Review Article
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Water pollution and aquatic biodiversity

Abstract

Water pollution is known to be a growing problem of 21st century all over the world. As a result of water pollution, pure water is transferred to less scare day by day. The most unique advantage of aquatic environment is the existence of life, and the most special feature of life is its biodiversity. There are many reasons for water pollution that affected negatively biodiversity. The planet's biological diversity is affected greatly by any human activity. Six threats affect aquatic biodiversity; climate change, overexploitation, water pollution, habitat degradation, flow modification and exotic species invasion. Biodiversity maintenance is considered one of the leading keys to ecosystem services retention. So it can be said that the ultimate challenge nowadays is the protection of freshwater biodiversity.

Keywords: biodiversity, water pollution, threats, conservation

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Introduction

Nowadays, water pollution is considered one of the most important universal challenges facing both developed and developing states, affecting greatly environmental health of people all over the world. While all globally focus on water quality, water conservation and distribution matters, bad dealing with wastewater resulted in severe problems in many countries, worsening the water crisis all over the world.[1] The importance of water quality was admitted in the 2030 Agenda for Sustainable Development that stressed the future policies to ensure that control of water pollution will be elevated in national and international priorities.[2] The major known sources of water pollution are: human settlements, agriculture and industries. Globally, about 80% of municipal wastewater is released untreated into water streams, also industrial activities are known by its responsibility on dumping millions of tons of pollutants every year (solvents, heavy metals, toxic sludge).[3]

Continuous population growth, increased economic movements in addition to climate change all participate in spoilage of natural water resources, so threatening aquatic systems and the whole ecosystem as well. Recently, it was noted that aquatic biodiversity faces many damages and consequently is subjected to severe decline in many countries. The most terrible issue is that almost primitive ecosystems are amongst the threatened ones.[4] Although aquatic ecosystems are known to be from the wealthiest habitats by their diversity and number of species, the Millennium Ecosystem Assessment (MEA 5) announced in 2005 that biodiversity degradation in freshwater systems occur double the ratio of other ecosystems. Therefore, their capability to present ecosystem services decreases causing negative impacts on human health. The detected annually ratio of all species suffered from extinction (marine, avian, aquatic and terrestrial), that is considered an indicator of biodiversity loss, is over tenfold higher than that level considered by scientists as the acceptable upper limit. The main reason for such situation is that ecosystem services are known to be a free service long time ago, leading to massive destruction, with bad impacts on livelihoods and human health generally.[4] Consequently, healthy ecosystem is an ultimate human centered goal that is a vital item in the Sustainable Development Goals (SDGs) adopted in September 2015. Freshwater ecosystems (streams, ponds, lakes and wetlands) cover about 15% of world's surface if all system sizes are considered. Previous estimates were incorrect as the small systems were neglected.

A total of 300 million natural lakes occupy about 4.2 million km^2, globally (small lakes less than 1 km^2 were the most dominating). Moreover, constructed lakes occupy about 335,000 km^2. Also, synthetic water bodies grow rapidly in volume and surface area. The universal network of all water streams cover approximately 500,000 km^2. In the same time, wetlands cover a continental area of 12.8 to 15.8 million km^2. The inland water bodies provide residence for more than 10% of all registered animals and also one third of the vertebrate species. The actual knowledge of registered freshwater species diversity differs widely among groups of organisms.[5] The current loss of biodiversity has a primary reason related to ecological function's loss. In spite of the intensive research covering linkages between ecosystems functions and biodiversity, a significant gap was detected when researchers try to understand effect of biodiversity loss on ecosystem,[6] specially in freshwater ecosystems.[7–9] In the following review, the term freshwater is utilized broadly to include all inland water systems (fresh or saline) encompassing lakes, wetlands, rivers in addition to estuaries. Biodiversity is an essential component of all water systems. In the following review, the relation between water pollution and biodiversity will be covered through the following topics; Importance of biodiversity and its relation to ecosystems then their main threats. Assessment of biodiversity impacts on ecosystems and communities is needed to be elucidated and finally what are the conservation challenges facing biodiversity.

What is water pollution?

Water quality issues are among major challenges that humanity is facing in the twenty-first century. Aquatic pollution is considered a great problem facing freshwater and marine environments; it causes negative impacts for human health in addition to other respective organisms.[10] Pollution affects fish immune system either directly or indirectly by changing water quality.[11] There are many sources of aquatic pollutants: Industrial effluents, agriculture runoffs in addition to municipal sewage that are dumped in River Nile, gradually transferring water to be ineligible for human consumption. Agricultural wastewater contains many pollutants from herbicides and pesticides that have negative impacts on river and people using its water. Industrial effluents are highly toxic, including toxic heavy metals that may combine with suspended solids found in domestic wastewater form muck.[12] Also water pollution in Egypt especially in Alexandria (El-Max bay and Bahary) affected fish biological responses and finally lead to food oxidation damage accompanied by environmental quality.[13] Moreover water pollution also affected some immune-genes of seabream *Pagrus auratus* and seabass *Dicentrarchus labrax* fish samples.[14]

Biodiversity importance

The term biodiversity is known to have a wide concept. Biodiversity is defined by the United Nations Convention on Biological Diversity as follows: "living species variations from sources that include terrestrial, marine, different aquatic ecosystems and also ecological groups to which they belong: including diversity among species and also ecosystems.[15] So it can be seen that, biodiversity involves the whole range of species, genetic and ecosystem variation. It underlies the most processes of biotic ecosystem, for example: production and decaying. From the overall number of species estimated on earth that falls between 5-30 million, only around two million of species were described.[5] Ecosystem serves human providing many economic benefits to the surrounding society. There are some roles of biodiversity in ecosystem serving summarized by The Millennium Ecosystem Assessment (MEA): Supporting: Boosting ecosystems by compositional, structural and practical diversity; Regulatory: Involves the impact of biodiversity on production, constancy, in addition to ecosystems resilience; Cultural: Comprises the spiritual, aesthetic and also some recreational advantages afforded by human from biodiversity; Supplying role: Involves direct and indirect food supply, fresh water, etc.

Moreover, biodiversity includes some substantial values, away from any other benefits and cannot be quantified.[5] As society endeavors to turn to more sustainable development paths, it is significant to duly conceptualize the joint between biodiversity (traits, species and genes) and human well-being (wealth, security, health). Data analysis from previous literature pointed out the increase engagement of the terms biodiversity, human well-being and sustainable development in public, but greatly as independent terms. It was suggested by some researchers that a suited framework for sustainable development should comprise biodiversity explicitly as a flank of internal variables that both affect and are affected by human well-being.[16]

Water pollution and biodiversity

Most of the aquatic organisms are very sensitive to any variation in the environment, they respond to any pollution by different ways. The most drastic responses are represented in death or migration to any other habitat. Fewer responses may include reduction in reproductive capacity and also suppression of some enzyme systems needed to conventional metabolism.[17] Zooplankton and macrobenthic components importance in trophic dynamics of freshwater ecosystems were recognized. Such organisms not only modulate the aquatic productivity through occupying intermediate level in food chain, but also they indicate the environmental status in a definite period.[18] Moreover, their diversity raised importance especially in recent years due to their certain species capability for indication of any deterioration in water quality resulted from pollution and eutrophication.[19,20] Any disruption in food chain due to diversity loss or degradation resulted in decrease in fish numbers at top of food webs. During1899-1902, Boulenger[21] recorded 85 fish species living in Egyptian Nile waters, while Bishai et al.,[22] recorded only 71 fish species and 22 species are found in the catch, while 49 were rare. River Nile from Aswan to Cairo represents evidence of some reduced taxa richness and also involved severe polluted points resulting from sewage drains, industrial and agricultural sources.[23,24] Lake Manzala is a considered to be a highly dynamic aquatic system that has been subjected to different pollutants.[25] Manzala Lake also suffers from environmental changes due to pollution that affects aquatic biota greatly. There is a great difference between the northern side of the lake and the southern side of the lake. The southern side of the lake receives waste water effluent containing high organic matter content from different drains mainly Bahr El Baqur drain.[26]

Regarding biodiversity, there has been a considerable diminishment recorded in the lake in the last few decades in both fish and bird species. The absolute most vital factor might be the decrease in water salinity, with the exception of the northwestern basin where a dam has result in a negative water balance, hypersalinity, and loss of different species variety. In the south east basin, water pollution and extreme eutrophication have caused the vanishing of numerous aquatic species. In a few areas of the Lake, the benthic fauna has been affected by pollutants from the waste water discharge.[27] Fish deformation have been reported in recent studies as it was observed that several types of fish have showed abnormal shape and this could be attributed to pollution due to high eutrophication of the Lake as it is exposed to high domestic and industrial waste discharge and also due to predation.[28]

Different aquatic pollutants found in the environment affected greatly biodiversity which appeared in different ways. For example pollution with heavy metals impacted the whole aquatic life. In 1992, a report was published denoting that 50% of industrial waste refers to the metallurgical industry while weaving, dyeing and spinning cause about 30% of industrial waste. In Egypt, approximately 250 of the industrial establishments in Greater Cairo represent 35% of the total industrial activity participate by 40% of heavy metals load dumped in water. Also there are about 150 industrial facilities responsible for exchange of about 25% of total heavy metals load in water streams. While in Alexandria there are about 175 facilities representing 25% of total industrial activity in Egypt, however it exchanges about 10% of heavy metals total loads in natural streams.[29] Effects of heavy metals (Zn, Cu, Cd, Pb and Hg) were examined in some commercial fish species collected from the Egyptian costal region along the Mediterranean Sea. It was found that there are no significant differences in some metal concentrations such as lead referring to age or size of collected fish.[30]

Moreover microbial contamination is considered from the most dangerous pollutants of water streams either freshwater or marine environments. Livestock excreta involve zoonotic microorganisms in addition to multicellular parasites which are harmful to all living organisms.[31,32] Livestock pathogens which affect public health include bacteria such as *Clostridium botulinum*, *Campylobacter* spp, *Salmonella* spp. and *Escherichia coli* O157:H7. Also parasitic protozoa are considered from the important pathogens including for example: *Microsporidia* spp., *Cryptosporidium parvum* and *Giardia* *lamblia*, all may cause hundreds of thousands of infections every year to many organisms.[33] Lake Qarun in Egypt receives huge mixture of crude agricultural, domstic and sewage effluents loaded with heavy metals contaminants. Unfavorable conditions in Lake lead to inhibition of fish immune defense mechanism. Thus, predisposes fish to various infections. *Vibrio alginolyticus, Aeromonas hydrophila* and parasitic *Isopoda sp.* were recorded in Lake Qarun and cause serious impacts on the population of fish.[34]

Biodiversity and human well-being relationships

Biodiversity, ecosystem services, ecosystem functions and human well-being (HWB) are complex structures and there are many connections among them which make the simultaneous seeking of such elements challenging. For example, (Figure 1) describes only 8 dimensions of biodiversity, 3 dimensions of ecosystem services, 4 dimensions of ecosystem functioning in addition to 4 dimensions of HWB for only 2 development pathways, which theoretically consists of 768 probable outcomes for only a single change in biodiversity to a minimal set of dimensions to the previous four constructs. Theoretical and experimental support are considered the strongest for relations among functional, taxonomic and to a restricted extent, ecosystem function and phylogenetic diversity.[16,35–37] However, still we suffer from knowledge gaps on biodiversity links to ecosystem services.[38,39]

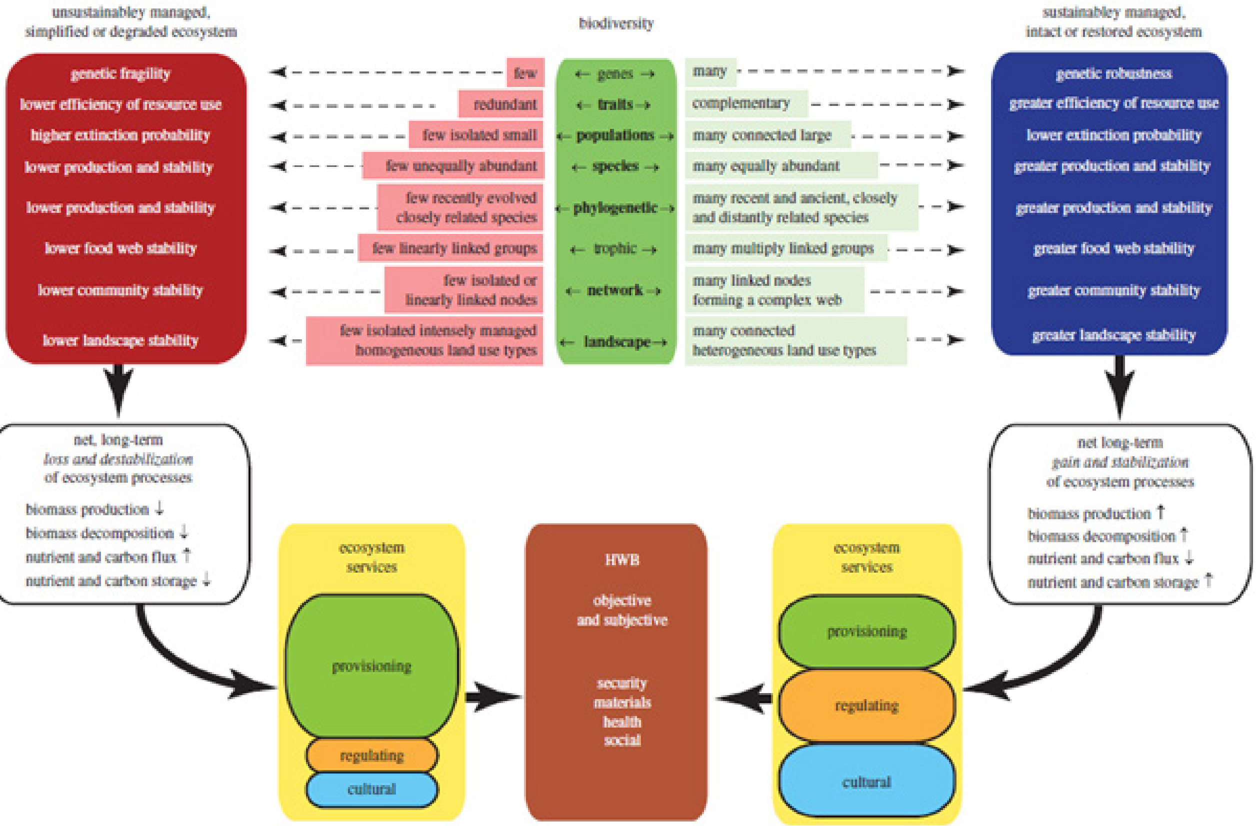

Figure 1 Linking economic development (sustainable or unsustainable), biodiversity, ecosystem functioning, ecosystem services and HWB. (16, used after author permission)

*Biodiversity is explained centrally as a multidimensional construct (top, central green box) in which a biota varies in its diversity of species, traits, genes, other dimensions. Such biodiversity endure collective change (decline to the left, increase to the right), each dimension changing as described to the left (declining) or right (increasing) depending on management (sustainable to the right, unsustainable to the left) or other human interventions. The merits of these changes are described in the boxes left and right of the biodiversity box. Change results in biodiversity-poor ecosystems (left, top) or biodiversity-rich ecosystems (right, top).

*Research has demonstrated, though results vary and knowledge gaps remain, that change in each dimension has different impacts on the stability of ecosystem functions which alter properties of ecosystems, as described in the top, left and top, right boxes.

*Development that leads to biodiversity-poor ecosystems results in a net loss and destabilization of ecosystem processes (left, white box) attributable to increases or decreases in ecosystem functions, only four of which are shown with up or down arrows to indicate increases or decreases. The converse occurs where development leads to biodiversity-rich ecosystems (right, bwhite box). These contrasting changes in ecosystem functions lead to differences in ecosystem service delivery (boxes adjacent to bottom central box).

*Biodiversity poor systems provide short-term, unstable increases in provisioning services with concomitant in regulating and cultural services (left). The converse occurs in systems managed to sustain biodiversity (right).

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The main threats to biodiversity

Global aquatic biodiversity suffers from major threats that can be grouped in the following categories: i) Climate change ii) Water pollution; iii) Overexploitation; iv) invasion by exotic species; v) habitat degradation and vi) flow modification.[36–39] Climate change is known as the alterations in atmospheric, biogeochemical and hydrological cycles. The fluctuations such as: delicate variations in average daily temperatures, the period of rainy seasons, carbon cycle, night-time temperature, and also solar radiation that may affect biological organisms. In the twentieth century the temperatures has elevated by about 0.6 degrees Celsius than past centuries. Research on the tree rings and ice cores, established scientific data needed to demonstrate such trend of increasing temperatures. As a result of temperature change, some oceanic coral reef ecosystems declined. The coastal regions may be quickly submerged due to the rapid increase of sea levels, which estimated to increase 0.1 to 0.2 metres by the last century. This is considered catastrophic to some species and also diverse communities in the ecotone. The past climatic changes lead to ecosystems with various species composition, due to species' different capabilities to adapt to the climate changes.

Water bodies' contamination by different pollutants (physical, biological, chemical and radioactive) resulted from many sources (mining activities, industrial effluents, domestic sewage and agricultural runoff) is considered a major threat to water biodiversity.[40–42] Pollution causes many diseases and even deaths all over the world but mostly in Asia and Africa. Visual water pollution may be caused by some physical pollutants such as; temperature change.[43] Different pathogenic pollutants were exuded by untreated sewage and nuclear power plants produce radioactive matter pollution.[44,45] There are two types of water pollutants either point sources or non-point sources, both of them resulted from agriculture drains and sewage.[46–49] It has been realized that pollution problems are pandemic and even some industrialized nations have proceeded in decreasing water pollution from different sources such as industrial and domestic sources other pollution sources are growing such as chemical pollution which act as important threats to water bodies.[50,51] Overexploitation (especially, overfishing) is affecting greatly marine vertebrates (large vertebrates and predators as sharks and tuna that were seen decreasing.[52] Overfishing of target species at law levels may also basically affect ecosystems particularly when constituting a high ratio of biomass or related to food webs.[53] For example, sand eel and cod stocks have subjected to overexploitation in UK waters,[54] by the effect being increased by synergism of sand eel overfishing and also range shift of copepod *Calanus finmarchicus*, which is considered a major food for sand eel.[55]

It was found that widespread invasion and willful submission of exotic species raises the chemical and physical impacts of humans over freshwater ecosystem, firstly because exotic species mostly invade ecosystems that were already degraded or modified by human activities.[56,57] Many examples were recognized representing dramatic impacts of exotics upon the indigenous species (the crayfish plague in Europe, salmonids in Southern Hemisphere streams and lakes, Nile perch, Lates niloticus, in Lake Victoria),[35] such impacts are projected to grow fast.[58] Also some indirect impacts are pronounced such as effect of terrestrial plants (*Tamarix spp*. (Tamaricaceae), that change water regime of riparian soils and also alter stream flows in North America and Australia.[59]

Habitat degradation refers to an arrangement of reactive factors that may include direct impacts on aquatic environment or indirect which occur from drainage basin changes. As an example, forest removal is usually with alterations in surface runoff and also raised river sediment loads which may lead to habitat changes such as erosion of shoreline, strangling of coastal habitats, blocking river bottoms or even aggradations of floodplain.[9] Flow modifications occur ubiquitously in running water bodies.[60] They differ in type and severity but resort to be highly aggressive especially in regions with extremely variable flow zones. This refers to humans in such areas have the highest need for water storage and food protection. That found dams retain about 10 000km^3 of water, equal to five times all world's water volume,[61] explains the global extent of human change of river flow. Recently some of the world's longest rivers suffer from dryness as a result of the large scale water abstraction.[62] Impacts also of flow modifications on river biota such as fish are likely to be severe and need to be considered in future research.[63,64]

Biodiversity loss and ecological communities

There is no clear proof that loss of biodiversity decreases the ability of ecological communities to capture biological important resources and generate biomass in addition to recycling essential nutrients. All data published since 2005 revealed that decrease in number of genes, species and all active groups of organisms decrease efficiency and also convert such resources to biomass.[65–68] Different impacts of biodiversity are seen to be remarkably proportionate through various groups of organisms, amongst trophic fields and different studied ecosystems.[69] There are general primary principals that command how the communities affect ecosystems functions although there are some exceptions that some ecosystems and processes present various chances for exploring boundaries that constrain effects of biodiversity.[70,71]

Biodiversity and stability of ecosystem functions and processes

Stability is described in many forms, and theoretically there is no evidence that biodiversity could enhance stability forms.[72] However both data and theory support higher temporal stability of a group property such as all biomass at different stages of diversity. It can be said that five syntheses have concise how diversity affected ecosystem functions variation by time, these showed that resource capture and production of biomass are more stable in different communities.[73–76] The techniques by which diversity grants stability involve statistical average, over yielding and also compensatory drive. Stability is promoted by over yielding when mean biomass output increases by diversity more rapidly than the standard deviation. The statistical average happens when random divergence in population multiplicity of various species reduces the variance of aggregate ecosystem variables.[77] The compensatory dynamics are made out by interactions and/or special responses to environmental inconstancy between various life forms, both of which result in desynchronization in environmental response.[78,79] Biodiversity impact on any ecosystem process is saturating and nonlinear so any change increases accompanying biodiversity loss. By taking into consideration the biodiversity and ecosystem functioning relationships the last experimental studies reveal that primary losses of biodiversity in various ecosystems have relatively low effects on ecosystem functions, but more losses lead to higher change rates. There are no definite quantitative estimates about the real level of biodiversity able to alter ecosystem functions to be significant for various processes which need more research.[80–82]

Biodiversity loss and common species

Most of previous research studies dealing with loss of biodiversity focused on results of species extinctions, however biodiversity loss also includes decrease in common species numbers and shifts in domination patterns of species.[6] It can be said that common species are the drivers of any ecosystem process,[83] and any decline could lead to bad implications for the ecosystem main function. For example, dominant fish have vital roles in freshwater ecosystems, mostly joining benthic and pelagic parts through their rapid mobility in addition to flexible foraging acts.[84] Dominant fishes are known to be less likely to be substituted by other functional equivalent ones as they frequently cover more trophic levels by lower species richness. Many examples were detected for such a process, that overharvesting of abundant fishes lead to exchanges in their ecosystem function.[85] Migratory fish numbers decline causes many problems that they often transfer materials through long distances while no functional equivalents were known to substitute them. As a real example, salmon fish transfer significant marine derived nutrients through large scales into freshwater and also terrestrial habitats, also re disseminate nutrients on finer ranges during their spawning.[86,87]

Cost efficiency plans for conservation

Dealing with the rising fierce competition for different water resources, freshwater conservation approaches should ideally include an explicit evaluation of conservation management costs. The freshwater conservation priorities detected based on social, biological in addition to economic costs qualify explicit assessment of the trade-offs between utilization and management and also are more likely to ensure commitment from decision-makers and politicians.[9] More thoughts about conservation costs were presented in literature considering selection of conservation regions, with acquisition costs, management and transition costs proceeding to the opportunity costs as well.[88] Concerning freshwater communities, examining conservation costs is very complexive that it includes the conception of costs for conserving definite region, and also associated costs dealing with required water for sustaining such area for a long time. That including quantification of costs and benefits across the whole catchments. A big variation of some formal techniques had developed in the environmental field flow evaluation which stresses alternative water allocations inside the catchment.[89] Basically, such methodologies estimate trade-offs in flow needs which would sustain both biodiversity and human needs for management of water resources. Full integration of such strategies dealing with conservation planning includes immense potential while to date it was not done. Multiple standard decision making tools had also been used in conservation planning of terrestrial areas aiding examination of a preferred scenario relied on quantitative or qualitative biological, social and also economic costs.[90,91]

Conclusion and recommendations

Aquatic pollution is considered a great problem facing freshwater and marine environments; it causes negative impacts for human health in addition to other respective organisms.

The freshwater ecosystems by their living biota are considered from the highly endangered globally among other ecosystems.

There are 6 threats facing freshwater biodiversity; climate change, overexploitation, water pollution, habitat degradation, flow modification and exotic species invasion.

Systematic conservation planning provides a strategic and scientifically defensible framework for biodiversity conservation.

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Conflicts of interest

The author declares no conflicts of interest.

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