the benthic fauna (animals) or flora (plants). These mixing exposes sediments from beneath the surface to either water or air are capable of enhancing the sediment-water interface causing a change in the redox state of the sediment. This may result in changes in the bioavailability of heavy metals previously locked into subsurface layers (Marjorie, 1999).

- **Physical and chemical factors**

In 1999, Marjorie found that the bioavailability of heavy metals is influenced by many physical and chemical characteristics of the sediment within which these metals may accumulate. This bioavailability is determined by the accessibility of the various chemical forms of a heavy metal to organisms. Duinker (1980) summarized the diversity of chemical forms of trace metals as follows: (i) fractions that are readily available (dissolved and adsorbed), (ii) fractions that become available after chemical changes (organically bound and in oxide coatings) and (iii) forms that are practically unavailable for release (in crystal structures of suspended particles).

Seasonal Variations

Seasons may influence body burdens of heavy metals. This seasonal variability may result from either internal biological cycles of the organism or from changes in the availability of metals in the environment of the organism (Marjorie, 1999). Periods of decreased salinity as a result of winter storm runoff to estuaries have been associated with increased metal uptake rates (Mance, 1987). There are also changes in trace metal adsorption characteristics with salinity resulting from changes in adsorption of organics. (Duinker, 1980). Organic complexation has been observed to decrease with increasing salinity (Abaza, 2004).

Temperature is important in temperate regions in determining seasonality of metal accumulation. The heavy metal toxicity increases with increasing of water temperatures due to the elevation of respiratory activities (Okbah, 1995; Clark *et al.,* 1997). The toxic behavior of each individual metal (pollutant) may differ when mixed with others (Konar and Mullick, 1993). Changes in rate of uptake and toxicity of metals with changing temperature varies considerably from metal to another and is complicated by interaction with salinity changes (Clark *et al.,* 1997) and mixing process with other metals (Konar and Mulick, 1993).

Wong and Yang (1997) mentioned that the decrease in the pH and an increase in the redox-potential in aquatic media causes a substantial release of some heavy metals (Cd, Cu, Pb, Ni, Mn and Zn), soluble Fe, NH_4^+ and PO_4^{-3}. The authors also stated that these results suggest that the dredging and disposal of sediments may enhance the mobilization of enriched heavy metals in sediments due to the more acidic and oxidized conditions. Yang*et al.* (2000) found a significant correlation between the toxicant uptake rate and fish oxygen consumption, regardless of fish size and species.

Sediment particle size

In 1999, Marjorie mentioned that sediment grain size is probably the most significant factor in determining the concentration of a trace element. Many factors including surface area, cation exchange capacity, surface charge, organic carbon, as well as clay minerology influence the ability of fine grained sediments to retain trace elements (Abaza, 2004). The distribution patterns of trace metals are negatively correlated with that of sediment mean grain-size, i.e. the finer the sediment, the higher the concentrations of trace metals (Fang and Hong, 1999). This is mainly because many geochemical phases known to increase the concentrate trace elements with the decrease of the sediment grain size (Marjorie, 1999). Concentrations of iron and manganese oxides and organic carbon increase with decreasing particle size (Horowitz and Elrick, 1987; Gaw, 1997). In muddy estuaries however this is not always true as Williamson *et al.* (1992) concluded that metal concentrations were largely independent of particle size in muddy sediments.

Organic carbon and sulfide content in sediments

The organic content in sediments is likely to be one of the factors controlling the bioavailability of metals (Ying *et al.,* 1993). Dissolved and colloidal organic matter in pore-waters also contributes in reducing metal bioavailability by forming stable complexes with heavy metals (US-EPA, 2001). In addition to this capability (complexing metals) the dissolved organic substance are capable of influencing the extent to which metals are adsorbed on suspended materials (Marjorie, 1999). Martinic*et al.* (1990) suggested that organic matter is not the predominant variable governing trace metal concentrations in estuarine sediment.

The presence of sulfides and particulate organic carbon has been identified as factors buffering the availability of heavy metals in contaminated sediments. Sulfides will combine with metals such as Cu, Cd, Zn, and Pb forming metal sulfides that are highly insoluble and will tend to be sequestered in the sediments (Irwin *et al.* 1997, US-EPA, 2001).

Antagonism and synergism between metal pollutants

The presence of multiple heavy metals in contaminated aquatic environment may result in disturbances in the normal pattern of bioaccumulation for a particular metal by a particular species. Clark *et al.* (1997) stated that in the natural environment, pollutant is rarely present in isolation and it interacts with others. Interactions between different metals generally reduce, rather than increase, the uptake of metals (Antagonism between metals) (Mance, 1987). In the seaweed *Laminaria*, for example, zinc uptake has been reduced by the presence of copper and cadmium (Coombs, 1980). Also in mollusks, copper uptake by *Mytilusedulis* has been disturbed and reduced by the presence of cadmium and zinc (Davenport and Manley, 1978). On the other hand, the toxic behavior of individual pollutant may differ when mixed with other pollutants. The mixture of pollutants may become highly lethal in the receiving water (Synergistic effect between metals) (Konar and Mullick. 1993; Clark *et al.,* 1997).

Clark *et al.* (1997) in his experiment on the resistance of fiddler crab *Ucapugilator* to Cd, noticed that a combination of low salinity (10‰) and high temperature (30 ^oC) reduces the LC_{50} for Cd to only 2-3 ppm. In other words we can say that a synergistic effect can be also noted in organisms exposed to natural environmental stress as well as to toxins.

In addition to all factors mentioned above, Coombs (1980) stated that there are many other factors that can affect the heavy metal uptake by the aquatic organisms such as the metal's chemical form which may affect the rate of the metal uptake due to the increase or decrease of its hydrophobicity (e.g. Selenium is taken up much faster as selenite than as selenate) and the metal complex formation may affect the rates of the metal uptake and its toxicity.

2.2.2. Terms and processes affecting the heavy metal uptake

In addition to all the previous factors mentioned above some terms and processes should be understood as they play important role in process of the heavy metal uptake. These processes are:

- **Bioavailability**

Bioavailability refers to the element or compound availability for assimilation by an organism. As expressed by Kennish (1992), many different biological (microbial degradation), physical (currents and tidal exchange) and chemical (dissolution, redox reactions and sorption-desorption of compounds) processes determine and influence this bioavailability. The author also reported that the chemical processes can alter the chemical form of contaminants.

US-EPA (2000) found that the bioavailability of sediment contaminants is controlled by several factors. Such as:

Physical factors: sediments are dynamic environments with a wide range of interacting processes with variable rates. The rate of mixing in surficial sediment layers by physical processes such as turbulence and bioturbation competes with the rate of sedimentation to determine the depth to which contaminated sediment will be buried. Diffusion and re-suspension can also have a large impact on the bioavailability by increasing the aqueous concentration of a contaminant via desorption from the particulates within the water column.

Chemical Factors: the characteristics of chemicals, such as its molecular size and polarity, have an effect on bioavailability as they determine to a large extent the association degree of the chemical with particles. Small, ionic species such as certain metals have high aqueous solubility and tend to be more bioavailable. Even between these extremes, chemical characteristics of contaminants have a large influence on the bioavailability. The concentration of total metals in sediment is generally not predictive on the bioavailability of these metals.

Biological Factors: bioaccumulation is a function of the bioavailability of contaminants in combination with species-specific uptake and elimination processes. Toxicity is determined by the exposure of an animal to bioavailable contaminants together with the animal’s sensitivity to the contaminant. These processes have been shown to be a function of the organism's lipid content, size, growth rate, gender, diet, and ability to metabolize or transform a given contaminant, as well as the chemical conditions of the surrounding medium. Other biological factors that can affect contaminant bioavailability include the burrowing and feeding behavior of the individual organism or species. The depth to which an organism burrows and the type of feeding mechanism it uses (e.g., filter feeding, particle ingestion), all have a large influence on the concentration of contaminant to which the organism will be exposed.

In addition to these processes mentioned above, the dietary and behavioral habits of an individual species can also affect this bioavailability (Phillips and Rainbow, 1988).

- **Bioaccumulation**

It refers to the accumulation or the increase in concentration of a substance; in certain tissues of organisms' bodies due to absorption from food and the environment; to concentrations greater than that found in its environment. Metal concentrations in aquatic organisms depend on its uptake/excretion balance in addition to its bioavailability (Rainbow *et al.,* 1990; Ying *et al.,* 1993). Presing *et al.* (1993) illustrated that the heavy metals are not equally accumulated in different organs of the body.

- **Bio-magnification**[2]

It refers to the progressive increase in concentration of an element or compound within organisms forming a food chain. Pathological symptoms may arise when a critical concentration is reached in the tissues. Although heavy metals bio-accumulate in individuals, they have been shown to seldom bio-magnify up the food chain (Bryan and Langston, 1992).

Despite the lack of evidence of bio-magnification of most metals, consumption of food containing high levels of one or more heavy metals is potentially harmful in those species with low detoxification abilities to a particular metal. Even in species with detoxification abilities, the constant demand for detoxification may create a stress upon the individual and ultimately the population.

2.3. Toxicity

Rand and Petrocelli (1985) defined toxicity of a chemical view as its potential harmful effect on a living organism. Contaminant speciation and its effect on bioavailability are critical to understand ecotoxicology (US-EPA, 2001). Clarke *et al.* (1981) mentioned that it is doubtful whether the term "toxic dose" has any real meaning as it is affected by so many different factors. Of such factors, Irwin *et al.* (1997) mentioned the environmental conditions, seasonal variations, nutrition and age (young animals are considerably more sensitive than old ones).However, Bryan (1976), summarized the factors influencing the toxicity of trace metals in water in Table (1).

[2] It occurs across trophic (food chain) levels while bio-concentration and bioaccumulation occur within an organism.

The surface activity of metals depends strongly on water pH, hardness, and complexation capacity. Regarding water hardness, its main effect is toxicity reduction due to competition for surface ligands between hardness metals and trace metals. Therefore, calcium and magnesium act as effective protectors (degree of protection varies with the metal and the log of the hardness concentration). Small variations in water hardness may have large effects upon metal toxicity (McDonald *et al.*, 1989).

Table 1. Factors influencing the toxicity of heavy metals in aquatic organisms.

Factor	Example
➢ Metal form in the water.	• Inorganic (soluble) • Organic (insoluble)
➢ Presence of other metals or pollutants.	• Antagonism (lesser than additive) • No interaction (additive) • Synergism (more than additive)
➢ Factors influencing either the organism's physiology or the metal form in the water or both.	• Temperature • pH • Dissolved Oxygen • Salinity
➢ Organism's condition	• Life history stage (egg, larva,... etc.) • Life cycle changes (moulting, reproduction) • Age and size • Starvation • Activity • Additional protection (shell) • Metal adaptation
➢ Behavioral response	• Altered behavior

2.4. Tolerance mechanisms

Some studies on metal tolerance showed that some planktonic species found in polluted areas are more tolerant to specific metals than identical species in non-polluted areas (Rand and Petrocelli, 1985). These authors also stated that the tolerance mechanisms are of two types: (i) exclusion from cells, e.g. the release of organic material by algae which can chelate free metal ions from water, and (ii) intracellular changes, e.g. biological oxidation, reduction or hydrolysis of metals into more water soluble or enhancement of excretion.

According to Coombs (1980), there are several processes for excreting and removing the excess unwanted pollutants depending on the organism or the fish itself. Such processes as mentioned by this author are: (i) diffusion or secretion over body surface (e.g. fish skin mucus), (ii) excretion into urine via kidneys, (iii) excretion into fecal matter by the intestine, liver and gall bladder, (iv) excretion through gill surfaces, and finally (v) permanently attach them to substratum.

Populations of organisms chronically exposed to chemical pollutants may develop increased tolerance to those pollutants. Abbas and Shakweer (1998) believed that it is difficult to find a general conception that can commonly describe the relationship between the fish body-length or weight and the trace elements concentrations, in the different organs of their body. Some elements concentrations increase in some cases with the length or weight of fish (e.g. Zn and Cu); while in other cases they decrease (like in Pb). The environmental conditions, the biological characters and the feeding behavior during the larval and adult stages are believed to play an important role that may affect the direction of such relationship either to the positive or negative directions. Concentrations of each metal in various tissues of the same species had no correlation with the size of the fish (Nayak, *et al.*, 1993). Generally, fresh-water species are more sensitive to metals than the marine species; however, this is not true in cases of Cu-poisoning in fish (Lloyd, 1992).

2.5. Detoxification (Detoxication)

It is the metabolic process by which the toxic qualities of a poison or toxin (such as metal contaminants) are removed or reduced by the organisms' body (Abaza, 2004). The metals may be stored in the organisms' skeletal structure or intracellular matrices (Kennish, 1992). In some groups like crustaceans and fishes, Metallothionein proteins bind metal ions and prevent their toxic action. Other invertebrate groups store heavy metals in calcium-containing granules or phosphatic granules (Rainbow, 1997). The release of faeces, eggs, and moulting products removes heavy metals, tends to counter storage effects. The crab *Carcinus minus* loses on the average about 61% of the total zinc with every discarded exoskeleton (Kennish, 1992). Most organisms have regulation and detoxification processes which provide at least partial protection from some toxins (Marjorie, 1999).

3. Impact of Pollution

It is beyond the scope of this article review to document the effect of every single pollutant or waste type that has ever polluted the water body, but it's made to point out the general effect and consequences of pollutants on the fish inhabiting these water bodies.

3.1. Impacts on aquatic habitat

3.1.1. Wastes pollutants

These types of pollutants include domestic, agriculture and solid wastes. All of these pollutants or wastes have deferent degrees of effects on the aquatic media and organisms.

Domestic most often contains organic matter that encourages the growth of microorganisms that spreads diseases and consumes the oxygen present in water. The aquatic organisms like fish cannot then survive in such waters.

A lowered level of dissolved oxygen due to the presence of organic pollution; which is not toxic in itself; may significantly reduce the number of fish reaching the spawning grounds because of fatigue and reduction of swimming velocity (Clark *et al.,* 1997).

The discharges of pesticides, are mainly poisonous to all sorts of aquatic life while the discharges of fertilizers; coming from agriculture waste disposal, domestic sewage and coastal development; ends up in excessive nutrient (nitrogen and phosphates) enrichments leading to an increase in the rate of productivity (i.e. algal bloom) of the aquatic ecosystem. This algal blooming process followed the enormous decay of these algae leading to increased activity by decomposers causing a depletion of the oxygen level is called *eutrophication.*

Certain types of algae are toxic. Overgrowths of these algae result in "harmful algal blooms," which we refer to as "red tides" or "brown tides". Zooplankton may eat the toxic algae and start passing the toxins up the food chain, affecting forage fish, and ultimately working their way up to higher predators and marine mammals. The result can be illness and sometimes death.

This blooming process, mentioned above, increases the water turbidity causing a massive death to the benthic plants leading to oxygen depletion due to bacterial decomposition of OM and consequent suffocation of fish and mollusks that inhabit deeper waters. These blooms are also responsible for consuming much of the oxygen produced. Fortunately, during daylight they usually produce more oxygen than they use, resulting in a surplus for fish and other organisms. At night or in cloudy weather, oxygen production through photosynthesis is totally/partially replaced by oxygen consumption through respiration, often resulting in a deficit in the oxygen "budget". Under certain conditions, the level of oxygen can become critically low and fish may suffocate or at least become stressed to the point of being susceptible to disease (Brunson *et al.,* 1994).

Soil particles due to land erosion, carried out run-off water and suspended matter present in sewage and trade wastes can either stay suspended causing water turbidity or gets deposited on the river bed or behind the weirs and cause silting of the bed.

In 1980, Alabaster and Lloyd found that high levels of water turbidity might affect fish populations in several ways: (i) directly irritates the fish gills causing direct death or smother for the fish inhabiting the area, (ii) decrease the penetration of light into the water which reduce the abundance of phytoplankton (fish feeding) and schooling practices, leading to a survival reduction,(iii) reduce the growth rate of swimming fish, and (iv) destroy the protective mucous covering the eyes and scales of fish, making them more susceptible to infection and disease.

On the other hand, Alabaster and Lloyd (1980) added that the suspended sediments may change the nature of the bottom when it settles down with high concentrations causing what is known as 'siltation'. This siltation in river and reservoirs diminishes: (i) both the quantum and the rate of water flow and (ii) water level, thereby reducing the spawning success (Clark *et al.,* 1997).Alabaster and Lloyd (1980) found that siltation can also suffocate and prevent the successful development of fish eggs and larvae by burying them. They also added that it can dislodge plants, invertebrates, and insects in the stream bed which affects the food source of fish. Heavy siltation also destroy the nesting materials (e.g. Aquatic vegetation) for fishes and cover the gravel structure by silt deposits thereby natural spawning of fish is prevented due to lack of suitable spawning area and increases of egg mortality. This can be serious concerning fishes that require special environment for breeding.

Finally, Sediment particles can carry toxic agricultural and industrial compounds. If these are released in the habitat they can cause abnormalities or death in the fish.

3.1.2. Industrial effluents (chemo-toxicants)

Thousands of chemicals are used in the industrial processes. It's well understood that many of these chemicals have direct adverse effects on aquatic life. High levels of industrial spills in aquatic media; mostly heavy metals (i.e. lead, cadmium, mercury.. etc.) and ammonia are quite harmful or even fatally toxic to fish and other aquatic populations (Abaza, 2004).

The heavy metal contaminants in water and sediment leads to complex ecological responses which are poorly understood (Kennish, 1992). Heavy metals are also considered as one of the most harmful materials, even more than carbon dioxide and radioactive wastes (Jorgensen and Johnson, 1989). They are known to be potentially toxic because of their ability to be concentrated in organisms' organs (Jaleel *et al.,* 1993), thus presenting a direct threat to both aquatic biota and man (Bryan, 1976).

3.1.3. Water temperature changes

As mentioned earlier, both thermal pollution and global warming can cause this type of changes which in turn affect both the aquatic habitats and the organisms inhabiting them.

Temperature is the most pervasive factor in the lives of fish. No study of fish ecology would be meaningful without considering thermal relationships (Coutant, 1976). Laws (2000) found that it is not hard to imagine some of the ways in which thermal effluents might adversely affect the aquatic biota. The author summarized the sub-lethal stress of this effluents on water biota in the following points: (i) causing dramatic change in the dissolved oxygen (DO) levels of the ambient water either through decreasing the ability of the aquatic system to hold DO supply (10% increase in temp reduces the oxygen solubility by about 20%) or increasing the respiratory demand of aquatic organisms, (ii) increases the biological demand of aquatic organisms for oxygen(iii) increases the metabolic rate of aquatic biota leading to fewer resources which in turn lower the aquatic biodiversity in the area, and (iv) increases plant growth rates which can cause an algae bloom leading to more decline of DO levels. In addition to these three effects, thermal pollution may also stirs up harmful substances such as copper, dioxin, mercury and PCBs which may harm aquatic animals like fish, amphibians and copepods (Selna, 2009). The sudden rise in water temperature known as 'thermal shock' can adversely affect the natural mortality as well as reproduction of fish and other organisms adapted to particular temperature range.

One of the main threats of 'Global warming' in terms of water pollution is the water temperature raising. This temperature raising will have varying, mainly negative, effects on the aquatic biota because each of them has its own limits to the temperature range in which it can exist.

Like the thermal pollution, global warming are expected to affect both fresh and marine water bodies but in a wider scale. These effects are: (i) declining water quantity and quality, (ii) current aquatic species may be replaced by those that favour warmer waters, (iii) changing both ocean currents and wind patterns which in turn changes the distribution patterns and decline and loss of some marine species, (iv) increasing of water acidity which in turn affects calcareous organisms, and (v) more frequent algal blooms (CSIRO, 2006; US-EPA, 2009).

Alabaster and Lloyd (1980) mentioned that changes in some biological parameters of fish communities (such as gonad development, spawning time growth of both adult and juveniles) have been observed in waters affected by heated effluents. In 1979, Kokurewicz also observed that there are relatively narrow temperature ranges (defer from one species to another) within which fish spawning succeed. The author added that this range difference indicates some adjustment of fish gonad development to the temperature regimes. In other words a change in water temperature regime can affect the gonadal cycle.

3.1.4. Ocean acidification

The two main factors leading to the pH level fluctuation in the aquatic bodies are: (i) acid rains, and (ii) global warming. The acid effluents from run off and some industrial drains can be considered as an additional source for water acidity in the water environment. These factors and their effect on the water pH levels have several adverse consequences on aquatic ecosystems as well as aquatic species.

Acid deposition is of concern because it can make lakes, and streams or even the oceans more acidic, which can harm individual fish or completely eliminate fish, and other aquatic species from the water, of the affected areas, which in turn reduce both species population and biodiversity (Alabaster and Lloyd, 1980; US-EPA, 2008 b; c). This harmful impact could be attributed to the effect of pH levels on the heavy metals availability; either in particulate or dissolved form; as well as their toxicity degree on aquatic organisms including fish (Abaza, 2004; Abaza *et al.*, 2009). In addition, these authors in their studies to one of the Egyptian lakes found that low pH together with increased dissolved heavy metals levels may cause stress that may not kill individual fish, but leads to lower body weight and smaller size (Abaza, 2004; 2008).

As previously mentioned, the increase in atmospheric CO_2 levels which in turn increase its level in the ocean waters causes the increase of the ocean acidity level (Fernand and Brewer, 2008).This will adversely affect organisms with shells, which may dissolve or become malformed if the pH drops low enough (MPA-NEWS, 2009; Sarah *et al.*, 2009).

Acidification (low pH and high CO_2) can affect fish directly through their physiology and depletion of calcifying species. It can also affect it indirectly through ecosystem effects such as: (i) absorption of CO_2 forms carbonic acid and lowers CO_3 ions causing coral damages (affecting both feeding and reproduction of reef-species), and (ii) depletion of food sources which in turn counts on both the availability of alternative prey species and the predator ability to switch to these alternatives (Sarah *et al.*, 2009). Both the author and MPA-NEWS (2009) found that in some fish species, CO_2 accumulation and lower pH in animals' body could result in "Acidosis" (build-up of carbonic acid in the body fluids). This acidosis would lead to lowered immunity, metabolic depression and asphyxiation.

Concerning the lethal effect of pH levels on aquatic organisms, Alabaster and Lloyd (1980), Fernand and Brewer (2008) mentioned various factors such as (i) free CO_2 in the water (ii) total hardness of water (fish tolerates more in hard waters), (iii) fish age (older fish tolerate more), (iv) time of the year (fish tolerate more in the winter than they do in summer), and (v) fish tolerance and acclimation (some species tolerate acidic waters while others are acid-sensitive and will be lost as the pH declines). Table (2) shows the impact of deferent pH values on fish.

In addition to all previously mentioned impacts of water pH level, Abaza (2004 and 2009) mentioned that the change of water pH values can also modify the toxicity of other poisons that might be already exist particularly those which dissociate into ionized and un-ionized fraction of which one is toxic.

Table 2. Effect of deferent pH ranges on fish.

pH range	Effect
3.0 – 3.5	Unlikely that any fish can survive for more than few hours in this range.
3.5 – 4.0	This range is lethal to salmonids[3]. Roach[4], tench[5], prech and pike fish can survive in this range (after a period of acclimation to slightly higher non-lethal ranges.
4.0 – 4.5	Likely to be harmful to salmonids, tench, bream, roach, pike, goldfish and common carp (which have not previously been acclimated to low pH values) but only pike may be able to breed.
4.5 – 5.0	Likely to be harmful to the eggs and fry of salmonids, and adults partically in soft waters (low in Ca, Na and chloride). Can be harmful for common carp.
5.0 – 6.0	Unlikely to be harmful to any species unless either the free CO_2 levels is >20mg/L or in the presence of $Fe(OH)_3$. The lower end of this range may be harmful to non-acclimated salmonids in soft or cold waters.
6.0 – 6.5	Unlikely to be harmful to fish unless free CO2 is >100mg/L.
6.5 – 9.0	Harmless to fish, but other poisons toxicity may be affected by changes within this pH range.
9.0 – 9.5	Likely to be harmful to salmonids and perch if present for a considerable time period.
9.5 – 10.0	Lethal to salmonids over a prolonged time period, but can be tolerated for short period. May be harmful to developmental stages of some species.
10.0 – 10.5	Can be tolerated by roach and salmonids for short time but lethal over a prolonged time period.
10.5 – 11.0	This range is rapidly lethal to salmonids but only prolonged exposure to its upper limit is lethal to carp, tench, goldfish and pike.
11.0 – 11.5	Rapidly lethal to all fish species.

Cited from: Alabaster and Lloyd (1980).

3.1.5. Oil spillage

Exposure to petroleum derivatives can alter the ecology of the aquatic habitats. When oil leaks into the water it floats on the water surface and prevent the atmospheric oxygen from mixing with the water. This can harmfully affect the ecosystem and its components as it can annihilate many animals in case they ingest a contaminated prey. It may also coat the body of the aquatic animals and birds which may also kill them. Oil and antifreeze makes the water have a foul odor and there is a sticky film on the surface of water that kills the aquatic animals.

In areas oil exploitation (oil rigs and refineries), the common reason for the discarding of catches is the tainting of the fish by unpleasant odors and tastes caused by petroleum derivatives, even at low concentrations.

3.2. Impact on food chain

Industrial wastes (acids, oils, heavy metals and other chemicals) have a direct effect on aquatic life. Many of these wastes can directly kill fish if they: (i) sufficiently change the water pH, (ii) cover the surface causing a reduction in dissolved oxygen, or (iii) are modified to toxic forms. A more subtle effect results if: (i) the contaminant dosage is sub-lethal to the fish but eliminates their food supply by poisoning the algae or herbivores, and(ii) the prey species is contaminated so that it is not accepted by the predator. On the other hand, if predator species is eliminated by pollution the pray species may have an improved chance of survival.

Some chemicals are accumulated biologically as they pass through the food chain. Herbivores consuming the algae accumulate these contaminants in their bodies, which in turn are concentrated to even higher levels in fish. The seriousness of biological magnification varies with different chemicals. Most frequently the influence is indirect, often resulting in a decreased population size, either by decreasing reproductive success or by influencing body functions, making the fish a less successful predator (Benndorf, 1992).

Organisms at the bottom of the food chain absorb the chemicals from the water and accumulate it in the tissues. Animals at the second trophic level, such as fish, feeding on these organisms receive a higher dose, and further accumulation takes place in their tissues and so on. Thus, organisms at the top of the food chain receive much higher level of the contaminant than present in the water. This concentration of the toxic chemicals through the food chain is called 'bio-magnification (Abaza, 2004).

3.3. Impact on fish biology

3.3.1. Impact of pollution in general

Al-Kahtani (2009) mentioned that pollutants enter the fish body through five main routes: via food or non-food particles, gills, oral consumption of water, and the skin. Then it is carried in blood to the liver to be stored there or excreted in bile or transported to other excretory organs such as gills or kidneys for

[3] Fish that spend most of their life at the sea before they return to the rivers only to reproduce.
[4] They are members of the carp and minnow family (Cyprinidae).
[5] It normally inhabits slow-moving fresh and brackish water habitats, particularly lakes and lowland rivers.

elimination (Heath, 1991; Nussev *et al.* 2000). The concentration of any pollutant in any given tissue therefore depends on its rate of absorption and the dynamic processes associated with its elimination by the fish.

Acidification has some direct and indirect impacts on fish and fisheries. The direct effects on fish may be relatively limited and will be equivalent to the effects of thermal and oxygen stress outlined earlier (Fernand and Brewer, 2008). Fish early life stages (eggs and larvae) are more sensitive to pH levels than adults (Ishimatsu *et al.,* 2004).Goodwin *et al.* (2006) found the natural mortality at these early stages of broadcast-spawning species to be typically great and highly variable.

The indirect effects of acidification on fish are likely to be more relevant than direct ones but yet harder to quantify. Acidification may change the structure and productivity of both primary and secondary benthic production which may indirectly affect the productivity of higher trophic levels including fish communities. Thus food sources might change which may result in shifts in species distribution, species abundance, or diet shifts. The possible effects of acidification on the timing of appearance, abundance, and quality of larval fish prey sources, such as phyto and zooplankton, remain unknown (Edwards and Richardson, 2004).

From the foregoing talk, one can say that the natural water bodies have been subjected to an indiscriminate ingress of many types of pollutants like industrial effluents (chemo toxicants), domestic sewage, oil spillage, waste coolant waters, and solid wastes. Such ingress are believed to be adversely affecting many aspects of fish biology and activities. Such aspects are: the migration, behavior, many physiological processes, life cycle, incidence of disease, nutrition, food chain and genetic make-up (Kennish, 1992). He also added that the continued exposure of organisms to elevated levels of metal pollutants often yields unfavorable pathological responses.

- **Migration**

Beside the normal migration pattern; in some cases; sub-lethal levels of pollutants (i.e. chemo-toxicants) as well as heavy siltation and flow of the coolant water masses play an important role in the fish migration mechanism thereby change the composition of population or species diversity (Alabaster and Lloyd, 1980). The author also attributed the exclusion of Salmon, trout and many other anadromous[6] fishes from their home streams to their offensive reaction to pollutants particularly chemo-toxicants. Heimstra and Damkot (1969) found that some fish select clear waters as turbid conditions reduces their activity behaviors.

Fish may fall to reach either their spawning or feeding areas, because they avoid polluted waters or perhaps because pollutants interfere with their chemical sense and they are not able to recognize their home waters.

- **Incidence of diseases**

In most cases organic pollutants are not directly toxic to adult fish. However, environment polluted with this type of pollutant is suitable for the development of bacteria and viruses. Thus, prolonged exposure to sub-lethal levels of this type of pollutants may cause the fish to be more susceptible to diseases.

- **Physiological processes**

Pollutants might affect several physiological processes of the fish without being lethal, which may interfere with the survival of a species. Thermal pollution for example remarkably increase the respiration rate when the fish is subjected to it while the toxic substances, suspended matter and ammonia (NH_3) have adverse effect on respiration as they injure the mucous membrane and damage the epithelium of the gills (Laws, 2000). Heavy metals particularly mercury inhibit the activities of digestive enzymes in addition to damage the nervous system of the organism (Alabaster and Lloyd, 1980).

- **Life cycle**

The larval stage of fish species is sensitive to pollution than the adults. In many aquatic species millions of eggs are produced and fertilized but their pre-adult mortalities rate is enormous even under the best of natural conditions. Interrupting any stage of the life cycle can be as disastrous for the population as death of the adults from acute toxicity of the environment.

3.3.2. Impact of heavy metals pollution in particular

It is beyond the scope of this article to document the effect of every single metal that has ever polluted the water body, but it's easy enough to point out some general effects and consequences on fish inhabiting it.

Many factors play important roles in metal poisoning of fish; generally the greater the hardness, alkalinity, salinity, pH, presence of complexing materials (e.g. Humic acids and organic material) and fish size, the more resistant fish are to heavy metals. Moreover elevated thermal levels increase fish sensitivity to some metals like Zn (Sorensen, 1991; Wren *et al.,* 1995).

Several trace metal ions are co-factors in enzyme systems of the aquatic organisms such as fish (Morel *et al.* 1994), and are able to block the catalytic site of Metallo-enzymes (Sunda and Huntsman 1992; 1995). Now it is accepted that the fundamental interaction of most metal ions with cell membranes and

[6] Fish born in fresh water, spends most of its life in the sea and returns to fresh water to spawn.

metalloenzymes, is controlled by free aquo-metal-cation concentration (Morel *et al.* 1991).

Trace metals can be classified into (i) essential trace metals (identifiable as serving a beneficial biological function), and (ii) non-essential trace metals (not identifiable as serving a beneficial biological function). However, the concept of essentiality is under constant review as research makes progress (Förstner and Wittmann, 1981).

- **Essential trace metals (e.g. Cu and Zn)**

A metal in trace amounts is essential when an organism fails to grow or complete its life cycle in the absence of that metal. However the same trace metal is toxic when the concentration levels exceed those required for correct nutritional response (Venugopal and Luckey, 1975). Essential trace metals (serving a beneficial biological function) such as Cu and Zn become toxic when the nutritional supply becomes excessive.

- ***Copper***

Minute amounts of Cu are essential in the diet for many organisms (serving as enzyme activators) (Leland and Kuwabara, 1985). Short-term copper deficiencies or excess may be regulated by a variety of organisms, thus minimizing its potential toxic effects (Rand and Petrocelli, 1985). Although Cu is an essential dietary element (serving as enzyme activators) for many organisms, elevated concentrations of copper in water can be toxic to fish and organisms (US-EPA, 1980).

In aquatic environment, Cu interacts with other common urban contaminants such as ammonia, Cd, Hg, and Zn forming more toxic effect on fish (Irwin *et al.*, 1997). Some researchers believe that negative effects of copper on fish are more likely the result of toxicity of high concentrations in water than toxicity from intake of prey containing copper (US-EPA, l980).

Some harmful effects reported for freshwater fish, after being exposed to Cu:

i. Irwin *et al.* (1997) while studying the freshwater fish *Clarias batrachus*, reported an increase in the protein content of the liver, kidney, stomach, intestine, testis, and ovary, and a decrease in the muscle after Cu treatment. The administration of Cu increased the free amino acids levels in all the fish organs. After these treatments a decrease in dry weight and an increase in tissue permeability were recorded in all the organs studied.
ii. Rand and Petrocelli (1985) reported that as Cu accumulated in the liver of the rainbow trout, the number of lysosomes increased, interruptions in the plasma membrane and an increased number of necrotic cells occurred.
iii. Iger *et al.* (1994) examined the skin of carp, *Cyprinus carpio* after exposure to 100 mg Cu/L for different periods, up to 43 days. During the first week, the skin surface were highly undulating and the merkel cells were depleted of their secretory vesicles (recovered afterwards). In the dermis, fibroblasts became more active in the synthesis and secretion of collagen. The pigment in the melanocytes was broke up in the first weeks, but this reversed towards the end of the experiment. These changes reflect the sensitivity of the skin of fish to waterborne copper. They are comparable to the effects of stressors such as cadmium, lead, or acid water.

- ***Zinc***

In addition to its physiological function, zinc is essential for normal cell growth, fecundity, enzymes & enzymatic functions, protein synthesis and carbohydrate metabolism but in the same time it can be harmful in excess to either fish or plants (Rand and Petrocelli, 1985). Little more amounts of Zn in the diet may lead to poor health, reproductive problems, and lowered ability to resist disease while too much Zn can be more harmful to health (Agency for Toxic Substances and Disease Registry, 1992).

Mostafa (1994) mentioned that many effects have been reported on fish after long term exposure to zinc such as: (i) skeletal calcium deposition reduction, (ii) mineral uptake and growth reduction, and (iii) teratogenicity in the embryo-larval stage. Both the movement pattern and the feeding habit of the fish species changes with the deferent levels of Zn (Sorensen, 1991).

- **Non-Essential Trace Metals (e.g. Cd & Pb)**
- ***Cadmium***

Accumulation and distribution of Cd in fish tissues depends on the exposure route (food and water vector). Wren *et al.* (1995) found that in fish, Cd accumulates in the gill, liver, and kidney (Wren *et al.*, 1995). Reproductive problems occur in fish when tissue concentrations exceed 0.1 μg/g (Rompala*et al.*, 1984).

Some harmful effects reported for freshwater fish, after being exposed to Cd:

i. Cd has several effects on *Clarias batrachus*, biochemical parameters such as: the protein content in the liver, kidney, stomach, intestine, testis, and ovary increase as well as the amino acids levels in all organs while it decreases in the muscle (Irwin *et al.*, 1997).
ii. Decrease in plasma calcium levels in the freshwater teleost *Oreochromis mossambicus* (Family: Cichlidae) follows exposure at 0.01 mg/L (Fu *et al.* 1989) (sub acute effect).
iii. Decrease in growth of the freshwater *Ophiocephalus punctatus* (Family: Channidae), following 13 days of exposure at 3.5 mg/L (Shukla and Pandoy, l988) (sub-acute effect).
iv. Long-term exposure (126+ days) to cadmium reduced growth and survival of brook trout (Family: Salmonidae) at 3.4 μg/L and 3.8 μg/L, respectively (Wren *et al.*, 1995).

o *Lead*

All Pb compounds are potentially harmful, very toxic to aquatic organisms especially fish as it can lead to excess mucous formation which can coat the gills and impact respiration (Rompala *et al.*, 1984).

Some harmful effects reported for freshwater fish, after being exposed to Pb:

i. Lead has adverse effect on the survival, growth, reproductive behavior and overall reproductive success for some fish species like fathead minnows (*Pimephales promelas*). It decreases the number of eggs oviposited, increases inter-spawn periods and suppressed embryonic development (Weber, 1993).

ii. Sub-lethal effects of lead are characterized by neurological defects, kidney dysfunction and anemia (Rand and Petrocelli, 1985).

Studies pertaining to the toxicity of trace metals follow the general trend that an undersupply leads to a deficiency, sufficient supply results in optimum conditions, while an oversupply results in toxic effects and lethality at the end. Thus it is of interest to note that all trace metals (essential and nonessential) are toxic when supplied in concentrations in excess of the optimum concentration levels (Figure 2) (Förstner and Wittmann, 1981).

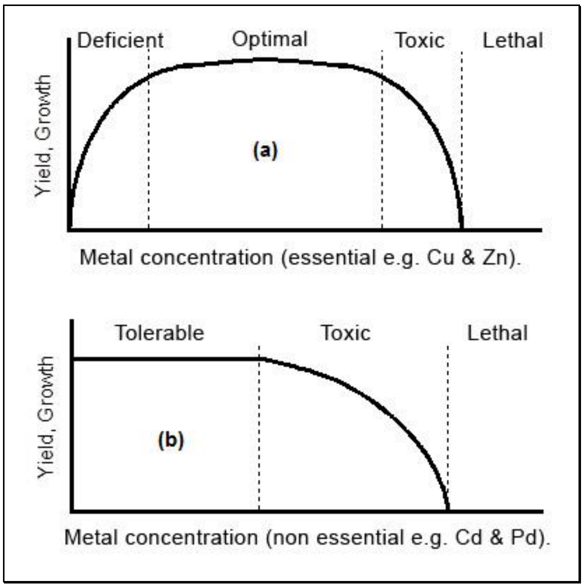

Figure 2. Deficiency and oversupply of essential and nonessential trace metals.

3.4. Impact on fishing operations

Fishing operations may be adversely affected by various types of pollutants. Fishing nets are frequently clogged due to the presence of many pollutant types in the area. In areas of excessive fertilization (eutrophication), nets get clogged by masses planktons (blue-green algae) while in areas of oil exploitation (oil rigs and refineries), the net clogging is from both crude oil and tar lumps.

The numerous objects on sea bed like wrecked cars and other junks often disturb fishing operations; like trawling; by mechanical damage to nets and boats.

It is clear, that for many pollutants, no single level can be put forward as the critical line between safe and harmful which is universally applicable for all aquatic situations. Many factors have to be taken in account when attempting to formulate criteria for safe levels. Such factors are the metal type, level and toxicity as well as differences between the susceptibility of the various fish species and presence of other pollutants (Abaza *et al.*, 2009).

4. Mitigating Measures For Improving Some of the Present Aquatic Condition

It is known that economic, political and/or social realities may overrule the wisest plans for biological or habitat management especially in inland waters. Hence, the challenge facing policy makers is to facilitate economic and social developments, while limiting accumulation of contaminants, preventing decline of the habitats and protecting their biota. From the foregoing words, one can realize that the prevailing conditions of many aquatic areas (mainly inland waters)needs some mitigation measures in order to be improve their environment which in turn will improve their suitability for the fishes inhabiting them.

Several mitigating measures were proposed to improve the polluted aquatic habitat worldwide. These measures can be implemented either as separate and/or as combined package. However, one should keep in mind that some of these measures are impossible to implement or may be costly enough to prevent developing counties from applying them.

Such measures that can be implemented are:

✓ **Enforce existing environmental protection laws**

✓ **Increasing public awareness**

✓ **Reducing nutrient and pesticide pollution**

- Encourage smart agricultural practices by using techniques like biodynamic farming, settling ponds, and buffer zones can help keep polluted runoff from entering streams.
- Prevent further destruction wetlands, and reestablish them wherever possible because coastal wetlands filter pollutants from runoff and flows.

✓ **Reducing sewage pollution**

- Fixing outdated municipal water treatment plants.
- Setting up programs that ensure septic system maintenance and monitoring.

✓ **Reducing chemical pollution (chemo-toxicants)**

- Re-establishing the "polluter pays" principle. Taxpayers should not pay the bill for decades of industry abuses.

- Eliminating all remaining industrial waste-water discharges to streams, enforcing a "zero emissions" policy for the waste water from the deferent factories.
- Activating the international treaties on persistent organic pollutants.
- Adopting the precautionary steps. Synthetic chemicals should be considered toxic unless it can be proved otherwise.
- Upgrading water treatment plants with the most technology possible so that they can filter out chemicals.
- Continuing the debate to stop emissions of acid-rain chemicals (sulfur and nitrogen) and gases (CO_2) that not only damage forests but also acidify water bodies especially inland water bodies.

✓ **Reducing petro-pollution (oil)**

- Tightening regulations governing maintenance and inspections of commercial ships, oil rigs and oil refineries.

✓ **Reducing coastal development and runoff pollution**

- Preserving undeveloped land as it help in soaking up rains and filtering water before it enters the water bodies.
- Constructing wetlands, stream buffer zones, and settlement pond as well as stopping the deforestation to allow contaminated runoff to undergo natural biological remediation before entering the nearby water bodies.

✓ **Miscellaneous solutions to water pollution**

- All countries should pass laws to prevent cruise ships from dumping untreated sewage and oily bilge water into coastal waters.
- Increasing the use of clean energy generators like solar energy, wind power, wave/tide energy, and other clean technologies that don't use freshwater resources.
- Better enforcement is needed to ensure that builders use proper mitigation actions, such as regular near-site road cleaning.

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