Journal of Environmental Science and Engineering B 6 (2017) 506-514
doi:10.17265/2162-5263/2017.10.002

Eutrophication of Aquatic Ecosystems: A Viewpoint on the Environmental Impact of Climate Change

Karim Morsy[1], Amr Morsy[1, 2], Mohamed Morsy[1] and Hoda Thakeb[3]

1. Department of Civil Engineering, Cairo University, Giza 12613, Egypt

2. Department of Civil, Architectural, and Environmental Engineering, the University of Texas at Austin, TX 78712, USA

3. National Organization for Potable Water and Sanitary Drainage (NOPWASD), Giza 12649, Egypt

Abstract: Environmental concerns associated with nutrient-oriented eutrophication phenomenon have become a serious issue and a major cause of water quality deficiency nowadays. This necessitated eutrophication to occupy a front seat in research accompanied with climate change. Climate change has revealed to be a key player and a main contributor in the occurrence of such phenomenon. This paper discusses the ever-growing concern about eutrophication as a cause of climate change. Climate change affects storms intensity, changing the precipitation regime and increasing temperature. These effects increase the nutrient loading diffusion and cause excessive nutrients accompanied with storm water runoff, domestic wastewaters, and agricultural discharges to pour into water bodies. Eutrophication conversely contributes in the global warming by releasing greenhouse gases from deoxygenated waters and sediments. Some control and mitigation measures are needed to fight climate change and achieve desired water quality goals. These measures include mitigation of climate change causes, enhancement of natural ecohydrological processes, application of proper integrated water resource management and participation of communities and governments.

Key words: Eutrophication, climate change, aquatic ecosystems, ecohydrological approach.

1. Introduction

Eutrophication is the phenomenon of the presence of excessive nutrients such as nitrogen and phosphorus in water bodies causing the growth of algae and plant life. This results in undesirable disruption to the balance of organisms and degrades the water quality [1]. Eutrophication can occur in different types of water bodies regardless their degree of salinity, such as lakes, rivers, seas and oceans. Excess fertilizers and chemicals entering the aquatic ecosystem result in creation of aquatic organic matter. This significantly harms the water quality and results in eutrophication as shown in Fig. 1. In the presence of excess nutrients, sunlight and slow water movement, algal blooms emerge. The beneficial uses of water body will be lessened by the presence of excessive amounts of pollution including domestic and industrial water supply, recreation and fisheries [2].

Climate change has been widely recognized to significantly affect life on our planet on various levels: (1) it boosts the intensity of storms; (2) it alters the precipitation regime; (3) it increases the temperature of soils and (4) it melts glaciers. These impacts increase the nutrient loading diffusion [3] and thus raising the eutrophication potential. Meanwhile, humans have a noteworthy contribution in exacerbate this process dramatically through run-off from agricultural land agricultural runoff (fertilizers washing and soil erosion) and septic systems [4]. The increase in the nutrient level and chlorophyll concentration are indications of eutrophication potential. Fig. 2 shows that there is a direct proportional relationship between nutrient concentration and algal biomass [5].

Biological processes are sensitive to the increase in temperature as a result of climate change which lead

Corresponding author: Karim Morsy, Ph.D. candidate, research fields: water resources and environmental engineering.

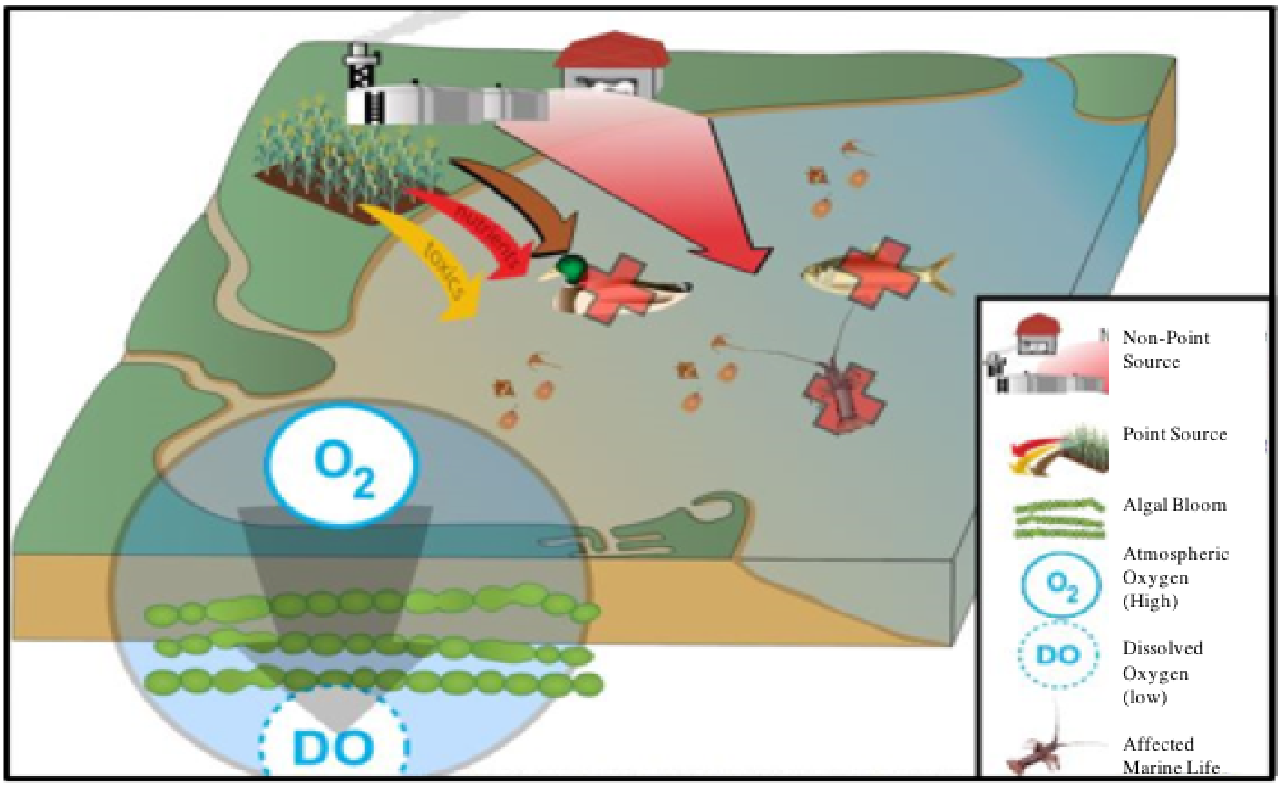

Fig. 1 Conceptual diagram showing the causes of eutrophication.

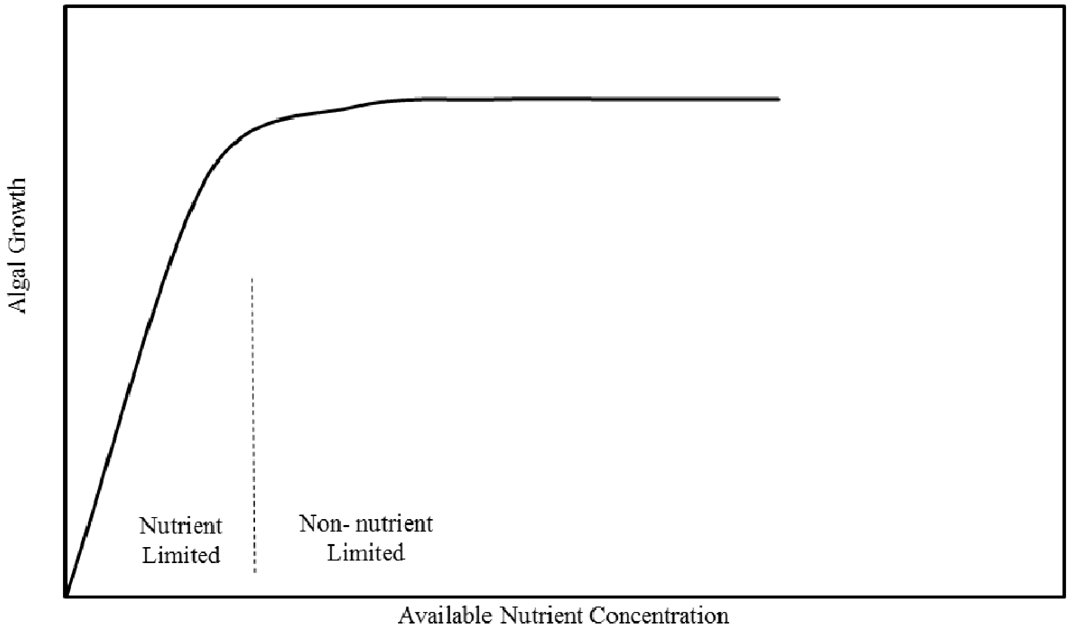

Fig. 2 Relation between nutrient concentration and algal biomass (adapted from Ref. [5]).

to (a) changes in growth rate and respiration process of biodiversity; (b) increase in the water temperature leading to a depletion of dissolved oxygen and cause death of fishes and many aquatic ecosystem; (c) excessive nutrient released from sediments and accordingly cause eutrophication of water bodies [6, 7].

2. Climate Change versus Eutrophication

Climate change and eutrophication are mutually dependent, the change in climate represented in the change of temperature and precipitation regime has a significant effect on the expansion of the eutrophication in water bodies. On contrary, the eutrophication has a contribution in changing the climate, specifically by producing methane, nitrous oxide and carbon dioxide gases.

2.1 Climate Change Influences on Eutrophication

Eutrophication concentration increases as a result of the combination of excessive nutrient inputs and increase in temperature. Algal blooms and floating plants cover the water surface in the presence of excess nutrients, sunlight and slow water movement. This results in algal foams and toxins as massive invasions of certain aquatic plants covering the water surface which blocks sunlight from reaching submerged plants and phytoplankton [5].

Climate change causes increase in atmospheric temperature leading to increase in the water temperature and change in precipitation regimes leading to intensive storms. The increase in water temperature even in the presence of low nutrient concentrations in deep waters leads to a complete loss of underwater vegetation [8]. Moreover, the increase in temperature results in increasing the mineralization rate in catchment sediments and soils leading to increase in the nutrient loading. The excess of nutrients causes depletion of the dissolved oxygen in water bodies which amplifies in summer as temperature increases. Meanwhile, the increase in the storm intensity increases land erosion and the rate of nutrients delivery to water bodies [8, 9]. Fig. 3 shows the climate change influence on eutrophication.

2.2 Eutrophication Influences on Climate Change

On contrary, eutrophication has indirect influence on climate change. Freshwater is a potential source of carbon dioxide [10]. Eutrophication causes an increase in carbon dioxide autotrophic fixation and an increase in the total production and respiration, that is, a higher release of methane from deoxygenated waters and

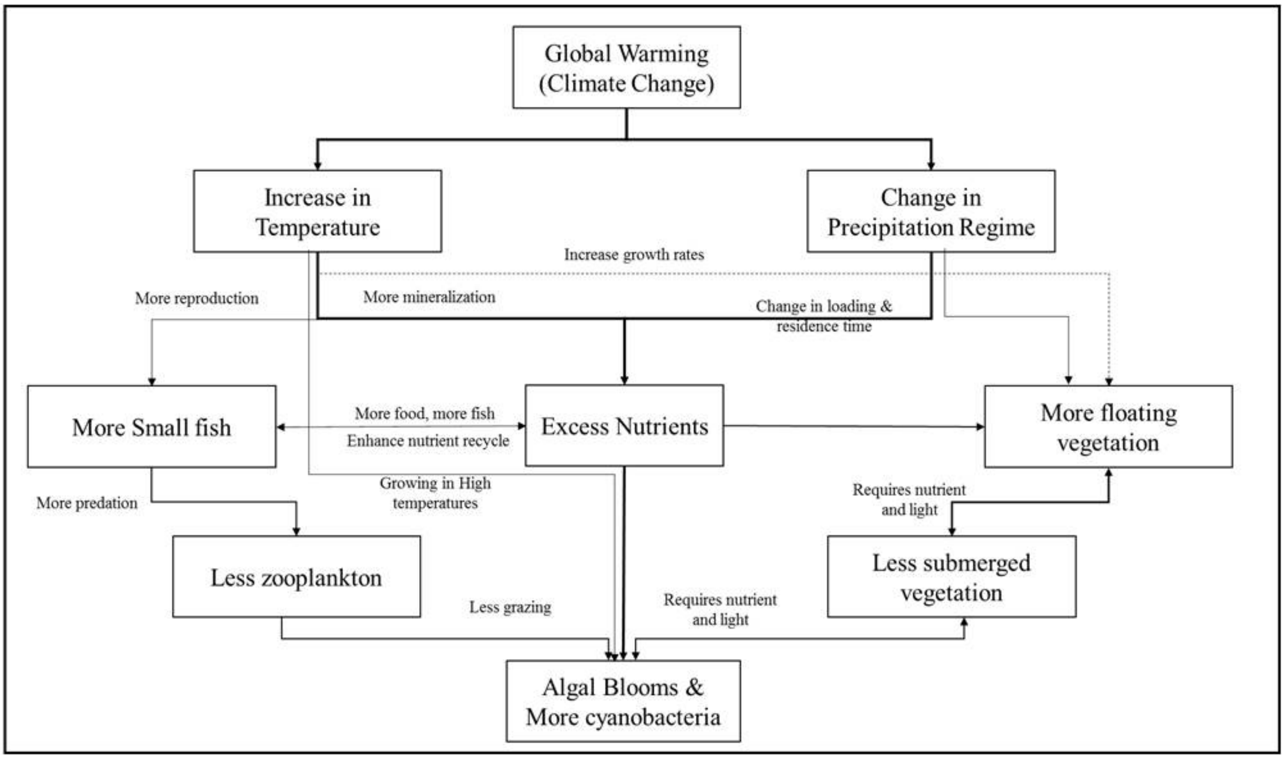

Fig. 3 Framework of the climate change influence on eutrophication.

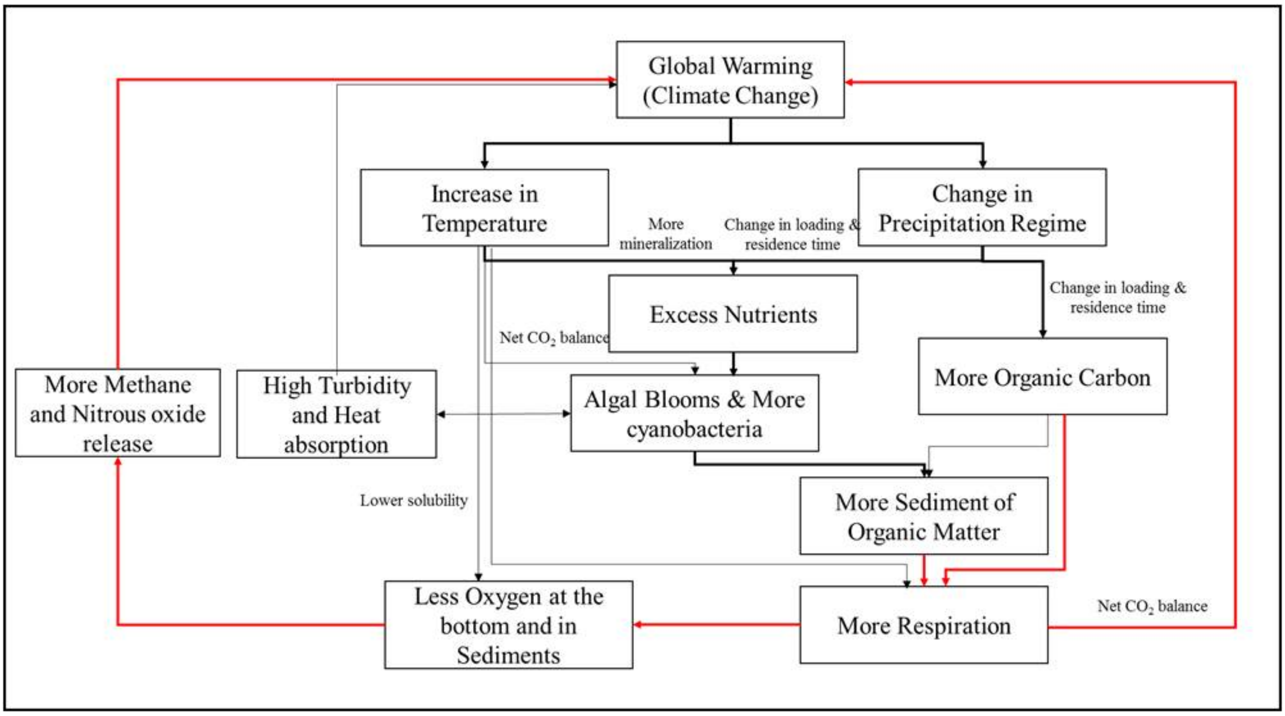

Fig. 4 Framework of the eutrophication influence on climate change.

sediments [11]. On the other hand, the denitrification causes more production of N_2O (Nitrous Oxide) which is also a greenhouse gas that increases the global warming potential [12].

The raise in temperature decreases the ability of sediments to store carbon and also releases the stored methane [13]. As the algal blooms and floating plants population rise, dissolved oxygen depletes and greenhouse gaseous will be released. Sediments turn into anaerobic condition, heat is absorbed, and increase in respiration rates takes place [14]. Fig. 4 shows the eutrophication influence on climate change.

3. Case Study

Eutrophication of water bodies has been spotted at many locations along the Mediterranean shoreline of Egypt, particularly in the Nile Delta lagoons and Alexandria coast. Manzalalagoon is one of the Nile Delta lagoons and is the largest natural lake in Egypt. This lagoon was considered in this paper for case study because of the severe eutrophication of water bodies and serious fish mortality known to exist in this district. Field measurements were undertaken to monitor the DO (Dissolved Oxygen) and water temperature at the eutrophied water bodies of the Manzala lagoonover 2016. The water column profiling was identified using YSI 6000 multiprobe, which is a device used for determining water physical properties.

Results of the distribution and variation of temperature and dissolved oxygen were obtained over depth at 1-m increments. The average of the measured data is shown in Fig. 5. It was observed that at low seasonal temperature, during November through January (winter season), the population of algal blooms and floating plants were relatively low and the dissolved oxygen in water was within the allowable limit (less than 4 mg/L) according to US EPA (Environmental Protection Agency). On the other hand, at high seasonal temperature, during June through August (summer season), the population of the algal blooms and floating plants have increased noticeably compared to that in winter. This caused a drastic depletion in the dissolved oxygen in water to a level below the allowable limit (less than 4 mg/L) causing severe eutrophication and fish mortality. In

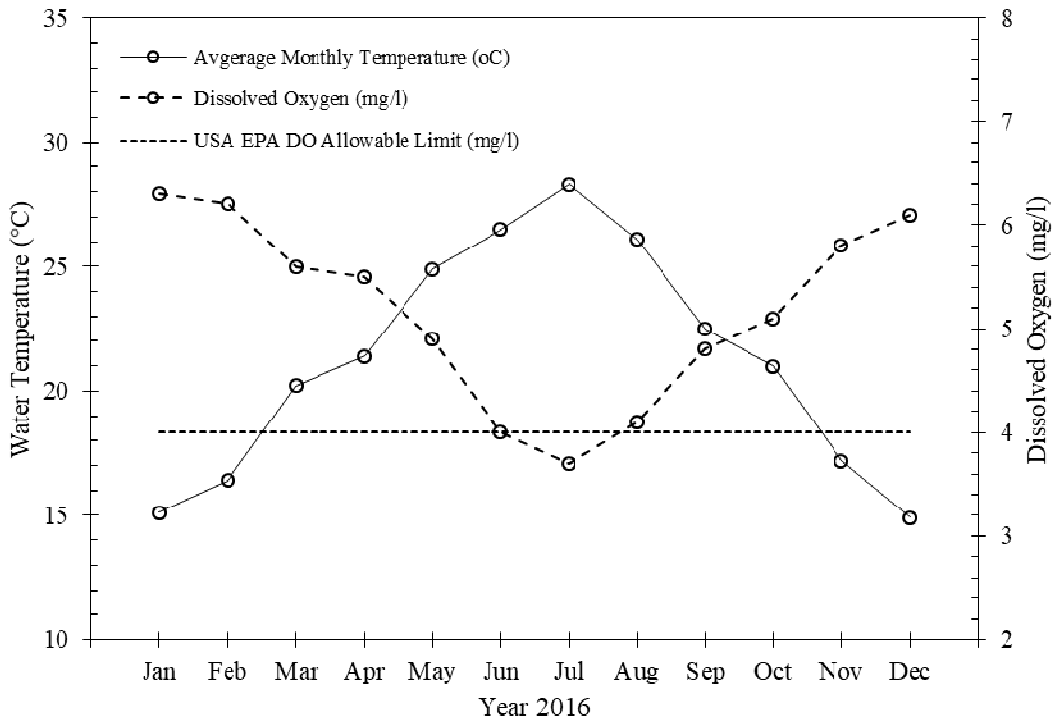

Fig. 5 Temperature and dissolved oxygen measurements at the Manzala Lagoon.

addition, the results demonstrated that the dissolved oxygen is very susceptible to the change in temperature and indicative to the severity level of eutrophication in water bodies.

4. Consequences of Eutrophication

Eutrophication occurs when excess amount of nutrients such as nitrogen and phosphorous are present in water body. The high rates of photosynthesis related to the eutrophication deplete the dissolved inorganic carbon and raise pH during the day time, in which the organisms that rely on the dissolved chemical impair their chemosensory abilities for survival [15]. When the algal blooms die, microbial decomposition takes place causing depletion of dissolved oxygen and creating a hypoxic or anoxic “dead zone”. The presence of hypoxia is very common in marine coastal environments which are rich in nutrient rivers and are noticed to affect more than 245,000 square kilometers in over 400 shore systems. Hypoxia and anoxia resulting from eutrophication have become worldwide threats to beneficial, commercial and recreational fisheries [16].

Many consequences arise from water eutrophication: (1) reduction in marine species diversity; (2) reduction in fish biomass; (3) change in the macrophyte vegetation composition of marine species; (4) increase in the phytoplankton biomass; (5) increase in the consumer species biomass; (6) water turbidity and decrease in its transparency; (7) change in water taste and odor and (8) drinking water treatment problems. Moreover, eutrophication also affects the human health as it increases the potential of water-related diseases such as blue baby syndrome as well as poisonous odors caused by the emission of gases such as methane and hydrogen sulphide [16].

5. Controls and Mitigation Measures

Eutrophication is not only harmful for our environment but also it has negative effects on economic and social dimensions. It is necessary to control the eutrophication phenomenon and mitigate its aftermath. The solution is clear: a proper management shall be implemented to control and eliminate sources of nutrient inputs to water bodies such as phosphorous and nitrogen. This can be adopted through natural echo hydrological processes, adaptive integrated watershed resource management and community participation.

5.1 Control through Natural Ecohydrological Processes

Wetlands and riparian zones are the most important natural components of riverine ecosystems regulating the quantity and quality of water. In addition, they play as effective buffers against excess erosion, nutrient inputs and contaminant runoff from agricultural fields and pastures [17]. Developing artificial wetlands in the headwater of watersheds act as buffers against contaminated runoff in a manner much like that of riparian forests and grass by facilitating the deposition of entrained sediments. Headwater wetlands produce pockets of anoxia that supports nitrate removal through denitrification process [18]. Nutrients uptake by wetlands vegetation is a common natural trend in capturing the excess nutrient and contaminant. It generally requires a short term duration [19], especially when it is taken up by rapidly turning over species and more efficient than longer term storage ones. Long term storage occurs when nutrients are taken up into trees. However, some trees uptake that phosphorus uptake only 10% of the total phosphorus uptake in a wetland. So that, only a small portion of nutrients are taken up into long term storage pools [20].

Riverine ecosystems play a crucial role to regulate flows and quality of water passing through them. The biological, physical or chemical interactions in nature provide resistance, resilience and adaptability to riverine ecosystems. That is, this process is a natural component of healthy riverine ecosystems [21]. In addition, riverine ecosystems have dual functions: (1) Filtration of nutrients and pollutant along catchments and converting them into organic matter and (2) Flood plain trapping of organic matter, nutrients and pollutants transported along water bodies accelerating of self-purification processes [22].

5.2 Adaptive Integrated Watershed Resource Management

According to the UNESCO (United Nations Educational, Scientific and Cultural Organization) Ecohydrology programme, ecohydrological guidance and wise IWRM (Integrated Water Resources Management), principles can be effective tools to fortify the aquatic systems and enhance the chances that engineering-based controls achieve their desired water quality goals in fighting the eutrophication [23]. During the last century, IWRM procedures have employed many approaches to mitigate the effects of eutrophication: (1) excess nutrients diversion [24]; (2) adjusting nutrient ratios [14]; (3) applying physical mixing [25]; (4) using some additives to the water bodies such as muddy liners or water stains and (5) applying powerful algaecides such as copper sulfate [26].

In some landlocked water bodies such as lakes, internal loading of nutrients from sediments may affect the water quality. The use of algaecides such as copper sulfate is an effective method to reduce the presence of algal blooms temporarily. However, these algaecides may have side effects on humans, wildlife, livestock and other aquatic organisms [26]. Reservoir ecosystems are important and can serve as a good solution, in which sedimentation of minerals and nutrients transportation can be controlled by regulating the biota within hydrological processes [26, 27]. The restoration of eutrophic reservoir by applying ecohydrological concepts and ecosystem biotechnologies along the water body are tools to control eutrophication as shown in Fig. 6 [28].

5.3 Community Participation

Communities and governments are the main stakeholders in finding effective solutions for their

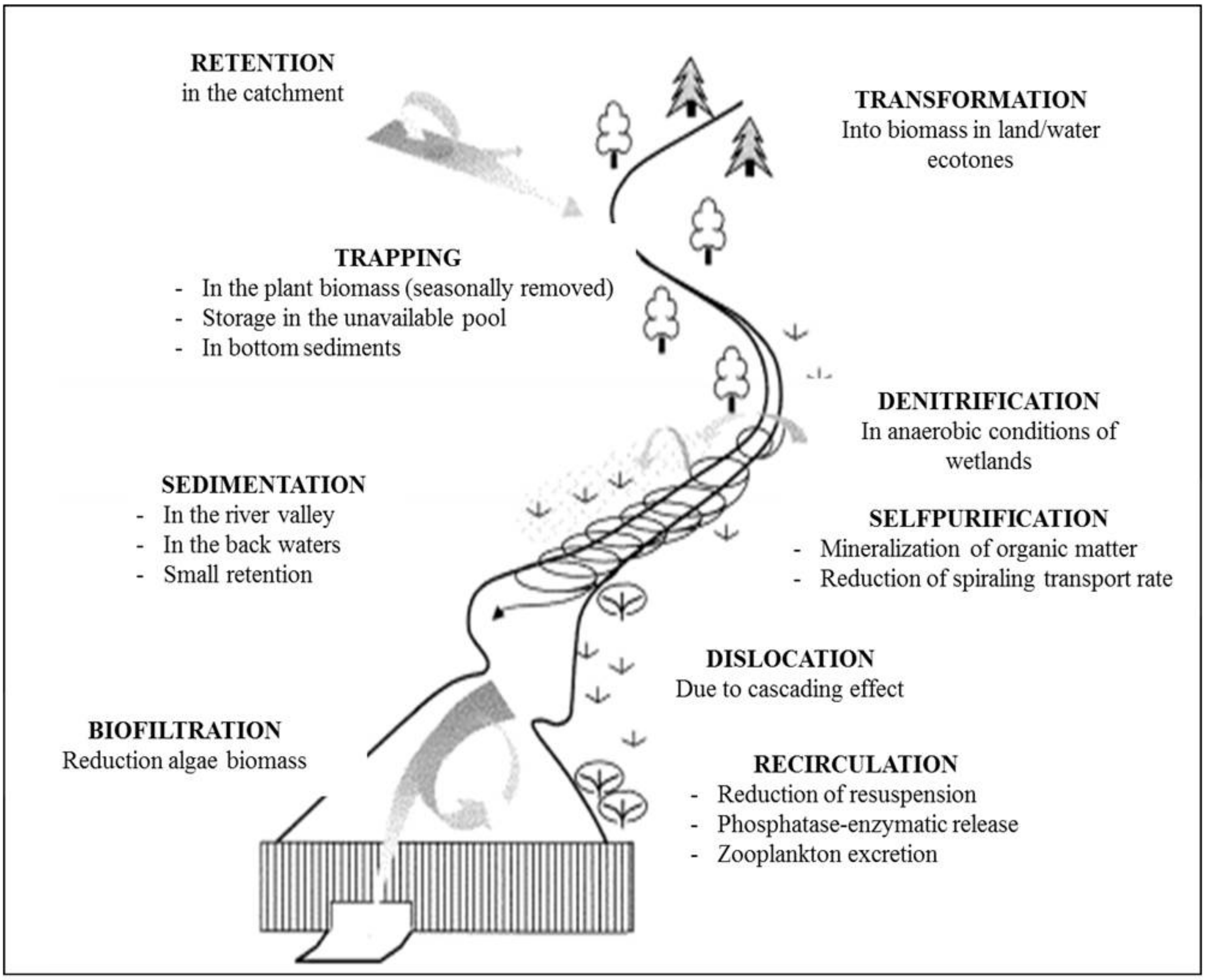

Fig. 6 Restoration of eutrophic reservoir [28].

noteworthy contribution in initiating the eutrophication phenomenon. Accordingly, effective participation of communities is a main pillar in solving this matter [29]. This can translated into action as:

(1) Organize activities to raise awareness of people about side effects of eutrophication and its main causes;

(2) Control the use of fertilizers by farmers;

(3) Positive participation of all stakeholders such as individuals, farmers, governments to avoid this phenomenon for each individual shared water body;

(4) Initiating legal requirement to prohibit discharging water pollutants directly into water bodies unless a proper treatment has been applied [29].

6. Conclusions

Eutrophication of water bodies has become a serious issue and a major cause of water quality degradation, which lessens the beneficial uses of water bodies due to the presence of excessive pollutants. These water bodies include domestic and industrial water supply, recreation and fisheries. Excessive nutrients accompanied with runoff after intensive storms, as well as domestic wastewaters and agricultural discharges pour into water bodies causing (1) water-related diseases; (2) water turbidity; (3) poisonous odors caused by gases emission; (4) poor water taste; (5) depletion of dissolved oxygen; and (6) fish mortality.

A noticeable relationship was found between the climate change and the occurrence of the eutrophication phenomenon. Specifically, the global warming was found to be strongly bonded to the eutrophication of water bodies with a direct relationship with its severity and an inverse relationship with the dissolved oxygen concentration in water. On the contrary, eutrophication has a contribution in the increase of global warming through greenhouse gases release from deoxygenated waters and sediments. Overall, this relationship may provide a breakthrough in the analyses of eutrophication potential.

Some measures are proposed in order to control and mitigate the consequences of the eutrophication phenomenon. These controls include the following:

(1) Mitigation of global warming effects by controlling emissions of greenhouse gases, especially carbon dioxide and methane;

(2) Integrative quantification of ecohydrological processes at the basin scale (integrative watershed management plan);

(3) Use of artificial wetlands and riparian zones to regulate the quantity and quality of water and to effectively buffer against excessive sediment erosion and nutrient flux;

(4) Regulation of nutrients, organic matters and organism fluxes between terrestrial and aquatic components of catchments;

(5) Establishing new water treatment systems to treat water before domestic supply and to treat wastes before disposal;

(6) Effective participation of communities and governments.

References

[1] Urban Waste Water Treatment Directive. 1991. “Council Directive of 21 May 1991 Concerning Urban Waste Water Treatment (91/271/EEC).” *Official Journal of the European Communities*.

[2] Ryther, J. H., and Dunstan, W. M. 1971. “Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment.” *Science* 171 (3975): 1008-13.

[3] Jeppesen, E., Kronvang, B., Meerhoff, M., Søndergaard, M., Hansen, K. M., Andersen, H. E., et al. 2009. “Climate Change Effects on Runoff, Catchment Phosphorus Loading and Lake Ecological State, and Potential Adaptations.” *Journal of Environmental Quality* 38 (5): 1930-41.

[4] Smith, V. H. 2003. “Eutrophication of Freshwater and Coastal Marine Ecosystems a Global Problem.” *Environmental Science and Pollution Research* 10 (2): 126-39.

[5] Lee, G. F., and Jones-Lee, A. 2005. “Eutrophication (Excessive Fertilization).” In *Water Encyclopedia*.

[6] Mooij, W. M., Janse, J. H., Domis, L. D. S., Hülsmann, S., and Ibelings, B. W. 2007. “Predicting the Effect of Climate Change on Temperate Shallow Lakes with the Ecosystem Model PC Lake.” *Hydrobiologia* 584 (1): 443-54.

[7] Blenckner, T., Adrian, R., Livingstone, D. M., Jennings, E., Weyhenmeyer, G. A., George, D., et al. 2007. “Large-scale Climatic Signatures in Lakes across Europe: A Meta-analysis.” *Global Change Biology* 13 (7): 1314-26.

[8] Moss, B., Kosten, S., Meerhoff, M., Battarbee, R. W., Jeppesen, E., Mazzeo, N., et al. 2011. “Allied Attack: Climate Change and Eutrophication.” *Inland Waters* 1 (2): 101-5.

[9] Rustad, L. E. J. L., Campbell, J., Marion, G., Norby, R., Mitchell, M., Hartley, A., et al. 2001. “A Meta-analysis of the Response of Soil Respiration, Net Nitrogen Mineralization, and Aboveground Plant Growth to Experimental Ecosystem Warming.” *Oecologia* 126 (4): 543-62.

[10] Cole, J. J., Caraco, N. F., Kling, G. W., and Kratz, T. K. 1994. “Carbon Dioxide Supersaturation in the Surface Waters of Lakes.” *Science-AAAS-Weekly Paper Edition* 265 (5178): 1568-9.

[11] Bastviken, D., Tranvik, L. J., Downing, J. A., Crill, P. M., and Enrich-Prast, A. 2011. “Freshwater Methane Emissions offset the Continental Carbon Sink.” *Science* 331 (6013): 50.

[12] Huttunen, J. T., Alm, J., Liikanen, A., Juutinen, S., Larmola, T., Hammar, T., et al. 2003. “Fluxes of Methane, Carbon Dioxide and Nitrous Oxide in Boreal Lakes and Potential Anthropogenic Effects on the Aquatic Greenhouse Gas Emissions.” *Chemosphere* 52 (3): 609-21.

[13] Dodds, W. K. 2006. “Eutrophication and Trophic State in Rivers and Streams.” *Limnology and Oceanography* 51 (1part2): 671-80.

[14] Downing, J. A., Cole, J. J., Middelburg, J. J., Striegl, R. G., Duarte, C. M., Kortelainen, P., et al. 2008. “Sediment

Organic Carbon Burial in Agriculturally Eutrophic Impoundments over the Last Century." *Global Biogeochemical Cycles* 22: 1.

[15] Turner, A. M., and Chislock, M. F. 2010. "Blinded by the Stink: Nutrient Enrichment Impairs the Perception of Predation Risk by Freshwater Snails." *Ecological Applications* 20 (8): 2089-95.

[16] Diaz, R. J., and Rosenberg, R. 2008. "Spreading Dead Zones and Consequences for Marine Ecosystems." *Science* 321 (5891): 926-9.

[17] Willems, H. P., Rotelli, M. D., Berry, D. F., Smith, E. P., Reneau, R. B., and Mostaghimi, S. 1997. "Nitrate Removal in Riparian Wetland Soils: Effects of Flow Rate, Temperature, Nitrate Concentration and Soil Depth." *Water Research* 31 (4): 841-9.

[18] Ann, Y., Reddy, K. R., and Delfino, J. J. 1999. "Influence of Chemical Amendments on Phosphorus Immobilization in Soils from a Constructed Wetland." *Ecological Engineering* 14 (1): 157-67.

[19] Hanson, G. C., Groffman, P. M., and Gold, A. J. 1994. "Symptoms of Nitrogen Saturation in a Riparian Wetland." *Ecological Applications* 4 (4): 750-6.

[20] Mitsch, W. J., Dorage, C. L., and Wiemhoff, J. R. 1979. "Ecosystem Dynamics and a Phosphorus Budget of an Alluvial Cypress Swamp in Southern Illinois." *Ecology* 60 (6): 1116-24.

[21] Naiman, R. J., Decamps, H., and Pollock, M. 1993. "The Role of Riparian Corridors in Maintaining Regional Biodiversity." *Ecological Applications* 3 (2): 209-12.

[22] Zalewski, M., and Harper, D. M. 2001. "Ecohydrology—the Use of Ecosystem Properties as Management Tools for Enhancement of the Absorbing Capacity of Ecosystems against Human Impact." *Ecohydrology and Hydrobiology* 1: 1-2.

[23] Zalewski, M., Janauer, G. A., and Jolankai, G. 1997. "Ecohydrology: A New Paradigm for the Sustainable Use of Aquatic Resources." *Ecohydrology. A New Paradigm for the Sustainable Use of Aquatic Resources.*

[24] Edmondson, W. T. 1970. "Phosphorus, Nitrogen and Algae in Lake Washington after Diversion of Sewage." *Science* 169 (3946): 690-1.

[25] Huisman, J., Sharples, J., Stroom, J. M., Visser, P. M., Kardinaal, W. E. A., Verspagen, J. M., et al. 2004. "Changes in Turbulent Mixing Shift Competition for Light between Phytoplankton Species." *Ecology* 85 (11): 2960-70.

[26] Tucker, C. S., Hanson, T. R., and Kingsbury, S. K. 2001. "Management of Off-flavors in Pond-cultured Channel Catfish with Weekly Applications of Copper Sulfate." *North American Journal of Aquaculture* 63 (2): 118-30.

[27] Staškraba, M. 1999. "Retention Time as a Key Variable of Reservoir Limnology." In *Theoretical Reservoir Ecology and its Applications*, edited by Staškraba, M., and Tundisi, J. G., 385-410.

[28] Zalewski, M. 2000. *Ecohydrology—the Scientific Background to Use Ecosystem Properties as Management Tools toward Sustainability of Water Resources*. Elsevier.

[29] Morsy, K. 2016. *Groundwater Dependent Ecosystem in Arid Regions*. Saarbrucken: LAP Lambert Academic Publishing.