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Article

Water Quality Index (WQI) in the Assessment of Lake Tinishu Abaya Water for the Suitability of Drinking Purpose

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Abstract: Water Quality Index (WQI) of Lake Tinishu Abaya was determined using Weight Arithmetic WQI method to assess the suitability of the lake water for drinking purposes as per WHO prescribed guidelines. The study was carried out on monthly basis from January to December 2016 from two pre-defined sampling sites (open water and offshore). All the in-situ and laboratory measurements of the physical and chemical parameters were measured using the standardized method. The WQI of the study lake was established from nine physicochemical parameters (pH, DO, Conductivity, Turbidity, Total alkalinity, TSS, Nitrate, Total Phosphate, and Temperature). It was observed from the results that the average value of WQI was to be 188.68±54.12 (90.92-249.34) and 222.64±69.38 (116.91-313.45) at the open water and offshore stations, respectively. As per WHO recommended standard and Weight Arithmetic WQI method of classification, the results of WQI in this study lake given strongly suggest that the water of Lake Tinishu Abaya was unsuitable for drinking purposes at both stations throughout the study year. Thus, it needs chemical as well as biological treatment for the lake water in order to be used for drinking purposes. The continuous monitoring of the lake water is required to protect the water in the future from any possible contamination due to growing agricultural practices near the shore area of the lake.

Keywords: Drinking purpose, Lake Tinishu Abaya, Physicochemical parameters, Water Quality Index, Weight Arithmetic WQI method.

1. Introduction

Drinking water quality is characterized on the basis of water parameters (physical, chemical and microbiological), and indicates water acceptability for human consumption (WHO, 2012) and human health is at risk if values exceed acceptable limits (BIS, 2012; WHO, 2012). Water Quality Index (WQI) is considered the most effective method of measuring water quality. The index was first developed by Horton (1965), to measure water quality for drinking purpose and it is commonly used for the detection and evaluation of water pollution and may be defined as a reflection of the composite influence of different quality parameters on the overall quality of water.

The water quality classification system used in the WQI denotes how suitable water is for drinking. WQI simplifies a complex dataset into easily understandable and usable information. The single value output of this index, derived from several parameters, provides important information about water quality that is easily interpretable, even by lay people (Chowdhury *et al.*, 2012). WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, unfit, etc.) for reporting to managers and the public in a consistent manner (Hülya, 2009). It is also helpful for the selection of appropriate treatment technique to meet the concerned issues (Shweta *et al*., 2013).

However, WQI depicts the composite influence of different water quality parameters and communicates water quality information to the public and legislative decision makers. In spite of the absence of a globally accepted composite index of water quality, some countries have used and are using aggregated water quality data in the development of water quality indices. In a poor country, like Ethiopia, where ensuring availability and sustainable management of water is one of the challenging areas towards development, availability of a quick index for judging the quality of water for human consumption is highly useful.

Lake Tinishu Abaya is a shallow inland water system in the rift valley lakes of Ethiopia. The lake is a source of livelihood and supports many socioeconomic activities of which small scale fish production, small-scale irrigation, recreation, bathing and washing, and drinking their cattle are among others where the community uses for their day to day activities. As observed by this author and communicated the nearby communities, the lake water used for drinking purpose by the local community without any form of treatment. Therefore, the present study applied Weighted Arithmetic WQI method to develop WQI of Lake Tinishu Abaya to assess the suitability of the lake water for drinking purposes as per WHO recommended.

2. Materials and Methods

2.1. Description of Study Area

Lake Tinshu Abaya, or interchangeably called, Small Abaya (nearly an oval shape Figure 1), is a small freshwater lake located in the Rift Valley nearly 160 km southwest of Addis Ababa, which is the capital city of Ethiopia. It located at 7°29´03.65´´N, 38°03`17.79´´E, and 1835 m above sea level. The lake is situated in a remote area 15 km from a small village in the township of Silttie. It is a shallow lake, having a surface area of 1253 ha (Kassahun *et al.* 2011), with a maximum and a mean depth of 3.7 m and 2.9 m, respectively. During this study, two major feeder rivers (Dacha and Boboda) and a single outlet (River Badober) were active. The former two rivers are relatively big.

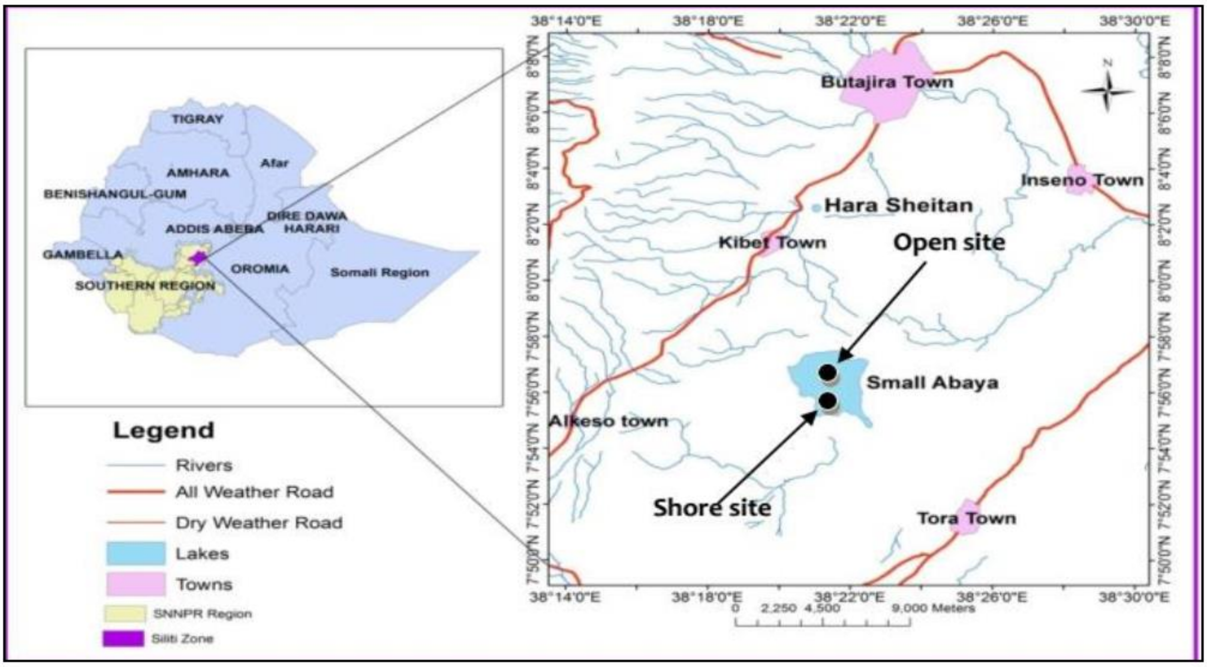

Figure 1. Location of Lake Tinishu Abaya represented on this map as Small Abaya and sampling sites (open site and shore site)

The lake has some commercially important fish species including the native *Tilapia zilli* and *Barbus* species, while Nile tilapia (*Oreochromis niloticus),* was stocked from the nearby Lake Ziway in 1997 (Kassahun et al., 2011). The study of the feeding ecology of *O. niloticus* in Lake Tinishu Abaya (Yirga and Brook, 2018) was found to be an omnivorous fish mainly feeding on plant origin phytoplankton, detritus, and macrophytes and a small portion of the animal origin zooplankton and insects. The major phytoplankton taxa which were recorded in Lake Tinishu Abaya includes Bacillariophyceae/diatoms (15 species), Chlorophyceae/green algae (11 species), Cyanobacteria/blue-green algae (7 species), Euglenophyceae (2 species), Dinophyceae (1 species), and Cryptophyceae/cryptomonads (1 species) (Yirga and Brook, 2018). The zooplankton communities which was found in Lake Tinishu Abaya were the large body-sized microcrustaceans (copepods and cladocerans) and the smaller rotifers, and of whom rotifers had the highest number of species (11 species) followed by cladocerans (5 species) and copepods (2 species) (Yirga and Brook, 2018).

The study of Yirga And Brook (2018) water quality assessments of Lake Tinishu Abaya for multiple designated water uses, showed that the various physicochemical factors responsible for the temporal variations in the physical, chemical and biological features of the lake were discussed and generalized that the lake water was well oxygenated, slightly warm, alkaline, contained more TSS, and EC, very turbid and low transparency. The lake water was fresh based on TDS value. Most of the inorganic nutrients were relatively higher and supports most aquatic lives. Based on the results of the study on various physicochemical factors, photosynthetic productivity and biomass of phytoplankton, Yirga, and Brook (2018) concluded that the water of Lake Tinishu Abaya was chemically and biologically productive and it supports the survival of most of the aquatic lives, production of fish, and other related multidimensional uses.

2.2. Sampling Protocol

For this study, two study sites (open water/center and shore/offshore site) were selected purposely. An open-water site located in the center; 2.5 km far from the shoreline and the shore site is so close (nearly 50 m) to the edge of the lake. The open- water site, which is a bit far from the offshore site, is relatively protected from the direct human impacts. The wastes from their domestic animals such as cattle and related agricultural byproduct cannot easily enter and reach the open-water site especially in a dry season where no flood to carries the waste matter from the watershed; and hence the site is considered relatively protected from human impacts. On the other hand, the offshore site is so close to the edge of the lake (no buffering zone) and this site is considered as a direct recipient of wastes from agricultural land as well as domestic materials; thus this site was taking into consideration as impaired by human activities compared to the open-water site.

Routine water sample collections were carried out on a monthly basis between January 2016 and December 2016 from two predefined sampling stations, one from an area of high human impact (offshore station: 07^0 57.234' N & 038 22.037'E at elevation of 1822 m) and the second was from a relatively less human-impacted area (open-water station: 07^0 56.658' N & 038^0 21.787' E at elevation of 1822 m). Water samples from surface collected in opaque one-liter plastic bottles and chilled in the icebox on site and transported to the limnology laboratory of Addis Ababa University for further limnological analysis. All physiochemical parameters were collected and, *in-situ* measurements were recorded in the early morning between 8:00 am and 11:00 am.

2.3. In-situ Measurements

In-situ measurements for the parameters temperature, dissolved oxygen (percentage saturation), conductivity and pH was measured using a portable multimeter (Model HQ 40d Multi Hach Lange) and water transparency was measured using a standard Secchi disc having 30 cm in diameter. The euphotic depth (Zeu), the depth at which 1% of the surface photosynthetic active radiation is detected, for the study area, was calculated from the relation Zeu = 4.6/Kd (Kalff, 2002). Extinction coefficient (Kd) was found on a Secchi disk (Sd) relationship of Holmes (2000) formula as Kd=1.44/Sd. Turbidity was measured using a portable digital turbidimeter (Model OAKTON: T-100).

2.4. Laboratory Measurements

In the Laboratory, total suspended solids (TSS) were determined through the standardized gravimetric method for examination of TSS in water analysis by Howard, 1933. TSS was measured by filtering 100 ml of water using Whatman GF/F glass microfiber filters (Diameter: 47 mm; Model PB-1825-047-BR) and dried at 105°C for 2 h. Then, weighted with suspended solid and subtract the dried weight from the weight of the GF/F fiber and this was divided by the volume of filtered water. Total Dissolved Solids (TDS), the portion that passes through a filter, in a sample was correlated to electrical conductivity as TDS=0.6 EC (Glenn, 2005). Total alkalinity was determined from the unfiltered water sample by titration with 0.1N HCl with bromocresol green used as endpoint indicator (Wetzel and Likens, 2000). The major dissolved inorganic nutrients were determined using the standard method of APHA, 1995.

2.5. Water Quality Index (WQI) Calculation

In this study, nine important physicochemical parameters (Temperature, DO, pH, Conductivity, Total alkalinity, Turbidity, TSS, Nitrates, and Total Phosphate) were chosen for the Water Quality Index calculations. The WQI has been calculated by using standards of drinking water quality recommended by the World Health Organization (WHO) and Indian Council for Medical Research (ICMR) and other agencies. The Weighted Arithmetic Index method has been used for the calculation of WQI in this study. Further, the quality rating or sub-index was calculated using the following expression. The overall WQI is calculated as equation-1(Asuquo and Etim, 2012):

$$\mathrm{WQI} = \sum \mathrm{qnWn} / \sum \mathrm{Wn}$$

$$\mathrm{qn} = 100(\mathrm{Vn}-\mathrm{Vi})/(\mathrm{Sn}-\mathrm{Vi})$$

$$\mathrm{Wn} = \mathrm{k}/\mathrm{Sn}$$

$$\mathrm{k} = 1/\sum(1/\mathrm{Sn})$$

Where, *n* is for number of water quality parameters used for this calculation, q^n = Quality rating for the n^{th} water quality parameter, *Vn* = Estimated value of the n^{th} parameter at a given water sampling station, *Sn* = Standard permissible value of the *nth* parameter, *Vi* = Ideal value of n^{th} parameter in pure water (i.e., 0 for all other parameters except the parameters pH (Vi=7) and dissolve oxygen (Vi= 14.6 mg/l), *Wn* = Unit Weight for n^{th} parameter and *k* = proportionality constant.

3. Results and Discussion

3.1. Aggregate Physicochemical Features

The results of the annual mean, minimum and maximum values of different physicochemical parameters of the study lake at the two sampling sites over a period of one year are presented in Table 1. The values of different physicochemical parameters of Lake Tinishu Abaya are obtained and most of these values are not in the normal range of drinking as per WHO recommended (Table 2). This is because the lake is highly impaired by wastes and human activities.

pH is an important parameter which determines the suitability of water for various purposes (Chaturvedi and Bassin, 2010). Chandaluri, *et al.*, 2010). The pH of most natural water bodies ranges from 6.5 to 8.5 (WHO, 2006). In the present study, pH ranged from 8.11 to 9.27 and 8.11 to 9.22 for the open-water and offshore stations water samples analyzed respectively. This shows that the pH ranges obtained for the lake water samples at both stations were outside of the recommended range of WHO and ICMR for drinking purpose. The annual mean total alkalinity of this study lake was 229 mg/l and 195mg/l at the open-water and at the offshore stations, respectively. The values of total alkalinity in this study lake were higher than the recommended standard (120 mg/l) for drinking use. In the study, the lowest alkalinity concentration noticed during the rainy season, which could be related to the inflow of water and dissolution of calcium carbonate ions in the water column caused by the rainwater.

Presence of DO in water may be due to direct diffusion from the air and photosynthetic activity of autotrophs (Shanthi et al., 2012). The annual mean values of DO for this study was 9.04 and 8.53 at the open-water and at the offshore station which indicated that high value of doing compared to the recommended values for drinking purpose. The maximum and minimum values of DO at both stations obtained in this study are also higher than the recommended standards. The maximum temperature recorded in this study were 27 ^{0}C and 29.2 ^{0}C at open and shore stations, respectively, which indicated that these values are below the recommended standard values for drinking purpose (40 ^{0}C).

Electrical conductivity (EC) is the measure of the ability of an aqueous solution to convey an electric current. This ability depends upon the presence of ions, their total concentration, mobility, valence, and temperature. The mean value of conductivity in the study lake was to be 420.53µS/cm and

384.53 µS/cm at the open water and offshore stations, respectively. The value of conductivity obtained in Lake Tinishu Abaya indicated that it is above the recommended standard. The maximum and minimum EC values recorded in this study were also above the recommended standards. A high level of conductivity clearly indicated that water in study areas was considerably ionized and has the higher level of ionic concentration activity due to excessive dissolve solids.

Lake Tinisu Abaya was very turbid throughout the study period and it ranged 57-188 NTU at the open-water station and 71-143 NTU at the offshore station. This value clearly indicated that much higher than the recommended value for drinking purpose. The high turbidity value might be the result of high rainfall which brought sediment-laden waters from the surface runoff and because of surface run-off water with soil, domestic waste, cattle washing, bathing activity, etc. The maximum values of TSS at the open-water station (243 mg/l) and at the offshore station (368 mg/l) were below the recommended value (500 mg/l) for drinking which indicated it is within the permissible limit for human consumption. High TSS was recorded during the rainy season, and this might be due to the effect of high runoff with solid particles from the watershed/agriculturally rich catchment area of the lake, and may be due to siltation, deterioration, heavy precipitation and mixing run-off rainwater which carried mud, sand etc. mixed in the lake water.

Nitrate is one of the most important nutrients in any ecosystem. Nitrate concentration depends on the activity of nitrifying bacteria which in turn get influenced by the presence of dissolved oxygen. In the present, study the maximum values of nitrate obtained at the open-water station (0.353 mg/l) and at the offshore station (0.341mg/l) were below the recommended standards (45mg/l) for drinking. The maximum concentration of total phosphorous in this study lake was 0.286mg/l and 0.295mg/l at the open-water and at the offshore station, respectively, which indicated that the values at both stations are within the permissible limit (0.4 mg/l) for human consumption.

Table 1. The results of the mean, minimum and maximum values of different physicochemical parameters of Lake Tinishu Abaya at the open-water station (OS) and at the offshore station (SS) from 01 January to 31 December 2016

	Observed values					
	Mean±SD		**Minimum**		**Maximum**	
Parameters	**OS**	**SS**	**OS**	**SS**	**OS**	**SS**
pH	8.47± .39	8.53 ± .35	8.11	8.15	9.27	9.22
DO	9.04± 3.07	8.53± 1.77	5.58	6.1	15.1	11.62
Conductivity	420.53± 352.34	384.53± 315.03	147.7	147.7	1006	1006
TSS	148.32± 56.76	200.47± 89.19	73	76	243	368
Nitrates	0.192±.21	0.043±.24	0.142	0.152	0.353	0.341
Total Phosphate	0.172±.23	0.185± .22	0.057	0.076	0.286	0.295
Turbidity	111.5± 31.32	135.42± 44.47	57	71	143	188
Total alkalinity	229±348	195±290	72	48	420	338
Temperature	23.08 ±3.0	23.23± 3.32	18.5	18.5	27	29.2

Table 2. Calculating Weight factor and proportion constant (k-value) for Lake Tinishu Abaya throughout the study period and recommended a standard for drinking purpose as per the respective recommending agencies

Physicochemical Parameters	Standard value(S_n)	Recommending agency	k-value	Weighting factor
pH	6.5-8.5	BIS	0.32483	0.038215
DO (mg/l)	5	WHO	0.32483	0.064966
Conductivity (µS/cm)	300	WHO	0.32483	0.001083
TSS (mg/l)	500	WHO	0.32483	0.00065
Nitrate-NO_3^- (mg/l)	45	BIS	0.32483	0.007218
Phosphate (mg/l)	0.4	WHO	0.32483	0.812074
Turbidity (NTU)	5	WHO	0.32483	0.064966
Total alkalinity (mg/l)	120	WHO	0.32483	0.002707
Temperature (^{0}C)	40	BIS	0.32483	0.008121

3.2. Water Quality Index (WQI)

In this study, the water quality index (WQI) of the Lake Tiinishua Abaya is established from nine important various physicochemical parameters including surface Temperature, Dissolved Oxygen, pH, Electrical Conductivity, Water Turbidity, Total Alkalinity, Total suspended solid (TSS), the nitrogen nutrients (Nitrates), and the phosphorus nutrients (Total Phosphate).

Water Quality Index (WQI) of Lake Tinishu Abaya was determined using Weight Arithmetic WQI method to assess the suitability of the lake water for drinking purpose as per WHO prescribed. The spatial and temporal variations of QWI calculated in the present investigation are given in Table 3 and Figure 2. It was observed from the results that the minimum and maximum values of WQI has been found to be 90.92 and 249.34 at the open-water station and 116.91 and 313.45 at the offshore station. The average value of WQI was to be 188.68$\pm$ 54.12 and 222.64$\pm$69.38 at open-water and at the offshore stations, respectively.

The minimum and maximum value of WQI was seen in January and July respectively at both stations. The WQI was greater than 100 in all the study months except in January (WQI= 90.91 at the open station). WQI for the study lake varied seasonally and spatially. As per Wight Arithmetic Water Quality Index (Table 4), the results of WQI in this study lake given strongly suggested that the water was unsuitable for drinking purposes at both station throughout the study year.

Water quality index (WQI) for the study lake significantly varied seasonally and spatially. It was higher at the offshore station than the open-water station. This high value of WQI at the offshore station could be due to the high concentration of nutrients at the site as a result of surface run-off water with soil, domestic waste, cattle washing, bathing activities, etc. Similarly, WQI was significantly higher during the main rainy season (June to September) than dry season (January-May and October-December).

Generally, WQI progressively increased from January to May and sharply increasing with the peaks in June and July (Figure 2). On the other hand, the relatively lower value WQI was observed in January, February, and April, but each month WQI was greater than 100. This high WQI during the time of rainy season may be due to the possible influx of nutrient-rich flood water into the lake water from the amount of contaminated sewage area.

The high water quality index (WQI) at both the sampling sites clearly showed that the status of the water body in Lake Tinishu Abaya was degraded and unsuitable for the human uses during the period of study because it was not within the WHO standards and guidelines for drinking purpose. It was also observed that the pollution load was relatively high during the rainy season when compared to the dry seasons. It has been concluded that discharging of domestic wastewater and also other anthropogenic wastes were the main factors for contaminating the lake water. The results of WQI suggested to us the water needs 'special treatment'.

Table 3. Calculated water quality index(WQI) of Lake Tinishu Abaya at sampling sites and months

Month	WQI	
	Open	Shore
January	90.9184	116.911
February	105.858	127.69
March	171.22	180.111
April	138.052	145.296
MAY	178.253	207.732
June	246.265	307.594
July	249.336	313.449
August	192.404	221.498
September	231.733	267.377
October	238.837	283.198
November	194.95	218.225
December	226.308	282.561
Average$\pm$SD	**188.68± 54.12**	**222.64± 69.38**

Table 4. Water Quality Rating as per Arithmetic Water Quality Index (WQI) methods for drinking purposes (after Asuquo and Etim, 2012a)

Weight Arithmetic Water Quality Index (WAWQI)	
0-25	Excellent water quality
25-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking

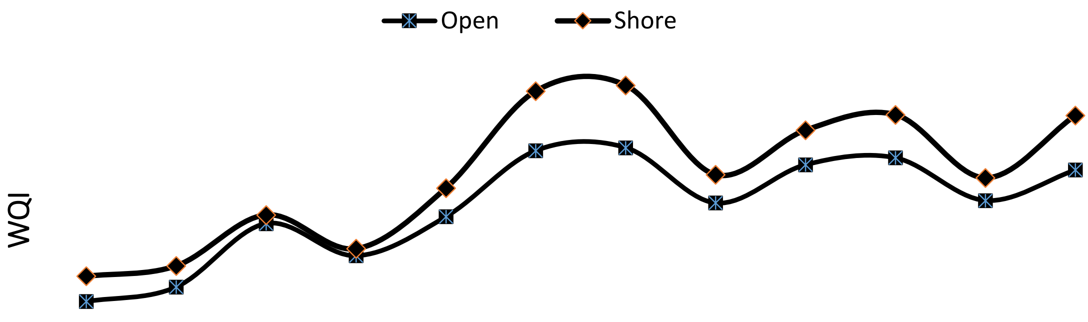

Figure 2. Temporal patterns of water quality index (WQI) of Lake Tinishu Abaya at the open water station and offshore station

4. Conclusion and Recommendations

Assembling different parameters into one single number leads an easy interpretation of index, thus providing an important tool for management purposes. An index is a useful tool for communicating water quality information to the public and to legislative decision makers; it is not a complex predictive model for the technical and scientific application. In the present study, water quality index (WQI) of Lake Tinishu Abaya (Ethiopia) has been computed using Weight Arithmetic WQI method based on nine different quality parameters to check the suitability of lake water for drinking purposes.

The overall computed WQI was immensely high compared to the values of Weight Arithmetic WQI for human consumption as per WHO prescribed, and most of the physicochemical parameters considered to develop the index results above the permissible limit for drinking upon WHO recommended. From the application of water quality index for the determination of the quality of water for drinking from the two sites of Lake Tinishu Abaya, it is concluded that the lake water samples are found unfit and unsuitable for human consumption based on the water quality index standard applied in this study. The source of pollution of this lake water as observed at the sites includes human activities as defecation and dumping of untreated waste via runoff.

The growing agricultural activities such as irrigation to produce vegetables in a very nearshore area of the lake watershed use pesticides. However, this chemical has a high probability to enter the lake with sediments and flooding in the time of the rainy period via runoff and this chemical may rich human body since they use lake water for direct consumption. Thus, it requires some kind of water treatment procedure for the lake water in order to use it for drinking.

The continuous monitoring of the lake water is required to maintain the appropriate water quality in future from any possible contamination due to growing agricultural practices near the shore area of the lake. In addition to treating the lake water, making an awareness creation for the community should principal action about the unfitness of the lake water for their drinking purpose, at least to use it by boiling or by using the SODIS method of water sterilization if there aren't any alternative safe water resources for the time being. Solar disinfection (SODIS) was developed in the 1980s to inexpensively disinfect water used for oral rehydration solutions. In 1991, the Swiss Federal Institute for Environmental Science and Technology began to investigate and implement SODIS as a household water treatment option to prevent diarrhea in developing countries. Users of SODIS fill 0.3-2.0 liter plastic soda bottles with low-turbidity water, shake them to oxygenate, and place the bottles on a roof or rack for 6 hours (if sunny) or 2 days (if cloudy). The combined effects of UV-induced DNA alteration, thermal inactivation, and photo-oxidative destruction inactivate disease-causing organisms.

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