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# Water Quality Assessment of the Feeder Rivers of Loktak Lake, Manipur

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## Abstract

The present study was conducted to determine water quality of the feeder rivers of Loktak Lake, a Ramsar Site in Manipur during April, 2022 to March, 2023. A total of six important feeder rivers of the lake were selected for the present investigation and they were Nambol River, Khujairok River, Thongjaorok River, Potsangbam River, Ningthoukhong River and Moirang River. The above rivers were selected on the basis of their pollution load which may directly contributed to the overall deterioration of water quality of the lake. Physicochemical parameters of the river water from selected study sites were analyzed on monthly basis following the standard methods given in Trivedy *et al*. (1987). Results of the study showed varied patterns indicating varying degrees of pollution of the feeders rivers indicating need of restoration and management of these feeder rivers in order to save the lake.

***Key words*:** Physicochemical, Feeder rivers, Loktak Lake, Manipur

Water ($H_2O$) is the most precious resource and abundant compound on Earth's surface, covering more than 70 percent of the planet [1]. About 0.3% of the water resources in the world are usable. Water shortages already exist in many regions, with more than one billion people without adequate drinking water. This situation is one of the most important indicators of why we should be very sensitive and conscious towards our water resources [2]. Overpopulation, Agriculture, Pollution of water and improper government policies are the important reasons for water scarcity [3]. All over the blue planet, even in the most rained-upon nations, people are engaged in conflicts over water. There are debates about who should own it, manage it, have access to it, profit from it, control it or regulate it [4].

Nearly 76 million people in India do not have access to safe drinking water, as polluted rivers and poor storage infrastructure over the years has created a water deficit which may become unmanageable in the future [5]. The river water pollution is a gigantic problem not only in India but also for the entire world. Both developed and developing countries are suffering from river water pollution, though the gravity of pollution differs from place to place [6]. Because of the flow characteristics of river water, river ecology is more vulnerable to external pollution. Moreover, once pollution occurs, it can easily spread to the whole river basin. In recent years, due to the rapid development of the urban economy, the rapid increase of the population, the deepening of the degree of industrialization, the increase of the urban water consumption and the discharge of river pollutants, the river self-purification and ecological compensation of the regulation ability of decline, the water quality significantly deteriorated [7].

There are various rivers which are directly or indirectly feeding the Loktak Lake, a Ramsar Site in Manipur. The lake is considered as the lifeline of Manipur, due to its importance in the socioeconomic and cultural life of the people. It is the largest natural fresh water lake in the north-eastern region of India with an area of 236.21 $km^2$ and plays an important role in the ecological and economic security of the region [8]. Thirteen large and small streams namely Nambul, Thongjaorok, Kharok, Potsangbam (Charoikhul at the upstream and Narkhong Turel at donwstream), Ningthoukhong Turel, Khujairok, Thinungei Khong, Lamganbi, Sanathoi, Irumbi, Thamnapokpi Khong, Laikhrambi and Moirang Turel (Turellu at upstream) which originate from the western mountain ranges stretching along the western boundary of Imphal Tampak drained into the Loktak Lake. In the past Nambol River was the prime tributary of the Nambul River but today the river empties into the Loktak Lake at the extreme north-western side. This Nambol river rises from the western hill ranges of Imphal Tampak and flows through Nambol Town [9]. Moirang River arises from the Thangjing Hills and flows a long distance passing through agricultural fields and Moirang Town and ultimately falls into the Loktak Lake. Some of the important sources of pollutants in the Moirang river are agricultural waste from the surrounding agricultural field, municipal sewage and solid waste from Moirang Town, which is a tourist area in Bishnupur District of Manipur [10]. The rivers which fed this lake are subjected to various anthropogenic interferences due to numerous dwellings along the bank of these rivers and their proximity to urbanized areas. Domestic and municipal solid wastes, domestic sewage, urban runoff and agricultural runoff have resulted in pollution of these feeder rivers and ultimately resulted in the deterioration of the water quality of the lake. As rightly observed by Gasim *et al*. [11], the physical environment of a lake is strongly influenced by total discharge and quality of the feeder rivers, it

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is important to study the water quality of the feeder rivers as the findings will help in making strategies for proper management and conservation of the lake. Therefore, the present study was carried out in order to identify the status of six important feeder rivers of Loktak Lake.

## MATERIALS AND METHODS

The feeder rivers of the Loktak Lake selected for Physicochemical investigation were Nambol River (Site-I), Khujairok River d(Site-II), Thongjaorok River (Site-III), Potsangbam River (Site-IV), Ningthoukhong River (Site-V) and Moirang River (Site-VI). River water samples were collected on monthly basis from April, 2022 to March, 2023 from the selected study sites and average of the five replicates of each sampling site studied were taken as one reading. The physicochemical characteristics studied were water temperature, pH, free $CO_2$, dissolved oxygen (DO), chloride, total hardness, sodium, potassium, phosphate and nitrate. Water temperature and pH were determined directly at the time of sample collection using water analysis kit. Other parameters viz. free $CO_2$, DO, chloride, total hardness, sodium, potassium, phosphate and nitrate were analyzed following standard methods given in Trivedy *et al*. (12].

## RESULTS AND DISCUSSION

Monthly variations in physicochemical characteristics in various feeder rivers of Loktak Lake are shown in (Table 1-6) below:

Table 1 Monthly variation in physicochemical characteristics of Nambol River, Manpur (Site I)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 20 | 25 | 26 | 27 | 24 | 24 | 23 | 22 | 15 | 16 | 18 | 19 |
| 2 | pH | 6.70 | 6.60 | 6.70 | 6.70 | 6,70 | 6.90 | 6.54 | 6.70 | 6.70 | 6.70 | 6.80 | 6.68 |
| 3 | Free $CO_2$ | 6.40 | 6.70 | 6.80 | 6.80 | 12.00 | 11.50 | 11.00 | 8.50 | 6.60 | 8.80 | 7.50 | 6.50 |
| 4 | DO | 5.00 | 5.20 | 5.30 | 6.60 | 5.40 | 5.40 | 5.60 | 3.30 | 3.70 | 3.61 | 4.00 | 4.80 |
| 5 | Chloride | 19.00 | 17.00 | 20.19 | 18.07 | 19.90 | 17.80 | 19.90 | 21.00 | 22.00 | 17.65 | 20.12 | 19.00 |
| 6 | Hardness | 40 | 38 | 37 | 37 | 36 | 34 | 32 | 33 | 32 | 30 | 34 | 32 |
| 7 | Sodium | 42 | 45 | 12 | 10 | 12 | 14 | 15 | 20 | 31 | 40 | 40 | 39 |
| 8 | Potassium | 8 | 7 | 3 | 1 | 5 | 5 | 0.4 | 4.1 | 3 | 0.6 | 2.5 | 2.5 |
| 9 | Phosphate | 0.124 | 0.133 | 0.075 | 0.07 | 0.071 | 0.08 | 0.085 | 0.125 | 0.122 | 0.08 | 0.085 | 0.071 |
| 10 | Nitrate | 0.54 | 0.452 | 0.234 | 0.342 | 0.401 | 0.4 | 0.5 | 0.611 | 0.5 | 0.522 | 0.527 | 0.56 |

*The values from S. No. 3 to 10 are expressed in mg/l

Table 2 Monthly variation in physicochemical characteristics of Khujairok River, Manpur (Site II)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 17 | 20 | 22 | 25 | 21 | 22 | 23 | 22.5 | 20 | 16.5 | 17 | 17 |
| 2 | pH | 6.00 | 6.70 | 6.80 | 6.70 | 6.80 | 6.10 | 5.93 | 6.63 | 6.90 | 5.96 | 6.00 | 6.70 |
| 3 | Free $CO_2$ | 6.80 | 6.90 | 6.90 | 7.00 | 8.60 | 8.60 | 8.80 | 7.10 | 6.60 | 6.70 | 6.90 | 6.90 |
| 4 | DO | 3.00 | 3.70 | 3.60 | 5.30 | 5.20 | 5.60 | 6.00 | 3.20 | 3.30 | 2.56 | 2.92 | 2.93 |
| 5 | Chloride | 17.00 | 17.00 | 21.00 | 19.00 | 20.00 | 18.60 | 17.20 | 20.00 | 20.12 | 18.60 | 16.20 | 19.00 |
| 6 | Hardness | 32 | 37 | 40 | 41 | 42 | 36 | 37 | 38 | 36 | 33 | 40 | 39 |
| 7 | Sodium | 34 | 36 | 25 | 10 | 13 | 14 | 16.5 | 18 | 30 | 35 | 32 | 29 |
| 8 | Potassium | 6.5 | 5 | 2 | 1 | 2 | 2.5 | 2 | 2 | 3 | 4 | 4 | 3.5 |
| 9 | Phosphate | 0.12 | 0.089 | 0.254 | 0.324 | 0.075 | 0.07 | 0.12 | 0.214 | 0.133 | 0.138 | 0.147 | 0.214 |
| 10 | Nitrate | 0.24 | 0.22 | 0.27 | 0.312 | 0.32 | 0.31 | 0.3 | 0.28 | 0.275 | 0.278 | 0.29 | 0.281 |

*The values from S. No. 3 to 10 are expressed in mg/l

Table 3 Monthly variation in physicochemical characteristics of Thongjaorok River, Manpur (Site III)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 18 | 22 | 25 | 25 | 26.5 | 27 | 23.5 | 21 | 17 | 16 | 17 | 17 |
| 2 | pH | 6.71 | 6.70 | 7.00 | 7.20 | 7.30 | 7.00 | 6.84 | 7.00 | 7.26 | 7.20 | 6.92 | 6.72 |
| 3 | Free $CO_2$ | 5.30 | 5.20 | 5.10 | 5.30 | 6.00 | 8.00 | 6.60 | 5.90 | 5.50 | 5.70 | 5.90 | 5.20 |
| 4 | DO | 3.91 | 4.62 | 4.30 | 4.31 | 3.61 | 3.72 | 4.10 | 4.20 | 4.30 | 4.36 | 3.42 | 3.46 |
| 5 | Chloride | 18.04 | 18.00 | 20.69 | 20.60 | 19.20 | 19.90 | 17.60 | 19.85 | 17.80 | 17.80 | 17.80 | 20.02 |
| 6 | Hardness | 37 | 36 | 35 | 37 | 39 | 40 | 42 | 43 | 42 | 36 | 42 | 36 |
| 7 | Sodium | 33 | 37 | 25 | 9 | 10 | 10 | 14 | 13 | 25 | 30 | 27 | 28 |
| 8 | Potassium | 6 | 5 | 3.5 | 0.3 | 1 | 1.2 | 2 | 2 | 3 | 1.5 | 2.5 | 7 |
| 9 | Phosphate | 0.089 | 0.133 | 0.215 | 0.334 | 0.083 | 0.085 | 0.081 | 0.161 | 0.17 | 0.162 | 0.124 | 0.089 |
| 10 | Nitrate | 0.36 | 0.345 | 0.41 | 0.442 | 0.451 | 0.42 | 0.41 | 0.405 | 0.4 | 0.43 | 0.45 | 0.47 |

*The values from S. No. 3 to 10 are expressed in mg/l

Table 4 Monthly variation in physicochemical characteristics of Potsangbam River, Manpur (Site IV)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 19 | 20 | 21 | 22 | 28 | 24 | 22 | 15 | 15.5 | 16 | 16 | 17 |
| 2 | pH | 7.00 | 6.90 | 6.80 | 6.80 | 6.72 | 6.62 | 6.70 | 6.70 | 6.71 | 6.70 | 6.77 | 6.70 |
| 3 | Free $CO_2$ | 9.12 | 9.20 | 8.54 | 8.55 | 7.30 | 7.30 | 7.20 | 7.10 | 9.90 | 8.21 | 9.00 | 9.30 |
| 4 | DO | 4.00 | 3.60 | 3.90 | 4.66 | 3.00 | 2.99 | 3.00 | 3.90 | 3.60 | 3.60 | 4.00 | 4.02 |
| 5 | Chloride | 18.40 | 19.30 | 19.30 | 20.19 | 19.80 | 19.87 | 18.60 | 19.90 | 20.02 | 18.00 | 19.00 | 20.03 |
| 6 | Hardness | 33 | 37 | 38 | 39 | 38 | 37 | 37 | 36 | 36 | 35 | 37 | 40 |
| 7 | Sodium | 37 | 35 | 24 | 11 | 10 | 11.5 | 12 | 23 | 30 | 26 | 32 | 31 |
| 8 | Potassium | 8 | 6 | 5 | 2 | 2 | 2.5 | 3 | 3 | 3 | 3 | 3 | 4 |
| 9 | Phosphate | 0.124 | 0.134 | 0.205 | 0.234 | 0.061 | 0.06 | 0.11 | 0.145 | 0.172 | 0.169 | 0.170 | 0.170 |
| 10 | Nitrate | 0.22 | 0.24 | 0.303 | 0.354 | 0.24 | 0.2 | 0.26 | 0.21 | 0.205 | 0.207 | 0.208 | 0.207 |

*The values from S. No. 3 to 10 are expressed in mg/l

Table 5 Monthly variation in Physicochemical characteristics of Ningthoukhong River, Manpur (Site V)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 20 | 23 | 24 | 26 | 25 | 25 | 24.5 | 21 | 20 | 16 | 17 | 17 |
| 2 | pH | 7.10 | 7.20 | 7.30 | 7.00 | 7.00 | 6.68 | 6.69 | 6.65 | 6.80 | 7.00 | 7.10 | 7.20 |
| 3 | Free $CO_2$ | 11.00 | 10.00 | 12.00 | 13.00 | 15.00 | 15.40 | 10.20 | 10.30 | 5.80 | 5.90 | 9.30 | 7.00 |
| 4 | DO | 3.90 | 2.47 | 3.80 | 4.00 | 4.00 | 3.90 | 3.90 | 4.00 | 3.90 | 5.00 | 4.69 | 4.32 |
| 5 | Chloride | 19.22 | 19.30 | 19.80 | 19.17 | 20.10 | 19.24 | 17.84 | 19.20 | 19.92 | 19.00 | 20.00 | 20.00 |
| 6 | Hardness | 36 | 36 | 37 | 39 | 36 | 37 | 37 | 33 | 35 | 35 | 39 | 41 |
| 7 | Sodium | 30 | 40 | 30 | 14 | 12 | 15 | 17.5 | 22 | 35 | 31 | 36 | 32 |
| 8 | Potassium | 7 | 8 | 5.5 | 3.5 | 4 | 4.5 | 4 | 3 | 3.5 | 3.5 | 4 | 5 |
| 9 | Phosphate | 0.075 | 0.078 | 0.133 | 0.214 | 0.094 | 0.075 | 0.125 | 0.123 | 0.125 | 0.094 | 0.099 | 0.090 |
| 10 | Nitrate | 0.385 | 0.399 | 0.41 | 0.56 | 0.528 | 0.541 | 0.41 | 0.51 | 0.505 | 0.53 | 0.54 | 0.54 |

*The values from S. No. 3 to 10 are expressed in mg/l

Table 6 Monthly variation in Physicochemical characteristics of Moirang River, Manpur (Site IV)

| S. No. | Parameters | Apr. 2022 | May 2022 | Jun. 2022 | Jul. 2022 | Aug. 2022 | Sep. 2022 | Oct. 2022 | Nov. 2022 | Dec. 2022 | Jan. 2023 | Feb. 2023 | Mar. 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp. (°C) | 20 | 24 | 25 | 25 | 26.5 | 25.5 | 25 | 20 | 20 | 16 | 17 | 18 |
| 2 | pH | 6.90 | 6.80 | 7.00 | 6.60 | 6.60 | 6.00 | 6.50 | 6.90 | 7.20 | 6.10 | 6.10 | 7.00 |
| 3 | Free $CO_2$ | 11.00 | 9.00 | 12.00 | 11.00 | 15.00 | 10.00 | 9.00 | 9.00 | 8.00 | 6.90 | 9.00 | 7.00 |
| 4 | DO | 4.20 | 4.20 | 4.67 | 3.97 | 3.90 | 4.00 | 4.00 | 4.30 | 4.88 | 4.12 | 4.67 | 4.59 |
| 5 | Chloride | 18.00 | 20.19 | 20.00 | 20.10 | 20.19 | 18.67 | 20.60 | 17.67 | 18.75 | 20.00 | 21.00 | 19.98 |
| 6 | Hardness | 37 | 42 | 40 | 39 | 33 | 36 | 36 | 37 | 34 | 36 | 40 | 37 |
| 7 | Sodium | 32 | 36 | 32 | 11 | 13 | 14 | 6 | 7 | 37 | 33 | 35 | 37 |
| 8 | Potassium | 13 | 14 | 8 | 3 | 3 | 4 | 4.5 | 5 | 3 | 10 | 7 | 9 |
| 9 | Phosphate | 0.090 | 0.099 | 0.314 | 0.342 | 0.089 | 0.085 | 0.06 | 0.158 | 0.169 | 0.232 | 0.234 | 0.236 |
| 10 | Nitrate | 0.345 | 0.4 | 0.402 | 0.505 | 0.541 | 0.541 | 0.41 | 0.41 | 0.545 | 0.56 | 0.56 | 0.54 |

*The values from S. No. 3 to 10 are expressed in mg/l

*Water temperature*

Temperature plays an important environmental factor in the aquatic system and temperature has a major influence in the rate of decomposition of organic matters in the water bodies. It also has its direct effect on various metabolic process and activities of the organism [13]. In an established system the water temperature controls the rate of all chemical reactions, and affects fish growth, reproduction and immunity. Drastic temperature changes can be fatal to fish [14]. Temperature fluctuation also affects the phytoplankton and zooplankton and hence affects the fish productivity [15]. Water Temperature of the present investigation varied from 27 °C in July, 2022 to 15 °C in December, 2022 at Site-I; 25 °C in July, 2022 to 16.5 °C in January, 2023 at Site-II; 27 °C in September, 2022 to 16 °C in January, 2023 at Site-III; 28 °C in August, 2022 to 15 °C in November, 2022 at Site-IV; 26 °C in July, 2022 to 16 °C in January, 2023 at Site-V; and 26.5 °C in August, 2022 to 16 °C in January, 2023 at Site-VI. Maximum water temperature was found at Site-IV (i.e. Potsangbam River) during August, 2022 (28 °C) while minimum water temperature of the present study was recorded during November and December, 2022 at Site-IV and Site-I respectively (15 °C). Freshwater fish have an optimum growing temperature in the range of 25-30 °C at which they grow quickly [16].

*pH*

pH is considered as an important ecological factor and provides an important piece factor and piece of information in many types of geochemical equilibrium or solubility calculation. pH is an important parameter in water body since most of the aquatic organisms are adapted to an average pH and do not withstand abrupt changes [17]. pH maintenance (buffering capacity) is one of the most important attributes of any aquatic system since all the biochemical activities depend on pH of the surrounding water [18]. It indicates the acid base balance of the water. The survival and growth of fish is also depending on pH of the water. The ideal pH for the growth of fishes is between 7.5 to 8.5, above and below this is stressful to

the fishes [19]. The pH values of the present study ranged from 6.90 in September, 2022 to 6.54 in October, 2022 at Site-I; from 6.90 in December, 2022 to 5.93 in October, 2022 at Site-II; from 7.30 in August, 2022 to 6.70 in May, 2022 at Site-III; from 6.90 in May, 2022 to 6.62 in September, 2022 at Site-IV; from 7.30 in June, 2022 to 6.65 in November, 2022 at Site-V; and from 7.20 in December, 2022 to 6.00 in September, 2022 at Site-VI. The highest value of pH during the whole study period was observed at Site-III and Site-V during August and June, 2022 respectively (7.30) while the lowest value of pH was observed at Site-II during October, 2022 (5.93). Generally, the pH values observed in all sites of the present study were slightly in acidic in nature and were also below the ideal range for the growth of fishes.

*Free $CO_2$*

Free carbon dioxide in water is the byproduct of metabolism. More than a particulate level, carbon dioxide in water is toxic to the life in water [20]. Water with concentration of free $CO_2$ less than 5ppm supports good fish production, where as its high concentration in water leads to asphyxiation and obtain death of fishes [21]. The values of free $CO_2$ ranged from 12mg/l during August, 2022 to 6.40 mg/l during April, 2022 at Site-I; from 8.80 mg/l during October, 2022 to 6.60 mg/l during December, 2022 at Site-II; from 8.00 mg/l during September, 2022 to 5.10 mg/l during June, 2022 at Site-III; from 9.90 mg/l during December, 2022 to 7.10 mg/l during November, 2022 at Site-IV; from 15.40 mg/l during September, 2022 to 5.50 mg/l during December, 2022 at Site-V; and from 15.00 mg/l during August, 2022 to 6.90 mg/l during January, 2022 at Site VI.. The maximum value of free $CO_2$ was recorded at Site-V during September, 2022 (i.e 15.40 mg/l) whereas minimum value was recorded at Site-III during June, 2022 (i.e. 5.10 mg/l). Most of the values observed for free $CO_2$ were higher than the maximum limit given for best designated use by BIS, 1992 under IS: 2296 - 1992 of surface water quality standard (i.e. 6 mg/l of free $CO_2$) [22].

*Dissolved oxygen (DO)*

DO is one of the most important parameters of water quality [23]. Dissolved oxygen levels are considered as the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life. Like terrestrial animals, fish and other aquatic organisms need oxygen to live. Dissolve oxygen plays an important role in precipitation and dissolution of organic substances in water [24]. The observed ranged values for DO were from 6.60 mg/l during July, 2022 to 3.61 mg/l during January, 2023 at Site-I; from 6.00 mg/l during October, 2022 to 2.56 mg/l during January, 2023 at Site-II; from 4.62 mg/l during May, 2022 to 3.42 mg/l during February, 2023 at Site-III; from 4.66 mg/l during July, 2022 to 2.99 mg/l during September, 2022 at Site-IV; from 5.00 mg/l during January, 2023 to 2.47 mg/l during May, 2022 at Site-V; and from 4.88 mg/l during December, 2022 to 3.90 mg/l during August, 2022 at Site-VI. The maximum DO was observed at Site-I during July, 2022 (6.60 mg/l) while minimum DO was observed at Site-V during May, 2022 (2.47mg/l). The water for designated best use of fish culture and wildlife propagation is 4 mg/l (minimum) as per IS: 2296 - 1992 under surface water quality standard [22]. Most of the DO values recorded were below this limit except at Site-VI indicating various degrees of organic pollution.

*Chloride*

In natural fresh waters, chloride concentration remains quite low [25]. Chloride usually occurs as NaCl, $CaCl_2$, $MgCl_2$, and in broadly fluctuating concentrations, in all natural waters. The presence of chloride in drinking water sources can be attributed to the irrigation drainage, dissolution of salt deposits, sewage, sea spray and seawater interruption in coastal areas. Each of these causes may result in local source of pollution in ground and surface water [26]. The range values of chloride of the present study were 22.00 mg/l during December, 2022 to 17.00 mg/l during May, 2022 at Site-I; 21.00 mg/l during June, 2022 to 16.20 mg/l during February, 2023 at Site-II; 20.69 mg/l during June, 2022 to 17.60 mg/l during October, 2022 at Site-III; 20.19 mg/l during July, 2022 to 18.00 mg/l during January, 2023 at Site-IV; 20.10 mg/l during August, 2022 to 17.84 mg/l during October, 2022 at Site-V; and 21.00 mg/l during February, 2023 to 17.67 mg/l during November, 2022 at Site-VI. The highest value of chloride was recorded at Site-I with a value of 22.00 mg/l during December, 2022 and lowest value was recorded at Site-II with a value of 16.20 mg/l during February, 2023. According to Stone and Thomforde [27] the desirable range of chlorides for commercial catfish production is above 60 mg/l and considering this desirable value, the finding values of chloride are seems to be low.

*Total hardness*

The total hardness of water is caused by Ca and Mg ions present in water. Hardness could be temporary due to carbonates and bicarbonates or permanent due to sulphates and chlorides. Biologically temporary hardness plays a key role in buffering capacity, thus neutralizing the pH due to addition of acidic products. It has a great effect on biotic diversity of an ecosystem [28]. The range values of hardness of the present study were 40 mg/l in April, 2022 to 30 mg/l in January, 2023 at Site-I; 42 mg/l in August, 2022 to 32 mg/l in April, 2022 at Site-II; 43 mg/l in November, 2022 to 35 mg/l in June, 2022 at Site-III; 40 mg/l in March, 2023 to 33 mg/l in April, 2022 at Site-IV; 41 mg/l in March, 2023 to 33 mg/l in November, 2022 at Site-V; and 42 mg/l in May, 2022 to 33 mg/l in August, 2022 at Site-VI. The highest value observed was 43 mg/l in November, 2022 at Site-III whereas the lowest value observed was 30 mg/l in January, 2023 at Site-I. Water hardness in the range of 50-150 mg/l as $CaCO_3$ is considered desirable, but the most preferable is above 100 mg/l as $CaCO_3$ [29]. So, the current findings values of hardness of feeder rivers are not preferable for growth and survival of freshwater fishes.

*Sodium*

The higher sodium content of water samples was recorded after mass bathing while the lower content was recorded before mass bathing. In surface water the sodium concentration may be less than 1 mg/l or exceed 300 mg/l depending upon the geographical area [30]. The values of sodium varied from 45 mg/l in May, 2022 to 10 mg/l in July, 2022 at Site-I; from 34 mg/l in April, 2022 to 10 mg/l in July, 2022 at Site-II; from 37 mg/l in May, 2022 to 9 mg/l July, 2022 at Site-III; from 37 mg/l in April, 2022 to 10 mg/l in August, 2022 at Site-IV; from 40 mg/l in May, 2022 to 12 mg/l in August, 2022 at Site-V; and from 37 mg/l in March, 2023 to 11 mg/l in July, 2022 at Site-VI.

*Potassium*

The major source of potassium in natural fresh water is weathering of rocks but the quantities increase in the polluted water due to disposal of waste water [31]. The ranged values of potassium were 8 mg/l during April, 2022 to 0.6 mg/l during January, 2023 at Site-I; 6.5 mg/l during April, 2022 to 1 mg/l during July, 2022 at Site-II; 7 mg/l during March, 2023 to 1 mg/l during August, 2022 at Site-III; 8 mg/l during April, 2022

to 2 mg/l during July and August, 2022 at Site-IV; 8 mg/l during May, 2022 to 3 mg/l during November, 2022 at Site-V; and 14 mg/l during May, 2022 to 3 mg/l during July, August and December, 2022 at Site-VI.

*Phosphate*

Phosphorus is an important nutrient for plant growth. In aquatic systems, a lack of phosphorus often limits aquatic plant growth. Excess phosphorus is usually considered to be a pollutant. Phosphorus is recognized as one of the major nutrients contributing to the increased eutrophication of lakes and other natural waters. This has led to many water quality problems including increased purification costs, interference with the recreational and conservation value of impoundments, loss of livestock and the possible sub-lethal effects of alga toxins on humans using eutrophic water supplies for drinking [32]. The ranged values recorded for phosphate were 0.133 mg/l in May, 2022 to 0.07 mg/l in July, 2022 at Site-I; 0.324 mg/l in July, 2022 to 0.07 mg/l in September, 2022 at Site-II; 0.334 mg/l in July, 2022 to 0.081 mg/l in October, 2022 at Site-III; 0.254 mg/l in July, 2022 to 0.11 mg/l in October, 2022 at Site-IV; 0.214 mg/l in July, 2022 to 0.075 in April and September, 2022 at Site-V; and 0.342 mg/l in July, 2022 to 0.06 mg/l in October, 2022 at Site-VI. According to Stone and Thomforde [27] the phosphate level of 0.06 mg/l is desirable for fish culture. Phosphate in the range of 0.1-5.6 µg/L could trigger eutrophication, limiting the primary productivity of aquatic ecosystem [33].

*Nitrate*

Organic pollution is indicated by the high nitrogen level. It is caused by nitrogen fertilizers, the rotting of dead plants and animals, animal urine and faces, and other factors. They are all converted to nitrate by natural processes [34]. Recorded values of nitrate of the present study varied from 0.56 mg/l in March, 2023 to 0.342 mg/l in July, 2022 at Site-I; from 0.32 mg/l in August, 2022 to 0.22 mg/l in May, 2022 at Site-II; from 0.47 mg/l in March, 2023 to 0.345 mg/l in May, 2022 at Site-III; from 0.303 mg/l in June, 2022 to 0. 20 mg/l in September, 2022 at Site-IV; from 0.56 mg/l in July, 2022 to 0.385 mg/l in April, 2022 at Site-V; and from 0.56 mg/l in January and February, 2023 to 0.345 mg/l in April, 2022 at Site-VI. Nitrate is not toxic to aquatic animals even in large concentration. Its favourable range is 0.1 mg/l to 4.5 mg/l in culture water [35].

## CONCLUSION

The findings of the present investigation on six feeder rivers of Loktak Lake showed a varied pattern without any general trend in any of the physicochemical characteristics of river water investigated. This indicates that there might be spatial and temporal variation in anthropogenic interferences in these rivers under study. Overall low values of DO and high values of free $CO_2$ indicates high decomposition of organic matter. Free $CO_2$ released during decomposition of organic matter can react with water producing carbonic acid which may be the reason for weak acidification shown by lowering the pH values of rivers of the present study. Weak acidification can occur in freshwater ecosystems when free $CO_2$ level increases and this phenomenon can limit species community diversity, especially in invertebrates and fishes. The values of phosphate and nitrate observed during the study also indicates eutrophic nature of these rivers. So, overall, it can be concluded that these feeder rivers need restoration and management in order to save Loktak Lake.

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