



Lake ecosystems as proxies of change in a post-pandemic era

Harini Santhanam^{1,2} · Shalini Dhyani^{2,3}

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Abstract

A wide spectrum of algal–bacterial–viral relationships in aquatic ecosystems provide a complex matrix of interactions with abiotic factors such as temperature, pH and total solids concentrations in water. These relationships are quite reflective of the summative status of changes undergone by the lacustrine environments. However, the environmental risks and vulnerability of aquatic ecosystems in the regions of Global South including India, owing to the increase in sewage and domestic discharges with high loads of viral particles in the post-COVID-19 times have only been sparsely reported. Collective scenarios emerging from the influential factors such as the increase in salinity and total solids need to be explored for scientific significance and understanding. The present article opines that while the changes in the biotic and abiotic factors can enhance or alleviate these risks, identification of the stable and alternate states of the ecosystems make excellent ecosystem level proxies for pandemic-related disturbances at a macro-scale. Further, the need to plan Nature based Solutions to counter these risks under pandemic-like scenarios is discussed.

Keywords COVID-19 · Lake ecosystems · Total solids · Environmental risks · NbS · Pandemic

Introduction

The pulse of interactions between the abiotic and biotic components of a lake ecosystem are sensitive to internal as well as external environmental changes over different spatio-temporal scales. While the internal changes may be sudden and transforming in nature, the external factors in the lakeshore area are participatory—either they alleviate or intensify the internal changes within various degrees of change. A good illustrative example appears in the form of direct and indirect impacts of the COVID-19 scenario on lake ecosystems in countries of the Global South such as

India, as well as the post-pandemic impacts on which sparse literature is accounted for at present (Yunus et al. 2020; Balamurugan et al. 2021). To understand the lake dynamics in the post-pandemic scenario from an ecological perspective, the intricacies involved between lake systems (inter-lake exchanges) as well as inherent ecological dependencies of the units and factors that ‘make’ a lake ecosystem (intra-lake changes) need to be recognised. Charles Darwin’s famous historical observations that the success of survival of clove and flowering plants in a certain region in England could be dependent on the existence of a healthy population of cats provides an interesting example. While at first look, the relationships between the cats and the survival of cloves may seem far-fetched, the ecological connectivity between different populations of organisms becomes apparent, especially with reference to the alteration in the stable states.

Such observations hence led to the theory that the presence or absence of one species or a group of individuals in an ecosystem will always be of consequence to another species or other groups of individuals, both within the same ecosystem or the ones which interacts with them. Applying this idea to the dynamics of lake ecosystems, the internal functional units as well as, the external limiting factors could be considered to constitute a system of ‘organs’ that exhibit feedback relationships within a ‘microcosm’ (Forbes 1887).

✉ Harini Santhanam
ecoharini@gmail.com; harini.santhanam@manipal.edu

Shalini Dhyani
shalinidhyanineeri@gmail.com; s_dhyani@neeri.res.in

¹ Department of Public Policy, Manipal Academy of Higher Education (MAHE), Bengaluru campus, Bangalore 560064, India

² Commission for Ecosystem Management, International Union for Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland

³ CSIR- National Environmental Engineering Research Institute (NEERI), Nagpur, India

If lakes were true ‘organisms’ of some kind, then Forbes’ theory (Forbes 1887) would stand validated and the balance of the prey-predator communities stand crucial to the evolution of lake floral and faunal communities. No two organisms being alike, the differences in lake ecosystems can be expected to be quite distinct as they respond to natural and anthropogenic pressures as a part of the transformations in the post-pandemic world, where a ‘new normal’ in the status of the environment has come to stay (Srivastava et al. 2021), hence functioning as ‘vortices’ of change.

Factors influencing the lake properties under a pandemic scenario

From a scientific perspective, lake systems can be perceived as integrated hydrological units (connected with other systems within a given region) and ecological units, which give rise to the complexity of the processes in operation. It then emerges that from the matrix of these interactions of water quality determinants (such as physical, chemical and biological parameters) with the medium (i.e., water) arise unique changes in the proximal factors, which can destabilise the ambient quality, such as the COVID-19 scenario in different ways such as: (1) direct and immediate changes, (2) subtle changes in near future and (3) long-term ecological changes. Of these, the direct and immediate changes, as well as the subtle changes, can be expected to contribute to unexpected changes in lake water quality especially with respect to several forcing factors in urban environments (Malmqvist and Rundle 2002).

Although the inherent component of seasonality may be dominant, the sudden changes to baselines such as the pH of water, as well as dissolved ionic concentrations, if monitored, can be expected to indicate the sudden fluctuations in the status. Proximate causes associated with the response to COVID-19 scenarios have been associated with the entry of ionic detergents, and volumes of domestic and mixed sewage during the lockdown, post-lockdown and unlock phases in India and other countries. These changes can possibly contribute to our unique understanding of in-lake processes, where the interactions of biotic and abiotic components are concerned, if holistically studied (Sivakumar 2020). Hence, the present work emphasises the larger idea of considering the lakes themselves as proxies of environmental changes as the countries and their citizens navigate the COVID-19 and the post-pandemic phase. On the other hand, it would be difficult, but nevertheless important, to plan for continuous observations of the biological indicators, which can cause simultaneous regime shifts in lake biotic communities over differential time scales. One significant perspective in this direction highlighted here is to consider the algal–bacterial – viral relationships in the lake waters especially under

the parallelly evolving impacts of climatic changes. An understanding of the feedback roles of bacteria, algae and viruses in water can be derived by exploring the pair-wise linear (e.g. bacterial-algal; bacterial-viral; algal-viral) and non-linear relationships, (i.e., algal–bacterial and bacterial-viral with the influence of abiotic factors). The Microbial Loop hypothesis (Azam et al. 1983) provides the basis for exploring such relationships between bacteria, phytoplankton and zooplankton in aquatic systems. The study illustrated the feedback mechanism in operation, which returned the dissolved organic carbon (DOC) assimilated by bacteria as particulate organic matter (POM) through trophic interactions between bacteria, flagellate and ciliate planktons in water (Fig. 1).

The survival and productivity of microbial and algal communities are hence known to be closely interlinked in aquatic systems. The POM released by bacterial assimilation provides support for growth and production of phytoplankton, thereby reflecting an increase in the concentrations of the algal photosynthetic pigment, chlorophyll-a (Maranger and Bird 1995). Thus, the increase in chlorophyll-a concentrations and dissolved total phosphates are known to correlate with increased bacterial abundances in water. Further, heterotrophic bacteria have also been known to form a large part of the diet of the grazing zooplankton (Tijdens et al. 2008).

On the other hand, it is interesting to note the relationships between the viral particles and the heterotrophic bacteria as shown in Fig. 2. Observations on biotic communities at Lake Loosdrecht (The Netherlands) established that the

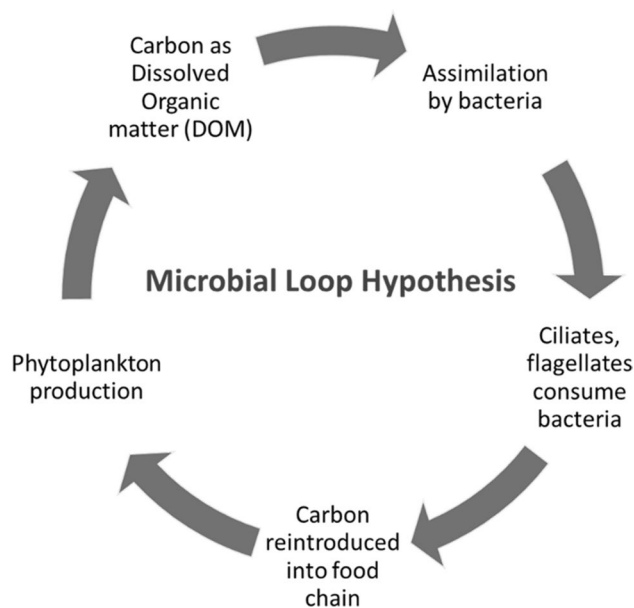


Fig. 1 Microbial loop hypothesis (Azam et al. 1983) illustrating the relationships between organic carbon and microbial communities in aquatic ecosystems

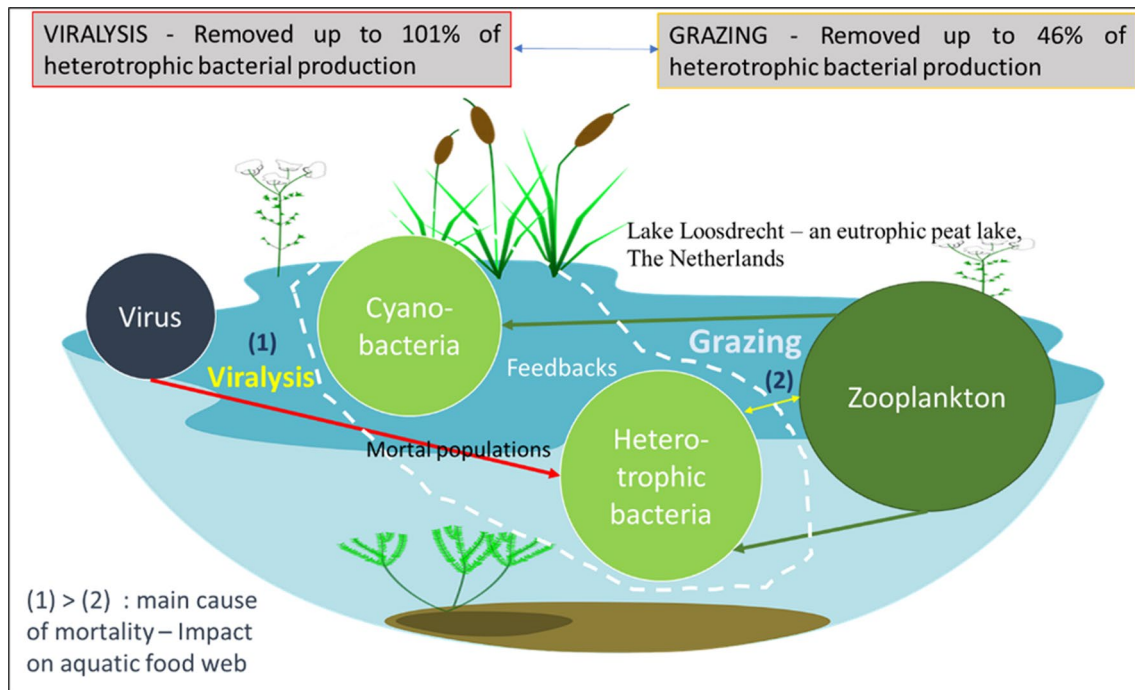


Fig. 2 Trophic relationships between phytoplankton, cyanobacteria, zooplankton with bacteria and viruses of relevance to study the impacts of COVID-19 in aquatic ecosystem (adapted from Tjeldens et. al. 2008)

process of viral lysis of bacterial cells (i.e. virus-induced lytic cycles of bacterial cells) was a dominant process triggered by the forcing factors such as eutrophication and increase in total solids concentrations. These lytic processes have been known to exert a feedback control on the natural bacterial and hence algal populations, via the DIC-POC as discussed earlier (Maranger and Bird 1995), indicating the fragile relationships between bacteria, viruses and zooplankton under the influence of abiotic factors (Tjeldens et. al. 2008). While the study belonged to a non-COVID period, it nevertheless seems to be an important perspective to examine feedbacks between heterotrophic bacteria and presence of viral particles in aquatic environments, which can accelerate the deterioration of the lake environments without direct human infringement and solid wastes pollution. Dhama et al. (2021) reported the presence of “SARS CoV-2” RNA in sewage and wastewater associated with high total dissolved solids (TDS) and total solids concentrations. In the light of such possible changes to the abiotic environment posed by COVID-19, in the present post-pandemic era such as increased solids due to entry of biomedical wastes in domestic wastewater streams into isolated or urbanised lake basins (Manoiu et al. 2022), it is possible that via the feedbacks between the microbial communities the ecosystems may reach several alternate states as well, with improved resiliencies against excessive eutrophication. It has also been proven through global research reports that among the various impacts of climatic change, the relationships between the abiotic factors such

as turbidity or total solids and the production characteristics of bacterial and viral populations are quite significant. Increases in the total solids concentrations through cultural eutrophication have a direct bearing on biotic survival in shallow and urban lake environments (Lin et al. 2021).

Some environmental factors which have been reported to impact these relationships include the ambient temperature and pH of the medium (i.e. water), the concentrations of TDS and total phosphates (Suttle and Chen 1992; Weinbauer et. al. 1993; Jiang and Paul 1994; Maranger and Bird 1995). There also seems to be distinct differences in the bacterial-viral-algal relationships in freshwater as well as marine lacustrine ecosystems, which needs closer examination. Further, survival and productivity are known to be related to salinity and the presence of solids (Maranger and Bird 1995). An increase in salinity, as well as the solids concentrations, are known to impact the thermal habitats in lakes, with special reference to shallow water environments, likely to alter the phenology of the organisms in response to these changes (Hansen 2021).

It hence emerges that viruses in aquatic systems, known to be responsible for lysis of bacterial cells, may exist in the medium as concentrated and non-concentrated populations, illustrating various scales of lytic activities. It has been reported that about 300 viruses may be released per 100 cells of native bacteria per lytic cycle, which maintain the normal feedback with bacterial production (Maranger and Bird 1995). Further, high rates of bacterial lysis possibly

correlates with high phytoplankton densities, nutrient-rich, eutrophic ‘algal bloom’ conditions as shown by a recent study in Dongting Lake in Wuhan, China (Kim 2020). While, Singh and Haq (2021) identified the wastewater as major route of transmission for the viral particles, Farkas et al. (2020) had earlier indicated the need for wastewater surveillance for viruses in urban areas with special emphasis on the COVID-19 viruses. Daughton (2020) emphasized that wastewater-based epidemiology for COVID-19 viral particles could provide a better methodology than insufficient clinical testing of human population, as a means to diagnose the magnitude and the spread of the pandemic. This is particularly true in the case of resource-constrained regions of the world such as the Sub-Saharan Africa, where wastewater surveillance of aquatic systems could provide a reliable proxy helping management of the pandemic (Street et al. 2020). The addition of novel viral particles to the water systems in India is a high possibility, given the inadequate number of sewage treatment plants (STPs) in the country, inefficiency of even operating STPs, leading to long residence times of the viruses in the aquatic systems (Bhowmick et al. 2020). This situation is a possibility in other developing as well as underdeveloped countries of the Global South, as well where in the absence of other high-resolution proxies, the lake ecosystems themselves can be excellent indicators of the changes and should be considered as ‘ecosystem-level proxies’ under pandemic as well as post-pandemic scenarios.

Investigating the algae-bacteria-viruses relationships with respect to pandemic and providing appropriate nature-based solutions

In this context, the immediate need to examine the spectrum of algae-bacteria-viruses interactions in aquatic systems seems to be very significant approach, especially given the adverse relationship between bacteria and viruses in the perspective of their interactions with the abiotic factors such as salinity and total solids within a lake. Further, the typology of the lake, its geomorphology and water recirculation characteristics are all significant factors that can either enhance or alleviate the risks of the entry of viral particles into the aquatic systems. Observations on the quantitative dependence of viruses on bacteria in short time scales as well their lytic cycles correlated with inputs of nutrients and solids into the lakes with respect to Indian conditions need to be explored to assess the risk of the entry of the viral particles through non-point sources. High viral abundances correlate with eutrophic conditions, higher in-situ temperatures, low non-specific adsorption to particles and these relationships need to be assessed further in finer details to understand the complexity of the issue. Finally, the inadequacies in the

management and treatment of domestic and mixed sewage streams need to be addressed and the risk of spread of any novel viruses through water medium needs to be factored for futuristic measures.

Nature based Solutions (NbS) have emerged as an efficient approach that has proven potential to address the inadequacies in the management and treatment of domestic and mixed sewage streams (Vymazal 2010). With inefficient STPs and lack of sufficient and regular supply of electricity to run these sewage plants, mainstreaming of NbS is one of the effective solutions (Dhyani et al. 2020). Presently, constructed wetlands and allied technologies that use grey water are well recognised across the world and also in Global South. NbS for treating grey water are reliable wastewater treatment technology that can help to conserve the ecosystem health of the natural fresh water wetland ecosystems as well. NbS based constructed wetland technology needs further enhanced adoption and implementation in ongoing pandemic as well as post pandemic times especially in developing and underdeveloped countries to treat domestic sewage that is less in trace metals and chemicals but high in mixed bacterial and viral populations to reduce chances of health hazards. There exist key concerns regarding the scale and design but more research in the direction is required to clarify the doubts and concerns. NbS can help to reduce eutrophication and enhanced concentration of viral and bacterial loads in the freshwater wetlands that are constantly being contaminated not just because of the increasing sewage load but also due to irresponsible disposal of the solid waste and sewage originating from households.

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Declarations

Conflict of interest The authors state that the present paper is an original work which has not been submitted for review or consideration elsewhere. The authors declare no competing interests.

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