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# The Effects of Algal Blooms on Oxygen Levels in Lakes Babati and Eyasi, Tanzania

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## Abstract

Globally aquatic ecosystems are reportedly overwhelmed by algal blooms due to excessive deposition of nutrients which ultimately cause hypoxia, leading to massive fish death. This study aimed at assessing the relationship between algae contents and dissolved oxygen (DO) in Lake Babati which is threatened by anthropogenic activities, whereas Lake Eyasi was used as a control. Algae contents (chlorophyll *a*), DO and surface water temperature were measured using standard methods. Results revealed that the mean algae content was significantly higher (4.47±0.88 mg/L) in Lake Babati than in Lake Eyasi (1.6±0.45 mg/L) ($P < 0.05$) and was beyond the standard permissible levels for domestic water supply and healthy ecosystem. Conversely, DO was significantly lower in Lake Babati than in Lake Eyasi ($P < 0.05$). There was no significant difference in water temperature in the two lakes ($P > 0.05$). Furthermore, there was an inverse relationship between algae content and DO in Lakes Eyasi and Babati ($r = -0.88$ and $r = -0.30$, respectively) suggesting that algal bloom is partly responsible for lowering DO. Responsible authorities are advised to enforce management policies and regulations to control unsustainable activities around these lakes that contribute to nutrient loading resulting into overgrowth of algae.

**Keywords:** Anthropogenic activities; Chlorophyll a; Eutrophication; Harmful algae; Hypoxia in lakes

## Introduction

Extensive growth of microalgae commonly called algal blooms, have been reported in many parts of the world, including Tanzania. Algal blooms have negative impacts not only ecologically but also on several sectors such as health, commercial fishery, tourism and recreation (Sanseverino et al. 2016, Katonge 2018, Mchau et al. 2019, Olokotum et al. 2020). An increase of nutrients mainly nitrogen and phosphorus from fertilizer runoff and other anthropogenic activities into aquatic ecosystems is the major factor for overgrowths of microalgae (Verschuren et al. 2002, Hamisi and Mamboya 2014, Ferris 2016, Sanseverino et al. 2016, Wang et al. 2016). In addition, algal blooms are associated with proliferation of the harmful phytoplankton species that produce toxins, the phenomenon known as "Harmful Algal Blooms" (HABs) (Paerl 1998, Anderson et al.2008, Sanseverino et al. 2016). Algal blooms result into oxygen depletion in the water body due to dissolved oxygen (DO) consumption by microorganisms in the process of decomposing dead algal biomass (Wilson 2010) following their competition for nutrients and overcrowding, ultimately converting organic matter into inorganic form. This situation reduces DO (hypoxia/anoxia), thus, creating a dead zone in the deep zones of water bodies where aquatic organisms cannot survive. Moreover, reduction of water clarity during algal blooms renders light starvation, stopping photosynthesis and production of oxygen (Verschuren et al. 2002, Schindler 2006, Wilson 2010, Fondriest 2013) aggravating anoxia as the organisms consume available oxygen in the water column.

Dissolved oxygen requirements varies among organisms whereas bottom feeders such as crabs, oysters and worms need minimal amount (1-6 mg/L), shallow water fish need higher levels (4-15 mg/L), sensitive freshwater fish such as salmon do not reproduce at DO below 6 mg/L (Fondriest, 2013). Prolonged exposure to low levels of DO may not directly kill an organism, but may significantly increase its susceptibility to other environmental stress and diseases whereas exposure to < 2 mg/L for 1-4 days is reported to kill most of the biota in a system (Wilson 2010).

It is from the above facts that some states have set forth standard levels of chlorophyll *a* as well as DO levels for domestic water supply. For instance, according to Kansas Department of Health and Environment (KDHE) Bureau of Water (2011), standard levels of chlorophyll *a* for domestic water supply lakes should be maintained at ≤ 10 µg/L (0.01 mg/L). On the other hand, Michigan State, set standard levels for DO, whereby the minimums for cold-water and warm-water fisheries are 7 mg/L and 5 mg/L, respectively. In Colorado State, the set standard levels of DO are 6 mg/L and 5 mg/L for cold and warm water aquatic life, respectively (Fondriest 2013). From the above literature, chlorophyll *a* and DO have a direct significant effect on fisheries sector, and other socioeconomic sectors, thus calling for much attention in terms of research and monitoring.

The actual amount of DO varies depending on temperature, pressure and salinity. Also, DO fluctuates due to photosynthesis, respiratory functions of aquatic organisms, decomposition of organic matter and many other chemical reactions. In freshwater systems such as lakes, rivers and streams, DO has been reported to vary with season, location, and water depth. As such, DO levels can range from <1 mg/L to>20 mg/L depending on how all of these factors interact (Verschuren et al. 2002, Fondriest 2013, Wang et al. 2016). Nonetheless, among the factors affecting DO in aquatic ecosystems, temperature is of critical consideration since it is associated with climate change which is currently threatening the globe. It is projected that in the coming 30 - 50 years, temperature will increase by 2 - 3°C (Intergovernmental Panel on Climate Change (IPCC) 2007), whereas in Lake Babati the temperature is projected to increase between 0.75 and 3.5 °C (Mbanguka et al. 2016). The projected increase in temperature will not only directly affect DO but also promote accumulation of algal blooms (Sanseverino et al. 2016, Ho and Michalak 2019), and possibly cause shallow lakes (such as Babati) dry-out due to evapotranspiration (Mbanguka et al. 2016). Warmer temperature has been reported to prolong water sedimentation in water bodies, ultimately accelerating the growth of harmful algae (Jöhnk et al. 2008; Environmental Protection Agency (EPA) 2013; Gobler 2021). It is reported further that, lengthening of water stratification lowers DO, ultimately releasing nutrients which promote flourishing of algae (Woolway et al. 2021), thus negatively impacting aquatic organisms (Kraemer et al. 2021). The solubility of oxygen and metabolic functioning of aquatic organisms are known to be affected by a slight increase or decrease of temperature (Wetzel 2001, Roman et al. 2019). In this regard, temperature was included in the current study so as to establish if there was a significant difference in the studied lakes that could be associated with DO findings.

In Tanzania several studies have been conducted concerning dynamics of nutrient levels and phytoplankton biomass (chlorophyll *a*) mainly in Lake Victoria (Verschuren et al. 2002, Hazenoot 2012, Olokotum et al. 2020, Frank et al. 2023) whereas findings indicate spatial and temporal variations. In all studies, higher values of chlorophyll *a* have been recorded in near shore, gulfs and bays attributed mainly to higher nutrient levels in these areas; while lower values have been recorded in open lake areas. Furthermore, in the aforementioned studies, seasonal as well as depth differences have been reported. But little is known on the relationship between chlorophyll *a* content and levels of DO in these studies.

Previous studies conducted in Lake Babati reported the depth of the lake to have been gradually decreasing from 6 to 8 m in 1960s, 5 m in 1970s, to only 3-4 m at the middle decreasing to 1-1.5 m at the southern end in recent years (Hongoa 2014) whereas Mbanguka et al. (2016) predicts that the lake will dry-out if the temperature will increase by 3.6 $^{o}$C. It is further reported that, the catchment area around the lake is being degraded due to deforestation coupled with poor agricultural practices leading to soil erosion and ultimate lake siltation. A study by Katonge (2018) reports DO in a range of 3.5 mg/L (recorded in May) to 4.8 mg/L (recorded in November), which is already below minimum threshold for shallow water and sensitive freshwater fishes (Fondriest 2013). On the other hand, the same study reports mean chlorophyll *a* content values of1.216 µg/L in dry season and 0.14 µg/L in wet season. Generally, Lake Babati has been negatively affected by extensive urbanization due to rapid population growth, agriculture (crop and livestock production), and climate variability (Hongoa 2014, Mbanguka et al. 2016, Katonge 2018, Peter et al. 2020).

However, little is known on the relationship that exists between algal blooms and oxygen levels in this water body. Being located in the semi-arid region of Tanzania where fresh water supply is already a crisis, Lake Babati calls for strong concerted conservation efforts which in turn need scientific evidence to support decision making. Therefore, this study aimed at investigating the relationship between algae content and oxygen levels in Lake Babati which is subjected to extensive human activities while Lake Eyasi which is protected from extensive human activities was included in the study as a control.

## Materials and Methods

### The study area

The present study was conducted at Lakes Babati and Eyasi. Lake Babati is located within Babati Town Council (Babati urban district) near Babati town, where the headquarters of Manyara region is also located. Lake Babati is geographically located along latitude 4º15’ S and longitude 35º45’E (Mbanguka et al. 2016) (Figure 1). The area is warm, with temperate climate with an average annual temperature of 23°C and precipitation of 1200 mm (Hongoa 2014). Babati district had a population of 93,108 people as per 2012 National Census (United Republic of Tanzania (URT) 2013), however the population is steadfastly increasing whereby in 2018 the population has reached more than 190,000 people (Peter et al. 2020). Various ethnic groups are found around Lake Babati including, Maasai, Barbaig, Iraqw, Irangi and Mang’ati. These societies practice different activities around the lake such as agriculture, livestock keeping, fishing, timber processing, brick making, mining and tourism (Löfstrand 2005, Hongoa 2014, Katonge 2018). Nevertheless, Lake Babati is a habitat for different aquatic organisms such as fish, prawns, eels, hippos and water birds. Thus, Lake Babati was selected by consideration of numerous human activities that are conducted in that area, some of which releasing nutrients into the water body.

Unlike Lake Babati, Lake Eyasi is located in southwest of Ngorongoro Crater and south of Serengeti National Park in Karatu district, Arusha region along3°35’S and between 34 and 35°E (Figure 1). The Hadzabe bushmen are living around the lake inhabiting *Acacia* forests and scrubland performing hunting and gathering, also there is Datoga ethnicity who are pastoralists (Wood et al. 2021). Different organisms inhabit the lake mostly birds such as Africa spoonbill, flamingos, pied avocet, great white pelicans as well as fish particularly catfish and lung fish. Lake Eyasi is not highly subjected to human disturbance as it is surrounded by Ngorongoro Crater and Serengeti National Park, hence it was used as a control.

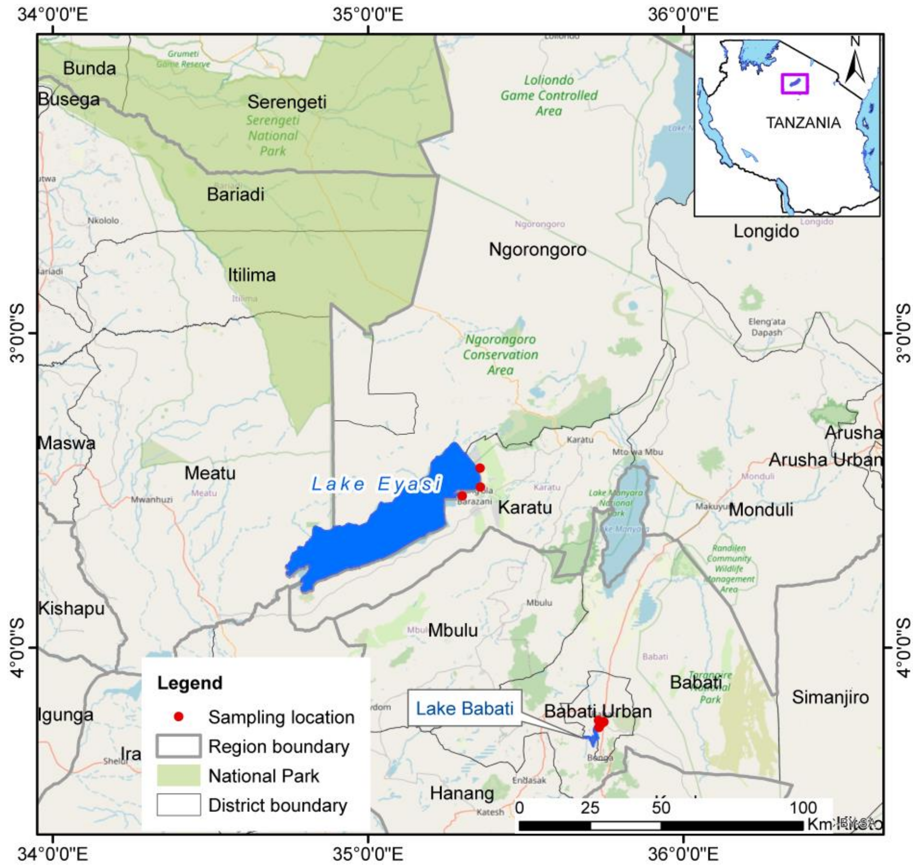


**Figure 1:** A map showing sampling points (red dots) in Lakes Babati and Eyasi, Tanzania.

**Data collection**

At each lake, three fishing villages were selected, and six sampling points (two in each village) were randomly established for field data collection (measurements of surface water temperature, DO and collection of water samples for the determination of chlorophyll *a* contents). At Lake Babati sampling was conducted at Bagara Ziwani, Hangoni and Nangara villages while at Lake Eyasi sampling was conducted at Malekchandi, Mikocheni and Barazani villages. At each sampling point, samples for Chlorophyll *a* were taken one meter from the lake shore. Dissolved oxygen was measured in the field using Dissolved Oxygen (DO) meter model HI 9147. Likewise, surface water temperature was recorded in the field at all sampling points using a thermometer. Sampling was done during the rainy season.

Water samples for the determination of chlorophyll *a* were collected into plastic bottles covered with aluminum foil paper to prevent direct light which could facilitate phytoplankton metabolic activities. Thereafter, bottles containing water samples were put in ice-box containing ice packs (Hamisi and Mamboya 2014) and transported to the laboratory of the Department of Aquatic Sciences, University of Dar es Salaam (UDSM), for chlorophyll *a* analysis. Chlorophyll *a* content was determined by Spectrophotometric method as described in Hamisi and Mamboya 2014, Trent *et al*. (2017) and Johan et al. (2018). Briefly, in the laboratory a known volume (0.5 L) of each water sample was filtered, filters were kept frozen at -20 ºC before analyses. Chlorophyll *a* was extracted from filters using 90% acetone and the concentration was analysed using a spectrophotometer (Shimdzu UV-Vis 1800).

**Data analysis**

Data from studied sites in Lake Babati were pooled before analysis, likewise for data from Lake Eyasi. Data on levels of algae (chlorophyll *a*) concentration and DO in the lakes were analysed using R software (V4.1.2; R Core Team 2021). The difference in the means of levels of surface water temperature, chlorophyll *a* concentration and DO in lakes Eyasi and Babati was assessed using paired t-test (Kothari 2004). Furthermore, the relationship between levels of chlorophyll *a* concentration and DO was calculated using Pearson's correlation test.

**Results**

Results for mean algae contents (chlorophyll *a* concentration) in the studied lakes are presented in Figures 2 and 3. The values at sampling sites ranged between 1.02–2.13 and 3.13–5.62 µg/cm$^3$ for lakes Eyasi and Babati, respectively. Generally, chlorophyll *a* concentration was higher in all sampling sites at Lake Babati (Bagara Ziwani, Hangoni and Nangara) than sites at Lake Eyasi (Melekchandi, Mikocheni and Barazani) (Figure 2). The overall mean values were 1.59±0.45 and 4.47±0.88 µg/cm$^3$ for Eyasi and Babati, respectively (Figure 3). Also, the results of paired t-test indicated a statistically significant difference in algae content between the studied lakes ($P < 0.05$, DF = 5 and t = 8.2).

Contrary to chlorophyll *a*, results showed higher DO in Lake Eyasi than Babati with values ranging between 7.3-11.3 and 5-11.3 mg/L, respectively (Figure 4). Mean values of DO in lakes Eyasi and Babati were 8.92±1.72 and 6.83±2.32 mg/L, respectively (Figure 5). Thus, there was a statistically significant difference in the mean DO between these lakes ($P < 0.05$, DF = 5 and t = 2.88). The relationship between chlorophyll *a* and DO concentrations is presented in Figure 6. The results of correlation test on the relationship between chlorophyll *a* concentration and DO show an inverse (negative) linear relationship in both lakes. However, the negative relationship was very strong in Lake Eyasi (r = -0.88) while it was weak in Lake Babati (r = -0.30).

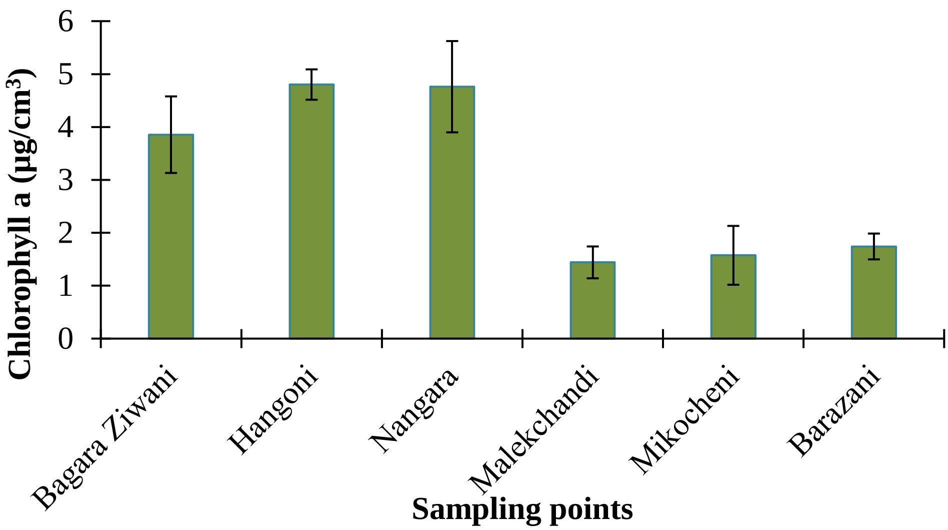


**Figure 2:** Comparison of Chlorophyll *a* concentration among the sampling points in lakes Babati (Bagara Ziwani, Hangoni and Nangara) and Eyasi (Malekchandi, Mikocheni and Barazani), Tanzania. Error bars are Standard Errors of the Mean (SEM).

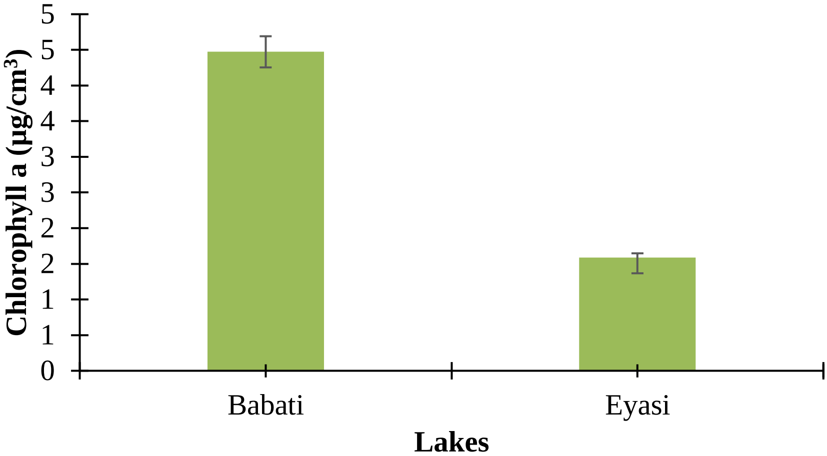


**Figure 3:** Mean chlorophyll *a* concentration during the sampling period in lakes Babati and Eyasi, Tanzania. Error bars are Standard Errors of the Mean (SEM).

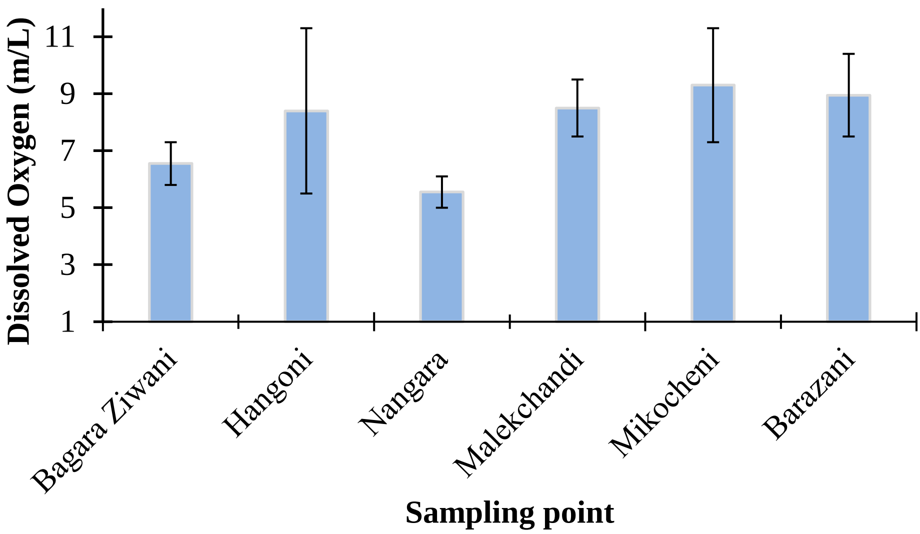


**Figure 4:** Comparison of Dissolved Oxygen concentration between sampling points in lakes Babati (Bagara Ziwani, Hangoni and Nangara) and Eyasi (Malekchandi, Mikocheni and Barazani), Tanzania. Error bars are Standard Error of the Mean (SEM).

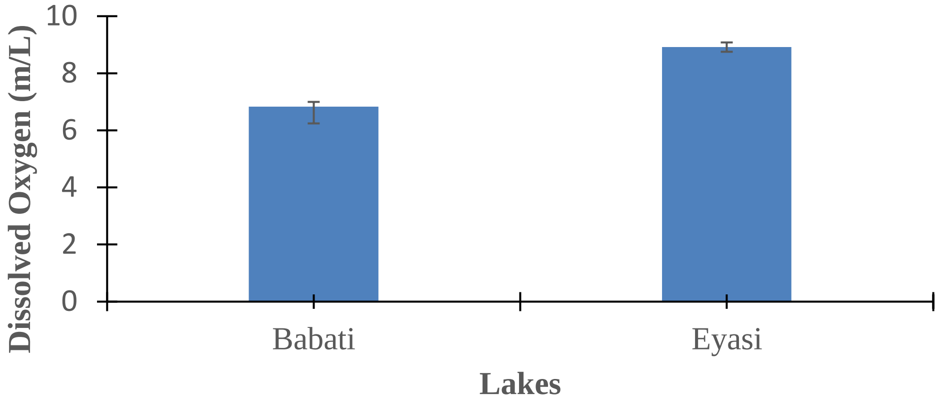


**Figure 5:** Mean Dissolved Oxygen concentration in lakes Babati and Eyasi during the sampling period in Tanzania. Error bars are Standard Error of the Mean (SEM).

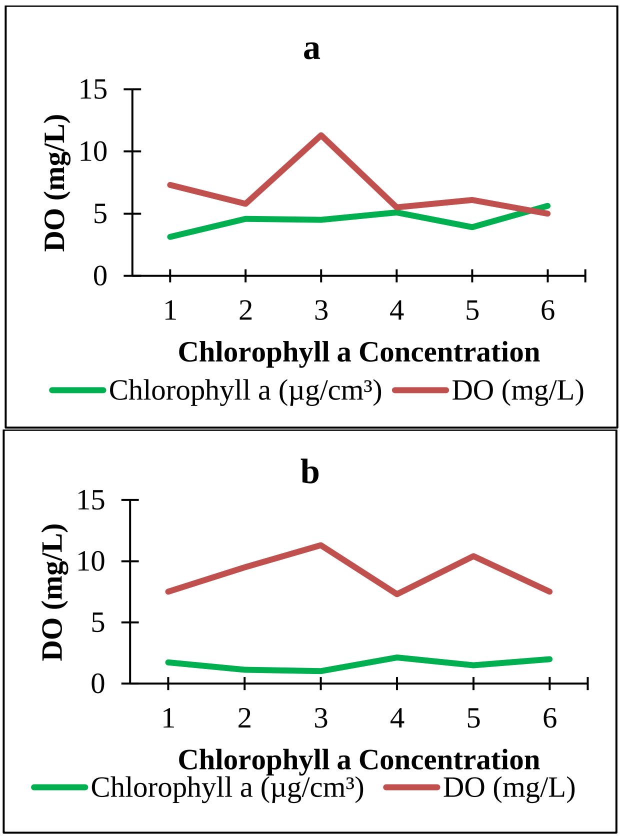


**Figure 6:** Relationships between chlorophyll *a* and DO concentrations in Lake Babati (a), and Lake Eyasi (b) in Tanzania. DO = Dissolved Oxygen.

With regard to surface water temperature in the studied lakes, in Lake Babati the temperature ranged from 23.3 to 25.9 °C, with mean value of 25.18±0.96 °C whereas in Lake Eyasi the temperature ranged between 24.2 and 26.5 °C, with mean value of 25.32±0.78°C. Nonetheless, there was no statistically significant differences in temperature between the studied lakes ($t = 0.303$, DF =5, $P = 0.774$).

**Discussion**

The results of this study show that algae contents were high in Lake Babati than in Lake Eyasi. Furthermore, the mean value (4.47±0.88µg/cm$^3$) i.e. 4470±0.88 µg/L obtained in the present study is higher than those reported in same lake (Katonge 2018), but agree with those reported in patches of Lake Victoria (274–4382 µg/L) (Simiyu et al. 2018) and polluted Lake Binder in Indonesia sampled during algal bloom (4.38 mg/L), i.e. 4380 µg/L) (Filazzola et al. 2020). The differences in algae content observed between the present study and Katonge (2018) in the same water body is attributed to spatial and temporal variations as reported in other studies (Hazenoot 2012, Simiyu et al. 2018, Olokotum et al. 2020, Frank et al. 2023) mainly linked to anthropogenic activities around the respective sampling areas of the water body, distance from the shore, depth and the season of sampling. Furthermore, algae content values obtained in present study were also far higher compared to the standard levels for domestic water supply lakes (KDHE, 2011) implying that in certain nearshore areas (such as those sampled during this study) this water body supplies water which is unfit for human use. Thus, may pose health risks to local users especially those who use untreated water (Simiyu et al. 2018, Mchau et al. 2019). Also, the algae content values classify the lake as hypereutrophic (KDHE, 2011), although this cannot be generalized for the whole lake as the study covered only a small area and was short-term covering only wet season. During the rainy season nutrients from land-based activities are brought into the lake through rain water and streams/rivers runoffs, hence supporting the increase of algal growth to the extent of forming visual blooms as it has been also reported by other studies in this water body (Hongoa 2014, Katonge 2018, Peter et al. 2020).

The significant differences in the levels of algae content between the studied lakes is attributed to the conservation status of the two lakes as explained earlier. Lake Eyasi is surrounded by Ngorongoro and Serengeti national parks at the northern parts which are conserved and hence only part of the lake is exposed to human influence particularly the Hadzabe who perform hunting and gathering, hence with little effect to the lake environment. During the study, however, other ethnicities were found practicing unsustainable activities within the lake’s buffer zone including seasonal fishing, livestock keeping and agriculture particularly onion cultivation and fishermen camps at Malekchandi, whereas at Mikocheni and Barazani the buffer zones were free from human activities (Personal observation). These human activities conducted near the lakeshore are associated with seasonal inshore localized eutrophication and algal blooms, and perhaps contributed to the obtained relatively higher mean chlorophyll *a* concentration value of 1.59 mg/L in Lake Eyasi. Although this value is much lower compared to that obtained at Lake Babati, but it is greater than the set standard value (≤10 µg/L =0.01 mg/L) for healthy ecosystem and domestic water supply (KDHE, 2011) implying that there occurs seasonal localized (nearshore) eutrophication and algal bloom even in this less threatened lake.

With regard to DO, results showed higher values in Lake Eyasi than Lake Babati. Moreover, DO levels were inversely correlated with algae contents in both lakes, suggesting that eutrophication of these freshwater bodies has direct implication in DO levels, and hence on fisheries (Wilson 2010, Fondriest 2013). These results are in agreement with Shukla et al. (2008) who reported an inverse relationship between algal bloom and DO in India. As discussed earlier, the values of chlorophyll *a* obtained in our study classify Lake Babati as hyper eutrophic lake, thus validating possible hypoxia in nearshore areas due to accumulation of organic matter following algae death and decomposing process. High nutrient levels in aquatic contaminated areas, associated with high phytoplankton biomass (chlorophyll *a* content) and consequently low levels of DO are reported by several studies in other water bodies (Arend 2011, Hamisi and Mamboya 2014, Wang et al. 2016). However, the weak negative correlation between algae content and DO in Lake Babati perhaps suggests an association relationship between the two parameters, instead of a causative relationship (Rocha et al. 2009), and/or there are other factors that possibly influence both parameters in Lake Babati which were not investigated in this study.

It has to be further noted that the minimum DO value (5 mg/L) obtained at Nangara (Babati) in our study is the minimum threshold for warm water fish whereby some sensitive freshwater fish such as salmon do not reproduce at DO below 6 mg/L (Fondriest, 2013). Also, the reported values in our study are from the surface water where DO is always higher than deeper waters implying that in this water body, DO levels might be lower in deeper waters than the observed thus directly affecting aquatic aerobes' performance including fish.

Moreover, results show that the difference in water temperature in the studied lakes was not statistically significant suggesting that the observed differences in DO levels between the two lakes were caused by factors other than temperature. Also, geographical location and altitude are factors responsible for lake temperatures (Xie et al. 2022). However, the two lakes are in the same geographical area (latitude 3–4 ºS and longitude 34–35ºE), thus in natural circumstances the similarities in temperature in the two lakes was expected, leaving the differences in DO attributed to other factors including algae contents.

## Conclusion and Recommendation

This study demonstrates that there is an inverse relationship between algal concentration and dissolved oxygen levels in the studied lakes implying that persistent nutrient loading into these water bodies (Lake Babati in particular which is threatened) will increase algal concentration thus causing a decrease in levels of dissolved oxygen. This in turn will limit the amount of oxygen available for normal performance of aquatic organisms in the lake. This information serves as an early warning, and can be used as evidence for advocating better management and monitoring of ongoing human activities near Lake Babati with emphasis to those which contribute to increased nutrient runoff into the lake hence aggravating eutrophication. However, this was a short-term study conducted during the rainy season, and only two parameters affecting DO were studied. Therefore, a more detailed study covering both dry and wet seasons as well as exploring other physical, chemical and biological parameters affecting DO in this water body is recommended.

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## Conflict of Interest

The authors declare to have no conflict of interest for publishing this paper.

## References

Anderson DM, Burkholder JM and Conchlan WP, Gilbert PM, Gobler CJ, Heil CA, Kudela RM, Parsons ML, Ransel JEK, Townsend DW, Trainer VL and Vargo GA 2008 Harmful algal bloom and eutrophication: examining linkages from selected coastal regions of the United State. *Harmful Algae* 8(1): 39-53.

Arend KK 2011 Seasonal and interannual effects of hypoxia on fish habitat quality in central Lake Erie. *Freshwater Biol.* 56: 366–383.

EPA 2013 Impacts of climate change on the occurrence of harmful algal blooms. *Office of Water.* United States.

Ferris R2016Why there are so many toxic algae blooms this year?*Environment.*https://www.cnbc.com/2016/07/26/why-are-there-so-many-toxic-algae-blooms-thisyear.html. Retrieved on 15th May, 2020

Filazolla A, Mahdiyan O, Shuvo A, Ewins C, Moslenko L, Sadid T, Blagrave K, Imrit MA, Gray DK, Quinlan R, O'Reilly CM and Sharma S 2020 A database of chlorophyll a and water chemistry in freshwater lakes. *Scient. Data.* https://doi.org/10.1038/s41597-020-00648-2.

Fondriest Environmental Inc. "dissolved oxygen" Fundamentals of Environmental Measurements 2013. https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen

Frank TH, Cornelissen IJM, Vijverberg J and Nagelkerke LAJ 2023 Spatial and seasonal variation in the phytoplankton community of Lake Victoria's Mwanza Gulf compared to northern parts of the lake. *J. Great Lakes Res.*49: 453–462.

Gobler C 2021 Climate change and harmful algal blooms. *Harmful Algae* 91: 101731.

Hamisi MI and Mamboya FA 2014 Nutrient and phytoplankton dynamics along the Ocean Road sewage discharge channel, Dar es Salaam, Tanzania. *J. Ecosyst.* http:/dx./doi.org/10.1155/2014/271456

Hazenoot C 2012 Effect of eutrophication on phytoplankton in the Mwanza Gulf (Lake Victoria, Tanzania). MSc. Thesis. Wageningen University, Netherlands.

Ho JC and Michalak AM 2019 Exploring temperature and precipitation impacts on harmful algal blooms across continental U.S. lakes. *Limnol. Ocean.* 65: 992–1009.

Hongoa PS 2014 The impact of population increase around Lake Babati. MSc. dissertation. The Open University of Tanzania.

IPCC 2007 Climate change: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Johan FB, Jafri MZM, San LH, Omar WMWO and Ho TC 2018 Chlorophyll a concentration of fresh water phytoplankton analysed by algorithmic based spectroscopy. The International Conference of Solid State Science and Technology (ICSSST 2017). *J. Phys*: Conf. Series 1083 (2018) 012015.

Jöhnk KD, Huisman J, Sharples J, Sommeijer B, Visser PM and Stroom JM 2008 Summer heatwaves promote blooms of harmful cyanobacteria. *Glob. Change Biol.*14: 495–512.

Kansas department of health and environment (KDHE) bureau of water 2011 Water quality standards white paper. Chlorophyll-*a* criteria for public water supply lakes or reservoirs 11pp.

Katonge JH 2018 Anthropogenic activities, land uses, limnology and management of fisheries resources in Lake Babati and Lake Burunge. PhD Thesis, University of Dodoma

Kothari CR 2004 Research methods. Second Revised Edition. New Age International Publishers.

Kraemer BM, Pilla RM, Woolway RI, Anneville O, Ban S, Colom-Montero W, Devlin SP, Dokulil MT, Gaiser EE, Hambright KD et al. 2021 Climate change drives widespread shifts in lake thermal habitat. *Nat. Clim. Change* 11: 521–529.

Löfstrand F 2005 Conservation agriculture in Babati district, Tanzania: Impacts of conservation agriculture for small-scale farmers and methods for increasing soil fertility. MSc. Thesis. Swedish University of Agricultural Science. Sweden.

Mbanguka RP, Lyon SW, Holmgren K, Lopez MG andJarsjö J 2016 Water balance and level change of Lake Babati, Tanzania:

Sensitivity to hydroclimatic forcings. *Water* 8: 572. doi:10.3390/w8120572

Mchau GJ, Makule E, Machunda R, Gong YY and Kimanya M 2019 Harmful algal bloom and associated health risks among users of Lake Victoria freshwater: Ukerewe Island, Tanzania. *J. Water Health* 17(5): 826-836.

Olokotum M, Mitroi V, Troussellier M, Semyalo R, Bernard C, Montuelle B, Okello W, Quiblier C and Humbert J-F 2020 A review of the socioecological causes and consequences of cyanobacterial blooms in Lake Victoria. *Harmful Algae* 96: 101829.

Paerl HW, 1998 Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and ground water as "new" nitrogen and other nutrient sources. *Limnol. Oceanogr*. 42(5): 1154-1165.

Peter KH, Nnko HJ and Mubako S 2020 Impacts of anthropogenic and climate variation on spatiotemporal pattern of water resources: A case study of Lake Babati, Tanzania. *Sustain. Water Resour. Manage.* 6: 47.doi.org/10.1007/s40899-020-00400-z

R Core Team 2021 R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL> https://www.R-project.org/.

Rocha RRA, Thomaz SM, Carvalho P and Gomes LC 2009 Modeling chlorophyll-a and dissolved oxygen concentration in tropical floodplain lakes (Paraná River, Brazil). *Braz. J. Biol.* 69(2): 491–500.

Roman MR, Brandt SB, Houde ED and Pierson JJ 2019 Interactive effects of hypoxia and temperature on coastal pelagic zooplankton and fish. *Front. Mar. Sci.* 6:139.

Sanseverino I, Conduto D, Pozzoli L, Dobricic S and Letteri T 2016 Algal bloom and its economic impacts. Joint Research Commission, Technical Reports. European Commission. Doi:10.2788/660478.

Schindler DW 2006 Recent advances in the understanding and management of eutrophication. *Limnol. Oceanogr.* 51(1): 356–363.

Simiyu BM, Oduor SO, Rohrlack T, Sitoki L and Kurmayer R 2018 Microcystin content in phytoplankton and in small fish from eutrophic Nyanza Gulf, Lake Victoria, Kenya. *Toxins*10: 275.

Shukla JB, Misra AK and Peeyush CP 2008 Modeling and analysis of the algal bloom in a lake caused by discharge of nutrients. *Appl. Mat. and Computation* 196: 782–790.

Trent T, Hendrickson J and Harwell MC 2017 A rapid, cost-effective screening tool for measuring Chl-'a' in water samples. *Lake Reservoir Manag.* 33(3): 217–222.

URT 2013 The 2012 Population and Housing Census. *National Bureau of Statistics*. Ministry of Finance, Dar es Salaam and Office of Chief Government Statistician President's Office, Finance, Economy and Development Planning, Zanzibar.

Verschuren D, Johnson TC, Kling HJ, Edgington DN, Leavitt PR, Brown ET, Talbot MR and Hecky RE 2002 History and timing of human impact on Lake Victoria, East Africa. The Royal Society, London. pp 289-294.

Wang J, Pan F, Soininen J, Heino J and Shen J 2016 Nutrient enrichment modifies temperature-biodiversity relationships in large-scale field experiments. *Nature Communicat.*7:13960.

Wetzel RG 2001 Limnology: Lake and river ecosystems. Third edition. San Diego, C.A. Academic Press.

Wilson PC 2010 Water quality notes: Dissolved oxygen. The Institute of food and Agricultural Sciences (IFAS), University of Florida. SL313 pp 1-9.

Wood BM, Millar RS, Wright N, Baumgartner J, Holmquist H and Kiffner C 2021 Hunter-Gatherers in context: Mammal community composition in a northern Tanzania landscape used by Hadza foragers and Datoga pastoralists. *PLoS ONE* 16(5): e0251076.

Woolway RI, Jennings E, Shatwell T, Golub M, Pierson DC and Maberly SC 2021 Lake heatwaves under climate change. *Nature* 589: 402–407.

Xie C, Zhang X, Zhuang L, Zhu R and Guo J 2022 Analysis of surface temperature variation of lakes in China using MODIS land surface temperature data. *Sci. Reports* 12(1): 2415.