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# Spatio-Temporal Variation in Water Quality of Selected Lakes in Eastern Dry Agro Climatic Zone of Karnataka State, India

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**ABSTRACT**
Monitoring water quality is a helpful tool for assessing the effects of pollution sources, ensuring effective management of water resources, and preserving aquatic life in surface water bodies. Hence, the present study focussed on evaluating the water quality of thirty-four selected lakes in Chikkaballapura taluk by characterizing physico-chemical parameters, Dissolved oxygen levels, organic loads (viz., BOD and COD) and WQI. The TDS level in the study area was well within the tolerance limit of 1500 mg/L, illustrating medium salinity (viz., electrical conductivity) in lake water. None of the lakes in the study area recorded nitrate concentrations above the tolerance limit of 50 mg/L during either season. Kolavanahalli and Varamallenahalli lakes witnessed nitrate levels of over 40 mg/L, while the pooled mean phosphate concentration was 0.40 mg/L during the study periods. High organic load in terms of COD was witnessed in selected lakes, as revealed by their ranges 64.0-144.0 mg/L (mean: 98.6 mg/L) and 60.8-136.0 mg/L (mean: 91.7 mg/L), respectively, during the pre- and post-monsoon seasons. Despite organic load, dissolved oxygen concentration ranged from 4.45-6.10 mg/L and 4.25-5.88 mg/L during these seasons, well above the desirable 4.0 mg/L limit. The present study also demonstrated the contribution of phosphate and nitrates towards organic loadings (viz., BOD and COD), illustrating increased anthropogenic contribution like entry of raw sewage, agricultural runoff, and others. Irrigation suitability was observed for most lakes, as revealed by their SAR, percent sodium and RSC values.

**Key words:** BOD, COD, DO, Pre-monsoon, Post-monsoon, WQI

## INTRODUCTION

The most valuable natural resource is water, and it is of the utmost importance to recognise the crucial significance of this precious resource for human and animal existence and for maintaining ecological balance for economic and developmental activity of all kinds. But, in recent years, a significant global issue is that the water quality in surface water bodies has worsened, brought on by human activities like population growth, urban sprawl, industrialization, intensive agricultural activities and runoff (Olajire and Imeokparia 2001, Murray et al. 2010, Poonam et al. 2013). Thus, there has been a dramatic rise in the demand for freshwater and a water crisis in arid and semi-arid areas in recent years (Poonam et al. 2013). Most people in larger cities and towns rely primarily on groundwater resources for drinking water and home, industrial, and agricultural applications because there is an inadequate supply of surface water. Most of the world's water bodies are experiencing several issues with their water quality because of the adverse effects of anthropogenic activity and population increase. There has been a significant volume of municipal sewage, industrial waste, and tourist nonpoint pollution entering river and lake systems along with surface runoff because of increased human activity, which immediately causes a rapid decline in the water quality of the related aquatic ecosystems (Hatvani et al. 2018) like rivers and lakes. To identify contaminants, classify water use, and plan remedial actions to maintain ecological health and restore the carrying capacity of the water body, it is now crucial to keep tabs on the changes in water quality in a water body. Hence, the present study assessed lake water quality in Chikkaballapura taluk and its suitability by selecting 34 lake systems.

## MATERIAL AND METHODS

### Study area

Chickaballapur district is the eastern gateway to Karnataka. It was newly formed by bifurcating the old Kolar district into Chickballapur and Kolar districts. The district is divided into six taluks:

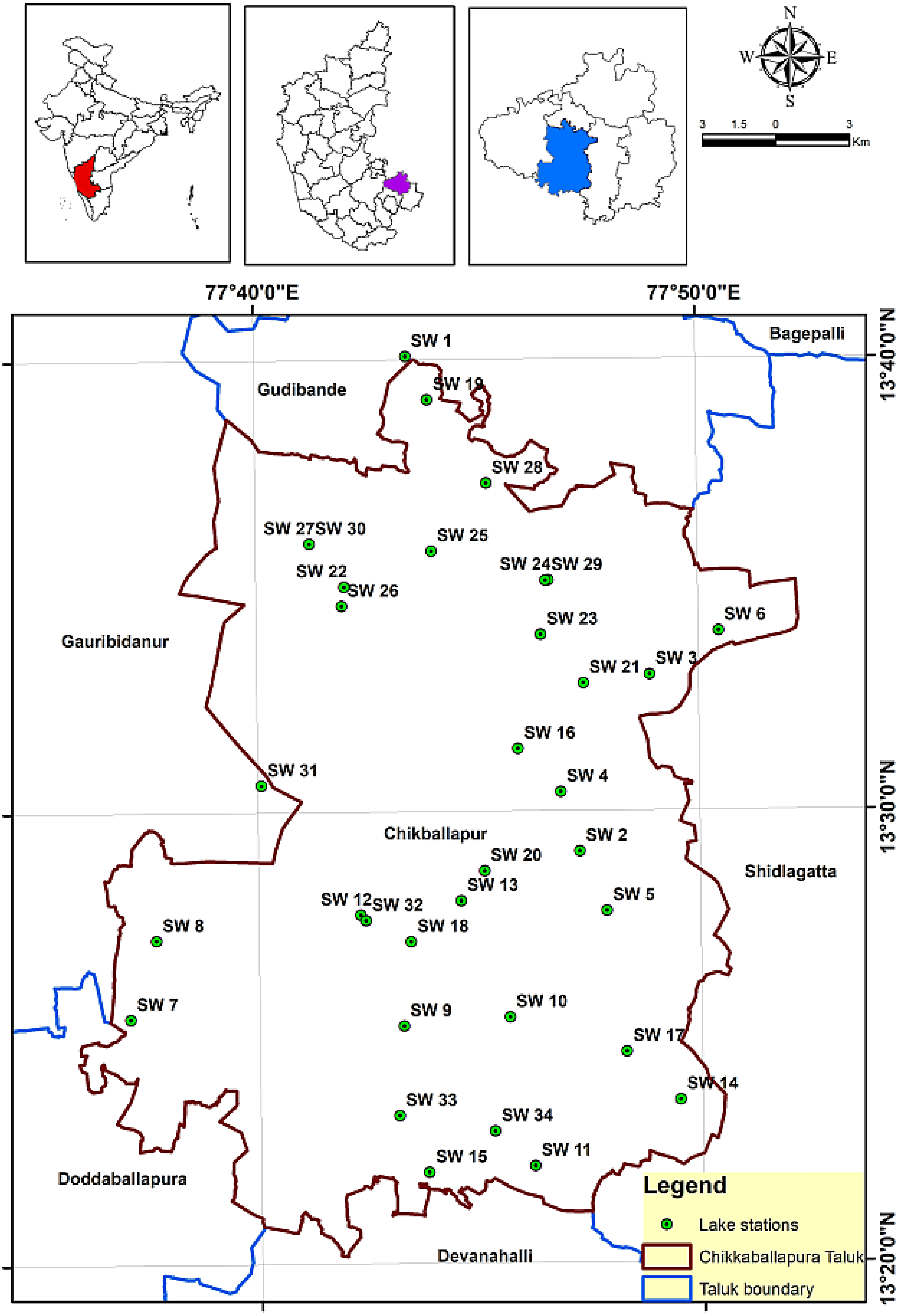


Figure 1. Study area map of Chikkaballapura taluk showing location of lakes

Gowribidanur, Begepalli, Gudibande, Shidlagatta, Chikkaballapur and Chintamani. Chikballapur Taluk of Chikballapur district geographically extends between 13°20'10.7" and 13°39'59.4" North latitude and 77°36'4.7" and 77°52'20.2" East longitude. Chikballapur taluk with adjoining taluks of Gudibanda taluk on the north, Devanahalli taluk on the south, Sidlaghatta taluk on the east and Gauribidanur taluk on the west side (Fig. 1). Agriculture is the main occupation of the district, with Kharif cultivation (namely maize, tur, ragi and vegetables) and Rabi cultivation (namely ragi, groundnuts, maize, horse gram, sunflowers and fruits). Chikballapur Taluk falls in Karnataka's eastern dry agro-climatic zone, classified as drought-prone with semi-arid to arid climate and experiences hot weather and drought throughout the year. Dry and hot weather prevails for most of the year. The entire western part of the taluk is covered with undulating hills, flat terrain and plateaus. The elevation profile ranges from 249 to 911 m amsl (above mean sea level). The taluk is drained by three seasonal and minor river basins, the Ponnaiyar, Palar and Pennar, which carry water only during the rainy season (Anonymous 2012). Chikballapur Taluk includes major soil types such as red sand, red clay and laterite. Granites, gneisses, shales, alluvium and laterites underlie the Chikkaballapura district, with alkaline dikes intruding in some places. Granites and gneisses occupy most of the district. Shales are generally restricted to the northwestern part of the Gauribidanur taluk, while small laterite patches are seen in the Sidlaghatta and Chickballapur taluks. The alluvial rock formations dominate river courses. Breaks or lineaments usually run in a NE-SW trend (Anonymous 2012). There are many irrigation tanks in Chickballapur district whose reliability in irrigation depends on the rainfall patterns.

**Sample collection**

Ninety-two surface water samples from 34 selected lakes spread across Chikkaballapura taluk were collected in 1-litre polythene bottles during the pre-monsoon (March 2022) and post-monsoon (November 2022) and were analysed for physico-chemical parameters. A potable HACH multiparameter analysing kit (HACH HQ30D) was used to determine pH, EC and TDS. Titrimetric methods were employed to analyse total hardness, alkalinity, calcium, magnesium, and chloride. The flame photometric method (Systronics μ-controller based Flame photometer with Compressor, Type: 128) was used to estimate sodium and potassium. The spectrophotometric method (ELCO SL-171 Spectrophotometer) was employed for analysing nitrate, phosphate, and sulphate. The organic load in the lake water samples were determined by assessing BOD and COD besides Dissolved oxygen. Anonymous (2017) prescribed analytical methods were employed during sample collection and analysis. Irrigational water quality parameters like sodium percentage, sodium absorption ratio (SAR) and residual sodium carbonate (RSC) were calculated using the equations mentioned in the article elsewhere (Ravikumar et al. 2015a).

**Water quality index (WQI)**

WQI was calculated by considering the eleven physico-chemical parameters listed in Table 1. The methodology followed to calculate WQI is mentioned elsewhere (Ravikumar et al. 2015b). Initially, weights were assigned to parameters selected based on their influence on water chemistry, and their respective relative weights were calculated (Table 1). Further, the quality rating (Q) was calculated for each parameter using equations 2 and 3, and finally, their sub-indices (SI) and WQI were

Table 1. Weight and relative weight of physicochemical parameters

| Parameters | BIS standard limit (IS:2296) | Weight (wi) | Relative weight (Wi) |
|---|---|---|---|
| pH | 6.5-8.5 | 4 | 0.108 |
| TDS | 1500 | 4 | 0.108 |
| TA | 200 | 2 | 0.054 |
| $SO_4$ | 400 | 4 | 0.108 |
| Cl | 600 | 3 | 0.081 |
| F | 1.5 | 2 | 0.054 |
| DO | 5 | 5 | 0.135 |
| BOD | 3 | 5 | 0.135 |
| $NO_3$ | 50 | 4 | 0.108 |
| Ca | 75 | 2 | 0.054 |
| Mg | 30 | 2 | 0.054 |
| **Total** | | **37** | **1.000** |

Table 2. Mean Physico-chemical composition of lake water during pre-monsoon

| Sample ID | Lake name | no. of samples | Long (degree) | Lat (degree) | pH | EC | TDS | TH | Ca | Mg | Na | K | Cl | TA | $HCO_3$ | $SO_4$ | F | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SW 1 | Amani Byrasagara kere | 4 | 77.725 | 13.670 | 7.20 | 203.9 | 130.5 | 74.0 | 19.4 | 6.2 | 18.0 | 3.9 | 28.0 | 36.0 | 43.9 | 50.0 | 0.60 | 3.6 | 0.10 |
| SW 2 | Dibbur kere | 2 | 77.790 | 13.485 | 7.50 | 213.3 | 136.5 | 62.7 | 17.2 | 4.8 | 18.0 | 4.0 | 30.0 | 33.2 | 40.5 | 30.0 | 0.80 | 4.2 | 0.10 |
| SW 3 | Reddyhalli Kere | 2 | 77.815 | 13.550 | 8.60 | 223.3 | 142.9 | 80.2 | 23.2 | 5.4 | 17.6 | 2.4 | 32.0 | 42.0 | 51.2 | 42.0 | 0.50 | 3.0 | 0.21 |
| SW 4 | Peresandra Hosakere | 2 | 77.780 | 13.505 | 8.70 | 232.5 | 148.8 | 82.3 | 22.4 | 6.4 | 18.0 | 3.1 | 30.0 | 25.8 | 31.5 | 62.2 | 0.80 | 3.8 | 0.50 |
| SW 5 | Kathriguppe Kere | 2 | 77.795 | 13.465 | 8.60 | 217.3 | 139.1 | 80.3 | 21.6 | 6.4 | 16.0 | 5.2 | 27.9 | 28.1 | 34.2 | 52.6 | 0.41 | 4.1 | 0.10 |
| SW 6 | Bomanahalli Kere | 2 | 77.840 | 13.570 | 8.40 | 247.3 | 158.3 | 79.6 | 19.7 | 7.4 | 22.6 | 4.7 | 26.7 | 29.8 | 36.4 | 68.2 | 0.70 | 3.5 | 0.20 |
| SW 7 | Jakalmadagu lake | 4 | 77.618 | 13.428 | 8.30 | 250.0 | 160.0 | 83.0 | 20.4 | 7.8 | 19.4 | 6.2 | 27.2 | 31.9 | 38.9 | 67.9 | 0.40 | 4.9 | 0.10 |
| SW 8 | SrinivasaSagar lake | 4 | 77.630 | 13.450 | 8.00 | 243.9 | 156.1 | 87.0 | 22.0 | 7.8 | 22.0 | 3.0 | 28.1 | 31.0 | 37.8 | 70.0 | 0.50 | 4.5 | 0.60 |
| SW 9 | Kandhwara Kere | 4 | 77.720 | 13.423 | 8.50 | 219.3 | 140.4 | 71.3 | 18.0 | 6.4 | 19.6 | 4.7 | 20.0 | 33.2 | 40.5 | 54.2 | 0.30 | 3.8 | 0.20 |
| SW 10 | Amani Gopalkrishna kere | 4 | 77.760 | 13.425 | 8.60 | 249.8 | 159.9 | 88.7 | 24.0 | 7.0 | 20.0 | 2.8 | 26.0 | 34.0 | 41.5 | 70.3 | 0.80 | 4.0 | 0.20 |
| SW 11 | Kanithahalli lake | 2 | 77.770 | 13.370 | 8.40 | 247.8 | 158.6 | 87.4 | 23.8 | 6.8 | 18.0 | 5.6 | 24.3 | 32.0 | 39.0 | 67.3 | 0.80 | 5.0 | 0.50 |
| SW 12 | Rangadhama Kere | 2 | 77.705 | 13.460 | 8.30 | 230.8 | 147.7 | 76.3 | 20.0 | 6.4 | 18.0 | 4.0 | 24.0 | 23.5 | 28.7 | 68.0 | 0.50 | 5.8 | 0.22 |
| SW 13 | Manchanabele kere | 2 | 77.740 | 13.470 | 8.10 | 248.9 | 159.3 | 90.2 | 24.6 | 7.0 | 17.2 | 3.2 | 26.0 | 26.1 | 31.9 | 74.0 | 0.50 | 6.0 | 0.20 |
| SW 14 | Hosahudya lake | 4 | 77.825 | 13.390 | 8.50 | 200.5 | 128.3 | 83.5 | 20.6 | 7.8 | 16.5 | 4.5 | 26.0 | 40.0 | 48.8 | 40.0 | 0.40 | 2.8 | 0.50 |
| SW 15 | Doddamaralli Lake | 4 | 77.730 | 13.370 | 8.00 | 674.6 | 431.7 | 126.2 | 26.8 | 14.4 | 32.2 | 4.1 | 32.0 | 47.8 | 58.3 | 90.0 | 0.80 | 28.0 | 0.70 |
| SW 16 | Poornasagar lake | 2 | 77.765 | 13.520 | 8.17 | 932.1 | 596.5 | 322.3 | 78.0 | 31.0 | 52.0 | 7.9 | 118.0 | 229.7 | 280.2 | 48.0 | 0.75 | 33.0 | 0.70 |
| SW 17 | Jathwara Kere | 4 | 77.808 | 13.410 | 7.71 | 907.7 | 580.9 | 321.5 | 82.6 | 28.0 | 49.5 | 7.3 | 106.0 | 240.0 | 292.8 | 52.0 | 0.65 | 27.5 | 0.50 |
| SW 18 | Mustoor kere | 2 | 77.720 | 13.450 | 8.31 | 886.8 | 567.6 | 316.7 | 70.8 | 34.0 | 55.0 | 4.5 | 120.0 | 220.0 | 268.4 | 58.0 | 0.30 | 11.0 | 0.20 |
| SW 19 | Kasankunte Lake | 2 | 77.730 | 13.650 | 8.40 | 929.9 | 595.1 | 363.4 | 92.8 | 32.0 | 65.0 | 2.8 | 132.0 | 263.6 | 321.6 | 62.0 | 0.35 | 7.0 | 0.20 |
| SW 20 | Amani Marsanahalli kere | 2 | 77.750 | 13.480 | 8.16 | 1001.0 | 640.6 | 463.9 | 124.0 | 37.5 | 52.5 | 4.1 | 126.0 | 300.0 | 366.0 | 52.8 | 0.80 | 36.5 | 0.70 |
| SW 21 | Chikkapylagurki | 2 | 77.790 | 13.550 | 8.09 | 1215.0 | 777.6 | 403.4 | 106.0 | 33.7 | 48.0 | 4.1 | 121.2 | 235.4 | 287.2 | 122.5 | 0.70 | 22.0 | 0.60 |
| SW 22 | Yadarlahalli lake | 4 | 77.700 | 13.583 | 8.03 | 897.1 | 574.1 | 411.3 | 112.0 | 32.0 | 54.0 | 7.5 | 112.0 | 220.0 | 268.4 | 135.8 | 0.38 | 37.8 | 0.61 |
| SW 23 | Aruru lake | 2 | 77.775 | 13.565 | 8.45 | 1157.0 | 740.5 | 497.4 | 130.0 | 42.0 | 72.0 | 6.1 | 137.8 | 340.0 | 414.8 | 72.0 | 0.22 | 22.0 | 0.52 |
| SW 24 | Hodekalu lake | 4 | 77.775 | 13.585 | 6.61 | 1128.0 | 721.9 | 475.0 | 114.6 | 45.9 | 84.0 | 4.1 | 125.0 | 320.0 | 390.4 | 78.0 | 0.20 | 31.8 | 0.50 |
| SW 25 | Mandikal lake | 2 | 77.734 | 13.596 | 7.99 | 1274.0 | 815.4 | 522.1 | 123.4 | 52.0 | 98.0 | 3.0 | 156.5 | 340.0 | 414.8 | 82.0 | 0.17 | 30.0 | 0.70 |
| SW 26 | Yardarahalli lake | 3 | 77.699 | 13.576 | 7.83 | 1131.0 | 723.8 | 456.0 | 120.0 | 38.0 | 68.0 | 7.7 | 136.0 | 300.0 | 366.0 | 74.0 | 0.72 | 37.0 | 0.50 |
| SW 27 | Parenahalli lake | 2 | 77.687 | 13.599 | 8.38 | 1207.0 | 772.5 | 455.5 | 116.5 | 40.0 | 96.7 | 7.0 | 146.5 | 280.0 | 341.6 | 96.0 | 0.22 | 29.5 | 0.30 |
| SW 28 | Hirenagavalli lake | 2 | 77.754 | 13.621 | 8.04 | 1257.0 | 804.5 | 441.2 | 104.5 | 43.8 | 60.4 | 4.3 | 144.2 | 280.0 | 341.6 | 68.0 | 0.20 | 20.5 | 0.40 |
| SW 29 | Madanpur lake | 3 | 77.776 | 13.585 | 7.85 | 1149.0 | 735.4 | 522.1 | 130.0 | 48.0 | 55.4 | 1.7 | 137.0 | 300.0 | 366.0 | 106.9 | 0.41 | 32.0 | 0.31 |
| SW 30 | Gudisihalli lake | 2 | 77.687 | 13.599 | 7.76 | 1117.0 | 714.9 | 508.9 | 128.0 | 46.0 | 60.0 | 3.0 | 123.3 | 320.0 | 390.4 | 114.2 | 0.16 | 39.5 | 0.70 |
| SW 31 | Dandiganhalli lake | 2 | 77.668 | 13.510 | 7.93 | 1207.0 | 772.5 | 496.7 | 122.8 | 46.2 | 65.0 | 7.1 | 129.8 | 290.0 | 353.8 | 86.0 | 0.30 | 20.5 | 0.73 |
| SW 32 | Dinnehosahalli lake | 3 | 77.707 | 13.461 | 7.83 | 1196.0 | 765.4 | 505.7 | 130.0 | 44.0 | 46.5 | 7.8 | 136.2 | 280.0 | 341.6 | 90.0 | 0.54 | 35.0 | 0.83 |
| SW 33 | Varamallenahalli lake | 2 | 77.719 | 13.388 | 7.67 | 1166.0 | 746.2 | 510.7 | 132.0 | 44.0 | 64.0 | 5.7 | 127.2 | 340.0 | 414.8 | 115.4 | 0.84 | 43.0 | 0.80 |
| SW 34 | Kolavanahalli lake | 3 | 77.755 | 13.382 | 7.82 | 1228.0 | 785.9 | 544.1 | 132.2 | 52.0 | 92.0 | 4.4 | 123.0 | 360.0 | 439.2 | 114.5 | 0.30 | 42.7 | 0.50 |

Table 3. Mean Physico-chemical composition of lake water during post-monsoon

| Sample ID | Lake name | no. of samples | Long (degree) | Lat (degree) | pH | EC | TDS | TH | Ca | Mg | Na | K | Cl | TA | $HCO_3$ | $SO_4$ | F | $NO_3$ | $PO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SW 1 | Amani Byrasagara kere | 4 | 77.725 | 13.670 | 7.12 | 194.3 | 124.3 | 69.5 | 18.6 | 5.6 | 16.2 | 3.4 | 24.5 | 32.2 | 39.3 | 48.2 | 0.46 | 3.4 | 0.06 |
| SW 2 | Dibbur kere | 2 | 77.790 | 13.485 | 7.43 | 186.8 | 119.6 | 52.9 | 15.6 | 3.4 | 14.0 | 2.8 | 25.4 | 28.4 | 34.6 | 27.8 | 0.74 | 3.8 | 0.08 |
| SW 3 | Reddyhalli Kere | 2 | 77.815 | 13.550 | 7.69 | 201.9 | 129.2 | 74.2 | 21.8 | 4.8 | 15.0 | 2.0 | 26.5 | 34.9 | 42.6 | 38 | 0.30 | 2.8 | 0.20 |
| SW 4 | Peresandra Hosakere | 2 | 77.780 | 13.505 | 7.60 | 206.4 | 132.1 | 75.1 | 20.5 | 5.8 | 16.0 | 2.2 | 26.8 | 24.2 | 29.5 | 57.2 | 0.75 | 2.7 | 0.48 |
| SW 5 | Kathriguppe Kere | 2 | 77.795 | 13.465 | 7.50 | 210.6 | 134.8 | 67.2 | 19.5 | 4.5 | 15.1 | 3.4 | 25.8 | 24.0 | 29.3 | 47 | 0.30 | 3.5 | 0.07 |
| SW 6 | Bomanahalli Kere | 2 | 77.840 | 13.570 | 7.90 | 234.8 | 150.3 | 74.3 | 18.7 | 6.7 | 21.0 | 3.2 | 25.8 | 27.7 | 33.8 | 66.4 | 0.56 | 2.9 | 0.15 |
| SW 7 | Jakalmadagu lake | 4 | 77.618 | 13.428 | 7.10 | 213.4 | 136.6 | 77.0 | 19.8 | 6.7 | 18.5 | 5.3 | 26.4 | 28.6 | 34.9 | 64.2 | 0.31 | 3.4 | 0.06 |
| SW 8 | SrinivasaSagar lake | 4 | 77.630 | 13.450 | 6.80 | 222.4 | 142.3 | 78.5 | 21.4 | 6.1 | 20.0 | 1.9 | 24.6 | 28.8 | 35.1 | 61.7 | 0.42 | 3.2 | 0.54 |
| SW 9 | Kandhwara Kere | 4 | 77.720 | 13.423 | 7.20 | 203.7 | 130.4 | 66.8 | 17.2 | 5.8 | 14.0 | 3.1 | 17.5 | 29.4 | 35.9 | 52.7 | 0.22 | 3.2 | 0.16 |
| SW 10 | Amani Gopalkrishna kere | 4 | 77.760 | 13.425 | 7.70 | 223.4 | 143.0 | 81.4 | 22.4 | 6.2 | 16.8 | 2.3 | 23.5 | 27.3 | 33.3 | 62.8 | 0.60 | 2.8 | 0.18 |
| SW 11 | Kanithahalli lake | 2 | 77.770 | 13.370 | 7.10 | 218.9 | 140.1 | 79.2 | 22.8 | 5.4 | 14.0 | 3.3 | 22.6 | 26.0 | 31.7 | 64.1 | 0.73 | 2.4 | 0.46 |
| SW 12 | Rangadhama Kere | 2 | 77.705 | 13.460 | 7.60 | 216.7 | 138.7 | 73.0 | 19.5 | 5.9 | 12.8 | 3.6 | 21.7 | 22.0 | 26.8 | 57.6 | 0.40 | 3.0 | 0.20 |
| SW 13 | Manchanabele kere | 2 | 77.740 | 13.470 | 7.80 | 191.9 | 122.8 | 83.9 | 23.4 | 6.2 | 14.5 | 2.9 | 21.4 | 24.0 | 29.3 | 60.5 | 0.43 | 4.6 | 0.14 |
| SW 14 | Hosahudya lake | 4 | 77.825 | 13.390 | 7.30 | 176.3 | 112.8 | 74.3 | 19.2 | 6.4 | 16.1 | 3.5 | 22.3 | 36.6 | 44.6 | 38.2 | 0.32 | 2.6 | 0.46 |
| SW 15 | Doddamaralli Lake | 4 | 77.730 | 13.370 | 7.50 | 574.7 | 367.8 | 116.5 | 24.4 | 13.5 | 29.8 | 3.8 | 30.8 | 40.7 | 49.6 | 84.5 | 0.67 | 23.5 | 0.30 |
| SW 16 | Poornasagar lake | 2 | 77.765 | 13.520 | 7.10 | 712.8 | 456.2 | 302.7 | 73.6 | 28.9 | 48.9 | 7.2 | 108.5 | 222.3 | 271.2 | 40.4 | 0.66 | 31.5 | 0.51 |
| SW 17 | Jathwara Kere | 4 | 77.808 | 13.410 | 7.10 | 870.4 | 557.1 | 300.5 | 78.0 | 25.7 | 44.2 | 6.7 | 102.5 | 225.7 | 275.4 | 40.2 | 0.58 | 26.2 | 0.38 |
| SW 18 | Mustoor kere | 2 | 77.720 | 13.450 | 7.00 | 661.4 | 423.3 | 307.0 | 68.9 | 32.8 | 50.5 | 2.3 | 114.8 | 209.7 | 255.9 | 52.4 | 0.24 | 9.1 | 0.08 |
| SW 19 | Kasankunte Lake | 2 | 77.730 | 13.650 | 7.40 | 839.3 | 537.2 | 338.3 | 87.2 | 29.3 | 56.2 | 2.4 | 126.3 | 259.3 | 316.4 | 52.4 | 0.29 | 5.5 | 0.17 |
| SW 20 | Amani Marsanahalli kere | 2 | 77.750 | 13.480 | 7.90 | 983.1 | 629.2 | 439.4 | 118.8 | 34.7 | 44.0 | 3.3 | 118.4 | 284.0 | 346.4 | 42.6 | 0.72 | 33.4 | 0.60 |
| SW 21 | Chikkapylagurki | 2 | 77.790 | 13.550 | 6.80 | 928.1 | 594.0 | 370.7 | 96.4 | 31.6 | 43.6 | 3.6 | 113.9 | 222.1 | 271.0 | 116.4 | 0.64 | 18.5 | 0.53 |
| SW 22 | Yadarlahalli lake | 4 | 77.700 | 13.583 | 7.30 | 755.6 | 483.6 | 383.0 | 104.6 | 29.6 | 34.8 | 6.8 | 104.9 | 201.7 | 246.1 | 122.4 | 0.33 | 34.8 | 0.53 |
| SW 23 | Aruru lake | 2 | 77.775 | 13.565 | 8.37 | 1029.0 | 658.6 | 474.2 | 124.0 | 40.0 | 58.0 | 5.4 | 127.6 | 322.7 | 393.7 | 63.8 | 0.19 | 20.4 | 0.46 |
| SW 24 | Hodekalu lake | 4 | 77.775 | 13.585 | 6.56 | 1037.0 | 663.7 | 461.2 | 111.7 | 44.3 | 54.0 | 3.7 | 117.8 | 297.1 | 362.5 | 64.2 | 0.16 | 30.7 | 0.44 |
| SW 25 | Mandikal lake | 2 | 77.734 | 13.596 | 7.80 | 1228.0 | 785.9 | 498.9 | 120.7 | 48.0 | 62.0 | 2.7 | 138.5 | 320.4 | 390.9 | 74.4 | 0.13 | 28.7 | 0.65 |
| SW 26 | Yardarahalli lake | 3 | 77.699 | 13.576 | 7.67 | 1098.0 | 702.7 | 434.6 | 118.0 | 34.0 | 60.0 | 6.4 | 126.4 | 271.9 | 331.8 | 63.6 | 0.66 | 34.7 | 0.46 |
| SW 27 | Parenahalli lake | 2 | 77.687 | 13.599 | 8.34 | 1104.0 | 706.6 | 437.7 | 114.3 | 37.0 | 33.0 | 6.1 | 139.6 | 270.0 | 329.4 | 84 | 0.18 | 24.9 | 0.25 |
| SW 28 | Hirenagavalli lake | 2 | 77.754 | 13.621 | 7.88 | 1179.0 | 754.6 | 420.3 | 102.4 | 40.0 | 52.0 | 3.9 | 136.8 | 234.4 | 285.9 | 64.2 | 0.15 | 19.2 | 0.35 |
| SW 29 | Madanpur lake | 3 | 77.776 | 13.585 | 7.75 | 1089.0 | 697.0 | 446.6 | 108.0 | 43.0 | 51.7 | 1.4 | 126.9 | 268.1 | 327.1 | 98.3 | 0.37 | 30.4 | 0.27 |
| SW 30 | Gudisihalli lake | 2 | 77.687 | 13.599 | 7.64 | 1097.0 | 702.1 | 469.2 | 120.0 | 41.2 | 40.0 | 2.4 | 117.2 | 290.3 | 354.2 | 103.8 | 0.12 | 35.7 | 0.65 |
| SW 31 | Dandiganhalli lake | 2 | 77.668 | 13.510 | 7.85 | 1183.0 | 757.1 | 457.8 | 120.7 | 38.0 | 40.5 | 6.3 | 118.6 | 283.9 | 346.4 | 78.4 | 0.21 | 19.4 | 0.62 |
| SW 32 | Dinnehosahalli lake | 3 | 77.707 | 13.461 | 7.78 | 1100.0 | 704.0 | 476.3 | 124.0 | 40.5 | 38.0 | 7.0 | 119.9 | 271.5 | 331.3 | 84.3 | 0.46 | 30.6 | 0.78 |
| SW 33 | Varamallenahalli lake | 2 | 77.719 | 13.388 | 7.62 | 1127.0 | 721.3 | 465.1 | 124.3 | 37.6 | 51.5 | 5.1 | 119.4 | 333.3 | 406.6 | 101.4 | 0.78 | 40.9 | 0.75 |
| SW 34 | Kolavanahalli lake | 3 | 77.755 | 13.382 | 7.76 | 1186.0 | 759.0 | 492.4 | 128.0 | 42.0 | 63.7 | 3.8 | 115.1 | 347.5 | 424.0 | 103.6 | 0.24 | 40.5 | 0.47 |

computed using equations 4 and 5.

$$W_r = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad .... (1)$$

$$Q_i = \frac{C_i}{S_i} \times 100 \; .... (2)$$

$$Q_{i\,pH,DO} = \frac{C_i - V_i}{S_i - V_i} \times 100 \; .... (3)$$

$$SI_i = W_r \times Q_i \; .... (4)$$

$$WQI = \sum SI_i \; .... (5)$$

## RESULTS AND DISCUSSION

Tables 2 and 3 summarize the mean of analytical results for all 34 selected lake samples for pre- and post-monsoon season samples. In the study area, pooled mean pH was 8.08 (viz., 7.20 to 7.82) and 7.50 (viz., 6.56 to 8.37) during pre- and post-monsoon seasons, respectively (Fig 2). Among 34 lake samples, 11.75% of the lakes (viz., Reddyhalli, Amani Gopalkrishna, Kathriguppe and Peresandra Hosakere lakes) during pre-monsoon had pH above 8.5 and were highly alkaline. During post-monsoon, none of the lakes showed a pH deviation from the standard limit.

Lake water sample analysis showed pooled mean electrical conductivity value of 732.1 µS/cm (viz., 200.5 to 1274 µS/cm) during pre-monsoon and 667.2 µS/cm (viz., 176.3 to 1228.0 µS/cm) during post-monsoon season (Fig 3). 41.76% of pre-monsoon samples and 35.3 % of post-monsoon samples had electrical conductivity values above 1000 µS/cm. Mean total dissolved solids varied between 128.3 to 815.4 mg/L during pre-monsoon and 112.8 to 785.8 mg/L during post-monsoon seasons, and their respective pooled mean values were 468.5 and 427.0 mg/L. It was apparent that 55.9% (viz., 19 lakes) and 47.06% (viz., 16 lakes) during pre- and post-monsoon seasons recorded TDS values beyond 500

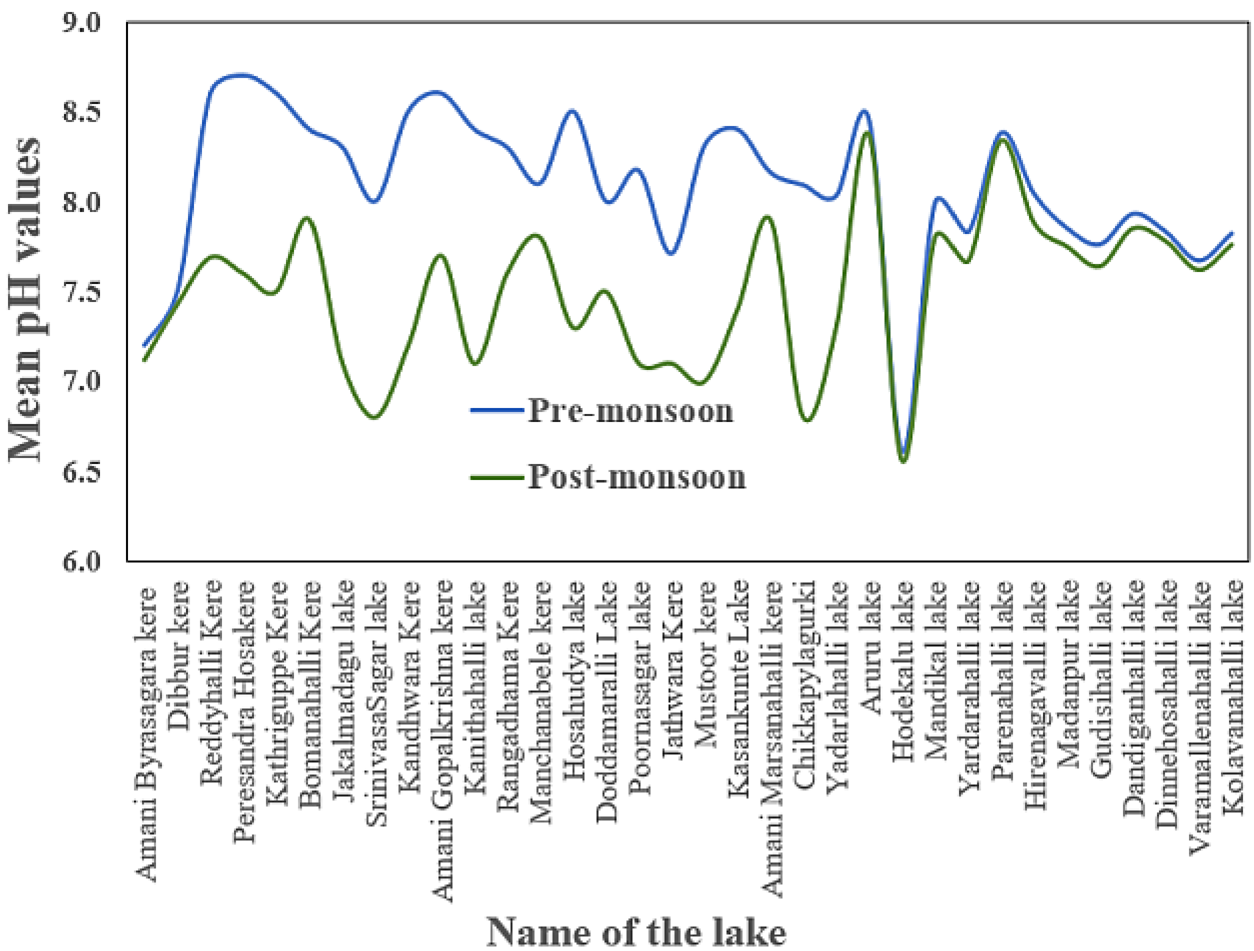


Figure 2. Spatio-temporal variation in mean pH value in lake water from the study area

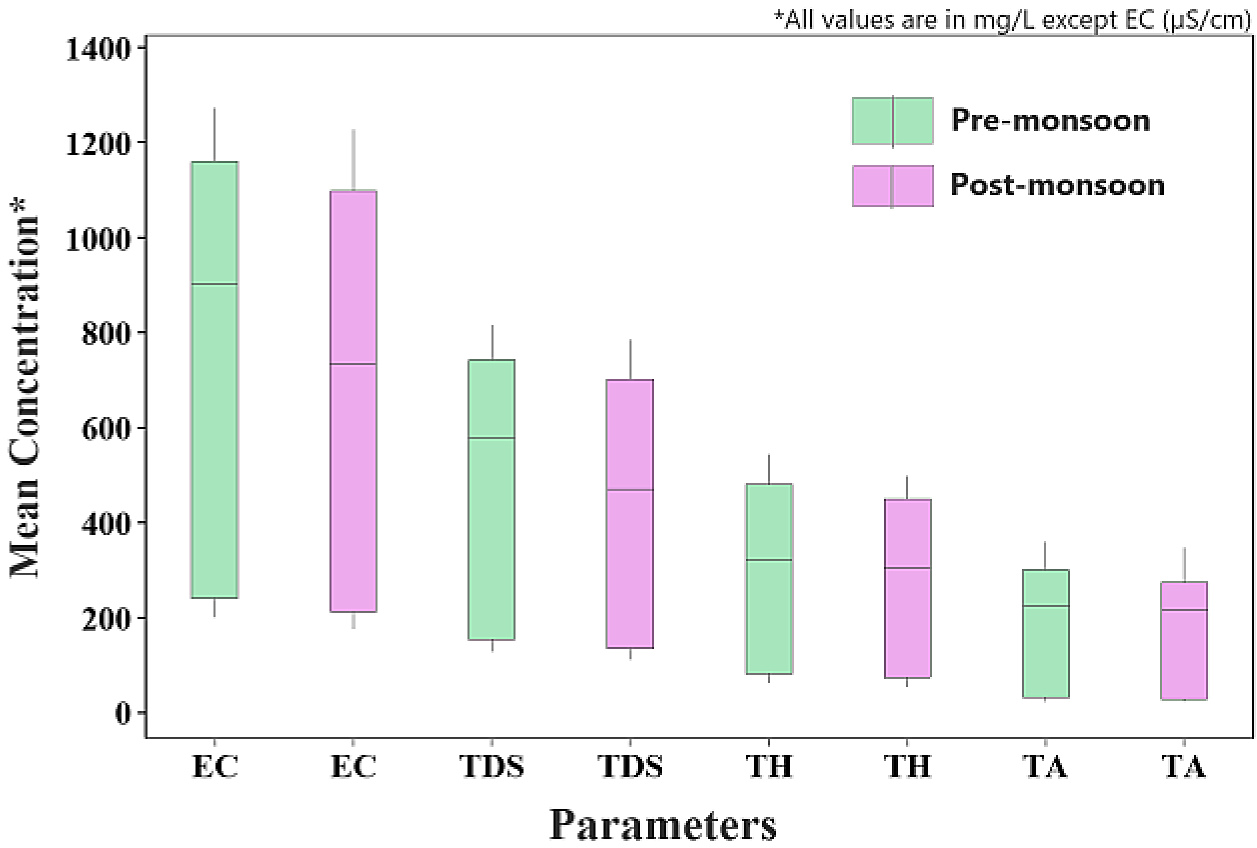


Figure 3. Spatio-temporal distribution in EC, TDS, total hardness, and total alkalinity inlake water samples

mg/L but were well below the permissible limit of 2000 mg/L (Fig 3). Overall, the TDS level in the study area was well within the tolerance limit of 1500 mg/L (IS:2296-1982).

When total hardness exceeds total alkalinity, Calcium and Magnesium are usually associated with $SO_4$, Cl, or $NO_3^-$ rather than $HCO_3$ and $CO_3$. Otherwise, the bicarbonate and carbonate are associated with potassium and sodium. Figure 3 shows that total hardness surpasses total alkalinity during both the seasons, illustrating non-carbonate or permanent hardness in the study area. In the study area, the mean concentration of total hardness ranged between 62.7 to 544.1 mg/L (pooled mean: 288.0 mg/L) and 52.9 to 498.9 mg/L (pooled mean: 268.2 mg/L) during pre- and post-monsoon seasons, indicating that 55.88% of the lake water samples during both the seasons were highly hard (viz., TH > 300 mg/L). Similarly, total alkalinity varied between 23.5 to 360.0 mg/L (pooled mean: 175.1 mg/L) and 22.0 to 347.5 mg/L (pooled mean: 163.9 mg/L) for pre- and post-monsoon season's lake samples.

**Determination of major cations and anions**

In the study area, the dominance of the combined concentration of (Ca+Mg) over that of (Na+K) can be easily observed from Fig 4. Similarly, the superiority of the combined concentration of ($HCO_3$) over that of ($Cl+SO_4$) can be witnessed in Fig 5. The pooled mean concentration of Calcium was found to be 72.8 mg/L (viz.17.2-132.2 mg/L) and 69.1 mg/L (viz. 15.6-128.0 mg/L), while magnesium was 25.8 mg/L (viz.4.8-52.0 mg/L) and 23.3 mg/L (viz. 3.4-48.0 mg/L), respectively, for pre-and post-monsoon season samples. In contrast, lake samples of pre- and post-monsoon season showed pooled mean concentrations of sodium of 45 (viz. 18.0-92.0 mg/L) and 34.7 mg/L (viz., 12.8-63.7 mg/L), respectively. The pooled mean potassium concentration was 4.74 (viz.3.90-7.90 mg/L) and 3.92 mg/L (viz. 1.40-7.20 mg/L) for pre- and post-monsoon season samples, respectively.

The pooled mean concentration of chloride was 84.3 (viz.20.0-156.5 mg/L) and 78.2 mg/L (viz. 17.5-139.6 mg/L), while sulphate levels were 74.6 (viz. 50.0-114.5 mg/L) and 67.1 mg/L (viz. 27.8-103.6 mg/

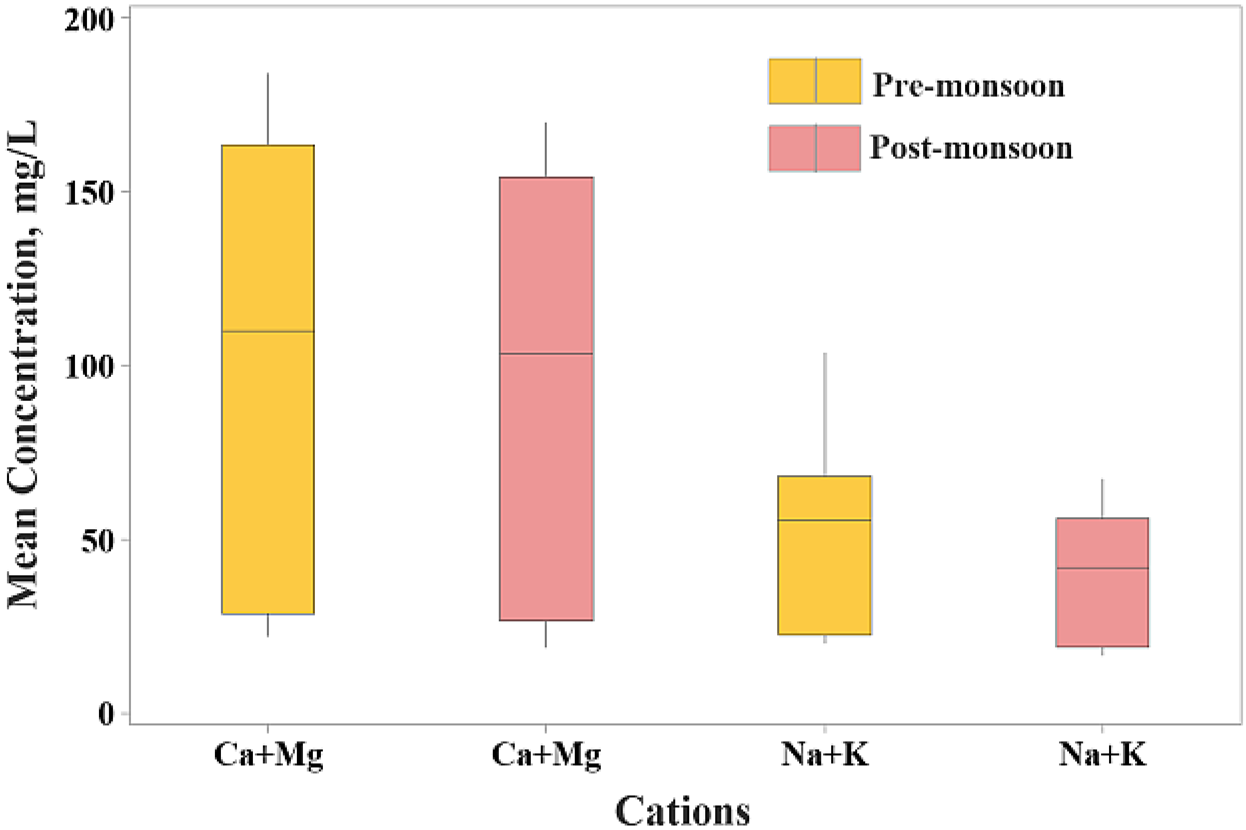


Figure 4. Box plot showing spatio-temporal variation among major cations

L), respectively, for pre-and post-monsoon season samples. Both chloride and sulphate concentrations were well within the tolerance limit of 600 mg/L and 400 mg/L, respectively (IS: 2296-1982). In contrast, lake samples of pre- and post-monsoon season showed pooled mean concentrations of bicarbonate as 213.6 (viz. 43.9-439.2 mg/L) and 199.9 mg/L (viz. 26.8-424.0 mg/L), respectively (Fig 5).

The pooled mean nitrate concentration was 19.0 (viz. 2.8-43.0 mg/L) and 17.1 mg/L (viz. 2.4-40.9 mg/L) for pre- and post-monsoon season samples (Fig 6a). In the study area, Kolavanahalli and Varamallenahalli lakes recorded nitrate levels of over 40 mg/L during both seasons. Despite this, none of the lakes recorded nitrate levels above the tolerance limit of 50 mg/L (IS: 2296-1982). The pooled mean phosphate concentration was 0.40 (viz.0.10-0.83 mg/L) and 0.40 mg/L (viz. 0.06-0.78 mg/L) for pre- and post-monsoon season samples (Fig 6b). Nearly 61.75% (viz.,21 lakes) and 55.88% (viz., 19 lakes) of samples showed phosphates over 0.3 mg/L. Pooled mean fluoride levels were 0.5 mg/L (viz. 0.2-0.8 mg/L) during PRM and 0.4 mg/L (0.1-0.8 mg/L) during POM season, well below the tolerance limit of 1.5 mg/L (IS:2296-1982).

**Lake water suitability assessment**

The analytical results, such as dissolved oxygen, BOD, and COD, and calculated water quality parameters, such as WQI, SAR, sodium percentage, and RSC for selected lakes from the study area are given in Table 4.

Dissolved oxygen (DO) indicates the amount of oxygen in dissolved form in the water bodies, which, along with BOD and COD, can be used to evaluate the pollution level in the water quality of the lotic and lentic systems. DO determines the stream's suitability for the fish's survival (Chang 2005) as its content <3 mg/L is considered fatal for fish (Novonty 2002). In the present study, pooled mean DO level was 5.1 mg/L (viz. 4.45-6.10 mg/L) and 5.00 (viz. 4.25-5.88 mg/L) during pre- and post-monsoon seasons (Fig 7a), well above the permissible limit of 4.0 (IS: 2296-1982). In contrast, pooled mean BOD levels were 12.5 (viz. 8.00-18.1 mg/L) and 11.0 (viz. 7.10-16.2 mg/L) for pre- and post-monsoon lake

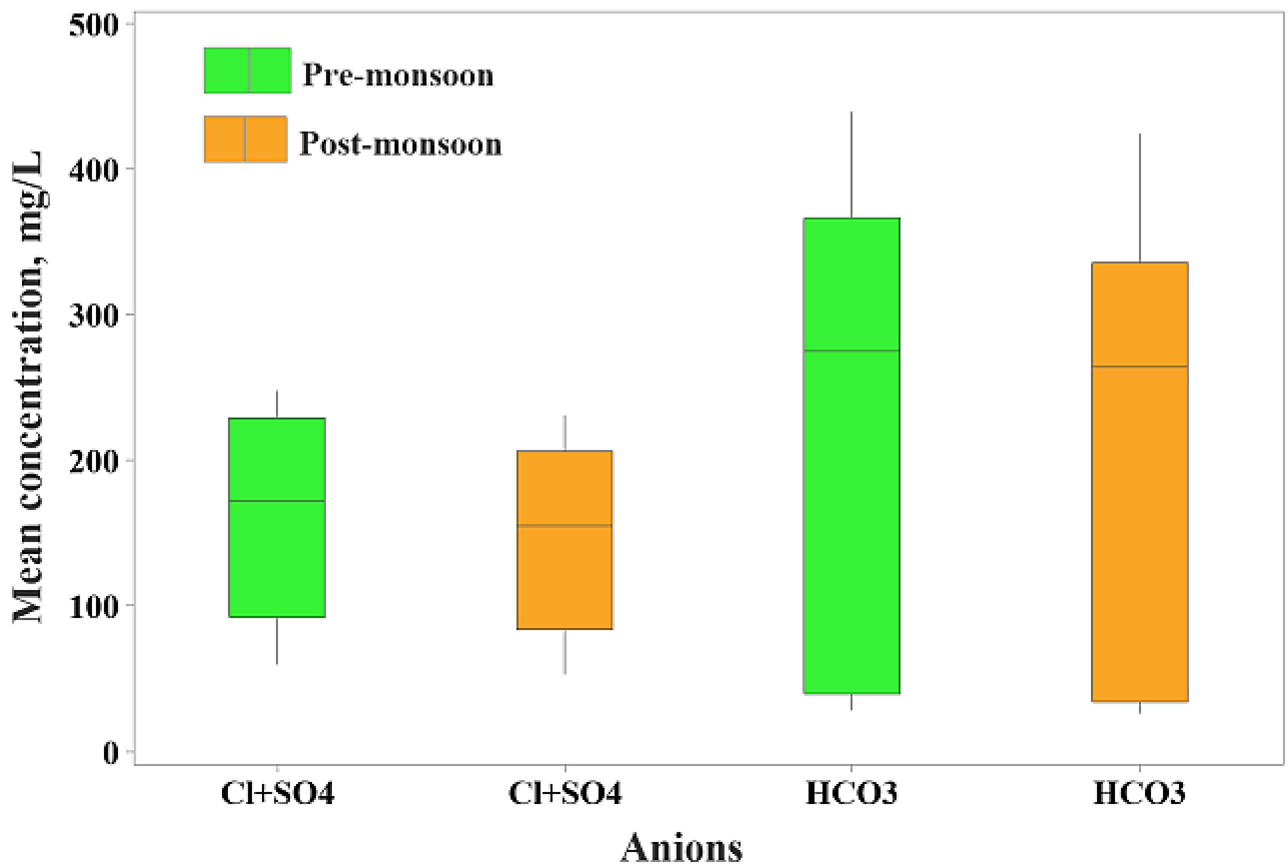


Figure 5. Box plot showing spatio-temporal variation among major anions

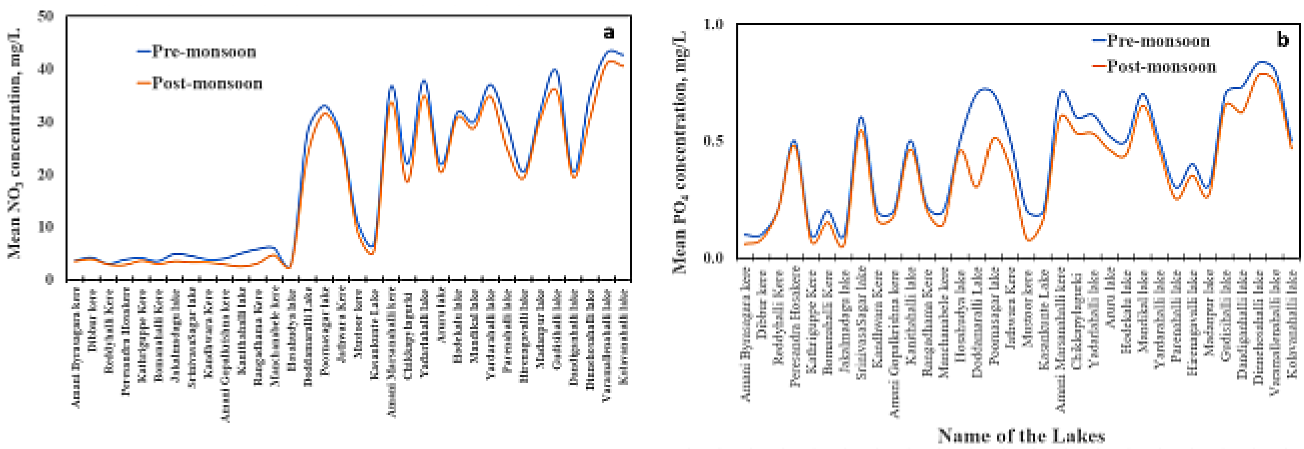


Figure 6. Spatio-temporal variation in (a) Nitrates and (b) Phosphates

samples (Fig 7b). All the lake water samples during both seasons showed BOD exceeding the permissible limit of 3.0 mg/L (IS: 2296-1982), indicating a slight increase in biological activity attributed to the entry of wastewater and agricultural runoff. Interestingly, chemical oxygen demand (COD) values in the lakes of the study area were also found on the higher side, indicating increased organic load in these lakes. The pooled mean concentration of COD for pre- and post-monsoon lake samples was 98.6 mg/L (viz. 64.0-144.0 mg/L) and 91.7 mg/L (viz. 60.8-136.0 mg/L), respectively (Fig 7c). On the other hand, water with too much organic material can harm the environment in which the wastewater is discharged.

**Inter-relationship among selected parameters**

A decreasing trend in DO in response to the increased organic load (BOD and COD) is quite a common scenario in the urbanized part of the world, attributed to agricultural runoff, municipal sewage interaction,

Table 4. The mean concentration of Dissolved Oxygen, Organic loads, WQI and Irrigational quality parameters of lake water samples

| Sample ID | Lake name | no. of samples | Long (degree) | Latitude (degree) | Pre-monsoon | | | | | | | Post-monsoon | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DO | BOD | COD | WQI | SAR | Na (%) | RSC | DO | BOD | COD | WQI | SAR | Na (%) | RSC |
| SW 1 | Amani Byrasagara kere | 4 | 77.724 | 13.668 | 4.63 | 12.0 | 96.0 | 75.53 | 0.91 | 37.4 | -0.76 | 4.33 | 10.0 | 89.0 | 66.04 | 0.85 | 36.3 | -0.75 |
| SW 2 | Dibbur kere | 2 | 77.788 | 13.485 | 5.50 | 11.0 | 88.0 | 71.13 | 0.99 | 41.4 | -0.59 | 5.15 | 10.2 | 80.0 | 66.85 | 0.84 | 39.1 | -0.49 |
| SW 3 | Reddyhalli Kere | 2 | 77.815 | 13.550 | 5.45 | 11.5 | 96.2 | 82.06 | 0.86 | 34.0 | -0.76 | 5.30 | 10.4 | 88.3 | 70.24 | 0.76 | 32.2 | -0.78 |
| SW 4 | Peresandra Hosakere | 2 | 77.781 | 13.507 | 4.95 | 10.0 | 80.0 | 77.63 | 0.86 | 34.4 | -1.13 | 4.70 | 9.2 | 74.8 | 65.70 | 0.80 | 33.4 | -1.02 |
| SW 5 | Kathriguppe Kere | 2 | 77.798 | 13.463 | 4.80 | 16.0 | 128.0 | 103.81 | 0.78 | 34.1 | -1.04 | 4.70 | 10.0 | 80.0 | 68.18 | 0.80 | 35.6 | -0.86 |
| SW 6 | Bomanahalli Kere | 2 | 77.841 | 13.566 | 5.25 | 14.0 | 112.0 | 93.15 | 1.10 | 40.9 | -1.00 | 5.15 | 12.3 | 96.0 | 81.59 | 1.06 | 40.1 | -0.93 |
| SW 7 | Jakalmadagu lake | 4 | 77.618 | 13.424 | 4.48 | 18.0 | 144.0 | 112.04 | 0.93 | 37.7 | -1.02 | 4.40 | 16.2 | 144.0 | 94.55 | 0.92 | 37.9 | -0.97 |
| SW 8 | SrinivasaSagar lake | 4 | 77.628 | 13.453 | 5.53 | 16.4 | 128.0 | 101.16 | 1.03 | 37.3 | -1.12 | 5.35 | 15.3 | 144.0 | 86.82 | 0.98 | 36.9 | -0.99 |
| SW 9 | Kandhwara Kere | 4 | 77.721 | 13.421 | 5.58 | 11.1 | 87.4 | 79.47 | 1.01 | 40.6 | -0.76 | 5.43 | 10.3 | 82.3 | 66.28 | 0.75 | 34.0 | -0.75 |
| SW 10 | Amani Gopalkrishna kere | 4 | 77.761 | 13.424 | 4.98 | 8.0 | 64.0 | 68.37 | 0.92 | 34.7 | -1.09 | 4.85 | 7.1 | 60.8 | 57.15 | 0.81 | 32.7 | -1.08 |
| SW 11 | Kanithahalli lake | 2 | 77.770 | 13.369 | 4.45 | 10.4 | 80.0 | 78.59 | 0.84 | 34.6 | -1.11 | 4.25 | 9.3 | 73.4 | 63.43 | 0.68 | 30.5 | -1.06 |
| SW 12 | Rangadhama Kere | 2 | 77.705 | 13.462 | 4.60 | 12.2 | 96.0 | 85.51 | 0.90 | 36.7 | -1.05 | 4.45 | 10.5 | 91.2 | 71.93 | 0.65 | 30.8 | -1.02 |
| SW 13 | Manchanabele kere | 2 | 77.743 | 13.467 | 4.75 | 11.8 | 95.6 | 82.80 | 0.79 | 31.5 | -1.28 | 4.63 | 9.5 | 90.4 | 69.24 | 0.69 | 29.6 | -1.20 |
| SW 14 | Hosahudya lake | 4 | 77.825 | 13.393 | 5.18 | 10.3 | 80.0 | 76.30 | 0.79 | 33.3 | -0.87 | 5.14 | 9.2 | 78.3 | 62.15 | 0.81 | 34.7 | -0.75 |
| SW 15 | Doddamaralli Lake | 4 | 77.730 | 13.367 | 4.70 | 11.4 | 88.2 | 89.08 | 1.25 | 37.4 | -1.57 | 4.50 | 9.3 | 82.4 | 74.38 | 1.20 | 37.4 | -1.52 |
| SW 16 | Poornasagar lake | 2 | 77.765 | 13.523 | 5.20 | 11.5 | 87.5 | 98.98 | 1.26 | 27.7 | -1.85 | 5.18 | 10.2 | 83.4 | 83.08 | 1.22 | 27.6 | -1.61 |
| SW 17 | Jathwara Kere | 4 | 77.805 | 13.411 | 4.80 | 10.1 | 80.0 | 88.40 | 1.20 | 26.7 | -1.63 | 4.63 | 9.5 | 79.4 | 79.99 | 1.11 | 25.8 | -1.49 |
| SW 18 | Mustoor kere | 2 | 77.724 | 13.452 | 5.70 | 11.2 | 87.8 | 93.24 | 1.34 | 28.4 | -1.93 | 5.64 | 10.2 | 82.7 | 77.36 | 1.25 | 26.9 | -1.94 |
| SW 19 | Kasankunte Lake | 2 | 77.732 | 13.652 | 5.45 | 14.2 | 112.0 | 108.61 | 1.48 | 28.5 | -1.99 | 5.38 | 12.5 | 106.4 | 91.88 | 1.33 | 27.0 | -1.58 |
| SW 20 | Amani Marsanahalli kere | 2 | 77.752 | 13.478 | 4.80 | 12.3 | 96.0 | 108.91 | 1.06 | 20.5 | -3.27 | 4.76 | 10.8 | 92.6 | 98.33 | 0.91 | 18.5 | -3.11 |
| SW 21 | Chikkapylagurki | 2 | 77.790 | 13.547 | 5.50 | 10.2 | 80.0 | 95.59 | 1.04 | 21.4 | -3.36 | 5.41 | 9.3 | 77.6 | 78.96 | 0.99 | 21.2 | -2.97 |
| SW 22 | Yadarlahalli lake | 4 | 77.700 | 13.583 | 6.10 | 12.1 | 96.0 | 105.12 | 1.16 | 23.6 | -3.82 | 5.88 | 11.3 | 90.8 | 93.86 | 0.77 | 18.1 | -3.62 |
| SW 23 | Aruru lake | 2 | 77.774 | 13.565 | 4.70 | 10.5 | 80.0 | 102.55 | 1.40 | 24.8 | -3.14 | 4.62 | 9.6 | 78.4 | 95.95 | 1.16 | 21.9 | -3.03 |
| SW 24 | Hodekalu lake | 4 | 77.777 | 13.585 | 5.13 | 15.9 | 128.0 | 114.53 | 1.68 | 28.4 | -3.10 | 4.88 | 14.2 | 119.6 | 105.3 | 1.09 | 21.0 | -3.28 |
| SW 25 | Mandikal lake | 2 | 77.733 | 13.596 | 5.05 | 18.1 | 144.0 | 137.06 | 1.87 | 29.4 | -3.64 | 5.00 | 15.7 | 128.9 | 123.1 | 1.21 | 21.7 | -3.57 |
| SW 26 | Yardarahalli lake | 3 | 77.699 | 13.576 | 5.20 | 16.2 | 128.0 | 124.72 | 1.39 | 25.7 | -3.12 | 5.06 | 14.9 | 119.8 | 115.9 | 1.25 | 24.2 | -3.25 |
| SW 27 | Parenahalli lake | 2 | 77.687 | 13.599 | 5.10 | 14.3 | 112.0 | 119.85 | 1.97 | 32.5 | -3.51 | 5.02 | 13.2 | 107.5 | 112.1 | 0.69 | 15.4 | -3.35 |
| SW 28 | Hirenagavalli lake | 2 | 77.754 | 13.621 | 5.15 | 12.6 | 96.4 | 106.98 | 1.25 | 23.7 | -3.22 | 5.08 | 10.4 | 90.2 | 94.34 | 1.10 | 21.9 | -3.72 |
| SW 29 | Madanpur lake | 3 | 77.776 | 13.585 | 5.20 | 12.3 | 96.1 | 109.72 | 1.05 | 19.0 | -4.44 | 5.10 | 10.6 | 90.8 | 98.02 | 1.06 | 20.4 | -3.57 |
| SW 30 | Gudisihalli lake | 2 | 77.687 | 13.599 | 5.70 | 14.6 | 112.0 | 119.66 | 1.16 | 20.9 | -3.77 | 5.64 | 12.7 | 105.3 | 107.6 | 0.80 | 16.1 | -3.57 |
| SW 31 | Dandiganhalli lake | 2 | 77.668 | 13.510 | 4.85 | 9.2 | 72.0 | 93.14 | 1.27 | 23.3 | -4.13 | 4.79 | 8.6 | 70.1 | 87.61 | 0.82 | 17.4 | -3.47 |
| SW 32 | Dinnehosahalli lake | 3 | 77.707 | 13.460 | 5.57 | 11.1 | 88.0 | 103.29 | 0.90 | 18.0 | -4.51 | 5.37 | 10.3 | 83.5 | 96.80 | 0.76 | 16.1 | -4.09 |
| SW 33 | Varamallenahalli lake | 2 | 77.719 | 13.388 | 5.25 | 12.3 | 95.8 | 110.33 | 1.23 | 22.3 | -3.41 | 5.16 | 11.2 | 93.7 | 102.3 | 1.04 | 36.3 | -0.75 |
| SW 34 | Kolavanahalli lake | 3 | 77.755 | 13.382 | 5.17 | 12.6 | 96.9 | 114.48 | 1.72 | 27.4 | -3.68 | 5.05 | 10.8 | 92.7 | 102.9 | 1.25 | 39.1 | -0.49 |

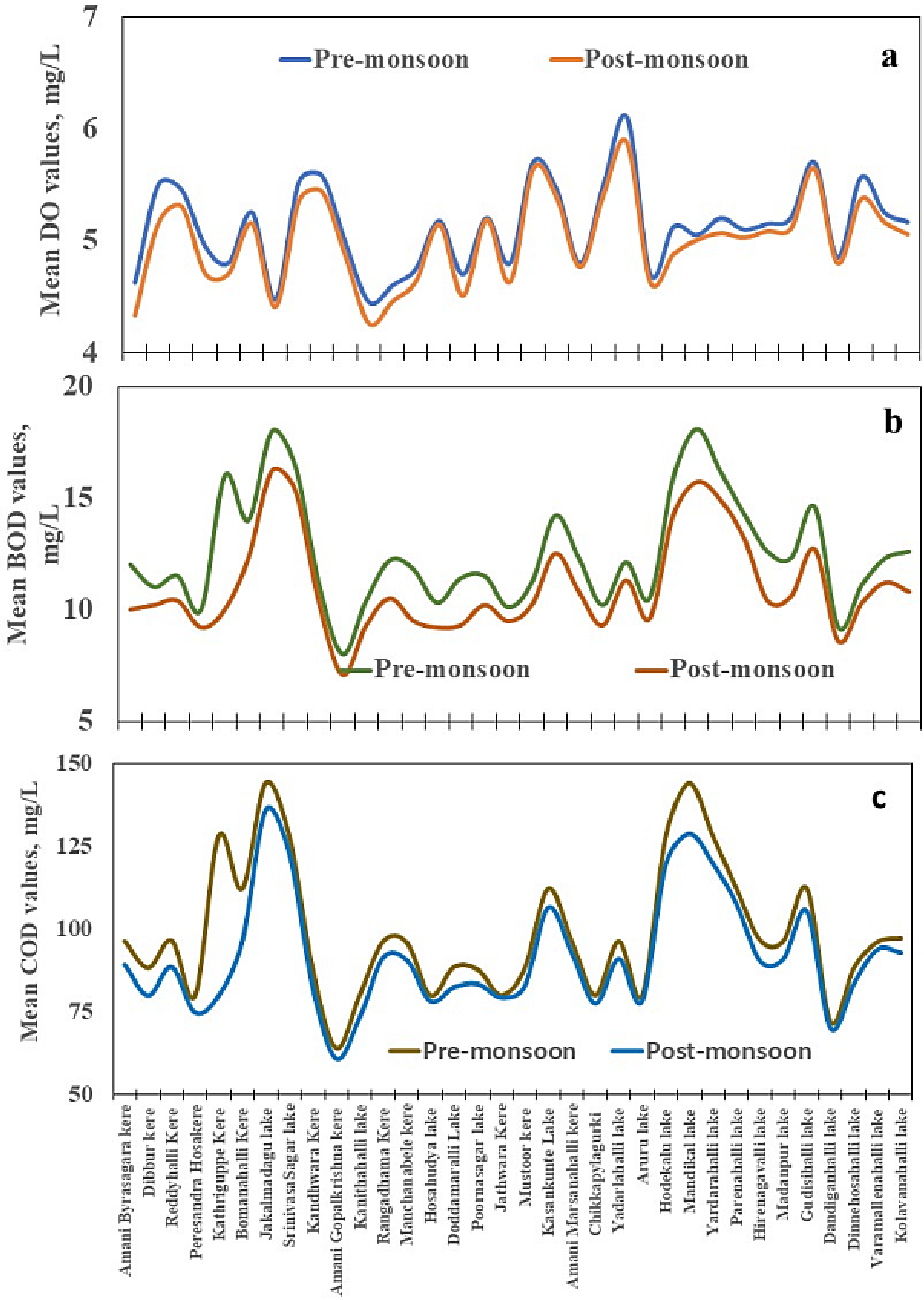


Figure 7. Spatio-temporal variation in (a) Dissolved oxygen, (b) Biochemical Oxygen Demand (BOD) and (c) Chemical Oxygen Demand (COD)

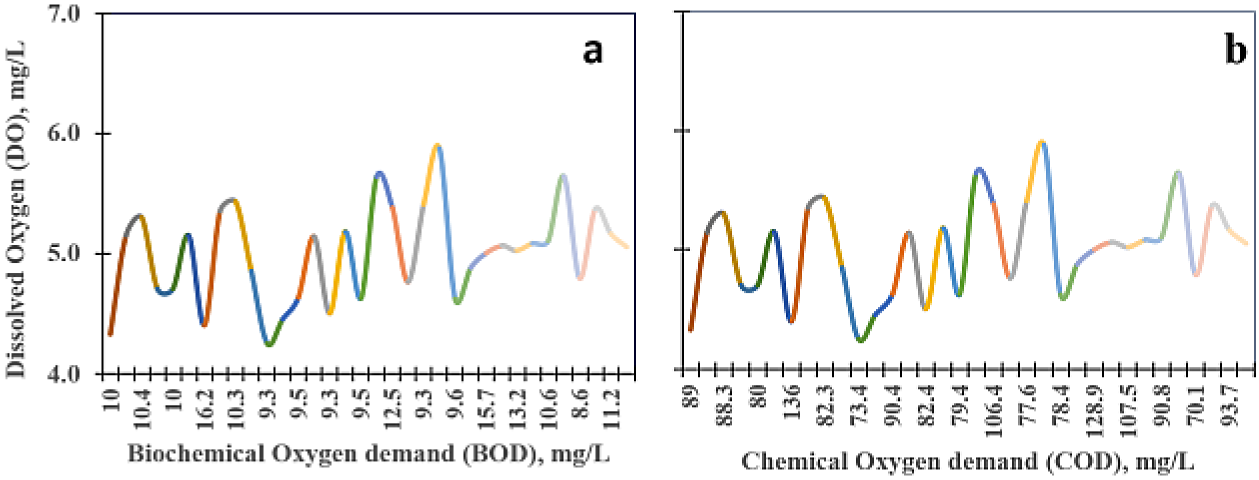


Figure 8. Bivariate Line plot of (a) DO vs. BOD and (b) DO vs. COD (Pre-monsoon)

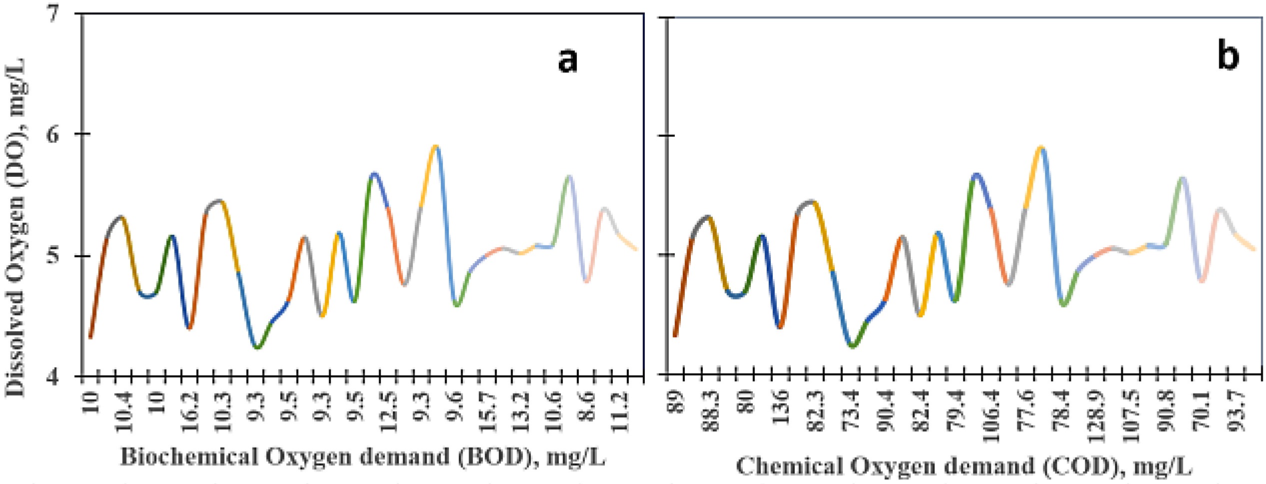


Figure 9. Bivariate Line plot of (a) DO vs. BOD and (b) DO vs. COD (Post-monsoon)

industrial *wastewater* discharge, stormwater runoff, etc. It is well established that BOD or COD and DO are inversely proportional to each other, viz., a decline in DO levels reflects a high level of BOD. Figures 8 and 9 demonstrate a negative relationship between DO vs BOD and DO vs COD for pre- and post-monsoon seasons. This trend clearly illustrates that lake water with high DO levels tends to have lower BOD and COD and vice versa in the study area.

Dayap et al. (2023) opined that a direct relationship exists between DO and pH in natural waters. This kind of observation is prevalent in the study area as revealed by their respective correlation coefficients (viz., r = 0.996 and 0.990) for pre- and post-monsoon season samples (Fig 10a, 11a). Scatter plots of BOD and COD (r = 0.9998 and 0.9985) also showed that lakes with higher BOD tend to have higher COD (Fig 10b, 11b). It is well documented in the literature that inorganic phosphorus and nitrogen, vital nutrients for the growth of aquatic plants, can contribute towards nourishment and habitation for fish and other aquatic organisms (Misra and Chaturvedi 2016). However, as too much nitrogen and phosphorus enter the environment, water can become contaminated (Manuel 2014). In this connection, scatter plots (Fig. 10d, 10f, 11d, 11f) illustrated the contribution of nitrates towards organic loadings (viz., COD and BOD levels) in the lake water of the study area. Phosphate also has an analogous role in enhancing the lakes' eutrophication rate. Scatter plots (Fig. 10c, 10e, 11c, 11e) illustrated the contribution of phosphates towards BOD (r=and COD levels in the lakes of the study area.

Lakes have been damaged by phosphate and nutrient contamination, which has impacted the

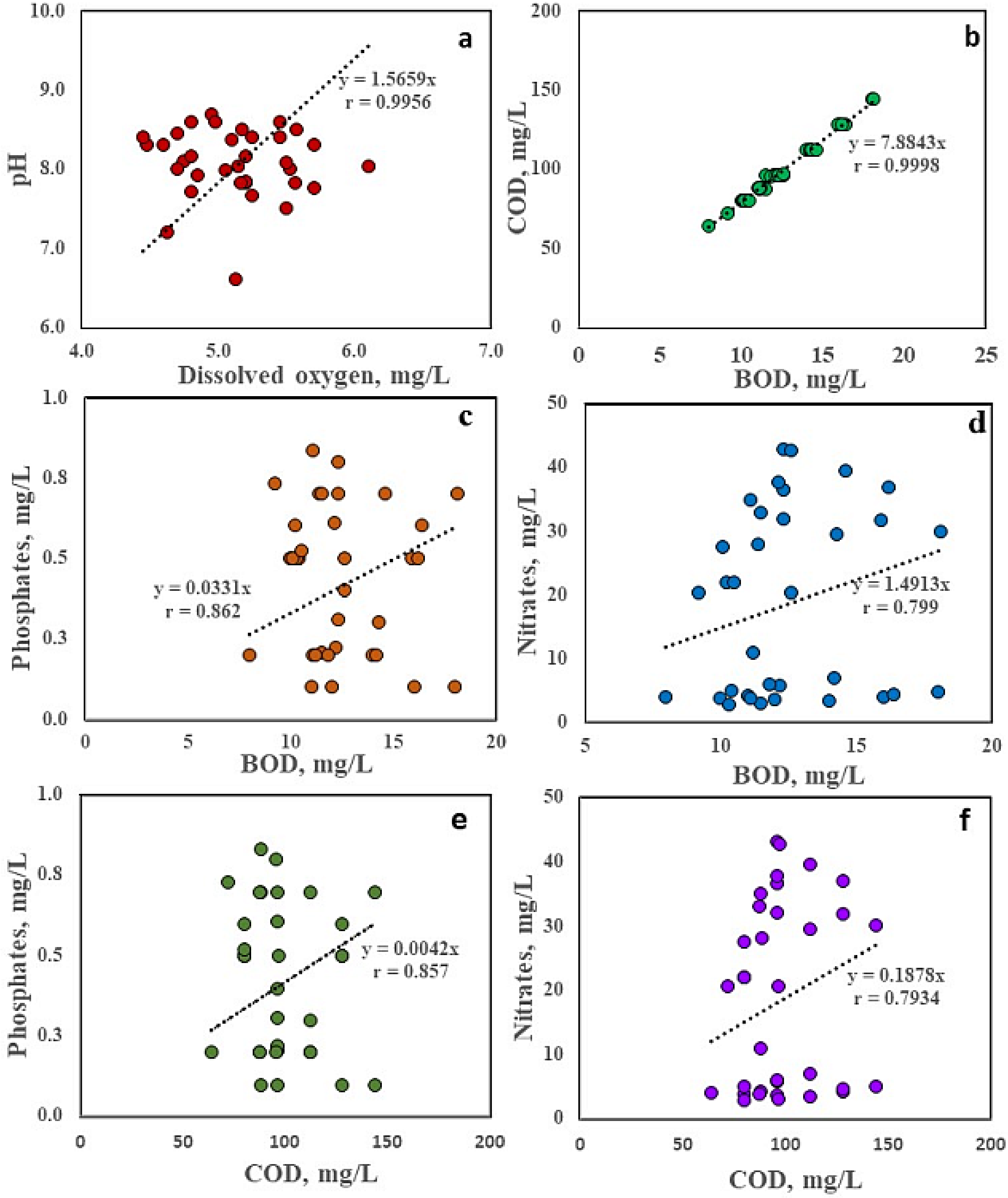


Figure 10. Bivariate scatter plot of inter-relationship among important lake water quality parameters (pre-monsoon)

economy, the ecosystem, and human health (Sampat et al. 2021). The quantity of oxygen needed for fish and other aquatic species to survive, as well as food sources, habitats, and water quality, are all negatively impacted by notable increases in the development of aquatic plants (Lambert et al. 2011). In the study area, there is an increase in pollution load, as revealed by the trend in BOD and COD against other vital parameters attributed to anthropogenic contribution. Further, Pushoo et al. (2023) opine that a lower

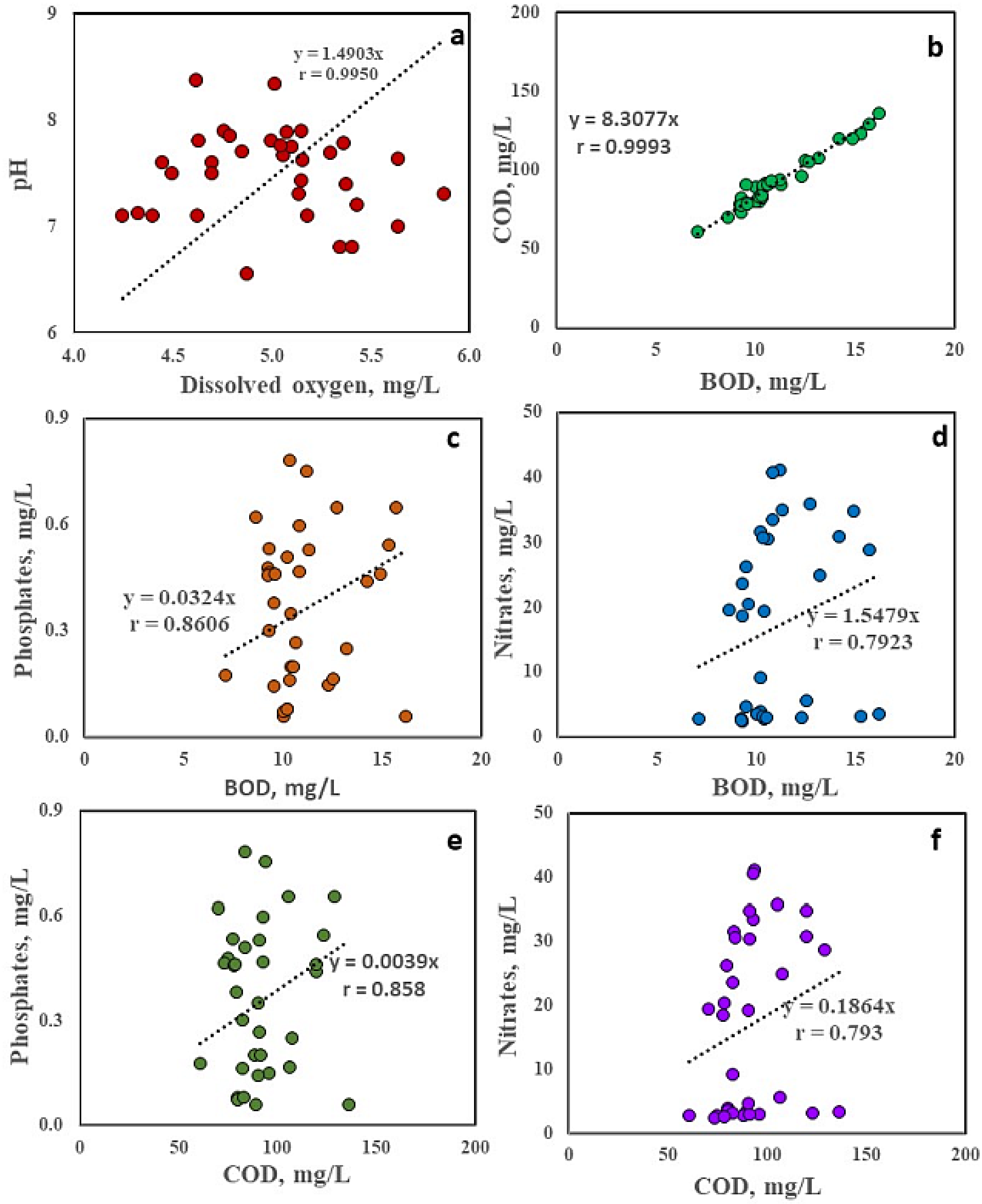


Figure 11. Bivariate scatter plot of inter-relationship among important lake water quality parameters (post-monsoon)

correlation trend (between DO vs BOD and DO vs COD) can endanger the lake ecosystem in the study area. The reasons for the increased organic load in the lake waters of the study area agree with the findings of Zheng et al. (2021) and Sun and Liu (2020) in that the contribution of human activities like agricultural nonpoint source pollution, economic development, accelerated urbanization, and tourism as the significant polluting factors of lakes. A similar opinion was expressed by Pushoo et al. (2023) that

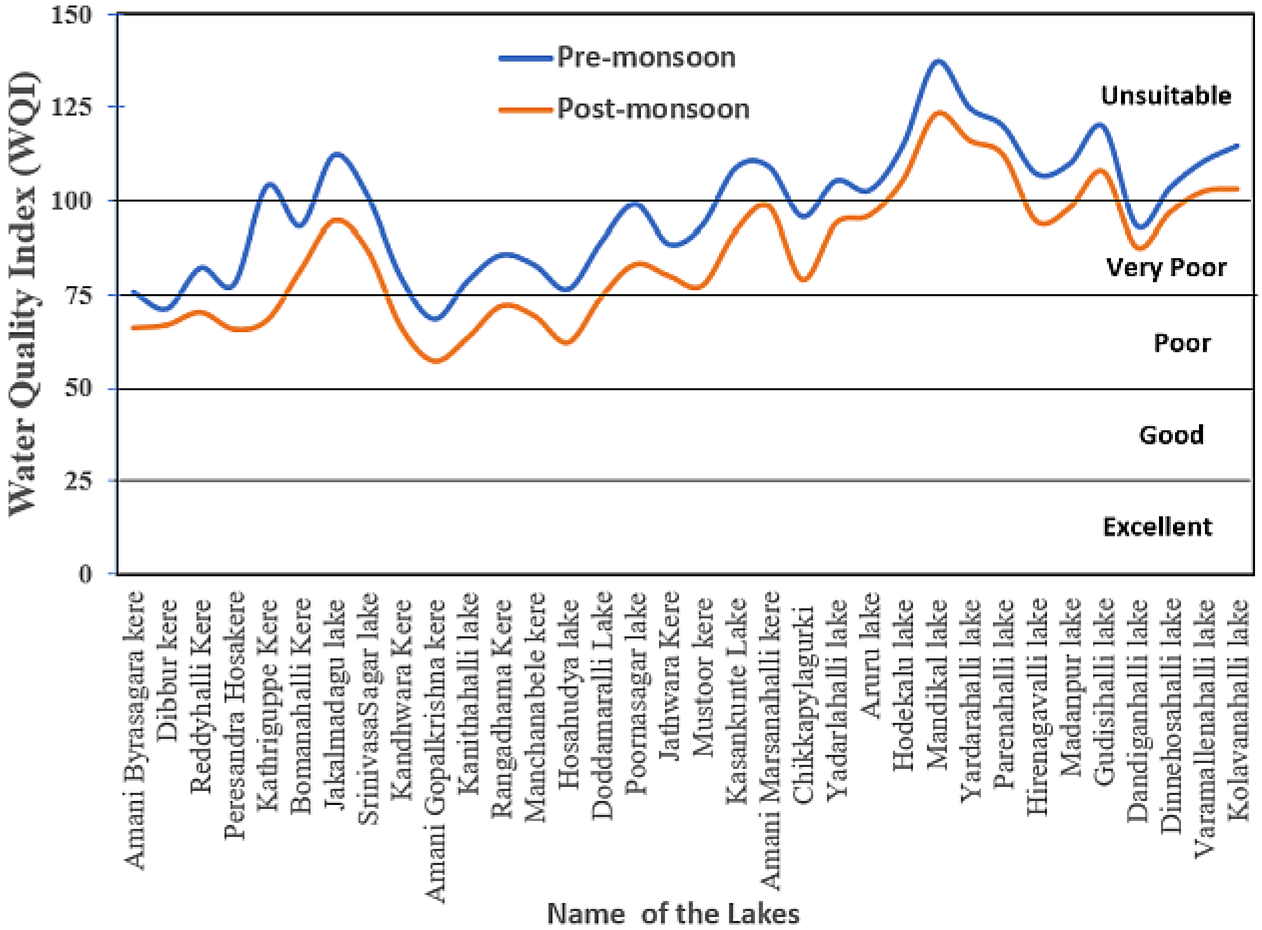


Figure 12. Spatio-temporal variation in WQI in the study area

the issues with sewage disposal and surface water contamination are getting worse quickly due to urbanization, modernization, and a rise in population in Dal Lake. Chen et al. (2021) believed that the lake water quality was better during the dry season over the wet season, with the highest total nitrogen (TN) and total phosphorus (TP) being observed post-monsoon seasons, preferably after September month due to increase in pollution load.

Mean SAR values ranged from 0.78 to 1.97 (mean: 1.20) and 0.65 to 1.33 (mean: 0.95), respectively, for pre-and post-monsoon seasons and were excellent for irrigation as SAR was below 10 (Richards 1954). Mean per cent sodium values varied between 18.0 and 41.4 (mean: 29.9) for pre-monsoon samples and 15.4 to 40.1 (mean: 27.2) for post-monsoon samples. It was apparent that 91.18% (viz., 31 lakes) and 97.06% (viz., 33 lakes) of the present study showed per cent sodium values well below 40%, and hence most of the lakes were classified as excellent (<20) to good (20–40) for irrigation (Wilcox 1955). The pooled mean value of RSC was found to be (-2.3) and (-2.1) and well below 1.25 meq/L during the study periods, hence suitable for irrigation. Overall, the lake waters were suitable for irrigation purposes.

Finally, the trend in WQI calculated for pre- and post-monsoon seasons for lake water samples from the study area is shown in Figure 12. During these seasons, the pooled mean WQI value was 98.0 (viz., 68.4-137.1) and 85.6 (viz., 57.1-123.1). Increased concentrations of some of the physico-chemical parameters like TDS, EC, total hardness, and organic loads (BOD) may be the reason for higher WQI values and poor to unsuitable water quality of lakes (viz., WQI>50). This demonstrated the contribution of anthropogenic inputs causing deterioration of lake water quality. In a similar study by Ravikumar et al. (2013), Mallathahalli Lake witnessed higher WQI values attributed to higher levels of TDS, electrical conductivity, total hardness, total alkalinity, etc, in the surface water. Zandagba et al. (2017) also reported higher water quality of Nokoue Lake during rainy seasons as compared to winter and summer season. Similarly, Kumar et al. (2018) reported extremely poor water quality in Tikkar Taal (WQI = 322.8), Braham Sarovar (WQI = 280.2), and Karan Lakes (WQI = 236.91) in parts of Haryana as higher levels of Fe, BOD, EC, nitrates, and lower levels of DO. Wang et al. (2019) observed poor water quality during the rainy season in Wuli and Taihu lakes of China. a study by Maansi et al. (2022) reported that WQI to range between 59.74 to 83.49 and found higher WQI in 2017-18 in comparison with WQI values for 2016-17, indicating deterioration of water quality of Lake Sukhna, Chandigarh, India.

## CONCLUSION

The present study demonstrated that significant ion concentrations in lake water sampled followed the order (Ca+ Mg) > (Na + K) for cations and $HCO_3$ > (Cl+ $SO_4$) for anions. These findings illustrate the prevalence of permanent or non-carbonate hardness in the lakes of the study area. Kolavanahalli and Varamallenahalli lakes witnessed nitrate levels of over 40 mg/L. Notably, the mean DO level was more than 4.0 mg/L in all the sampled lakes from the study area. The present study also highlights the importance of the WQI tool, which can be used for conveying water quality status in an easy-to-understand way. The values of WQI, BOD and COD indicated the contribution of human activities like agricultural runoff, nonpoint source pollution, entry of sewage, economic development, accelerated urbanization, and tourism as the significant polluting factors of lakes. It can be concluded that regular water quality monitoring is needed to understand the changes in physio-chemical parameter concentration so that an action plan can be taken after that.

## ACKNOWLEDGEMENTS

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**Authors' contributions:** Both the authors contributed equally

**Conflict of interest**: Authors declare no conflict of interest

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