

ENVIRONMENTAL PROTECTION OF WATER RESOURCES FROM POLLUTANTS. A REVIEW

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Abstract

This paper is a review of environmental protection of water resources from pollutants and includes eight chapters: introduction, types of water resources, pollutants, biodegradation, environmental protection, effect of climate and environmental changes, conserving water resources and conclusion. Each chapter is separated. Water resources occupy a special place among other natural resources. Water is the most widely distributed on our planet: albeit in different amounts, it is available everywhere and plays a vital role in both the environment and human life. Of most importance is fresh water. Human life itself is impossible without it because it can be substituted by nothing else. Pollution of the environment has been one of the largest concerns to science and the general public in the last years. Biodegradation can be used to remove or to transform pollutants found in the environment, dissolved in natural bodies of water, into harmless compounds. To avoid further water problems and lessen projected harsh outcomes for the future we must conserve water and energy, and protect land and biological resources that are vital for a sustainable economy and environment.

Keywords: water resources, pollutants, biodegradation, effect of climate

1. INTRODUCTION

Human beings have always consumed fresh water and used the various natural surface water bodies for a whole range of purposes. According to Shiklomanov 1998 [1], for many hundreds of years man's impact on water resources was insignificant and entirely of a local character. The magnificent properties of natural water - their renovation during the water cycle and their ability for selfpurification - allowed a state of relative purity, quantity and quality of fresh water to be retained for a long time. The situation has changed drastically during recent decades. In many parts of the world the unfavorable results of man's long-term – often unreasonable - activities, have now been discovered. This concerns both the direct use of water resources and also the surface transformations that have taken place in many river catchments.

Water is a renewable resource, but its availability is variable and limited [2]. Nearly every country in the world experiences water shortages during certain times of the year [3], and more than 80 countries now suffer from serious water shortages [4]. Factors such as rainfall, temperature, evaporation, and runoff determine water availability. Clean water resources per capita are declining rapidly as the needs of the growing population increase [5]. Population growth not only reduces water availability per person but stresses the entire environmental system.

Major difficulties exist in allocating the world's scarce fresh water resources. These problems exist between and within countries, between industries and between individual communities. Consider that agriculture alone consumes 87% of the fresh water withdrawn in the world [6]. Water shortages can be expected to severely reduce biodiversity in both aquatic and terrestrial ecosystems.

Clearly, the availability and quality of fresh water is a major international problem. Water shortages already affect many countries and the problem continues to grow. Limited water resources, inefficient water use, and a rapidly growing world population will further stress the world's finite fresh water supply. Water is vital to maintaining the world's food supply. More than 99% of the world's food comes from the terrestrial ecosystem supplied with fresh water. It takes more than 1,000 kilograms of water to produce one kilogram of food.

Worldwide, most human activities adversely affect the quality of fresh water resources. Chemical and pathogen pollution of water especially limits the use of fresh water. Equally important, about 90% of all illnesses in developing countries result from waterborne diseases.

2. WATER RESOURCES

With growing concerns for sustainable development world over, planners of natural resources are focusing their attention on vulnerability arising from availability and use of water resources. Past studies of water resource vulnerability have either been too aggregate, or have focused on one single dimension of these issues. The study by Surendra 1998 [7] presents a comprehensive analysis of global (using national scope) water resource-based vulnerability (WRV) using a joint criteria of water availability and its relative use. Vulnerability status for each country was assessed for the present (1990) situation, as well as for the year 2025. Four factors were taken into account to determine the nature of the WRV for a country: population growth, food self-sufficiency, industrial development, and climate change. World population growth, which is projected to increase to 8.45 billion people by the year 2025, by itself would trigger 40% of the population residing in countries facing some degree of WRV. Combined with food self-sufficiency, industrial growth, and climate change, by the year 2025, some 5.1 billion (60% of the total world population) would live in regions potentially experiencing moderate to extreme WRV. The study suggests that the regions that are at great risk are those already facing some degree of WRV; the climate change would most likely accentuate the already worsening situation in many regions, while improve it in regions that are not projected to be vulnerable.

World water resources are passing through a stage of transition. This transition is, perhaps, an aftermath of rapid economic development process, coupled with other human activities in various parts of the world. According to Rodda 1995 [8] ‘a world water crisis seems likely to emerge during the 21st century as demand for water is rising at a faster rate’. An obvious question that needs answering is ‘what regions of the globe are more likely to face such a crisis situation?’ Effective management of water resources for any region demands a certain degree of foresight – to anticipate how regional water resources are going to change in the future under anticipated anthropogenic changes and as a result of attaining the aspirations of various nations for economic development. Armed with this knowledge, policy makers can then decide on realistic development goals, as well as devise measures to mitigate adverse impacts on the society resulting from the predicted threats from water resources.

Vulnerability of a region resulting from water resources availability and use (referred to, in the subsequent discussion, as ‘water resource-based vulnerability’ – WRV) has been a topic of several past studies. In most of these studies, however, the major emphasis has been on the supply of water, usually expressed on a per capita basis. In several of these studies, secondary data on water supply were used, obtained mostly from the same source of primary data. For example, estimates of world water supply on a country and continental basis have been made by L’vovich 1979 [9], and by Shiklomanov and Markova 1987 [10]. Using these data, several authors, such as [11], [12], [13], [14], have described the global water situation. Special case studies for Europe and Africa have also been reported by Falkenmark 1989 [15] and by Brouwer and Falkenmark 1989 [16]. Some of these studies have been carried out on a continental scale, with the result that many of the unique spatial features of distribution of water are not taken into consideration. Even in the studies that are based on more disaggregated data, the emphasis has primarily been on the effect of population in determining WRV. Although population levels are a major determinant of a water resource-based vulnerable situation, some consideration of other factors affecting WRV needs to be investigated. This suggests the need for a fresh look at global water resources.

Shiklomanov 1998 [1] describes two types water resources – municipal and industrial:

Municipal water resources

Municipal water use is directly related to the quantity of water withdrawn by populations in cities, towns, housing estates, domestic and public service enterprises. The public supply also includes water for industry that provides directly for the needs of urban populations and this demand also consumes high quality water from the city water supply system. In many cities, a considerable quantity of water is used in market gardening and for watering vegetable gardens and domestic garden plots.

The volume of public water use depends on the size of an urban population and the services and utilities provided, such as the extent of pipe networks for supply and sewerage, or centralized hot-water supply where available. Also, much depends on climate conditions. In many large cities, present water withdrawal amounts to 300-600 liters per day per person.

The modern trend in the development of public water supply all over the world is the construction in both large and small cities of effective centralized water supply and sewerage systems, connecting together an even greater number of buildings and populated areas. In the future, however, the specific per capita water withdrawal is expected to increase, while water consumption per se, expressed as a percentage of water intake, will decrease considerably.

Industrial water resources

Water in industry is used for cooling, transportation and washing, as a solvent, and also sometimes entering the composition of the finished product. Thermal and atomic power generation lead the list of major users. It requires a great amount of water to cool assemblies. The volumes of industrial water withdrawal are quite different within individual branches of industry and also within different kinds of production, depending on the technology of the manufacturing process.

Again, it depends on climatic conditions since, as a rule, industrial water withdrawal seems to be considerably less in northern than in southern regions where higher air temperatures prevail.

In addition to thermal power, the other principal industrial water users are chemical and petroleum plants, ferrous and non-ferrous metallurgy, the wood pulp and paper industry [17, 18], and machinery manufacture. The major characteristics of industrial water use – the volume of fresh water withdrawal, water consumption, water diversion - depend to a very large extent on the water supply system in use. The development of industrial water withdrawal is one the main causes of water pollution in the world. This is explained by the rapid industrial growth in different countries and exacerbated by the fact that much of the intake is discharged as waste water to natural water courses, for the most part untreated or only partially purified. To struggle with such pollution problems, many countries have undertaken energetic measures to decrease industrial water withdrawals and discharges.

3. POLLUTANTS

Nowadays, the industrialized world is confronted with the contamination of soils, water sources and air with hazardous and toxic xenobiotics. While regulatory steps have been implemented to reduce or eliminate the production and release to the environment of these chemicals, significant environmental contamination has occurred in the past and will probably continue to occur in the future. The industrialization of agriculture, rapid growth in the chemical industry and the need to generate cheap forms of energy has all caused the continuous release of very organic chemicals into the biosphere.

Emerging pollutants reach the environment from various anthropogenic sources and are distributed throughout environmental matrices [19]. Although great advances have been made in the detection and analysis of trace pollutants during recent decades, due to the continued development and refinement of specific techniques, a wide array of undetected contaminants of emerging environmental concern need to be identified and quantified in various environmental components and biological tissues. These pollutants may be mobile and persistent in air, water, soil, sediments and ecological receptors even at low concentrations. Robust data on their fate and behavior in the environment, as well as on threats to

ecological and human health, are still lacking. Moreover, the ecotoxicological significance of some emerging micropollutants remains largely unknown, because satisfactory data to determine their risk often do not exist.

The paper by Gavrilesco et al. 2015 [19] discusses the fate, behavior, (bio)monitoring, environmental and health risks associated with emerging chemical (pharmaceuticals, endocrine disruptors, hormones, toxins, among others) and biological (bacteria, viruses) micropollutants in soils, sediments, groundwater, industrial and municipal wastewater, aquaculture effluents, and freshwater and marine ecosystems, and highlights new horizons for their (bio)removal. Our study aims to demonstrate the imperative need to boost research and innovation for new and cost-effective treatment technologies, in line with the uptake, mode of action and consequences of each emerging contaminant. They also address the topic of innovative tools for the evaluation of the effects of toxicity on human health and for the prediction of microbial availability and degradation in the environment.

Many chemical and microbial agents that were not traditionally considered contaminants can be found in various environmental compartments and/or in areas where they were never used, mainly due to their persistence during long distance transport. The sources and pathways of these emerging contaminants can be increasingly associated with the waste and wastewater resulting from industrial, agricultural or municipal activities [20]. Because of their particular characteristics, these pollutants require changes in the conventional approach to pollution prevention and control, although they result from similar domestic, commercial and industrial activities, as conventional contaminants [21]. Chemical micropollutants are often generated through degradation of organic compounds resulting in accumulation of persistent metabolites [22] or from the disposal of products such as pharmaceuticals in the natural environment. The increased appearance of biological pollutants during the production and distribution of drinking water may be related to several factors including changes in human demographic behavior. Also, changes in agricultural practice towards intensive farming and spreading of manure or sludge on agricultural fields may cause leaching to surface and groundwater and health problems [23, 24]. Pesticides continue to be detected in surface and groundwater, although some of them have gradually been banned and replaced by environmentally friendly substitutes [25, 26]. Currently, research interest is directed toward pesticide metabolites, often detected in water sources and wastewater effluents at higher concentrations, being also biologically active and toxic [27, 28]. Consequently, there is high interest in some categories of environmental contaminants, with particular chemical structures and properties, which interfere with endogenous hormone systems. These contaminants, denoted endocrine disruptors, are poorly inventoried and regulated and insufficient information exists regarding their occurrence, fate and impact in the environment. Also, because many have pharmaceutical, personal care and household uses (hormones, glucocorticoids, analgesics such as ibuprofen, estriol, additives in drugs and cosmetics such as siloxanes and parabens, and household cleansers), more information about their ecotoxicological effects is essential for their analysis and removal. Apart from the above endocrine disruptors, other products such as fire-retardants, heavy metals (cadmium, lead or mercury), widely used industrial chemicals (Bisphenol A) and some pesticides have been shown to impact natural endocrine systems [29, 30, 31, 32]. Consequently, endocrine disruptors and their degradation intermediates constitute a topic of extensive research [29, 30]. Pertinent studies indicate that toxicity data are not yet available for these compounds, which originate from various sources, among which the most relevant are direct releases into water, wastewater treatment plants (WWTPs) (effluent and sludge), seepage from septic tanks, landfilling areas and surface water run-off [33]. Pharmaceuticals, for example, are more concentrated in the wastewater discharged from hospitals, long-term care facilities and other medical facilities [34, 35, 36].

Although studies and reviews can be found in the literature on sources, occurrence, environmental behavior and fate of emerging contaminants [25-27, 37, 38], the pathway of these pollutants from sources to receptors continues to be an essential subject for advanced research. This is because information is still poor, mainly due to the problems generated by the physico-chemical properties of target compounds, and the complexity of environmental characteristics, among others, which may determine an unexpected behavior of the emerging pollutants in air, water, or soil [25, 29, 31, 37]. To illustrate this situation, a schematic view of the routes by which some emerging pollutants enter

various receptors (groundwater, surface water, consumers) was provided by Stuart et al. 2012 [25] (Fig. 1).

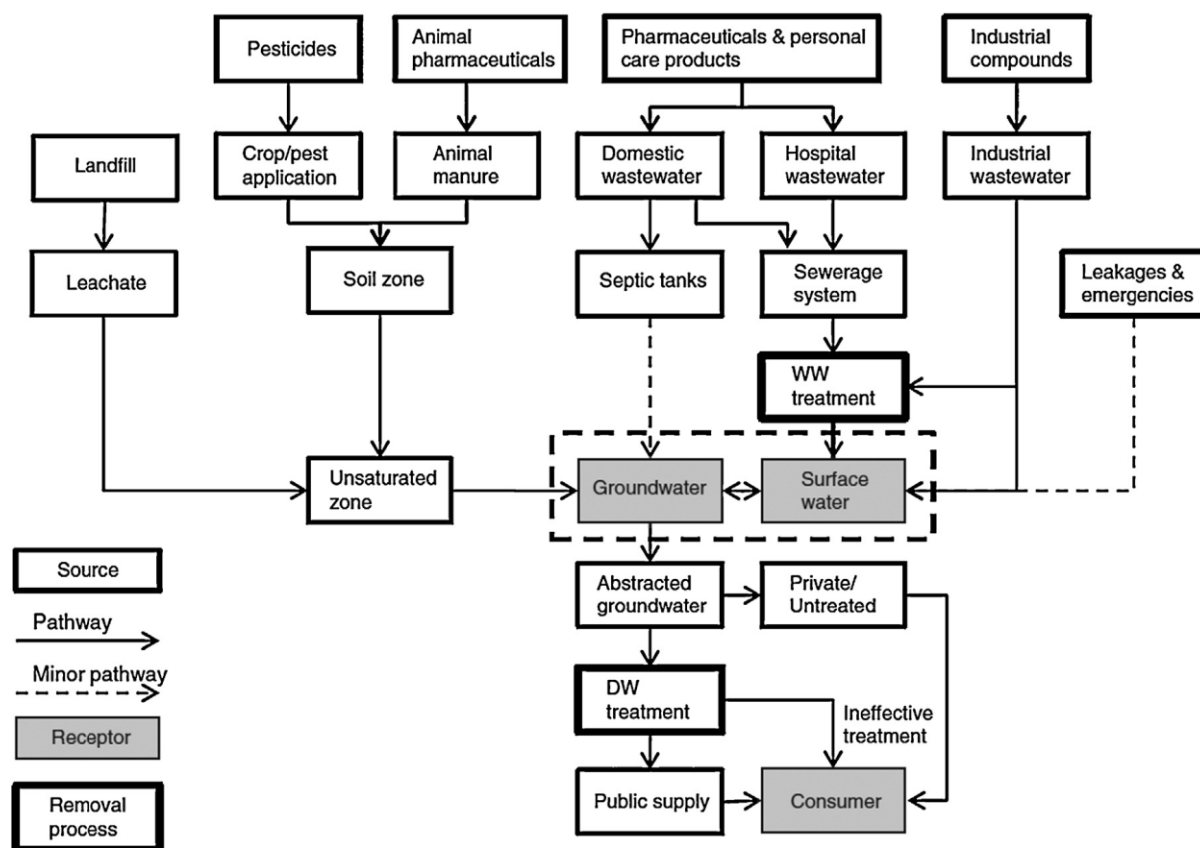


Figure 1. Schematic pathways of some emerging pollutants from sources to receptors [25]

Other studies have been carried out on the pathways of EP, in particular from humans and animals to environmental components [25, 37, 39, 40].

Heavy metals consist less than one percent of living mass organisms, and their different density cause to some disorders. Surface water and also acidic rains can transfer these metals to oceans via washing polluted environment. Heavy metals naturally exist in very little amount in watery places. Metals pollution of the sea is less than other types of watery pollution but its effects on marine ecosystems and humans are very extensive [41]. Industrial wastes in aquaculture cause toxic effects in aquatic organisms specially in fishes. Aquatic organisms absorb the pollutants directly from water and indirectly from food chains. Some of the toxic effects of heavy metals on fishes and aquatic invertebrates are; reduction of the developmental growth, increase of developmental anomalies, reduction of fishes survival - especially at the beginning of exogenous feeding or even cause extinction of entire fishes population in polluted reservoirs. These consequences can affect on geological, hydrological and finally on biological cycles. Thus it seems that more consideration of bioconservation protocol is so important.

Every pollution in the aquatic environment which impacts physiology, development, growth or survival of fish, affects human that, at the top of the food chain, consume fish [41]. The accumulation of heavy metals in the tissues of organisms can result in chronic illness and cause potential damage to the population. Aquatic animals have often been used in bioassays to monitor water quality of effluent and surface water. The development of biological monitoring techniques based on fish offers the possibility of checking water pollution with fast responses on low concentrations of direct acting

toxicants. Development of chemical and biological methods for effectively monitoring environmental levels of heavy metals is a subject of interest and a critical step in development of environmental waste management [42].

A relative homeostatic environment is essential for the survival of organisms in ecosystem. This necessitates the study of the chemical composition of air, water, and soil in order to monitor any abnormal changes due to industrial progression and consequent advancement of society [43].

Water is one of the most valuable natural resources. The quality of water is of vital concern for the mankind since it is directly link with human welfare [44]. A major environmental concern due to dispersal of industrial and urban wastes generated by human activities is the contamination of soil and water. Controlled and uncontrolled disposal of waste, accidental and process spillage, mining and smelting of metalliferous ores, sewage sludge application to agricultural soils are responsible for transferring of contaminants into non-contaminated sites as dust or leachate and contribute towards contamination of our ecosystem [45]. A wide range of inorganic and organic compounds cause contamination, includes heavy metals, combustible and putrescible substances, hazardous wastes, explosives and petroleum products, Phenol and textile dyes. Major component of inorganic contaminates are heavy metals. They have some different problems than organic contaminants [45, 46, 47]. Fish accumulate substantial concentrations of mercury in their tissues and thus can represent a major dietary source of this element for humans. Fish are the single largest sources of mercury and arsenic for man. Mercury is a known human toxicant and the first sources of mercury contamination in man are fishes. Biotransformation of mercury and methyl mercury formation constitutes a dangerous problem for human health. Soil microorganisms can degrade organic contaminants, while metals need immobilization or physical removal. Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes disrupting their function. Thus, metals render the land unsuitable for plant growth and destroy the biodiversity [45].

Heavy metals have variously been used to denote: (I) metals with atomic number 23 (i.e. vanadium) onwards except Rb, Y, Cs, Ba, and Fr; (II) metals with density greater than 5; and (III) metals which are toxic to man and other life forms when found in the environment. The eight most common pollutant heavy metals listed by the Environment Protection Agency (EPA) are: As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn [43].

Heavy metals are diluted and affected by various surface water components (carbonate, sulphate, organic compounds, humic, fulvic, amino acids) that formed insoluble salts or complexes. These salts and complexes are predicted to be not harmful to aquatic organisms. Part of them sink and are accumulated in bottom sediments. However, when water pH has declined (during acidic rains or other acidic episodes) heavy metals can be mobilized and released into the water column and become toxic to aquatic biota. In addition, low concentrations of heavy metals can cause a chronic stress which may not kill individual fish, but lead to a lower body weight and smaller size and thus reduce their ability to compete for food and habitat [47].

A great number of industry such as textile, paper and pulp, printing, iron-steel, coke, petroleum, pesticide, paint, solvent, pharmaceuticals, wood preserving chemicals, consume large volumes of water, and organic based chemicals [17]. These chemicals show a great difference in chemical composition, molecular weight, toxicity, etc. Effluents of these industries may also contain undesired quantities of these pollutants and need to be treated. Dyes usually have a synthetic origin and complex aromatic molecular structures which make them more stable and more difficult to biodegrade. Dyes are classified as follows: anionic—direct, acid and reactive dyes; cationic—basic dyes; non-ionic—disperse dyes [48, 49, 50]. The chromophores in anionic and non-ionic dyes are mostly azo groups or anthraquinone types. The reductive cleavage of azo linkages is responsible for the formation of toxic amines in the effluent. Anthraquinone-based dyes are more resistant to degradation due to their fused aromatic structures and thus remain colored for a longer time in the wastewater. Reactive dyes are typically azo-based chromophores combined with different types of reactive groups e.g., vinyl sulfone, chlorotriazine, trichloropyrimidine, difluorochloropyrimidine. They differ from all other classes of dyes in that they bind to the textile fibers such as cotton to through covalent bonds. They are used

extensively in textile industries regarding favorable characteristics of bright color, water-fast, simple application techniques with low energy consumption. Water-soluble reactive and acid dyes are the most problematic, as they tend to pass through conventional treatment systems unaffected. Hence, their removal is also of great importance [51-58]. Basic dyes have high brilliance and intensity of colors and are highly visible even in a very low concentration [59, 49, 50, 60 - 62]. Metal complex dyes are mostly based on chromium, which is carcinogenic [59, 48, 49, 63]. Disperse dyes do not ionize in an aqueous medium and some disperse dyes have also been shown to have a tendency to bioaccumulate [49]. Due to the chemical stability and low biodegradability of these dyes, conventional biological wastewater treatment systems are inefficient in treating dye wastewater. Dye wastewater is usually treated by physical - or chemical-treatment processes. These include chemical coagulation/flocculation, ozonation, oxidation, ion exchange, irradiation, precipitation and adsorption [48-51, 53, 63-73].

According to Aksu 2005 [74], phenols, another group of organic pollutants, are considered as priority pollutants since they are harmful to organisms at low concentrations and many of them have been classified as hazardous pollutants because of their potential to harm human health. It should be noted that the contamination of drinking water by phenolics at even a concentration of 0.005 mg l^{-1} could bring about significant taste and odor problems making it unfit for use. Phenol containing water, when chlorinated during disinfection of water also results in the formation of chlorophenols. The most important pollution sources containing phenols and phenolic compounds such as nitrophenols, chlorophenols, are the wastewater from the iron-steel, coke, petroleum, pesticide, paint, solvent, pharmaceuticals, wood preserving chemicals, and paper and pulp industries [75-78]. Current methods for removing phenolics from wastewater include microbial degradation, adsorption on activated carbon, chemical oxidation (using agents such as ozone, hydrogen peroxide or chlorine dioxide), deep-well injection, incineration, solvent extraction and irradiation. Although biological treatment has shown great promise, a wide variety of pure and mixed cultures of microorganisms are capable of degrading phenol and phenolics under both aerobic and anaerobic conditions and microbial degradation of these compounds is seen as a cost effective method, the biological treatment of phenolics is limited by the intrinsic properties of these compounds owing to their toxicity; they are slow to biodegrade, and the degrading microorganism must be exposed to only low concentrations of the substrates. Therefore, alternative technologies have to be explored [79-87].

Researches have shown that some physical or chemical pretreatment processes can increase the adsorption capacity of biomass. These pretreatment methods mainly included drying, autoclaving, contacting with organic chemicals, such as formaldehyde, or inorganic chemicals, such as NaOH, H_2SO_4 , NaHCO_3 , and CaCl_2 .

Since pH is the most important parameter affecting not only the biosorption capacity, but also the color of the dye solution and the solubility of some dyes, various researchers have investigated the effect of pH on color removal. Hu 1992 [52] demonstrated that the optimal pH for biosorption of 11 reactive dyes by *Aeromonas* sp. cells was at acidic range. Zhou and Banks 1993 [88] reported that the biosorption of humic acid by *R. arrhizus* increased with decreasing pH. They suggested that at lower pH, more of humic acid functional groups were uncharged and humic acid had a lower solubility and was thus more adsorbable. On the other hand, the lower pH results in high concentrations of protons which neutralize the negative charge on both *R. arrhizus* and humic acid, leading to increased adsorption [88].

Aksu and Yener 1998 [89] defined the pH of the sorption medium as the most critic parameter in the treatment of phenol and monochlorinated phenols by the dried activated sludge that affects biosorption capacity. They obtained that phenol and monochlorinated phenols were more effectively adsorbed to the biomass at very low values of pH and they determined the optimum initial pH as 1.0.

As various textile dye effluents are discharged at relatively high temperatures ($50\text{--}60^\circ\text{C}$), so temperature will be an important design parameter affecting the biosorption capacity in the real application of biosorption by biomass in future [49,50]. Zhou and Banks 1993 [88] investigated the effect of temperature on humic acid biosorption by *R. arrhizus*. They observed that low temperature (from 36 to 16°C) caused a high biosorption. Hu 1996 [90] studied the effect of temperature on the

removal of six reactive dyes by three Gram-negative bacteria (*P.luteola*, *E. coli*, and *Aeromonas* sp.) and reported that temperature had slight or no effect on the equilibrium uptake suggesting the feasibility of directly using dead biomass in the dyeing wastewater to absorb dyes without decreasing the temperature of wastewater [90].

Dye concentration also affects the efficiency of color removal. Initial concentration provides an important driving force to overcome all mass transfer resistances of the dye between the aqueous and solid phases. Hence a higher initial concentration of dye may enhance the adsorption process.

The study by Yen et al. 2002 [91] designed to investigate the toxicity of some environmental pollutants to the aquatic organisms *chlorella*, *daphnia*, carp, and tilapia.

The acute lethal toxicity of environment pollutants including chlorophenol, haloalkane, quinone, and substituted nitrobenzene (i.e., nitrophenol, nitrobenzene, nitrotoluene, and aniline) compounds to aquatic organisms was determined. Determination of toxicity of chemicals was performed. The toxicity of chlorophenols had no relation to the number of chlorine atoms on the benzene ring, but monochlorophenol had lower activity than more chlorine-substituted compounds.

Chlorophenol, haloalkane, quinone, and substituted nitrobenzenes such as nitrophenol, nitrobenzene, nitrotoluene, and aniline compounds are undoubtedly the most toxic chemicals dispersed in environments. Chlorophenol formulations have been used in many ways for more than 50 years. Because of their versatility and long history as major industrial chemicals, chlorinated phenols have been detected in soil, sediments, and natural water [92] as well as in food and human urine [93, 94]. The sorption of haloalkane and chlorobenzene compounds in soil humic acid [95] and the partition equilibrium of chlorobenzene compounds between soil organic matter and water have been investigated [96]. Thiboldeaux et al. 1994 [97] examined the effect of 1,4-naphthoquinone on *Actias luna* survival and found that late-instar *A. luna* are resistant to several related 1,4-naphthoquinones. Study of the toxicity of chlorinated phenols to duckweed revealed that the toxicity of chlorinated phenols increases with increasing numbers of chlorine substitutions on the phenol ring [98]. The correlation between octanol-water partition coefficients and water solubility for aromatic compounds such as substituted benzene, aniline, and biphenyl has also been studied [99]. In a study of residues of pesticides in irrigation and drainage of paddy water, it was found that these residues posed a threat to carp [100]. Many studies have reported accumulation and/or LC₅₀ values of pesticides in aquatic organisms [101, 102, 103, 104, 105, 106] and acute toxicity of industrial pollutants to organisms [107, 108, 109].

In the paper by Henk et al. 1992 [110], a scheme is presented that makes it possible to classify a large number of organic pollutants into one of four classes, viz: (1) inert chemicals, (2) less inert chemicals, (3) reactive chemicals and (4) specifically acting chemicals.

It is widely recognized that knowledge on the emissions, environmental fate and acute and chronic toxicity of pollutants is a basic need in environmental risk assessment. The environmental fate of a chemical comprises its partitioning between water and suspended solids, partitioning and uptake into biota (bioconcentration), adsorption to sediments, volatilization from water and degradation, both biotic and abiotic. Quantitative knowledge of emissions during the life cycle of a chemical, as well as of its environmental fate enables us to model the concentrations of a certain pollutant in the different compartments of the environment (environmental exposure assessment).

The aim of the work presented here is to define a number of distinctive classes of chemicals that can either be assigned a mode of action, or that can otherwise be assigned a quantitative relationship between the structure of those chemicals falling in it and their acute aquatic toxicity. Based on work by Hermens 1989 [111] four classes of chemicals are defined. These four classes are:

1. Inert chemicals are chemicals that are not reactive when considering overall acute effects, and that do not interact with specific receptors in an organism. The mode of action of such compounds in acute aquatic toxicity is called narcosis. Narcosis type toxicity is considered to be brought about by an absolutely nonspecific mode of action, in that the potency of a chemical to induce narcosis is entirely dependent on its hydrophobicity.

2. Less inert chemicals are chemicals that are not reactive when considering overall acute effects, but are slightly more toxic than baseline toxicity. These chemicals are often characterized as compounds acting by a so-called "polar narcosis" mechanism [112]. Without elaborating on the physiological distinction between nonpolar (inert) and polar narcosis, we can still state that it is possible to identify structural requirements for these chemicals. These chemicals are usually characterized as possessing hydrogen bond donor acidity, e.g. phenols & anilines [113].
3. Reactive chemicals. Despite the fact that reactive chemicals can have all kind of different modes of action, we use the notion of chemical reactivity only to identify chemicals with enhanced toxicity as compared to baseline toxicity. This enhanced toxicity is related to the phenomenon that these chemicals react unselectively with certain chemical structures commonly found in biomolecules (e.g. epoxides, which react with sulfhydryl groups of cysteine residues of peptides), or chemicals that are metabolized into more toxic species [114, 115]. This last effect is called bioactivation.
4. Specifically acting chemicals form a diverse set of chemicals that exhibit toxicity due to specific interaction with certain receptor molecules, such as organic phosphorus esters, which inhibit acetylcholinesterase, or DDT, which interacts with sodium channel regulating receptors in neurons (specific or receptor toxicity); see Ariens 1986 [116].

In addition to this, it should be noted that in environmental aquatic hazard assessment, one rarely has to deal with a single, isolated toxicant [117, 118, 119, 120]. The normal situation is that of a body of water being contaminated with a number of compounds, some of which may not even be detectable at the levels of contamination. Many of these compounds will either be inert chemicals, or will be more specifically acting chemicals, but at levels at which they do not yet display any specific activity. This is because compounds with a more specific mode of action will generally possess dose-effect curves that are not linear but show, a.o., a threshold concentration.

4. BIODEGRADATION

In modern society, an increasing number of hazardous organic compounds are being discharged into the environment. Most are degraded or detoxified by physical, chemical and biological treatments before released into the environment. Although the biological treatments are a removal process for some organic compounds, their products of biodegradation may also be hazardous. Moreover, some nondegradable compounds discharged into the environment along with the treated compounds can cause problems because they usually come back to humanbeings through the several channels such as bioaccumulation. As a result, organic molecules that are not biodegradable, can still be removed from the wastewater by the microbial biomass via the process of biosorption. Biosorption is also becoming a promising alternative to replace or supplement the present removal processes of organic pollutants from wastewater. Among these pollutants, dyes, phenolics and pesticides have recently been of great concern because of the extreme toxicity and/or persistency in the environment. Biosorption of these type of hazardous organics by selected live and dead microorganisms has been investigated by various workers. The review [74] examines a wide variety of microorganisms (fungi, yeasts, bacteria, etc.), which are capable of uptake of organic pollutants, discusses various mechanisms involved in biosorption, discusses the effects of various parameters such as pH, temperature, concentrations of organic pollutant, other ions, and biomass in solution, pretreatment method, etc.

Although a number of aerobic biological processes for the removal of dyes from textile effluents have been explored, such as decolourization through liquid fermentations by white-rot fungi (among these microorganisms *Phanerochaete chrysosporium*, *Trametes versicolor*, *Coriolus versicolor* biotransformed or mineralized several azo dyes through catalytic action of extracellular enzymes, such as lignin peroxidases and manganese dependent peroxidase) and bacterial cultures (such as *Pseudomonas* strains, mixed bacterial cultures, *Bacillus subtilis*), yeasts (such as *Kluyveromyces marxianus*, *Candida zeylanoides*), biochemical oxidation suffers from significant limitations since more dyestuffs found in the commercial market have been intentionally designed to be resistant to

aerobic microbial degradation. Kostadinova et al. 2018 [121] have been investigated the antioxidant enzyme activity in the white-rot fungus *trametes trogii*.

In the paper Bulai and Venturino 2016 [122] introduce a non-linear model for the biodegradation of organic pollutants in a water body. They assume that the pollutants are removed using fungi that need nutrients and dissolved oxygen to thrive.

Finding abundant drinkable water is becoming a major issue in this century. In this respect, discovering cheap ways of purifying water is fundamental for addressing and helping to solve this problem. To achieve this goal it can be accomplished by the use of chemical, physical or biological entities, such as microorganisms, fungi and green plants, through the enzymes that they produce. For instance, bacteria and fungi could help with the pollutant oxydation, because many species can produce oxygenases and peroxydases that degrade organic pollutants [123]. Biodegradation can especially be employed in the treatment of wastewater and some mathematical models are known [124, 125].

In the last few decades, highly toxic organic compounds have been synthesized and released into the environment for direct or indirect application over a long period of time. Fuels, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides and dyes are some of these types of compound [126, 127-129].

Microorganisms have the ability to interact, both chemically and physically, with these substances, leading either to changes in their structure or to the complete degradation of the target molecule.

Organic matters and organo-phosphorus pesticides have relatively high water solubility and low acute toxicity. The degradation process of organic matter can be performed either aerobically or anaerobically. In aerobic biodegradation oxygen is needed by degradable organisms in two metabolic stages, initially to attack the substrate and at the end of the respiratory chain. The biodegradation rates of many organic pollutants are known.

The dissolved oxygen concentration is a measure of the healthy state of an aquatic ecosystem. This concentration can be enhanced by re-aeration from the atmosphere, photosyntetic oxygen production from aquatic plants, denitrification and external oxygen inputs. In general, oxygen is used by animals, bacteria, fungi and plants to digest nutrients by breaking down organic matter and sugars. Dissolved oxygen is essential for life in water bodies, as aquatic organisms use it to breathe: fish through their gills, while water plants need it for respiration. But too high or too low a level may harm aquatic life and degrade water quality.

Microbes as well as bacteria and fungi at the bottom of the water body decompose organic material using dissolved oxygen, thereby substantially contributing to the recycling of nutrients. But stratification, i.e. an excess of decaying organic material with no or infrequent turnover, depletes dissolved oxygen. In such case anaerobic decomposition takes over, with the release of hydrogen sulfide and methan, both obnoxious gases.

Bioremediation is a process by which living organisms degrade or transform hazardous organic contaminants to less toxic compounds [130]. Microorganisms in the indigenous environment have been known to play key roles in the biodegradation of organic compounds. Unlike prokaryotes, eukaryotic fungi have shown diverse metabolic potential resulting in metabolites similar to those produced from mammalian metabolism. These metabolic properties may help us to directly elucidate the metabolic fates of organic compounds occurring in mammalian liver cells instead of using mammalian microsomal fractions or live organisms. Fungal metabolism also provides an easy preparative method for the production of metabolites in large quantity.

Biocatalysis has been demonstrated to be a powerful tool for the pollutants degradation, which is a priority for scientists in the current industrialized world.

Chemical methods have several disadvantages in the degradation of pollutants because they usually use contaminant catalysts and their use in large-scale contaminated field sites is difficult. On the other hand, biocatalytic reactions can be carried out at ambient temperature and atmospheric pressure, under

safety, health, environmental, and economical conditions. In this regard, fungi have been shown to possess a variety of catabolic activities that can be harnessed to transform contaminants in less toxic compounds for the environment.

Most of the research on fungal bioremediation has been conducted on laboratory scale and conditions, so further work is required to study these capacities taking into account the natural variables and their applicability in large-scale contaminated fields. In addition, the screening of new fungal strains with interesting enzymatic activities is necessary for the degradation of the new pollutants from the increasing industry contamination. This microorganism screening, in combination with current biotechnologies such as genetic engineering, will pave the way to the future use of fungal whole cells and enzymes for bioremediation.

The use of fungi as a method of bioremediation provides an option to clean up environmental pollutants [131]. Bioremediation using fungi has drawn little attention in the past two decades since most bioremediation research has focused mainly on the use of bacteria. Nevertheless, recently fungi have received considerable attention for their bioremediation potential which is attributed to the enzymes they produce. In addition, fungi have advantages over bacteria such as fungal hyphae that can penetrate contaminated soil to reach the pollutants [132].

The revolutionized development of resources and technologies has produced more chemicals and compounds which have consequently increased the number of compounds identified as being potential environmental threats to living organisms. Pharmaceuticals and personal care products (PPCPs), surfactants, various industrial additives and numerous chemicals are purported to be pollutants. These pose challenges to the designers of future treatment plants and related methodology for their eradication [133].

Aromatic Hydrocarbons

The biodegradation of aromatic hydrocarbons by fungi has traditionally been considered to be of a cometabolic nature. Recently, however, an increasing number of fungi isolated from air biofilters exposed to hydrocarbon-polluted gas streams have been shown to assimilate volatile aromatic hydrocarbons as the sole source of carbon and energy. The biosystematics, ecology, and metabolism of such fungi were reviewed, based in part on the re-evaluation of a collection of published hydrocarbon-degrading isolates obtained from authors around the world [134]. For example, the degradation performance of benzene, toluene, styrene and xylene by fungi was widely studied [135, 136].

Aliphatic Hydrocarbons

Fungi can also degrade *n*-alkanes such as tridecane, tetradecane, pentadecane, hexadecane, heptadecane, octadecane (C13-C18) and crude Omani oil. Biodegradation by the fungi *Aspergillus niger*, *A. ochraceus*, *Trichoderma asperellum* strain TUB F-1067 (SA4), *T. asperellum* strain Tr48 (SA5), *T. asperellum* strain TUB F-756 (SA6), *Penicillium* species (P1), and *Aspergillus* species (P9) was studied [137].

Cyanide Compounds

Organic and inorganic cyanide compounds are widely distributed on the planet and they are among the most common corrosive pollutants. The degradation of simple cyanides has also been demonstrated in fungi [138, 139]. A fungal mutant of *Trichoderma koningii*, TkA8, constructed by restriction enzymemediated integration, was shown to have a high cyanide degradation ability [140].

Metals

Soil contamination by toxic metals has become a serious problem, because of their long-term persistence and their diffusion into underground water. Heavy metal and non-degradable chemical contamination of soil and water is a major environmental threat. In recent years, worldwide researchers are investigating new sustainable methods to mitigate such environmental contamination, such as biodegradation by fungi.

The common filamentous fungi can absorb heavy metals (Zn, Cd, Pb, Fe, Ni, Ag, Th, Ra & U) from aqueous solutions. The availability of a variety of fungi with different characteristics and metal binding potential makes it an economical and sustainable option for the removal and recovery of heavy metals [141].

Lignin and Cellulose Degradation

Cellulose is the main polymeric component of the plant cell wall, the most abundant polysaccharide on Earth, and an important renewable resource. Basidiomycetous fungi are among its most potent degraders because many species grow on dead wood or litter which are rich in cellulose. For the degradation of cellulose, basidiomycetes utilize a set of hydrolytic enzymes typically composed of endoglucanase, cellobiohydrolase and β -glycosidase [142, 143, 144].

Polymers

The increasing consumption of plastics has generated environmental problems because it takes more than a hundred years for a discarded polymer to degrade. The ideal plastic should present desirable industrial properties and be degradable within a satisfactory time period [145]. The biodegradation ability of fungi is being investigated for polymers and plastics [146]. One example is the biodegradation of plasticized polyvinyl chloride (pPVC) by *Penicillium janthinellum* and *Doratomyces* spp. in grassland soil. The incorporation of biocides into pPVC was also studied affecting both fungal growth and the richness of species isolated [147].

Biodegradation is increasingly being considered as a less expensive alternative to physical and chemical means of decomposing organic pollutants. Pathways of biodegradation have been characterized for a number of heterotrophic microorganisms, mostly soil isolates, some of which have been used for remediation of water. Because cyanobacteria are photoautotrophic and some can fix atmospheric nitrogen, their use for bioremediation of surface water would circumvent the need to supply biodegradative heterotrophs with organic nutrients. The paper by Kuritz and Wolk 1995 [148] demonstrates that two filamentous cyanobacteria have a natural ability to degrade a highly chlorinated aliphatic pesticide, lindane (g-hexachlorocyclohexane); presents quantitative evidence that this ability can be enhanced by genetic engineering; and provides qualitative evidence that those two strains can be genetically engineered to degrade another chlorinated pollutant, 4-chlorobenzoate.

Cyanobacteria, free-living photoautotrophic microorganisms, can derive energy from sunlight and carbon from the air [149, 150]. Some cyanobacteria are also able to fix atmospheric nitrogen [149, 150] and are therefore especially inexpensive to maintain. Filamentous cyanobacteria, including nitrogen-fixing strains that combine aerobic metabolism in their vegetative cells with anaerobic metabolism in their differentiated cells called heterocysts [151], are widespread in many ecosystems, including polluted ones [152, 153, 154]. The viability and metabolic activity of these cyanobacteria, unlike those of heterotrophic microorganisms, are not subject to reduction by the decrease in the concentration of the pollutants that they may break down. Cyanobacteria have been shown to degrade both naturally occurring aromatic hydrocarbons [155-157, 158, 159] and xenobiotics [160]. The paper [150] presents evidence of a natural ability of cyanobacteria to degrade lindane. This is also the first report that cyanobacteria can be genetically engineered to enhance their degradation of organic pollutants.

Many bacteria can denitrify [161], and some can couple denitrification to biodegradation [162]. Nitrate supports the anaerobic biodegradation of halogenated aromatics by *Pseudomonas* sp. [163], and anaerobic catabolism of phthalic acid was described for a *Bacillus* sp. that respire nitrate both aerobically and anaerobically [164]. Although heterocysts provide microaerobic sites in O_2 -producing cyanobacteria [151], the presence of nitrate blocks the formation of heterocysts by the *Anabaena* sp. and by *N. ellipsosporum*, so that low- pO_2 sites for metabolism are presumably absent during continuous illumination.

Halophilic and halotolerant microorganisms are able to thrive and grow in saline and hypersaline environment. These microorganisms are being the object of basic studies in relation to the origin of

life in our planet and the molecular mechanisms of adaptation to saline and hypersaline conditions [165].

Petroleum Hydrocarbons

Petroleum hydrocarbons are the origin of important pollution in almost all types of ecosystems. Atmosphere, soils, superficial and underground water, and marine environment have been continuously affected by pollution produced during the extraction, refining, transport and use of petroleum. There is a significant amount of literature concerning hydrocarbon biodegradation by marine microorganisms, starting by the classical reviews, such as Atlas and Bartha 1972 [166] and Colwell 1977 [167], or more recent reviews [168, 169, 170, 171]. However, information on hydrocarbon degradation in the presence of high salt concentrations is scarce. As mentioned above, hydrocarbon biodegradation in the presence of high salt concentrations is important because the bioremediation of oil polluted salt marshes and treatment of industrial wastewater.

Several studies were performed using microbial consortia because they generally show higher degradation performance than axenic cultures [172]. Unfortunately, most microbial consortia are not characterized in terms of their biodegradation capacity, as in the case of an oilbearing stratum that showed oxidation of petroleum hydrocarbons at salinities higher than 15% NaCl and in which the presence of extreme halophilic archaea was detected [173].

Aromatic Compounds

Aromatic Acids: This category includes compounds that contain both an aromatic ring and a COOH group. Aromatic acids are abundant in the biosphere originated by natural and anthropogenic activities, and some of them are pollutants. The 4-hydroxybenzoic, ferulic, *p* - coumaric, vanillic, cinnamic, and syringic acids are naturally present in plants and plant root exudates. Aromatic acids may also enter the environment due to their use as raw materials for the production of agrochemicals, pharmaceuticals, varnishes and other specialty materials. In addition, they can also indirectly enter the environment as intermediates during the biodegradation of natural polymers (lignins and tannins), from aromatic amino acid precursors and as intermediates during the biodegradation of pollutants such as pesticides or PAHs.

Phenols and Phenolic Compounds.

Phenols are major pollutants of industrial wastewater since they are commonly used in many industries such as oil refining, coke conversion, pharmaceutical and resin manufacturing plants. Biodegradation of phenol in hypersaline wastewater was reported by Woolard and Irvine 1994, 1995 [174, 175]. Alva and Peyton 2003 [176] reported phenol and catechol biodegradation by the haloalkaliphile bacterium *Halomonas campisalis*.

Benzene, Toluene, Ethylbenzene, Xylenes (BTEX).

BTEX compounds are partially soluble in water and can contaminate soils and aquifers. These compounds can be found in the environment after oil and oil derivatives (gasoline, solvents) spills or released from oilfield wastewater. Benzene is a well-known carcinogenic compound which makes it a priority pollutant. Little is known concerning the degradation of BTEX by halophilic and halotolerant bacteria. The biodegradation of benzene by an enrichment culture developed from an oil-brine soil sample in the presence of 145 g/l of NaCl was recently reported [177].

Halogenated Hydrocarbons

Halogenated hydrocarbons cover a wide group of aliphatic and aromatic compounds in which one (or more) of the hydrogen atoms is substituted by a halogen group (chlorine, fluorine, bromine or iodine). These compounds are used for industrial, petrochemical, food industry, and agricultural applications. Halogenated hydrocarbons are of environmental concern because of their persistence and toxicity, some of them are thought to cause damage to the ozone layer and have been forbidden by most countries. In particular, chlorinated hydrocarbons are widely used because of their chemical and thermal stability as well as their fungicidal, herbicidal and insecticidal properties.

Organic Solvents

Trichloroethylene (TCE) is a chlorinated hydrocarbon commonly used as an industrial solvent. Fuse 1998 [178] reported the use of a halophilic methane-oxidizing bacterium *Methylobacterium* sp. strain NI to oxidize TCE in a medium with a salt concentration of 2–6 % (w/v). Such bacteria could be useful for the bioremediation of TCE contamination in seawater or ecosystems containing salt concentration close to seawater.

5. ENVIRONMENTAL PROTECTION

Water is essential for maintaining an adequate food supply and a productive environment for the human population and for other animals, plants and microbes worldwide. As human populations and economies grow, global freshwater demand has been increasing rapidly [179, 180, 181, 182, 183, 184]. In addition to threatening the human food supply, water shortages severely reduce biodiversity in both aquatic and terrestrial ecosystems, while water pollution facilitates the spread of serious human diseases and diminishes water quality [185, 186].

Although water is considered a renewable resource because it is replenished by rainfall, its availability is finite in terms of the amount available per unit of time in any one region.

Water from different resources is withdrawn both for use and for consumption in diverse human activities. The term *use* refers to all human activities for which some of the withdrawn water is returned for reuse (e.g., cooking water, wash water and wastewater). In contrast, *consumption* means that the withdrawn water is nonrecoverable. For example, evapotranspiration of water from plants is released into the atmosphere and is considered nonrecoverable [187].

Increases in pollution of surface and groundwater resources not only pose a threat to public and environmental health but also contribute to the high costs of water treatment, thus further limiting the availability of water for use.

Closely associated with the overall availability of water resources is the problem of water pollution and human diseases. At present, approximately 20% of the world's population lacks safe drinking water, and nearly half the world population lacks adequate sanitation [188, 189]. This problem is acute in many developing countries, which discharge an estimated 95% of their untreated urban sewage directly into surface water [186].

Various avenues exist to minimize the effects of the current water crisis in some regions of the world and the more widespread problems that will threaten the world in the future. Active management of existing water resources and a reduction in population growth in water-scarce areas are needed to minimize the effects of the water crisis. National boundaries do not effect water systems. Cooperation and commitment of local, national, and international governments, institutions, and other organizations are needed to manage water systems [190]. Development in each country must entail conscientious and effective balancing of unavoidable manipulations of the land and the unavoidable environmental impacts of those manipulations. The conditions of environmental sustainability must include protection of land productivity, ground water potability and biodiversity. Humans must deal with these factors either by adopting methods to protect natural systems or by correcting existing damage and reducing future problems. They need to understand the demographic forces in each country so they can balance society's rising needs for clean water with the finite amount of water available. Factors affecting future needs at all levels include rapid rural-urban migration, high fertility and changing patterns of international population movement. Given an increased awareness of global water systems, demographic trends, and active management of resources, the fragile balance between population and water can be maintained.

6. EFFECTS OF CLIMATE AND ENVIRONMENTAL CHANGE

Estimates of water resources and their future availability can only be based on present world climate patterns. The continued loss of forests and other vegetation and the accumulation of carbon dioxide, methane gas, and nitrous oxide in the atmosphere are projected to lead to global climate change. Over time, such changes may alter precipitation and temperature patterns throughout the world [191, 192]. With major shifts in water availability, future agriculture, forestry, biodiversity, and diverse human activities will be affected.

The paper by Arnell 1999 [193] describes an assessment of the implications of climate change for global hydrological regimes and water resources. Global warming, due to the enhanced greenhouse effect, is likely to have significant effects on the hydrological cycle [194]. The hydrological cycle will be intensified, with more evaporation and more precipitation, but the extra precipitation will be unequally distributed around the globe. Some parts of the world may see significant reductions in precipitation, or major alterations in the timing of wet and dry seasons. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) warned that global warming would lead to increases in both floods and droughts. Many aspects of the environment, economy and society are dependent upon water resources, and changes in the hydrological resource base have the potential to severely impact upon environmental quality, economic development and social well-being. There have, so far, been few assessments [195] at the global scale of the potential impacts of climate change on water resources. Climate change, however, is just one of the pressures facing water resources and their management over the next few years and decades [196]. In the most general terms, there are both supply-side and demand-side pressures. The supply-side pressures include climate change (reducing or increasing the amount of water available), but also include environmental degradation, where for example pollution reduces the amount of water available for use. Demand-side pressures include population growth and concentration, leading to increased demands for domestic, industrial and agricultural (particularly irrigation) water, increased environmental demands, and the effects of changes in the way demands for water are managed. Climate change may affect the demand side of the balance as well as the supply side.

The estimates of water resources and their availability are based on present world climate patterns. However, the continued loss of forests and other vegetation and the accumulation of carbon dioxide, methane gas and nitrous oxides in the atmosphere may lead to global warming [197, 198]. If warming occurs, precipitation and temperature patterns are expected to change throughout the world. Because of this, many scientists predict that global warming will adversely affect water resources because of the increased evaporation and changing precipitation patterns. Meeting agricultural and other societal needs for fresh water will become even more difficult. In some regions, however, benefits might accrue. In addition to global warming, however, population growth and activities may influence water resources through environmental changes, such as deforestation, desertification, soil erosion and loss of biodiversity [199, 200, 201, 202]. Water resources are withdrawn for use and consumption in many human activities. The term use implies that some of the withdrawn water is returned for reuse, e.g., cooking water, wash water. In contrast, consumption means that the water is non-recoverable and is not returned to the water resource. In addition to human requirements, large amounts of clean water are needed to maintain biological diversity and the continued productivity of ecosystems. Studies of terrestrial ecosystems demonstrate a strong correlation between species diversity and the amount of rainfall [203, 204, 205].

Water limits exist in many regions of the world even without the effects of a projected global warming. By causing changes in rainfall patterns and more rapid evaporation, global warming will intensify the water crisis in many regions of the earth [197, 198]. Increased water stress, with or without global warming, is projected to have a major impact on agriculture, deforestation, desertification and other environmental aspects in the future [3, 6].

7. CONSERVING WATER RESOURCES

There are several factors [193] influencing the growth of future water resource use:

- Population growth: an increase in population means greater demand for water.
- Population concentration: population, particularly in developing countries, is becoming increasingly concentrated in large cities. This has two implications. First, water use is different in an urban environment than in a rural environment. For example, water will be supplied through a pipe network, so more is used than in rural areas, and water is lost through leakage. Second, the increasing concentration of demand means greater pressure on resources in specific areas.
- Industrial change: industrial development increases the demand for water, but industrial restructuring may reduce it (as in large parts of Europe). As water is seen as more of an economic good, it will be used more efficiently in industry.
- Expansion of irrigation: the growth in irrigated areas will lead to more usage by agriculture, but this may be offset to a certain extent by improvements in irrigation efficiency.
- Water use efficiency and demand management: more generally, increased water use efficiency and demand management measures will bring down domestic, municipal and service industry demands, particularly in western countries.
- Environmental requirements: increasing demands for environmental protection will put additional constraints on water resource use. These demands are currently not included in estimates of resource use.

Over the next few years, an increasing population and increasing use of water will put increasing pressure on global water resources: pressures will increase most rapidly in Africa and parts of southern Asia. In the absence of climate change, around 5 billion people by 2025 will be living in countries using more than 20% of their water resources.

Another indicator of the effect of climate change on water resource stress is the difference between the number of people in stressed countries (using, for example, more than 20% of their resources in the absence of climate change) with an increase in stress minus the number of people in stressed countries with a decrease in stress, plus the number of people in countries which become stressed due to climate change.

Conserving the world's water must become a priority for individuals, communities, and countries. An important approach is to find ways to facilitate the percolation of rainfall into the soil instead of allowing it to run off into streams and rivers. For example, the increased use of trees and shrubs makes it possible to catch and slow water runoff by 10% to 20%, thereby conserving water before it reaches streams, rivers, and lakes [186]. This approach also reduces flooding.

The critical situation with water supply will require enormous financial and material expense to eliminate the deficit of pure freshwater found under different physiographic conditions. According to Shiklomanov 1998 [1] at the present time and for the foreseeable future, the most realistic and efficient measures will be:

- economy in the use of and protection of water resources by a drastic decrease in specific water consumption, especially in irrigated land use and industry; reduction or complete cessation of waste water discharge into hydrological systems;
- more use made of local water through seasonal and long-term river runoff regulation;
- more use of salt and brackish water; an active influence on precipitation-forming processes;
- use of secular storage in lakes, underground aquifers and glaciers;
- spatial and temporal redistribution of water resources.

All these measures require rather large material expense and have different limitations. Almost all of them exert a pronounced effect on the natural environment which means that they are far from being harmless in terms of ecological consequences. Such consequences could be very significant and difficult to predict, with the exception of waste-water treatment and decreasing specific water withdrawals which are always necessary, desirable and useful for preserving both water resources and the natural environment.

8. CONCLUSION

Ensuring the elimination of emerging contaminants of environmental concern requires future studies and research to develop robust (bio-remediation) processes elaborated on a sustainable basis. The analysis shows that emerging contaminants continue to cause new and serious challenges to water, air, soil, natural resources, ecosystems and human health. It is also evident that the production of new chemicals extends and often goes beyond the power of current safety monitoring and risk assessment methods, as well as of existing preventative and remediation technologies. Some issues should be addressed so as to generate a synergistic effect between the environmental influence on fate and (bio)availability of chemical (organic and inorganic) contaminants and the selection and performance of the most appropriate bioremediation processes, as well as of complementary techniques that support the effective operation and monitoring of a bioremediation approach.

All water resources estimates are optimistic because no account is taken of the qualitative depletion of water resources through the ever increasing pollution of natural water. More reliable and detailed water availability values for the future can be obtained but they will need to consider river runoff variability over a long period, to include data on groundwater resources plus the dynamics of resource quantity and quality under both a static climate and anthropogenic global climate change. To solve this problem, it will be vital to achieve close co-operation between scientists from different countries and international organizations dealing with the problems of hydrology, climatology, and the complex use and protection of water resources.

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