State of Water Quality of Two Tropical Urban Lakes Located at Mumbai Megacity

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Abstract: ***The study focused on identifying the significant physico-chemical parameters to understand the prevailing water quality conditions of two urban lakes located at Mumbai megacity. Out of the different water quality parameters analyzed, biochemical oxygen demand, total organic carbon, ammonia, alkalinity and minerals showed higher mean values in Powai Lake compared to Vihar Lake. Physico-chemical parameters were subjected to factor analysis to decipher the significant factors loaded with parsimonious variables which can explain the total variation. Two factors extracted explained the cumulative variation of 62.75% and showed significant loadings of water quality parameters. Separation of Powai and Vihar lakes with respect to water quality parameters is quite evident based on score plot. Powai showed higher score coefficients for the two factors in comparison with Vihar. Phytoplankton evaluation was carried out to determine the trophic status of both the lakes and identified mesotrophic condition in Vihar and eutrophic condition in Powai. The study also identified substantial reduction in Powai Lake area in recent years which will exacerbate the lake pollution. The findings will serve as baseline information for detailed studies in near future and also helps in devising remedial measures to prevent the deterioration of health of the lake ecosystem.***

Keywords: Factor analysis, Powai Lake, Vihar Lake, Algal indices

1. Introduction

Aquatic ecosystems contribute to biodiversity on the earth's surface. The quality of aquatic systems has now become a serious concern due to its direct effects on aquatic and human health. Lake water is a source for drinking and domestic purposes for both rural and urban population of India [1]. The rapidly expanding human population within the catchment area of lakes has brought about a series of changes in its biotic components [2]. Unplanned urbanization, rapid industrialization and indiscriminate use of chemicals as fertilizers are causing substantial pollution in aquatic environments, leading to the deterioration of water quality and depletion of aquatic biota [3]. The over-exploitation of water for irrigation, drinking and industrial purposes has caused a drastic decline in the quality and quantity of available water in recent years. It has not only caused a perceptible decline in the water table, but also has resulted in enormous increase in pollutant concentration. Eutrophication, a result of high-nutrient loadings (mainly phosphorus and nitrogen), is the major concern in lake systems. It substantially vitiates the beneficial use of water in lakes and reservoirs.

The proper knowledge of the prevailing water quality condition is necessary to understand the hydrobiological characteristics and their ecological interrelationships. A previous study which was carried out in Powai Lake, Mumbai, concluded the positive correlations between productivity and physico-chemical properties of water [4]. Hence, the rigorous monitoring and periodic assessment of water quality is relevant in adopting proper management measures for environmental problems. The studies will be relevant and informative when the comparison of one ecosystem is carried out with another similar ecosystem.

The planktonic study is a very useful biological tool for the assessment of water quality in any type of water body and it also contributes to the understanding of the basic nature and general ecology of the lake [5]. Algae are useful for the estimation of the environmental impact on aquatic ecosystems due to the quick response to changes in the environmental condition enabling a quick assessment of the prevailing water quality [6]-[8].

The analysis of physico-chemical parameters can infer better results if the data are adequately processed. Different statistical approaches were followed for the assessment of water quality data based on various multivariate techniques [9] - [14]. In this study, we used factor analysis, a multivariate statistical method in which, the initial set of variables is substituted by a smaller group of factors or hypothetical variables, which preserve as much information contained in the original variables as possible [15]. Factor analysis identifies and quantifies the basic standards of variation in the data set, and allows the construction of an index that accounts for the variability with a smaller and simpler number of vectors than those obtained using the original data [16]. By applying this technique, it is possible to evaluate the existence of associations between the variables, to determine the degree of relevance of each one in the environmental diagnosis, and to compare the sampling units over time and space, detecting the existence of trends [15]. The lakes and surface water bodies often face the threat of reduction in their area due to developmental activities. This reduction in lake volume can affect the assimilative capacity of lakes for various pollutants.

Thus, the present situation demands a rigorous investigation of water quality status of the lakes in order to generate baseline information for its sustainable usage. Therefore, this study was carried out in two lakes located at Mumbai to assess the status of water quality on the basis of physico-chemical parameters and algal indices.

2. Materials and Methods

2.1 Study area

Mumbai, situated in the state of Maharashtra along the west coast of India, is a coastal megacity (with population more than 10 million), as well as the commercial capital of the country. Along with the elevated population level, the region is also heavily industrialized, which adds other pollutant loading to the region [17]. Heavy industrialization and urbanization in the city have deleterious effects on the environment, especially the aquatic ecosystems. Powai and Vihar are two artificial lakes situated in northern Mumbai. Both the lakes were created for drinking water purpose by constructing dams between two hillocks across Mithi River. Powai- Kanheri hill range forms the catchment area for both the lakes. Powai Lake is situated in the suburban area and the water is used only for non-potable purposes, i.e., gardening and industrial purposes as the water quality has deteriorated. Vihar Lake is located near Vihar village within the precincts of the Borivali National Park, also called the Sanjay Gandhi National Park, and so protected. The information on the sampling points from these two lakes is given in Figure 1 and Table 1

Table 1: Summary of sampling area selected for the study

Attribute	**Lake**	
	Vihar	**Powai**
Location	Sanjay Gandhi National Park, Mumbai	Northern suburb of Mumbai
State	Maharashtra	Maharashtra
Lake type	Reservoir, Fresh water	Reservoir, Fresh water
Construction year	1859	1891
Primary inflow	Mithi River	Mithi River
Catchment area	18.96 km^2	6.61 km^2
Maximum depth	34 m	12 m
Surface elevation	80.42 m	58.5 m

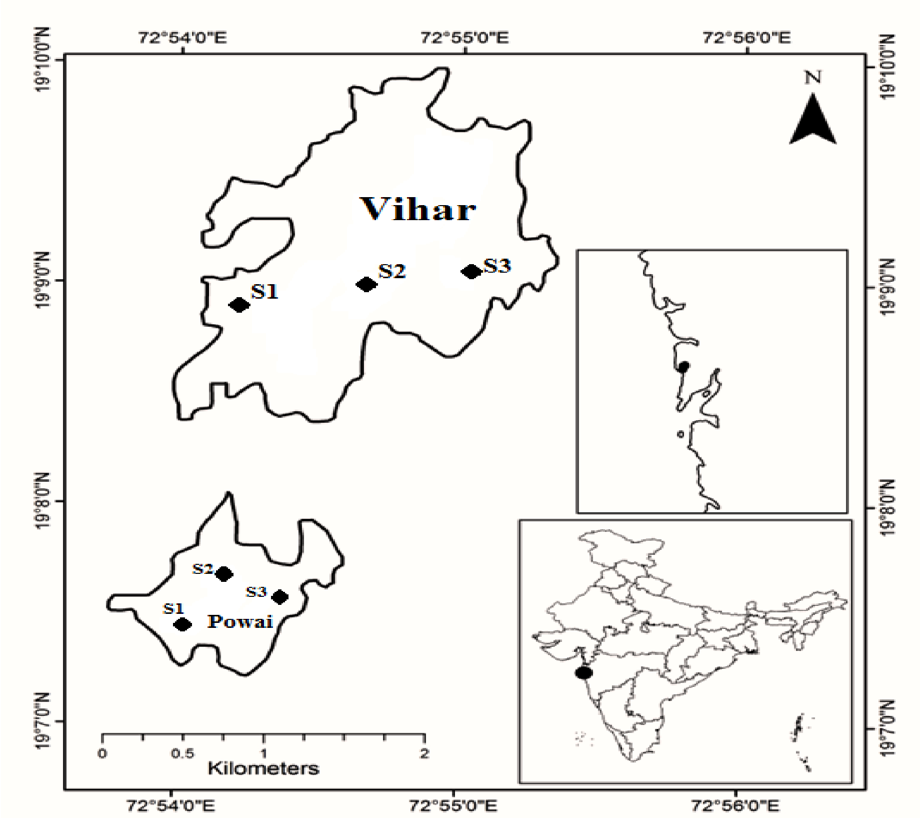

Figure 1: Sampling stations selected from Powai and Vihar Lake

2.2 Collection and Analysis of Samples

Monthly sampling was carried out to measure selected water quality parameters and for phytoplankton analysis from the three selected sampling stations of each lake; water samples were collected during the morning hours in triplicate. Water samples were collected in plastic bottles, properly labeled and preserved as per the American Public Health Association Standard Method for Water and Wastewater Analysis [18]. A total of 22 physico- chemical parameters: water depth, water temperature, transparency, pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), total alkalinity (TA), reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total carbon (TC), total organic carbon (TOC), sodium, potassium, calcium, and heavy metals such as copper, chromium, nickel, iron, magnesium and lead were recorded. The samples were filtered through Whatman Filter Paper

Number 1 and were preserved at 4ºC. All the parameters were analyzed according to APHA (2005). EC, pH and temperature of water samples were measured in-situ using conductivity meter (Eutech Instruments, Singapore), a pH meter (Eutech Instruments, Singapore) and thermometer (G H Zeal Ltd, England), respectively. The dissolved heavy metal concentrations in the filtered and digested samples were determined using flame atomic absorption spectrophotometry (AAnalyst 800, Perkin Elmer, USA).

2.3 Algal indices

Phytoplankton are the primary producers in the aquatic ecosystems. The number and species of phytoplankton give insights on the quality of a water body [19]. For analyses, the plankton samples were collected using bolting silk cloth (No. 25) plankton net of 50 cm diameter from each sampling station. The plankton samples were collected and concentrated to 50 ml by filtering 50 L of water from the respective site. The collected plankton samples were preserved in 0.4% Lugol's solution for further qualitative and quantitative analyses. Organisms were identified using keys and monographs [18], [20]- [25]. Based on the assessment of algae, the extent of pollution in a water body can be evaluated on the basis of algal pollution indices. If there were 5 or more cells of a particular kind of algae on a slide, the algae were identified and recorded, and those which were present in all the six samplings where only considered for further analysis. In the present study, an attempt was made to evaluate the water quality of both the lakes using Nygaard's [26] algal index and Palmer's [27] indices. According to Nygaard, certain algal groups are indicative of the levels of nutrient enrichment. Palmer's index is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. So, we used Nygaard's and Palmer's indices to evaluate the organic pollution in the lakes.

2.3.1 **Nygaard's index** (compound quotient)

Nygaard proposed five indices to evaluate the organic pollution of water bodies based on various groups of planktonic algae. These indices include cyanophycean or myxophycean index, chlorophycean index, bacillariophycean index, euglenophycean index and a combination index for all these known as the compound coefficient. All these indices are useful in the determination of the trophic status of a particular lake. The calculation is based on the fact that some algae have the capacity to grow and multiply even in polluted aquatic environment. Such specific algal groups are considered to represent organic pollution. The oligotrophic or eutrophic status is based on the calculation of these indices proposed by Nygaard. In the present study, we used Nygaard's compound quotient to evaluate organic pollution. The formula (1) used for calculating Nygaard's compound quotient, CQ is the following:

$$CQ = \frac{(N_{CN} + N_{BA} + N_{CH} + N_{EU})}{N_{DS}} \quad \ldots\ldots\ldots\ldots (1)$$

Where, N_{CN} = Number of cyanophyceans
N_{BA} = Number of bacillariophyceans
N_{CH} = Number of chlorophyceans
N_{EU} = Number of euglenophyceans
N_{DS} = Number of desmidaceans

The underlying assumption about CQ in estimating the trophic state of a lake follows:
CQ ≤ 2 is oligotrophic, CQ between 2 to 6 is weakly eutrophic, CQ > 6 is eutrophic

2.3.2 Palmer's Index

Palmer's Index is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. A pollution index score of 1 to 5 has been assigned to each of the 20 types of algae that are most tolerant to organic pollution. The most organic pollution-tolerant algal types were assigned a score of 5. The scores obtained for individual algal taxon are presented in Table 2. Any algae that are not listed will have a score of zero. A total score of 20 or more reflects high organic pollution. A score of 15-19 indicates probability of organic pollution. A score of less than 15 points means low organic pollution.

Table 2: Score card for palmer's pollution index

Name of taxon	**Score**
Ankistrodesmus	2
Chlamydomonas	4
Chlorella	3
Closterium	1
Cyclotella	1
Euglena	5
Gomphonema	1
Melosira	1
Navicula	3
Nitzschia	3
Oscillatoria	5
Pandorina	1
Phacus	2
Phormidium	1
Scenedesmus	4
Stigeoclonium	2
Synedra	2

2.4 Statistical analysis and lake area calculation

The data on the arithmetic mean with standard error were calculated for each physico-chemical parameter using PROC MEANS procedure of SAS (2010). Further, the measured physico-chemical parameters were subjected to factor analysis to identify the important factors based on the loadings of various variables on them. PROC FACTOR procedure of SAS (2010) was used for the factor analysis

using VARIMAX rotation option. In the present study, differences in the area for Vihar Lake and Powai Lake at temporal as well as spatial scale were calculated. Satellite imageries from Landsat MSS for 1973 and Landsat 8 for 2014 were used in the GIS environment to calculate the differences in area. Raster data imagery was converted in vector data in forms of polygons for study area and the difference was calculated using Arc GIS 10.1.

3. Results and Discussion

The water temperature and transparency were observed to be high in Vihar Lake than in Powai while Powai always showed higher pH and EC in comparison with Vihar during the study period. DO was observed to be high in Vihar and BOD was higher in Powai. High levels of alkalinity were observed in Powai during the sampling period in comparison with Vihar. The organic matter in water bodies resulting from metabolism and from external sources such as waste water contributes to the decrease in DO and increase in BOD in the water column. The leveling of hills near Powai Lake for residential purpose and urbanization lead to soil erosion and siltation, and disposal of untreated sewage and solid waste into the lake. But Vihar is comparatively less disturbed by anthropogenic activities since it is located inside the national park.

The samples from Powai showed higher values of reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, TC, TOC, sodium and calcium in comparison with Vihar whereas potassium concentration showed higher range in Vihar Lake.Organically polluted waters have normally higher concentrations of ammonia, which is a product of ammonification of organic matter [28]. TOC provides an important role in quantifying the amount of organic contamination in water [29]. With reference to ammonia and TOC, Powai was showing higher organic load in comparison with Vihar.

Higher concentrations of iron, copper, chromium, nickel and lead were observed in Vihar Lake compared to Powai. However, the concentrations of all the trace metals studied were found to be below the critical limits and national standards in both the lakes. The minimum value, maximum value and the mean value of all the water quality parameters analyzed from both the lakes during the study period are shown in Table 3.

Table 3: Water quality parameter data

No.	Parameter	Powai lake			Vihar lake		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
1.	Water temp (°C)	20.33±0.33	26.33±0.33	22.96	21.33±0.33	27.67±0.33	23.78
2.	Transparency (cm)	59.33±0.33	84.33±0.33	73.87	83.00±1.52	109.33±0.70	92.65
3.	pH (no unit)	7.8±0	8.4±0	8.01	7.50±0	7.9±0	7.71
4.	EC (mS/cm)	0.30±0	0.43±0	0.35	0.10±0	0.24±0	0.14
5.	DO*	3.58±0.023	7.19±0.27	5.04	5.6±0.14	8.8±0.12	6.65
6.	BOD*	1.77±0.067	4.68±0.24	3.05	0.92±0.05	2.11±0.08	1.46
7.	Total alkalinity*	136.10±2.01	159.00±2.52	144.95	46.47±1.10	66.50±0.97	54.06
8.	Reactive phosphorus*	0.087±0.002	0.210±0.01	0.1370	0.010±0.001	0.182±0.001	0.1044
9.	Nitrate-nitrogen*	0.366±0.005	0.622±0.003	0.4971	0.123±0.006	0.321±0.005	0.2331
10.	Ammonia-nitrogen*	0.061±0.002	0.556±0.010	0.2696	0.037±0.002	0.332±0.007	0.1211
11.	Sodium*	10.13±0.384	24.23±0.145	20.48	1.47±0.07	9.30±0.60	5.50
12.	Potassium*	6.33±0.088	11.07±0.033	8.36	10.90±0.06	12.30±0.058	11.33
13.	Calcium*	14.21±0.116	31.47±0.088	25.55	1.73±0.21	7.13±0.07	4.29
14.	Magnesium*	2.78±0.003	10.32±0.031	6.71	3.91±0.0109	12.17±0.030	6.58
15.	Total carbon*	56.52±0.14	88.04±0.43	65.89	17.83±0.29	32.79±0.67	23.39
16.	TOC*	24.04±0.99	47.85±0.42	30.36	6.31±0.17	22.57±0.58	11.97
17.	Copper*	0.004±0.0003	0.015±0.0003	0.0066	0.0027±0.0003	0.0377±0.0262	0.0195
18.	Chromium*	0.001±0.0006	0.004±0.0006	0.0027	0.0037±0.0009	0.0197±0.0015	0.0081
19.	Iron*	0.114±0.001	0.485±0.001	0.2826	0.106±0.0032	0.844±0.0279	0.4512
20.	Nickel*	0.0213±0.002	0.0357±0.002	0.0312	0.0187±0.0037	0.043±0.0015	0.0269
21.	Lead*	0.0035±0	0.0053±0	0.0044	0.0038±0	0.0054±0	0.0048

*represents mg/l

The water quality parameters were subjected to factor analysis to find out the significant factors loaded with parsimonious variables which could explain the total variation between the two lakes. Sampling adequacy was observed with respect to the Kaiser-Meyer-Oilkin measure of 0.831 for factor procedure. Using VARIMAX rotation, rotated-factor pattern explained cumulative variation of 62.75% (unweighted) in which, the first factor contributed 33.58% and the second factor contributed 29.18% to the variation (Fig. 2).

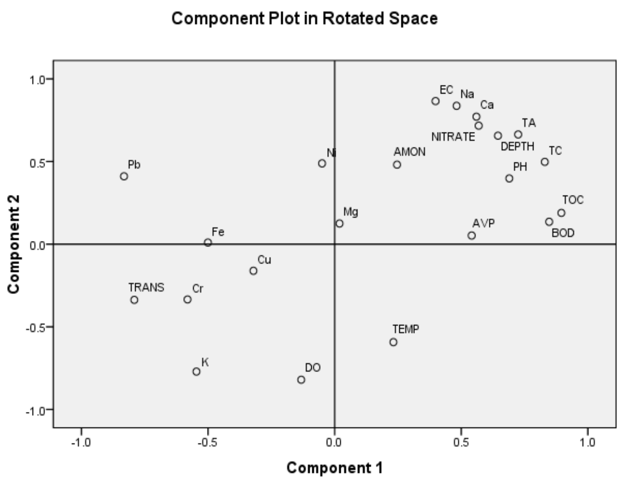

Figure 2: Rotated factor pattern for the first two factors based on the water quality parameters

The rotated component matrix showed strong (>0.75 loading value) positive loading of BOD and TOC on Factor 1. Reactive phosphorus and pH showed moderately positive loadings (0.5-0.75 loading value) on Factor 1. A strong negative loading of dissolved iron was observed on Factor 1. Factor 2 showed strong negative loading of DO, strong positive loading of EC, moderate positive loading of ammonia and dissolved nickel, and moderate negative loading of water temperature (Table 4)

Table 4: Rotated component matrix for the water quality parameters for factor 1 and 2

Parameters	Component	
	1	2
Temperature	.232	**- .593**
Depth	.645	.656
Transparency(TRANS)	-.791	-.337
pH	**.690**	.398
Dissolved oxygen(DO)	-.132	**-.820**
Biochemical oxygen demand(BOD)	**.847**	.136
Electrical conductivity(EC)	.398	**.866**
Sodium(Na)	.481	.837
Potassium(K)	-.546	-.771
Magnesium(Mg)	.019	.125
Calcium(Ca)	.560	.771
Total carbon(TC)	.830	.498
Total organic carbon(TOC)	**.895**	.189
Alkalinity(TA)	.725	.664
Ammonia(Amon)	.246	**.481**
Nitrate	.569	.717
Reactive phosphorus (AVP)	**.541**	.052
Copper(Cu)	-.321	-.161
Nickel(Ni)	-.050	.489
Chromium(Cr)	-.581	-.334
Iron(Fe)	**-.501**	.010
Lead(Pb)	-.832	.411

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 3 iterations

BOD can reveal the extent of pollution of a given water body [30], which when loaded in Factor 1, may represent the amount of organic matter in the form of municipal and domestic wastes discharged into the lake systems requiring much amount of oxygen [31]. Similar correlation between the BOD and TOC with their loadings on the first factor has been observed during the analysis. TOC also showed positive correlations with pH. Similar case was encountered at Bellandur Lake (Bangalore), where urbanization resulted in higher values of alkalinity, BOD and COD, and low levels of DO, which are indicators of the polluted nature of the lake [32]. High pH may be due to the utilization of bicarbonate and carbonate buffer system [33]. Ammonia is one of the attention seeking pollutants in aquatic environment because of its relatively high toxic nature and its ubiquity in surface water systems. It is discharged in large quantities from industrial, municipal and agricultural wastewater discharges. Anaerobic environments create a condition that favours the denitrification process; therefore, ammonia trends are usually reversed compared with that of DO. The loading of ammonia on the second factor proves the statement. Thus, the physico-chemical parameters loaded on the first factor showed the organic pollution indicators which contributed significantly to the total variation in water quality. Moreover, water quality parameters showed significant coefficients on Factor 1 with high loadings for Powai samples in comparison to Vihar. It is evident from the score plot that there is a clear separation of Powai from Vihar on the basis of water quality parameters (Fig. 3).

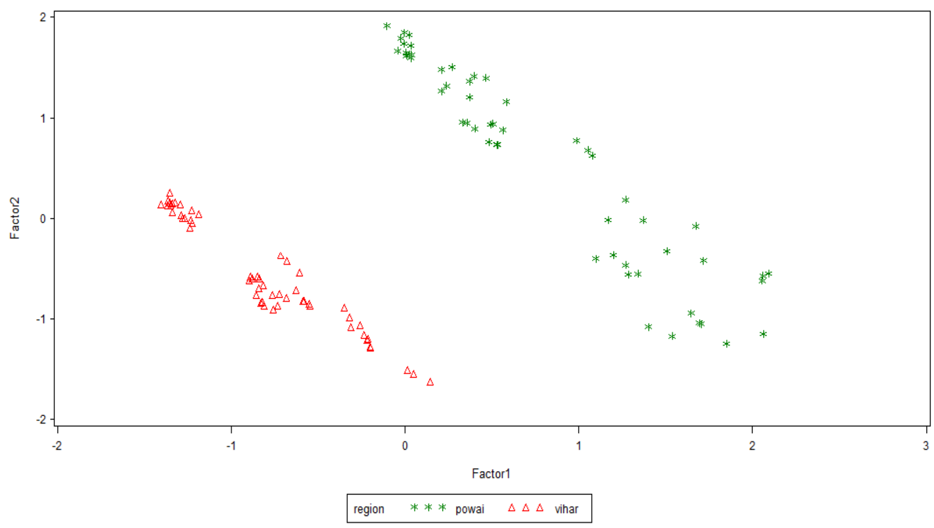

Figure 3: Score plot between the first and second factors based on the physic-chemical parameters for Powai and Vihar. A total of 34 genera of phytoplankters were observed in Powai Lake whereas it was 51 in Vihar (Table 5).

Table 5: Number of genus identified from the lakes

Family	Powai	Vihar
Chlorophyceae	16	25
Bacillariophyceae	7	12
Dinophyceae	1	2
Euglenophyceae	2	1
Cyanophyceae	8	1
Total	34	51

It was noticed that even though the plankton diversity was more in Vihar Lake, the plankton density was found to be more in Powai and the most dominant species in Powai were the pollution-tolerant ones. The pollution-tolerant algal communities are used as bioindicators of organic pollution. In Powai, the major groups observed were Cyanophycea (44%), Chlorophycea (29%), Bacillariophycea (13%), Euglenophycea (13%) and Dinophycea (1%) and in Vihar, the major groups were Chlorophycea (46%), Cyanophycea (27%), Bacillariophycea with (18%), Dinophycea with (7%) and Euglenophycea (2%). The species of phytoplankton which were abundant in Powai Lake are pollution tolerant, which indicates organic pollution in the lake. Both the phytoplankton indices yielded higher values for Powai Lake compared to Vihar Lake (Table 6).

Table 6: Algal pollution indices of Powai and Vihar lakes

Attribute	Algal pollution index	
	Nygaard's Index (CQ)	Palmer's index
Powai Lake	9 (>6 is eutrophic)	32 (>20 means high organic pollution)
Vihar Lake	4.85 (2 to 6 is weakly eutrophic)	15 (>15 means probable organic pollution)

Hence, it can be concluded that pollution is high in Powai Lake compared to Vihar. This may be on account of the high nutrient content and organic pollutants in Powai which have already been observed from the analysis of physico-chemical parameters. A value above 6 for Nygaard's index and above 20 for Palmer's index represents eutrophication. In Vihar, both the indices are on the margin of eutrophication limit suggesting the need for proper management. Thus, the analysis of the algal indices indicates the mesotrophic condition of Vihar Lake and the eutrophic condition of Powai Lake.

Though both the lakes share the same location and have common primary inflow, the water quality analysis revealed that the water quality of Powai Lake significantly differs from that of Vihar Lake. Most of the parameters showed higher values for Powai compared to Vihar. The higher concentrations of nutrients, particularly carbon, are naturally expected in polluted waters [34]. The first factor loadings showed the significance of BOD, TOC and pH on Factor 1, and ammonia, DO and EC on Factor 2. The clear separation of Powai and Vihar lakes based on the score plot generated through the coefficients of factors 1 and 2 revealed the same. Moreover, most of the parameters as BOD, ammonia, nitrate, phosphorus and TOC, which are the indicators of organic pollution, showed higher values in Powai. Urbanization and agricultural operations can cause organic pollution in closed water bodies [35]. The untreated disposal of sewage and garbage from the nearby residential and squatter settlements has affected the quality of the Powai water [36]. The catchment of the lake has also been affected badly due to unplanned quarrying activities. Appreciating the problem of silting, growth of aquatic weeds like water hyacinth and eutrophication of the lake, the Indian Institute of Technology - Bombay's Class of 1980 launched "Revitalization of Powai Lake" with the objective of restoring the lake to its original pristine and sustainable form by adopting eco-friendly designs and materials for the restoration works. In 1995, the National Lake Conservation Plan of the Ministry of Environment and Forests, Government of India, reviewed the condition of Powai Lake and included the lake in its list of ten major lakes in the country for revival and improvements [4]. The present study showed that in spite of all these initiatives, Powai is presently facing organic pollution threats due to the accelerated growth of residential, commercial and industrial areas around the lake. The calculated areas for Powai and Vihar lakes in 1973 and 2014 are presented in Table 7.

Table 7: Change in area of lakes from 1973 to 2014

	Powai Lake		Vihar Lake	
Year	1973	2014	1973	2014
Area(Sq Km)	1.264556	0.963217	3.310656	3.775545
Satellite Sensor	Landsat MSS	Landsat 8	Landsat MSS	Landsat 8
Resolution (m)	60	30	60	30

The results indicate substantial reduction in the Powai lake area in recent years. There is 26% decrease in the lake area by 2014 when compared to 1973. This might also be the reason for the increased pollution state of the lake as shown by the prevailing physico-chemical parameters. Vihar Lake shows not much differences and some increment in lake area has been observed in recent years (Fig. 4).

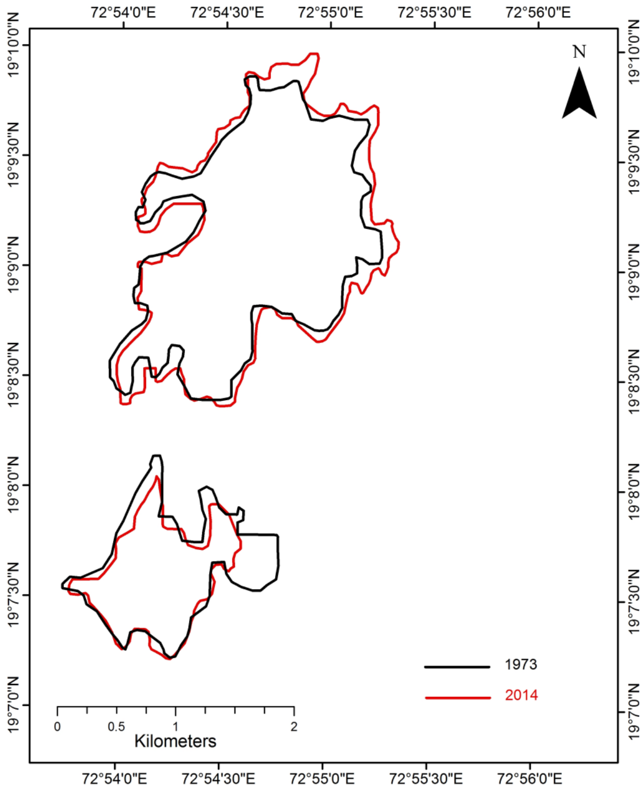

Figure 4: Change in area of lakes from 1973 to 2014

The physico-chemical and biological parameters thus revealed the present pollution level and trophic status of the lakes. Powai Lake is polluted mainly by sewage disposal, growth, death and decay of aquatic weeds, and blooms in the lake. Regular cleaning of the macrophytes, enhancing public awareness, scavenging of polluted sediments, bioremediation, proper regulatory measures for anthropogenic waste disposal and strict measures to prevent further encroachment to the catchment area are needed for the restoration of Powai Lake. Vihar Lake is comparatively less polluted and is suitable for public water supply. However, Vihar Lake has reached the threshold level of water quality and requires concerted efforts to maintain the quality. The future approaches can focus on improving the water quality status of Powai and maintaining the present quality in Vihar.

4. Conclusion

Factor analysis showed significant separation of Powai and Vihar lakes based on factors extracted from different physico-chemical parameters. The parameters showed significant loadings on the first factor with high coefficients for Powai in comparison to Vihar. The analysis of the algal community indicates the mesotrophic condition of Vihar Lake and eutrophic condition of Powai Lake. Powai Lake showed higher mean values for most of the physico-chemical parameters. The area of Powai Lake has decreased during recent years which can also affect the assimilative capacity of the lake for various pollutants. The higher values of the Powai Lake signal the future threat of water quality deterioration unless proper water quality management actions are initiated. Moreover, in the case of Vihar Lake, which is an important source of drinking water, more focus should be given on water quality management. The present approach can be used in water quality studies to understand the integrated water quality status for different water bodies, especially with regard to pollution.

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