Assessment of the water quality of Glacier-fed lake Neel Tal of Garhwal Himalaya, India

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ABSTRACT
Neel Tal is a glacier-fed lake, located at an altitude of 4,382 m above m.s.l. in the Garhwal Himalaya, India. This lake is located at 30 km from Gangotri, the world famous shrine of Hindus and 13 km from the snout of Gangotri glacier known as “Gaumukh”, that has been considered as the origin place of Holy River ‘Ganga’. Assessment of surface water quality of a high altitude lake is important for providing drinking water to the trekkers, sages, and consumption by wildlife along with its conservation and management. Water Quality Index (WQI) method was applied to assess the water quality of Neel Tal, using 18 water quality parameters. The data for all the physical, chemical and biological parameters were collected in the months of June and August for a period of two years during 2014 and 2015 due to the accessibility of the lake as it remains under frozen condition for most of the time. The value of WQI was estimated to be 17.85 based on all the water quality parameters, which categorized the quality of water as ‘excellent’ during the study period. The coliform test also supported the findings of water quality of Neel Tal by WQI method.

Introduction
High altitude lakes including the glacier-fed lakes are the major source of drinking water for the trekkers, sages, and wildlife in the Himalayan region for their sustainability and livelihood. According to the United Nations Conference on Sustainable Development (UNSD, 2012) which was held at Rio de Janeiro in Brazil, “the mountain ecosystem plays a key role in fulfilling the water requirement to a large population of the world”. The hydrologic status of water of a lake in terms of quality and quantity is the result of complex processes of physical, chemical and biological inputs (Singh et al., 2008). The lakes of Himalayan region are either rain-fed, spring-fed, ground-water fed or glacier-fed/snow-fed. Mostly, all the lakes which are located above an altitude of 3,500 m above m.s.l. are considered to be glacier-fed (WWF, 2005). The source of water for such type of glacier-fed lakes is the melting of ice or snow from a nearby glacier (Fairbridge, 1968). Water is one of the most important natural resources on the Earth, which is commonly shared by all the living organisms present on the Earth. The glacier-fed lakes are generally having clean and fresh water with no such pollutants and contaminants, because of its location at a very high altitude. A glacier-fed lake is defined as water mass existing in a sufficient amount and extending with a free surface in, under, beside, and/or in front of a glacier and originating from glacier activities and/or retreating processes of a glacier (Dimri et al., 2016).

Generally, two types of glacier-fed lakes are found, that are moraine-dammed lakes and ice-dammed lakes. In moraine-dammed, due to the continuous flow of water by melting of ice/snow, a tarn has been created which is covered by the large boulders, and the melted water has been stored in that tarn. This type of lake is known as moraine-dammed lake. When an iceberg or large block of ice breaks down and erodes the land and melts, filling the space with melted water that has been created by the iceberg. Such types of lake are dammed by ice without lateral moraine. All the lakes are associated with debris over on glacier ice that caused differential melting and increased surface irregularities in developed lakes (Ageta et al., 2000).

Water quality of such glacier-fed lakes gives an indication towards the suitability of water for human consumption (Vaux, 2001). There are various methods to assess the quality of water. One of the most effective ways to assess the water quality of a water body is the Water Quality Index method (Dwivedi & Pathak, 2007). The WQI method is based on various physico-chemical and biological properties of water collected during the sample analysis. Though, few works have been done on different aspects of glacial lakes. These include the works of Ageta et al. (2000) on glacier lakes of Bhutan; Raj et al. (2013) on glacial lakes of Sikkim; Ghimire et al. (2013) on Gokyo and Imja Lakes; Pu et al. (2013) on glacial Lake Ximencuo; Che et al. (2014) on glacial lakes of Tibet; Bhambri et al. (2015) on inventory of...
glacier lakes of Uttarakhand; Sharma and Kumar (2017) on glacier-fed Lake Satopanth; Wu et al. (2017) on water quality assessment Poyang Lake; Chaudhary et al. (2018) on water quality of Deoria Tal; Rana et al. (2018) on Himalayan lake Beni Tal; and Kumar et al. (2018) on high altitude lake Dodi Tal. However, no work has been done so far on the water quality of the glacier-fed lake, Neel Tal of Garhwal Himalaya. Therefore, it was felt desirable to assess the water quality of Neel Tal of Garhwal Himalaya for its conservation and management.

Materials and methods

Study area

Neel Tal is a glacier-fed lake that is located in Uttarkashi district of Garhwal Himalaya in the Uttarakhand state of India. It is located at an altitude of 4,382 m above mean sea level (Figure 1). This beautiful blue water lake is also known as Gandharva Lake that is located in the center of snow-capped peaks, at latitude 30°55.181′ N and longitude 79°04.540′ E. Neel Tal is located around 30 Km far from Gangotri temple, the world famous shrine of Hindus and around 13 Km from Gaumukh (snout of Gangotri Glacier), the origin place of holy River Ganga. The lake remains under freezeed condition from the end of September to the end of May or sometimes up to the end of June. This beautiful lake is situated at the base of Mt. Meru peak or Meru Parvat. The approximate area of the lake is 2,500 m² with the length of about 300 m and width of 250 m. The average depth of this lake is approximately 10–12 m. This lake was
created in the year 1991 by tectonic movement during a high-intensity earthquake (6.8 Richter scale) in Uttarkashi district. The water of the lake is held by the vast boulders and lateral moraines of the nearby glacier. No vegetation is found at and near the Neel Tal. However, *Saussurea obvallata* (Brahma Kamal), the state flower of Uttarakhand is dominantly found 3–5 Km away from the Neel Tal. *Saussurea obvallata* is a flower that is native to the Himalaya, growing at an altitude of around 4,500 m. This flower is widely used in Uttarakhand by the Hindus for offering to “Lord Vishnu” in Badrinath, the world famous shrine of Hindus.

**Water sampling and analysis**

The lake water was sampled during 2014 and 2015 in two sampling operations each year. In both the years, sampling was made in the months of June and August, when the lake was accessible. Water samples were collected from three different sites ($S_1$, $S_2$, and $S_3$) of the lake at about 30 cm below the surface water using autoclaved thermoflask during the morning time between 9:00 and 11:00 hrs. Water quality parameters like pH, air temperature, water temperature, and dissolved oxygen were measured at the sampling site. However, for the remaining parameters, the water samples were transferred to the Laboratory of Freshwater Biology, Department of Environmental Sciences, H.N.B. Garhwal University (A Central University), Srinagar-Garhwal, Uttarakhand, India. All the physico-chemical parameters and coliform test were analyzed by following the standard methods outlined in Wetzel and Likens (1991); APHA (2005).

Water temperature was measured by dipping the digital thermometer 10 cm below the surface in the lake carefully. The temperature range of digital thermometer was ($−50°C$ to $+300°C$). pH was measured both at the site by using litmus paper and portable pH meter of Electronics India (Model No. 7011) and in Laboratory by using the Toshcon Bench Top Multiparameter analyzer (Model No. TPC-17). Dissolved oxygen was measured by using the Modified Winkler method at the sampling site. Conductivity and Total Dissolved Solids (TDS) were measured by using the Toshcon Bench Top Multiparameter analyzer (Model No. TPC-17). Free CO$_2$, total alkalinity, total hardness, Calcium hardness, chlorides, and Magnesium hardness were measured by following the protocols available in APHA (2005). Nitrates, Sulphates, and Phosphates were measured by the spectrophotometric method by using the Systronic UV-VIS Spectrophotometer (Model No. 117). The statistical mean with standard deviation of all the replicates of samples for each sampling site was also calculated.

**Coliform detection**

For water quality analysis, coliform group of bacteria may be differentiated by the presumptive test, the confirmed test, and the complete test. The presumptive test was done to confirm the presence of lactose fermenting gas-producing bacteria. It was used to determine the Most Probable Number (MPN) of coliforms in a sample of water beside their properties of fermenting lactose and producing gas. The confirmed and the complete test are meant for differentiating the coliform with that of non-coliforms. All these tests were performed by following the standard methods outlined in APHA (2005).

**Water Quality Index (WQI)**

WQI is an abyssal number that combines the various water quality values into a single number by normalizing values to subjective rating curves. All these parameters or characteristics occur in variable ranges and expressed in various units. The WQI takes the complex scientific information into a single number. For this purpose, 15 water quality parameters were selected. Values used for each parameter were the mean value of all three sites and four replicates of each site.

In the formulation of WQI, the ‘standards’ (permissible values of various parameters) for the drinking water used in this study were those recommended by the World Health Organization (WHO, 2004). The calculation and formulation of the WQI involved the following steps (Prati et al., 1971; Sharma & Kumar, 2017; Kumar et al., 2018):

**First step**: Each of the 15 parameters has been assigned a weight ($AW_i$) ranging from 1 to 4 depending on the collective expert opinions taken from different previous studies (Prati et al., 1971; Ramakrishnaiah et al., 2009; Alobaidy et al., 2010; Sharma & Kumar, 2017; Kumar et al., 2018). The mean values for the weights of each parameter have been shown in Table 1. However, a relative weight of 1 was considered as the least significant and 4 as the most significant.

**Second step**: The relative weight ($RW$) was calculated by using the following equation:

$$RW = \frac{\sum_{i=1}^{n} AW_i}{n}$$  

where $RW$ = the relative weight, $AW_i$ = the assigned weight of each parameter, $n$ = the number of parameters. The calculated relative weight ($RW$) values of each parameter have been given in Table 2.

**Third step**: A quality rating scale ($Qi$) for all the parameters except pH and DO was assigned by dividing its concentration in each water sample by its
Table 1. Assigned weight values of physico-chemical parameters of water of Neel Tal adopted from Prati et al. 1971; Ramakrishnaiah et al. 2009; Alobaidy et al. 2010; Sharma and Kumar 2017; Kumar et al. 2018.

| Parameters          | Sampling sites | Mean value |
|---------------------|----------------|------------|
| pH                  | S1  | S2  | S3  |          |
| DO (mg.l⁻¹)         | 3   | 3   | 3   | 3.0      |
| Conductivity (µS/cm)| 4   | 4   | 4   | 4.0      |
| TDS (mg.l⁻¹)        | 3   | 2   | 3   | 2.3      |
| Free CO₂ (mg.l⁻¹)   | 2   | 2   | 2   | 1.0      |
| Total hardness (mg.l⁻¹) | 3   | 3   | 3   | 3.0      |
| Calcium (mg.l⁻¹)    | 3   | 2   | 3   | 2.7      |
| Magnesium (mg.l⁻¹)  | 2   | 3   | 2   | 2.3      |
| Chlorides (mg.l⁻¹)  | 4   | 4   | 4   | 4.0      |
| Total alkalinity (mg.l⁻¹) | 4   | 3   | 4   | 3.7      |
| Nitrates (mg.l⁻¹)   | 1   | 1   | 1   | 1.3      |
| Sulphates (mg.l⁻¹)  | 1   | 1   | 1   | 1.0      |
| Phosphates (mg.l⁻¹) | 2   | 3   | 2   | 2.7      |
| Fecal coliform      | 4   | 4   | 4   | 4.0      |
| Total coliform      | 4   | 4   | 4   | 4.0      |

relative standard according to the drinking water guidelines recommended by the WHO, the result was then multiplied by 100.

\[ Q_i = \left( \frac{C_i}{S_i} \right) \times 100 \]  

(2)

While, the quality rating for pH or DO (Q_{pH, DO}) was calculated on the basis of,

\[ Q_{pH, DO} = \left( \frac{C_i - V_i}{S_i - V_i} \right) \times 100 \]  

(3)

where \( Q_i \) = the quality rating, \( C_i \) = value of the water quality parameter obtained from the laboratory analysis, \( S_i \) = value of the water quality parameter obtained from recommended WHO, \( V_i \) = the ideal value which is considered as 7.0 for pH and 14.6 for DO (Prati et al., 1971; Ramakrishnaiah et al., 2009; Alobaidy et al., 2010; Sharma & Kumar, 2017 & Kumar et al., 2018).

Equations (2) and (3) ensure that \( Q_i = 0 \) when a pollutant is totally absent in the water sample and \( Q_i = 100 \) when the value of this parameter is just equal to its permissible value. Thus, the higher the value of \( Q_i \) is, the more polluted is the water (Mohanty, 2004).

**Fourth step:** Finally, for computing the WQI, the sub-indices (SIi) were first calculated for each parameter, and then used to compute the WQI as in the following equations:

\[ SI_i = RW \times Q_i \]  

(4)

\[ WQI = \sum_{i=1}^{n} SI_i \]  

(5)

The computed WQI values could be classified as <50 = Excellent; 50–100 = Good; 100–200 = Poor; 200–300 = Very poor; >300 = Unsuitable (Prati et al., 1971; Ramakrishnaiah et al., 2009; Alobaidy et al., 2010; Sharma & Kumar, 2017; Kumar et al., 2018).

**Results and discussion**

**Physico-chemical characteristics of water**

Data of all the 18 physico-chemical parameters obtained under four sampling operations during the period of two years (2014–2015) in the months of June and August, from the glacier-fed lake Neel Tal of Garhwal Himalaya have been presented in **Table 2**. A little variation in the value of air temperature was recorded during the study period. The air temperature was recorded within a temperature range of 3.5°C to 4.7°C at the sampling site. The mean value of air temperature was recorded at 4.08°C. This low temperature was due to extreme altitude and cold winds at the lake. The water temperature of the Neel Tal ranged from 4.1°C (minimum) to 5.7°C (maximum). The temperature of the surface water was recorded about 13°C to 14°C from Ximencuo, a glacial lake located on the eastern Qinghai-Tibetan plateau (Pu et al., 2013).

**Table 2.** Relative weight of the various water quality parameters.

| Parameters          | Water quality standard (WHO) | Water quality standard (BIS/ICMR) | Assigned weight (AW) | Relative weight (RW) |
|---------------------|------------------------------|---------------------------------|----------------------|----------------------|
| pH                  | 6.5–8.5 (8.0)                | 6.5–8.5                         | 3.0                  | 0.070258             |
| DO (mg.l⁻¹)         | 5.0                          | 6.0                             | 4.0                  | 0.093677             |
| Conductivity (µS/cm)| 250                          | 300                             | 2.7                  | 0.063232             |
| TDS (mg.l⁻¹)        | 500                          | 500                             | 2.3                  | 0.053864             |
| Free CO₂ (mg.l⁻¹)   | 250                          | NA                              | 2.0                  | 0.046838             |
| Total hardness (mg.l⁻¹) | 200                        | 200                             | 3.0                  | 0.070258             |
| Calcium (mg.l⁻¹)    | 75                           | 75                              | 2.7                  | 0.063232             |
| Magnesium (mg.l⁻¹)  | 30                           | 30                              | 2.3                  | 0.053864             |
| Chlorides (mg.l⁻¹)  | 250                          | 250                             | 4.0                  | 0.093677             |
| Total alkalinity (mg.l⁻¹) | 200                        | 200                             | 3.7                  | 0.086651             |
| Nitrates (mg.l⁻¹)   | 45                           | 45                              | 1.3                  | 0.030445             |
| Sulphates (mg.l⁻¹)  | 200                          | 200                             | 1.0                  | 0.023419             |
| Phosphates (mg.l⁻¹) | NA                           | 0.3                             | 2.7                  | 0.065232             |
| Fecal coliform (CFU/100 ml) | 00                   | 00                              | 4.0                  | 0.093677             |
| Total coliform (CFU/100 ml) | 10                    | 00                              | 4.0                  | 0.093677             |

**Total** 42.7 1.0
The pH of the glacier-fed lake, Neel Tal varied from 6.8 to 7.3 with a mean value of 6.97 during the period of study. Almost the same range of pH was recorded by Pu et al. (2013) for the lake Ximencuo and Sharma and Kumar (2017) for the Satopanth Lake. The pH value was within the acceptable range of 6.5–8.5 recommended by WHO for drinking water. The dissolved oxygen (DO) of Neel Tal ranged from 6.0 to 6.6 mg/l−1 with a mean value of 6.27 mg/l−1. This range of DO was within the permissible limit (5.0 mg/l−1) recommended by WHO for drinking water. The similar observations were recorded by Mihaiescu et al. (2012) for Balea and Caltun lakes from Fagaras Mountains and Sharma and Kumar (2017) for Satopanth Lake of Garhwal Himalaya. The value of electrical conductivity (EC) of water affects its taste. Lower the conductivity, greater is the taste and higher is the conductivity, lower is the taste of water. Electrical conductivity of Neel Tal was recorded between 135 µS/cm and 142 µS/cm. The values of electrical conductivity were within the range as recommended by WHO. Minimum electrical conductivity is an indication of good water quality. Salinity is the amount of salts dissolved in water. Lower salt concentration in water indicates the lower salinity in water. During the sampling period, salinity was recorded as 0.1 SAL in each sampling operation. Similar findings were observed by Saini et al. (2008) for three Himalayan lakes and Mihaiescu et al. (2013) for Balea and Caltun lakes from Fagaras Mountains.

Total Dissolved Solids (TDS) are the amount of all solids dissolved in the water. The values of TDS were observed within a range of 72–79 mg/l−1 with a mean value of 75.5 mg/l−1. It was very less as compared to the permissible limit of 500 mg/l−1 recommended by WHO for drinking water. Lower concentration (44.0 mg/l−1) of total dissolved solids was also recorded in the glacial Lake Ximencuo (Pu et al., 2013). The value of free CO2 in Neel Tal was recorded within a range of 4.4 mg/l−1 to 8.8 mg/l−1 with a mean value of 7.7 mg/l−1 against the value (250 mg/l−1) recommended by WHO for drinking water. Similar results were observed by Sharma and Kumar (2017) for Satopanth Lake of Garhwal Himalaya and Kumar et al. (2018) for Dodi Tal. The value of free CO2 indicates a high level of pollution (Coole, 1979). Use of water depends on its quality, whether to be used for domestic, agricultural or industrial purpose. Total hardness is also an important parameter to measure the quality of water. The values of total hardness in Neel Tal ranged from 20 mg/l−1 to 24 mg/l−1 with a mean value of 23 mg/l−1 during the two years of the study period. Similar value of total hardness was recorded by Sharma and Kumar (2017) for Satopanth Lake. The permissible limit of total hardness in drinking water was recommended by WHO as 200 mg/l−1. During the study period, the concentration of Calcium ranged from 5.6 mg/l−1 to 6.4 mg/l−1 with a mean value of 6.0 mg/l−1 against the 75 mg/l−1 of WHO standard, recommended for drinking water. A little high concentration of Calcium (7.95 mg/l−1) was recorded by Sharma and Kumar (2017) for Satopanth Lake. However, it was recorded within a range of 4.16 mg/l−1 to 7.21 mg/l−1 for Dodi Tal by Kumar et al. (2018). Magnesium concentration was recorded within a range of 1.47 mg/l−1 to 2.44 mg/l−1 with a mean value of 1.95 mg/l−1 against 30 mg/l−1 of WHO standard recommended for drinking water. A low concentration of Magnesium (0.66 mg/l−1) was recorded for Satopanth Lake by Sharma and Kumar and Chacon-Torres and Rosas-Monge (1998) for high altitude Mexican lake. Chlorides concentration in the water sample of Neel Tal during the study period was

### Table 3. Statistical summary of the physico-chemical parameters of water of glacier-fed lake Neel Tal of Garhwal Himalaya.

| Parameters                  | Minimum | Maximum | Median | Mean ± S.D. |
|-----------------------------|---------|---------|--------|-------------|
| Air Temperature (°C)        | 3.5     | 4.7     | 4.05   | 4.08 ± 0.48 |
| Water Temperature (°C)      | 4.1     | 5.7     | 4.85   | 4.86 ± 0.58 |
| pH                          | 6.8     | 7.3     | 6.9    | 6.97 ± 0.16 |
| Dissolved Oxygen (mg/l−1)   | 6.0     | 6.6     | 6.2    | 6.27 ± 0.18 |
| Conductivity (µS/cm)        | 135.0   | 142.0   | 138.0  | 137.92 ± 2.61 |
| Salinity (SAL)              | 0.1     | 0.1     | 0.1    | 0.1 ± 1.45  |
| Total Dissolve solids (mg/l−1) | 72.0   | 79.0    | 75.5   | 75.5 ± 2.39 |
| Free CO2 (mg/l−1)           | 4.4     | 8.8     | 8.8    | 7.7 ± 1.99  |
| Total Hardness (mg/l−1)     | 20.0    | 24.0    | 24.0   | 23 ± 1.81   |
| Calcium (mg/l−1)            | 5.6     | 6.4     | 6.0    | 6.0 ± 0.42  |
| Magnesium (mg/l−1)          | 1.47    | 2.44    | 1.95   | 1.95 ± 0.36 |
| Chlorides (mg/l−1)          | 11.36   | 11.36   | 11.36  | 11.36 ± 0.0 |
| Total alkalinity            | 30.0    | 35.0    | 35.0   | 32.92 ± 2.58 |
| Nitrates (mg/l−1)           | 0.631   | 0.713   | 0.668  | 0.67 ± 0.04 |
| Sulphates (mg/l−1)          | 0.307   | 0.342   | 0.320  | 0.32 ± 0.02 |
| Phosphates (mg/l−1)         | 0.064   | 0.079   | 0.066  | 0.07 ± 0.01 |
| Fecal coliform (CFU/100 ml) | 0.0     | 0.0     | 0.0    | 0.0 ± 0.0   |
| Total coliform (CFU/100 ml) | 7.0     | 11.0    | 9.0    | 8.58 ± 1.56 |
recorded 11.36 mg/l⁻¹ during all the sampling operations against the value of 250 mg/l⁻¹ recommended by WHO for drinking water.

The total alkalinity of water is due to the presence of carbonates, bicarbonates, and hydroxyl ions. Alkalinity is not considered as a pollutant for assessing the water quality. It is a total measure of substances present in the water that have “acid-neutralizing” ability. It was recorded within a range of 30 mg/l⁻¹ and 35 mg/l⁻¹ with a mean value of 32.92 mg/l⁻¹ in the water of Neel Tal. These recorded values were very less as compared to the permissible limit (200 mg/l⁻¹) recommended by WHO for drinking water.

The concentration of nitrates in the water samples of Neel Tal ranged from 0.631 mg/l⁻¹ to 0.713 mg/l⁻¹ with a mean value of 0.670 mg/l⁻¹ against the permissible limit (45 mg/l⁻¹) recommended by WHO. Concentration of sulfates ranged from 0.307 mg/l⁻¹ to 0.342 mg/l⁻¹ with a mean value of 0.320 mg/l⁻¹ against 200 mg/l⁻¹ recommended by WHO. Phosphates concentrations were recorded from 0.064 mg/l⁻¹ to 0.079 mg/l⁻¹ with a mean value of 0.070 mg/l⁻¹ against the value (0.3 mg/l⁻¹) recommended by BIS, Indian standards, as no such standard value is available for phosphates in the WHO guidelines. Almost similar range of findings for phosphates concentrations were observed by Chacon-Torres and Rosas-Monge (1998) for high altitude Mexican lake, Saini et al. (2008) for three Himalayan lakes and Sharma and Kumar (2017) for Satopanth Lake.

No fecal coliform was recorded in the water samples during all the sampling operations. This is due to its location at extremely high altitude and negligible anthropogenic pressure. As per WHO and Indian standards, complete absence of fecal coliform was recommended for drinking water. However, total coliforms were recorded within a range of 7 to 11 CFU/100ml with a mean value of 8.58 CFU/100ml in the glacier-fed lake, Neel Tal against the permissible level (10 CFU/100ml) recommended by WHO for drinking water.

**Water Quality Index (WQI) analysis**

The Water Quality Index (WQI) is a single value that displayed water quality of Neel Tal. WQI was used to accumulate various physical, chemical, and biological parameters and their dimensions to assess the water quality of a water body to find out whether its water is fit for human consumption or not. From all the computed data for all the water quality parameters (physical, chemical and biological), it was estimated that the value of WQI was 17.585 (Table 3). On the basis of this obtained value of WQI, the water of Neel Tal can be categorized as “Excellent” during the two years of the study period. Thus, the water of Neel Tal is safe for human consumption.

In the coliform test, no fecal coliform colony was shown on the Eosin Methylene Agar (EMB) plate. However, few colonies of total coliform were shown on the media plates which were recorded within the range recommended by WHO for drinking water. This coliform test also confirms the “excellent” quality of water of Neel Tal during the study period.

**Conclusions**

Water Quality Index (WQI) analysis has been considered as one of the most reliable and best method for assessing water quality. Accumulating and analyzing the various physical, chemical, and biological parameters of water and their dimensions to assess the water quality of Neel Tal, the value of WQI (17.585) revealed that the water quality of Neel Tal is “excellent” and is fit for human consumption and usage. This pioneer attempt on the assessment of water quality of glacier-fed lake Neel Tal located at the highly inaccessible area of the Garhwal Himalaya can be a good reference for further study on Himalayan glacier-fed lakes and their management.

**Acknowledgments**

One of the authors (Rahul Kumar) is thankfully acknowledge for the fellowship given by the University Grants Commission, New Delhi through H.N.B. Garhwal University (A Central University) for undertaking the present work.

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