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Microcystis aeruginosa bloom, a looming threat to high altitude Lake Tsokar in Ladakh, India

Aniket Kumar
Department of Environmental Sciences, Dyal Singh College, Delhi, India

Abstract
Blue green algae are known to form algal blooms in many parts of the world. *Microcystis* sp is colony forming bloom seen in hypersaline lake Tsokar in Ladakh. The lake was studied for three years from 2011-2013 and sampling of phytoplankton and water sample for various parameters was carried out in early summer and late summer season. Nutrient enrichment with high phosphate content with presence of *Microcystis aeruginosa* bloom was seen in late summer in the lake. The formation of algal bloom in late summer each year dominated phytoplankton with decreased diatom density in the lake. The high salinity, nutrient enrichment in the lake and presence of *Microcystis* bloom may affect ecology of the lake in the future. The nutrient enrichment needs to be reduced for reducing algal blooms and keeping the lake healthy.

Keywords: eutrophication, *Microcystis*, Himalaya, high altitude lake

Introduction

Microcystis spp. species have been reported as one of the bloom formers in freshwater and saltwater lakes leading to toxic effects. Various factors like nutrient enrichment, stagnant water, rising temperature, etc. are attributed to the bloom formation of *Microcystis* spp. (Otten *et al*. 2012) [14]. Primarily, the anthropogenic activities, which trigger the nutrient repletion in water bodies are foreseen to facilitate the conducive environment for algal blooms (Schindler *et al*. 2008) [21]. In present scenario where climate change and nutrient loading has been reported from high altitude lakes across the world, the study of these high-altitude lakes becomes more important where these lakes are known to be pristine, healthy and a huge support to healthy ecosystem. Notably, high elevation areas of Himalaya are highly vulnerable to the climate change (Pandit 2017) [3]; it has also been established that occurrence of harmful algal bloom will increase with climate change and in more warmer areas (Peperzak 2003) [19]. Major socio-economic and environmental consequences led by the blooms of *M. aeruginosa* include the depletion of dissolved oxygen contents, bad odour and taste, human health problems due to high concentration of hepatotoxic microcystins and harmful impacts on aquatic life (Lehman *et al*. 2005; Tonk 2007) [10, 24].

The lakes in the Himalayan region are lifeline to existing fauna and flora that survives in harsh environmental conditions. The lakes in the Ladakh region provides sojourn to livestock and feeding grounds of wildlife with existing pastures in the vicinity. The present study area namely Tsokar lake is located in Ladakh region of India at 4500 m asl. This study is aimed to provide the first information on the spatial distribution, characterization of algal bloom, habitat characteristics and its impacts on the other aquatic life. Such information would be useful in providing the baseline data that can used in the monitoring programs and future impacts of blooms in the surrounding areas.

Materials and Methods

Study Area

Tsokar Lake lies in the Trans Himalayan region of Ladakh, located at an elevation of ~4550msl, approximately 160 km south of Leh town in Changthang region of Tibetan Plateau. Geographically, the lake is located between 33º 18" N latitude and 78º 02" E longitude The Changthang region is a semi-arid dry desert with annual rainfall precipitation <95 mm. The Tsokar lake is an endorheic lake with area of 18 km^2. The northwestern part of the Tsokar lake has large borax deposits which has rendered the lake more saline.

Water Sampling and Analyses

In order to assess the impact of water quality on algal bloom, detailed characterization of physical and chemical parameters of Tsokar lake was carried out. A total of 5 sites were selected in the lake. For each parameter, three replicates were taken. The parameters like water temperature, pH, electrical conductivity, total dissolved solids (TDS), salinity, turbidity and dissolved oxygen were measured at the sampling sites. Water temperature was measured with the help of graduated thermometer (in °C). We used pHTestr 3 for pH, TDScan3 for electrical conductivity, TDScan1 for TDS and SalTestr for salinity measurement (Eutech Instruments, Singapore). Turbidity was measured by using portable nephelometer-TN-100 (Eutech Instruments, Singapore). Dissolved oxygen (DO) was measured with the help of dissolved oxygen test kit (Aquamerck, Germany), which is based on Winkler's iodometric method. Rest of the parameters, such as alkalinity, chloride, total hardness, calcium hardness, magnesium hardness, sodium, potassium, iron, silicate, sulphate, nitrate ($N\text{-}NO_3$) and phosphate ($P\text{-}PO_4$) were determined in the laboratory. For this reason, samples were collected in a sampling bottle and

Brought to the laboratory for further analyses. However, prior to sample collection bottles were rinsed with the water from lake/stream. The samples were stored in dark and cool place at 4ºC till further analysis. Standard methods of analysis given in APHA (2005) and other published sources were followed to assess the various physico-chemical parameters.

Ecological Data

The Tsokar lake was sampled for three consecutive years for phytoplankton during two seasons-early summer (April-May) and late summer (August-September). Five sites in each season were sampled, each with three replicates. The center of the lake could not be sampled because of lack of accessibility due to logistics constraint. Plankton samples were retrieved by filtering 50 litres of water through plankton net of 25 u mesh size. The residue left, was transferred with a fine brush to a 50 ml sampling vial and preserved in Lugol's solution and brought to the laboratory for further analysis. (see Bhatt *et al*. 2008, 2012) [3].

Diatom density in the benthic as well as planktonic forms was calculated with the help of drop count method. We followed drop count method to determine the density of phytoplankton (see Adoni, 1985) [1]. Blue green algae were identified with the help of phase contrast microscope at 40x.

Results

The physico-chemical parameters with two different seasons are given in Table 1. In the physical and chemical characteristics of Tsokar lake, significant variation was calculated for water temperature ($p<0.001$), turbidity ($p<0.01$), total dissolved solids ($p<0.05$), salinity ($p<0.05$); electrical conductivity ($p<0.05$), sodium contents ($p<0.01$), potassium ($p<0.05$) and sulfur contents ($p<0.05$). The values of all characteristics except sulfur contents increased significantly from early summer to late summer. The nitrate content in the lake remained constant but other important nutrient phosphate increased significantly ($p<0.01$) from early summer to late summer from 1.27±0.51 mg/l to 7.53±1.06 mg/l. The silicate required for growth of diatoms was found to slightly decrease from 7.6±1.67 mg/l in early summer to 6.11±0.94 mg/l to late summer.

In the planktonic sample the density of the diatoms was found to be 4618±2614 in early summer and 1072±574 cells/l in late summer (Figure 1.1). The blue green algae consisted of *Microcystis aeruginosa* and density was found to be 1063±382 cells/l in early summer and sharply increased to 14,554±3073 cells/l in late summer. The algal bloom can be easily observed during late summer (See figure 1.2). The diatom community was dominated by *Nitzschia* and *Stauroneis* sp, and *Microcystis* sp dominated the BGA community.

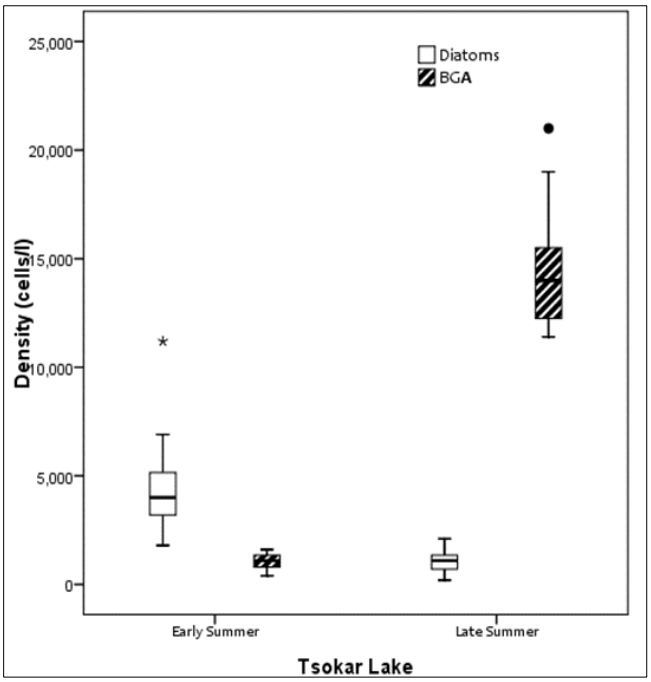

Fig 1: The boxplot shows the variation between density of BGA and diatoms in early summer and late summer.

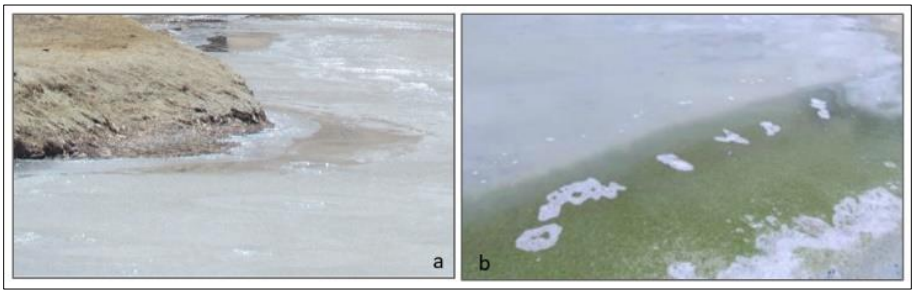

Fig 2: Tsokar lake in a) early summer and b) late summer with algal bloom.

Table 1: Physico chemical variables in two sampling seasons in Tsokar Lake

Lakes	Tsokar	
	Early Summer	Late Summer
Water Temp (ºC)	10±0.5	14±0.2
TDS (mg/l)	4254±624	104985±11023
Turbidity (NTU)	2.19±1.1	5.03±2.3
Electrical Conductivity (µS)	74460±10650	178346±17936
pH	8.78±0.23	8.64±0.15
Salinity (ppt)	38±14	69±10
DO (mg/l)	1.57±0.38	1.56±0.59

Alkalinity(mg/l)	854±172	1684±203
Total hardness (mg/l)	22850±15880	27829±4894
Ca hardness as $CaCO_3$ mg/l	2682±1425	5949±2300
Mg as mg/l	3538±1896	4914±485
Sodium(mg/l)	72±1.1	6710±121
Potassium(mg/l)	112±16	3393±511
Chloride(ppm)	14373±5460	12431±1413
SO_4 mg/l	3.29±2.82	1.60±0.96
Silicate mg/l	7.67+1.67	6.11+0.94
Nitrate(mg/l)	2.5±0.3	2.59±1.25
PO_4-(mg/l)	1.27±0.51	7.53±1.06
Total iron (mg/l)	0.08±0.03	0.14±0.13

Discussion

The hydro-chemical characters of the Tsokar lake are attributed to geomorphology, regional climate and human settlements. With minimal precipitation the main source of discharge is from the overflow of nearby springs. This surface runoff carries salts and sediments to the lake. The diatoms dominated in early summer when there was fresh feed of water from springs and ice water was melting but as the summer progresses the average temperature increases and density of BGA's also increased. Two most important reasons are, firstly, the increase in temperature increases the nutrient availability to the cells, and secondly the presence of gas vacuoles in BGA helps it to remain afloat to favorable light and temperature (Michalak *et al*. 2013) [12] whereas, diatoms sink with weak buoyancy mechanism (Wagner and Adrian, 2009; O'Neil *et al*. 2012) [26, 13]. In the present study *Microcystis* flourished in high salinity (>55ppt) environment, whereas in early studies it has been observed from salinity up to 20 ppt (Tonk 2007; Preece *et al*. 2017) [24]. Phytoplankton community in the lake comprised of diatoms and BGA dominated by diatoms genera like *Navicula*, *Nitzschia* and *Surirella*, which are known to be tolerant to high salinity and eutrophic conditions and BGA consisting of *Microcystis* and *Planktothrix sp*.

The environmental variables, which have been reported to determine the dominance of *M. aeruginosa*, are nutrient, mainly phosphate that is mostly available from the sediments (Trimbee & Harrris 1984). The phosphate concentration was found to increase in late summer as release of phosphate from sediments takes place under the conditions of depleted oxygen in water column in bloom environments (Dokulil & Teubner 2000) [5]. The *Microcystis* sp is a non-nitrogen fixing cyanobacteria thus not only phosphate but also availability of nitrate is a major nutrient concern for these algae. They are known to dominate planktonic assemblages during warmest period of the year (Paerl and Huisman 2008; Liu *et al* 2016) [17, 11]. The low density of diatoms in late summer could be attributed to dominance of *Microcystis as* HAB's like *Microcystis* are known to secrete Microcystin, which are harmful to plants and other planktons.

Previous studies have also shown *Microcystis* to affect the population of diatoms (Paerl *et al*. 2016). The studies have suggested that *M. aeruginosa* can affect phytoplankton composition through allelopathy i.e inhibition on the growth of other plants with the release of chemical compounds (see Sukenik *et al*. 2002; Legrand *et al.* 2003). *Microcystis* is known to produce an array of metabolites including microcystin, organic and amino acids, peptides, alkaloids, carbohydrates, and lipopolysaccharides (Lehman *et al*. 2010) [10], that promote its invasibility in aquatic systems and affect higher trophic levels (Paerl *et al*. 2001; Smith *et al*. 2008) [22]. *M. aeruginosa* species is one of the few freshwater blue green algae which have become a global concern because of their increasing distribution and abundance in water bodies the world over except Antarctica (Fristachi and Sinclair 2008) [6]. Though effect of *Microcystis* is being studied extensively, its potential impact on the structure and function of aquatic biota is not fully understood (Ibelings & Havens 2008). Thus, the *Microcystis* blooms probably depend upon more than one environmental factor and their response to plankton community is variable as has been established in earlier studies (Graneli *et al*. 2008) [7].

The presence of *Microcystis* blooms has the potential to harm the aquatic biota in the Tsokar lake. The health of the ecosystem is threatened as it could be dispersed with water birds or the livestock in the vicinity of the lake that accompanies the nomads. The nutrient discharge in the lake needs to be controlled for protection from blooms. The watershed managers should look for all non-point sources and save the lake from eutrophication.

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