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# STUDY ON AQUATIC POPULATION DYNAMICS UNDER POLLUTION AND GLOBAL WARMING: MATHEMATICAL REVIEW

**Shreya[1] and Preety Kalra[2*]**
Department of Mathematics/School of Chemical Engineering and Physical Sciences/Lovely Professional University, Phagwara, Punjab, India.
E-mail: [1]shreyatangri25@gmail.com, [2*]kalra.preety@gmail.com

## Abstract

It is a well-known fact the growing water pollution and global warming are the key areas of concern in current times. The carbon content in atmosphere is increasing due to activities carried out by humans, which results in global warming. The rise in carbon also leads to acidification of water. These phenomena combined with the pollutants and toxicants entering the water bodies; prove very harmful for the aquatic ecosystem. The dissolved oxygen in the water bodies is also declining due to global warming and pollution which is causing death of aquatic organisms. Mathematical studies focusing on single effect of pollution, acidification or global warming are available which are studied in this review article. Also, the need for a mathematical model studying two or more effects together is also identified, thus, giving the future scope in the area, which would further help environmentalists to form policies to safeguard the aquatic ecosystem.
***Keywords***: Pollution, Global Warming, Acidification, Algal Blooms, Dissolved Oxygen, Aquatic Population, Toxicant, Mathematical Model, Review.

## Introduction

A healthy aquatic ecosystem is very essential for the survival of the human population which is dependent on it for its various needs. Rivers, rivers, wetlands, aquifers and oceans are part of the water bodies which act as a source of transportation, food and employment for the humans. But in recent times, this aquatic ecosystem is facing serious threats from pollution and contamination. Water pollution is a global problem requiring serious assessment of different water resource policies. Most of this pollution is occurring due to different human activities being carried out due to urbanization and industrialization in today's times. The specific type of contaminants that lead to water pollution cause many changes in physical and chemical properties of water including changes in colour and temperature of water. A lot of chemical substances entering the aquatic bodies such as heavy metals, detergents, herbicides and insecticides, disinfection by-products, hydrocarbons from petroleum, chemical drugs cause the water bodies to become toxic. The pollutants also lead to increase in acidity of water. The increasing fossil fuel burning is rising carbon content in atmosphere is also leading to global warming which is warming the water bodies. The increasing pollution, acidification and global warming are also contributing to algal bloom rise in water bodies which is a threat for survival of aquatic organisms. These are also leading to mass deaths of aquatic organisms (Bijma *et al.,* 2013). Carbon dioxide emissions prediction study is also done in recent (Ahmadi *et al*., 2019), (Ghazvini *et al.,* 2019).

In reality, humans are observed to be accountable for the deaths of whales, fishes and other aquatic species which are washed ashore often on various beaches worldwide. Water pollution also damages important resource i.e. dissolved oxygen in water and make water bodies inappropriate for survival of aquatic life (Sweetman *et al*., 2017). Deoxygenation also affects marine biogeochemical cycle. The deoxygenation epidemic is expected to worsen in the years to come. Due to continued greenhouse gas emissions, global warming is projected to exacerbate deoxygenation during the twenty-first century. A recent study on alternative arrangements of power generation energy resources and reserve in India is also done (Kumar *et al.,* 2019). Under the same nutrient loads, most areas are expected to experience more extreme and prolonged hypoxia than at present (Keeling *et al.,* 2010) .The excess nutrients washed off in water bodies and the growing acidity leading to uncontrolled growth of algal blooms further reduce the dissolved oxygen content in water (Chapra *et al*., 2017, Michalak *et al.*, 2013) .

Mathematical models are now widely recognized as a planning tool of proven effectiveness. It has become very easy to study alternatives to solve most physical problems with the advent of very fast computing facilities. It is therefore important to integrate the use of mathematical models in planning sectors in order to evaluate measures to be taken to mitigate a physical problem such as river pollution (Kamal *et al.*, 1999). Various ecological models are available which study the environmental management techniques (Jorgensen, 2016). This review focuses on the growing problem of water pollution, acidification, resulting growing algal growths and consequent reduction in dissolved oxygen in water, which can be detrimental for aquatic life and the mathematical models available which study these harmful impacts on the aquatic ecosystem. This study also explores the future scope that can be studied by mathematicians in this area.

### Stress of pollution and increased atmospheric carbon on aquatic ecosystem

The aquatic habitats are currently under constant pressures from various activities such as eutrophication and acidification triggered by intractable discharges in water bodies of agricultural, household and industrial waste in water. Water toxicity levels have significantly risen due to increased toxins, pollutants rich chemicals and carbon containing compounds being discharged into water bodies. Another disastrous consequence of humandriven activities in anthropocene was found to be rise of quantity of pollutants and toxicants in water bodies leading to ocean acidification. Bijma *et al.* proved by their theoretical study, the prevalence of the three risk factors in oceans namely water warming, ocean acidification and reduction in oxygen content in water. These occurred on ecosystems that were already stressed by many human-induced stressors like contamination, eutrophication, overfishing and pollution, thus pushing them towards further deterioration (Bijma *et al.,* 2013). The study done by Issakhov presented a mathematical model of the liquid thermal load on aquatic environment (Issakhov, 2016). The rising concentration of carbon dioxide in the atmosphere leads to a reduction in the pH of water, resulting in water acidification. McNeil and Matear also showed from their empirical study that ocean acidification shall follow the increase in anthropogenic carbon emissions. The lowered pH will impact the marine biological species adversely; hence they raised the concern to stop the future acidification of water by reducing the carbon emissions to atmosphere through activities such as fossil fuel burning (McNeil and Matear, 2006). According to Sweetman *et al.*, pH of water, dissolved oxygen in water, water temperature and food supply of benthic species were the key environmental variables predicted to be altered due to increased carbon emissions (Sweetman *et al.*, 2017). Dixson *et al.* showed through their empirical study that the acidification of water was disrupting the ability of organisms like fishes and snails to detect predators (Dixson *et al.*, 2015). Some nonlinear mathematical models have studied the effect of single or multiple toxicants on single or interacting biological interacting organisms. A model suggested by Shukla and Agrawal regulates a subset of affected population with harsh symptoms such as deformities, infections, blister, etc. (Shukla and Agrawal, 1999). Survival of aquatic biotic species in polluted water was further studied mathematically by Shukla *et al.* The study was conducted on a food chain and modelled using the parameters of pollutant concentration, biological population, bacteria concentration, dissolved oxygen density of protozoa. Through stability analysis and numerical example, it was demonstrated that if the discharge rate of pollutants is made very large, the dissolved oxygen content will decrease and threaten the survival of various species living in water (Shukla *et al.*, 2007). Meyer and Diniz also conducted a mathematical study for effect of pollution in the wetland systems. The significance of the work developed by them is that it can be potentially used for both preventing and cleaning-up strategies in practical environmental assessment processes (Meyer and Diniz, 2007). A mathematical model designed by Mukherjee *et al.* defined the changes in inorganic carbon due to respiration, photosynthesis and calcium carbonate deposition in aquatic systems (Mukherjee *et al.*, 2002). Further Rana *et al.* conducted a mathematical study the effect of nanoparticles released in the aquatic bodies on phytoplankton-zooplankton system and found that these nanoparticles suppress the phytoplankton growth. The food chain was also found to be destabilized via Hopf-bifurcation. They also observed that the depletion /removal of nanoparticles from the aquatic system play a crucial role in both phytoplankton and zooplankton populations' stable coexistence. Moreover, their investigation suggested that out of widely available functional responses, the Beddington functional response represents the interaction of phytoplankton-nanoparticles most appropriately (Rana *et al.*, 2015). The growing carbon content and eutrophication also leads to increase in the algal bloom growth in water bodies which shall be discussed in the next section.

**Impacts of growing algal bloom growth on aquatic ecosystem**

The increased eutrophication under global change is thus likely to cause many harmful impacts such as poor water quality, loss of habitat, biodiversity loss and boom in harmful algal blooms (Rabalais *et al.*, 2009). The carbon content entering water bodies through pollutants and the atmospheric carbon dioxide react with the dissolved oxygen in water forms carbonic acid and lowers the pH of water (Hasler *et al.*, 2018, Raven *et al.*, 2005). Also, excess nutrients enter the water bodies through eutrophication. This increasing pollution and acidic content in water gives rise to algal bloom growth in water bodies (Chapra *et al.*, 2017, Michalak *et al.*, 2013). The increased algal blooms also give rise to oxygen depletion in water as it uses oxygen for the decomposition process (Bhateria and Jain, 2016, O'Boyle *et al.*, 2016). Rabalais *et al.* showed through empirical studies that the harmful algal blooms are increasing manifold which can prove harmful for aquatic and water dependent populations. Glibert *et al.* used a global modeling approach to study the impacts of harmful algal blooms to coastal ecosystems. Through a statistical model, they proved due to the sudden increase in frequency and magnitude of algal blooms due to increasing temperatures, detrimental effects on aquatic life have been seen and these warming conditions have caused contamination of seafood with toxins and disrupted the functioning of the ecological processes of the ecosystem (Glibert *et al.*, 2014). These findings received support by Gobler *et al.* who through their experimental study put forward the finding that intensification of harmful algal bloom due to global warming was leading to an increased human health threat and concern (Gobler *et al.*, 2017). The growth of algal blooms in water due to nutrient discharge in form of agricultural and domestic wastes was deduced from mathematical study conducted by Shukla *et al.* Their model considered the combined interactions of concentration of nutrients, algal density, detritus density and concentration of dissolved oxygen in the water. Through equilibria analysis it was found that with increase in eutrophication, the rate of algal blooms had increased (Shukla *et al.*, 2008). The study carried out by Eltarabily *et al.* also examined the effect of nitrate pollution due to use of nitrogen fertilizer in the central southern part of the Nile Delta using numerical modelling technique (Eltarabily *et al.*, 2016).

**Effect of global warming on aquatic ecosystem**

It is observed that the increased atmospheric carbon dioxide level contributes to global warming (Solomon *et al.*, 2009). Increasing carbon pollution been shown to increase the Earth's temperature by 0.4 K if the carbon dioxide concentration is doubled (Specht *et al.*, 2016).

Among the early authors, Meyer *et al.* examined the theoretical models to examine climate change impacts on freshwater ecosystems. In terms of environmental shifts, they analyzed the intensified risks caused by anthropogenic climate change, modified in stream flows and other consequences such as reducing habitat quality and altering nutrient loading in water (Meyer *et al.*, 1999). Climate change is likely to lead to a decline in freshwater quality and loss of dissolved oxygen (Chapra *et al.*, 2017, Kundzewicz *et al.*, 2008). Hoegh-Guldberg and Bruno demonstrated that climate change could lead to irreversible effects such as altered species distribution, changed food web dynamics, reduced ocean productivity and increased disease probability. Under global warming, the species' metabolic rates are also changed (Hoegh-Guldberg and Bruno, 2010). The climatic changes also influence the flow of matter and energy in an ecosystem (Sarmento *et al.*, 2010). Studies have also revealed that the growth relationships of aquatic species alter due to changes in water temperature (Danovaro *et al.*, 2001, Carstensen *et al.*, 2014). Global warming also contributes to a loss of coral reef biodiversity (Wolff *et al.*, 2018). In order to study the adverse effects of rising atmospheric carbon dioxide due to human activity, Shukla *et al.* suggested a non-linear mathematical model with six complex variables consisting of concentration of atmospheric carbon dioxide, human population, ice sheet size, mean surface temperature and sea level and area of land submerged in water.They found that the rise in carbon can effect the ice sheets by increase in their melting and adversely effect the population size (Shukla *et al.*, 2017). Gleckler *et al.* have demonstrated through their empirical analysis that ocean heat absorption has increased in recent decades due to anthropogenic warming. The increase in carbon emissions in atmosphere shall lead to an increase of ocean temperature of 1 degree and a decrease in the dissolved oxygen in water (Glecker *et al.*, 2016). This will further impact the availability of food for aquatic organisms and alter their growth and survival rates (Sweetman *et al.*, 2017).

### Declining dissolved oxygen in water bodies due to pollution and global warming

One of the troubling effects of the harm caused by climate change to marine ecosystems was the decreased oxygen content of water due to the rising temperature. Global climate change-related ocean warming results in deoxygenation with reduction in global oxygen content and negative effects on ocean productivity and marine habitat (Keeling *et al.,* 2010). In the statistical studies carried out by various researchers such as Joos *et al.*, it has been concluded that the declining oxygen due to global warming is very harmful to aquatic species (Joos *et al.,* 2003). It has been pointed out by Sekerci and Petrovskii in their mathematical study that the changing dynamics of oxygen depletion due to global warming negatively impact the plankton population. Also, the pollution and wastes in water deplete the oxygen level in water. Hence, the aquatic species may die due to condition of hypoxia having negative effects on the functioning of life due to less oxygen (Sekerci and Petrovskii, 2015). Misra *et al.* carried out a mathematical study on the effect of releasing pollutants such as industrial and household organic waste into water bodies and consequently dissolved oxygen depletion (Misra *et al.*, 2006). They developed a mathematical model with variables including zooplankton and phytoplankton concentration and amount of oxygen in water. Kamal *et al.* also developed a one-dimensional water quality model to study the quality of river water of river Buriganga under the effect of industrial and household untreated wastes. They replicated the alarmingly low level of dissolved oxygen in river Buriganaga through model simulations (Kamal *et al.*, 1999).

The mathematical studies available till now have focussed on the depletion of resource, i.e. dissolved oxygen under the single effect of pollution, acidity, algal bloom etc. and the resulting negative results on the aquatic species such as fishes , whales, etc. However, there is no study available which incorporated the effect of two or more factors in a single mathematical model.

## Conclusion and future scope

It is concluded from our study, that the invariably growing water pollution and global warming are having very negative impacts on the aquatic population dynamics. The growing carbon in atmosphere is making the waters acidic and lowering the pH of water. The algal bloom growth is also increasing which is leading to hypoxic conditions in the water bodies. Oxygen levels are further declining due to warmer temperatures of water bodies. These conditions, if continued can lead to mass deaths and impairments in the aquatic species. Various theoretical studies conducted in recent times have highlighted this growing problem of water contamination (Kaur *et al.*, 2017, Patel *et al.,* 2020, Rashid *et al.*, 2016, Shukla *et al.*, 2019, Singh *et al.*, 2018, Singh *et al.*, 2015). Some researches have also aimed at developing measures to combat the issue of water pollution (Bansal and Geetha, 2018, Bhandari *et al.*, 2018, Bhatia *et al.*, 2017, Dhanjal *et al.,* 2018, Garg *et al.*, 2018, Jain *et al.*, 2019, Kandhari and Dutta, 2018, Kanjilal *et al.*, 2014, Karnwal *et al.,* 2018, Kaur *et al.*, 2018, Kaur and Kamboj, 2019, Kushwaha and Gupta, 2018, Parihar *et al.*, 2015, Rahul *et al.,* 2018, Sharma *et al.*, 2016, Sharma *et al.*, 2018, Vise *et al.*, 2018). Many biological processes have been studied using mathematical modelling (Kumar 2014, Kumar 2015, Kalra and Kumar, 2018, Kumar and Kumar, 2019, Sahoo and Patra, 2020, Yadav and Priyanka, 2019, Yadav, 2019, Kalra and Kumar, 2018). We have available mathematical studies, which evaluate the individual effect of a single parameter such as pollution, acidification, global warming etc. on the aquatic populations (He and Wang, 2009, Shukla *et al.*, 2008). However, in future, there is need of mathematical studies which focus on the effects of two or three factors taken together on aquatic populations, evaluated in a single study only. For example, we have a theoretical study by Jansson *et al.* which studies the harmful consequences of combined effects of low pH and hypoxia on juveniles (Jansson *et al.*, 2015), however there is a need of corresponding mathematical study which models the combined effects of pollution, acidity etc. on the aquatic organisms. With the anticipated future negative changes in the supply of oxygen and growing acidity and water toxicity, studying how benthic organisms shall react and adapt to multiple environmental stressors, will be critical to understanding the nature of the environment in the face of change. It shall be essential to develop thresholds for the minimum amount of carbon and pollutants that the aquatic ecosystem can handle. Along with this, mathematical studies calculating the thresholds for the rate of input of oxygen into the water bodies in order to make them capable of sustaining aquatic life under growing pollution and water bodies can also prove helpful in future.

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