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Microalgae as Indicators to Assess Trophic Status and Organic Pollution in the Seven Brackish Lakes, North of Benghazi, Libya

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A B S T R A C T

This study investigates the use of microalgae as bioindicators to assess the trophic status and organic pollution levels in the Seven Brackish Lakes located north of Benghazi, Libya. Microalgae, due to their rapid response to environmental changes and their central role in aquatic ecosystems, serve as effective indicators of water quality. Over four seasons sampling period, qualitative and quantitative analyses of microalgae communities were conducted across 6 sites within the lakes. Key ecological indices, including Nygaard index, Palmer Pollution Index and trophic diatoms index were employed to evaluate trophic status and pollution levels. During the four seasons from October 2022 to July 2023, 33 species following to 27 genera and 5 divisions were recorded from in the seven lakes north of Benghazi. The most diverse group was Chlorophyta (49%), followed by Cyanobacteria (21%), Bacillariophyta (12%), Euglenophyta (9%) and Dinophyta (9%) as well. Results revealed significant organic pollution conditions based on palmer index (score = 36) with higher abundances of eutrophication based on the compound Nygaard index indicated(score =9) and trophic diatoms index (score = 4 to 4.5). These findings suggest a gradient from mesotrophic to hypereutrophic conditions within the lake system, corresponding to varying degrees of anthropogenic impact, particularly domestic and agricultural runoff.

الطحالب الدقيقة كمؤشرات لتقييم الحالة التغذوية والتلوث العضوي في البحيرات السبع قليلة الملوحة شمال بنغازي، ليبيا

منى عبالقادر الطيرة و لجين مفتاح المغربي

تبحث هذه الدراسة في استخدام الطحالب الدقيقة كمؤشرات حيوية لتقييم الحالة التغذوية ومستويات التلوث العضوي في البحيرات السبع قليلة الملوحة الواقعة شمال بنغازي، ليبيا. تعمل الطحالب الدقيقة، نظراً لاستجابتها السريعة للتغيرات البيئية ودورها المحوري في النظم الإيكولوجية المائية، كمؤشرات فعالة لجودة المياه. تم تجميع العينات على مدى أربعة مواسم وأجريت تحليلات نوعية وكمية لمجتمعات الطحالب الدقيقة في 6 مواقع داخل البحيرات. واستخدمت المؤشرات البيئية الرئيسية، بما في ذلك مؤشر نيغارد، ومؤشر بالمر للتلوث، ومؤشر الدياتومات التغذوي لتقييم الحالة التغذوية ومستويات التلوث. خلال المواسم الأربعة من أكتوبر 2022 إلى يوليو 2023، تم تسجيل 33 نوعاً تتبع 27 جنساً و5 أقسام في البحيرات السبع شمال بنغازي. كانت المجموعة الأكثر تنوعًا هي الطحالب الخضراء (49%)، تليها الطحالب الخضراء المزرقة (21%)، الدياتومات (12%)، الطحالب اليوجلينية (9%) والطحالب النارية (9%) أيضًا. كشفت النتائج عن وجود حالات تلوث عضوي كبيرة استناداً إلى مؤشر بالمر (الدرجة = 36) مع وفرة أعلى من التخثث استناداً إلى مؤشر نيغارد المركب المشار إليه (الدرجة = 9) ومؤشر الدياتومات الغذائية (الدرجة = 4 إلى 4.5). تشير هذه النتائج إلى وجود تدرج من الظروف المتوسطة التغذية إلى الظروف المفرطة التغذية داخل نظام البحيرة، وهو ما يتوافق مع درجات متفاوتة من التأثير البشري، وخاصة الجريان السطحي المنزلي والزراعي.

INTRODUCTION

Algae represent a pivotal nutritional and respiratory resource for consumers inhabiting aquatic ecosystems. They exert a direct influence on primary production by establishing the fundamental trophic level within the food chain. It has been determined that algae play a pivotal role in the assessment of water contamination and the purification of wastewater (Stevenson, 2014). Algae are considered to be among the most significant bioindicators of alterations in water quality (Gökçe, 2016). This is primarily attributed to algae brief life cycles, rapid response to contaminants, and the ease with which their population sizes can be determined (Tolboom *et al.*, 2019). Bioassessment of water bodies by diatoms is a widely adopted scheme in a lot of previous studies (Lobo *et al.,* 2016; Çelekli *et al.* 2021; Costa & Schneck, 2022; Viso & Blanco, 2023). The reason why diatoms are so commonly used in lakes bioassessment due to many reasons; they are very sensitive to the environmental fluctuations; and diatoms prefer specific physical and chemical parameters such as nutrient levels, pH, dissolved oxygen and temperature. Diatoms can be found in all aquatic ecosystems at any time of year; alongside their tolerance level to environmental variables (Delgado, Pardo, 2015; Lobo *et al.,* 2015; Çelekli *et al.,* 2022; Lekesiz *et al.,* 2024). The development and utilisation of biotic indices based on diatoms in diverse ecological regions has been enabled by a combination of these factors. Palmer (1969) provided confirmation of the hypothesis that certain genera of algae can be utilised as indicators of water pollution in lakes. In a similar manner, Nygaard's index is utilised to evaluate the trophic status of lakes based on the number of algal species classified into distinct groups. Previous studies on these lakes have often focused on pollution by heavy metals, but there is no study integrated microalgae, water trophic status and organic pollution in brackish lakes. This research seeks to fill that gap by investigate the trophic status of the seven lakes at north of Benghazi, with a particular focus on the dynamics of algae populations and the implementation of indices for the assessment of water quality. The aim of this study is using microalgae as bioindicators to assess the trophic status and organic pollution levels by Nygaard index, Palmer index and Trophic Diatom index in the seven brackish lakes located North of Benghazi, Libya.

MATERIALS AND METHODS

Study area

The seven northern lakes of Benghazi are a vast, flat expanse, situated in the northern border at the east entrance of Benghazi. They are connected together with total area of 1.203 km2 and the length of the lake's boundary is 9.86 km which measured by (offline maps) Phone online application based on the global positioning system (GPS) as presented in Figure (1). These water bodies are referred to as seven lakes of El-thama region. The area has been used as a municipal landfill for a considerable period of time, with a wide range of waste materials, including discarded vehicles, oil, and other hazardous substances having been deposited there.

Figure 1: The study area and sampling sites.

Samples Collection and Algae Identification

Water samples were collected seasonally from six sites from the borders of the connected lakes during the period between October 2022 to July 2023. Microalgae species were counted three times from each sample by Haemocytometer chamber according to the Utermöhl method (Utermöhl, 1958). 10 ml of 4% formalin solution were added to the samples for algae fixation (Kumar, 2012). Microalgae were identified at species level according to a key of algae identification (Bellinger and Sigee, 2010) and algae base web site (Guiry, MD & Guiry, GM, 2013; Guiry MD & Guiry, GM, 2008, Guiry, 2024).

Nygaard's trophic state index

Nygaard Species Index (Nygaard, 1949) calculation was based on the species number of microalgae in each algae group. The index comprises five sub-indices, which can be classified according to the trophic state of the lake, as outlined below.

Index 1 = Cyanophyceae / total algae

Index 2 = Chlorococcales/total algae

Index3 = Centrales/Pennales

Index4 = Euglenineae / (Cyanophyceae + Chlorococcales)

Index 5 = (Cyanophyceae + Chlorococcales + Centrales + Euglenineae)/pennales diatoms

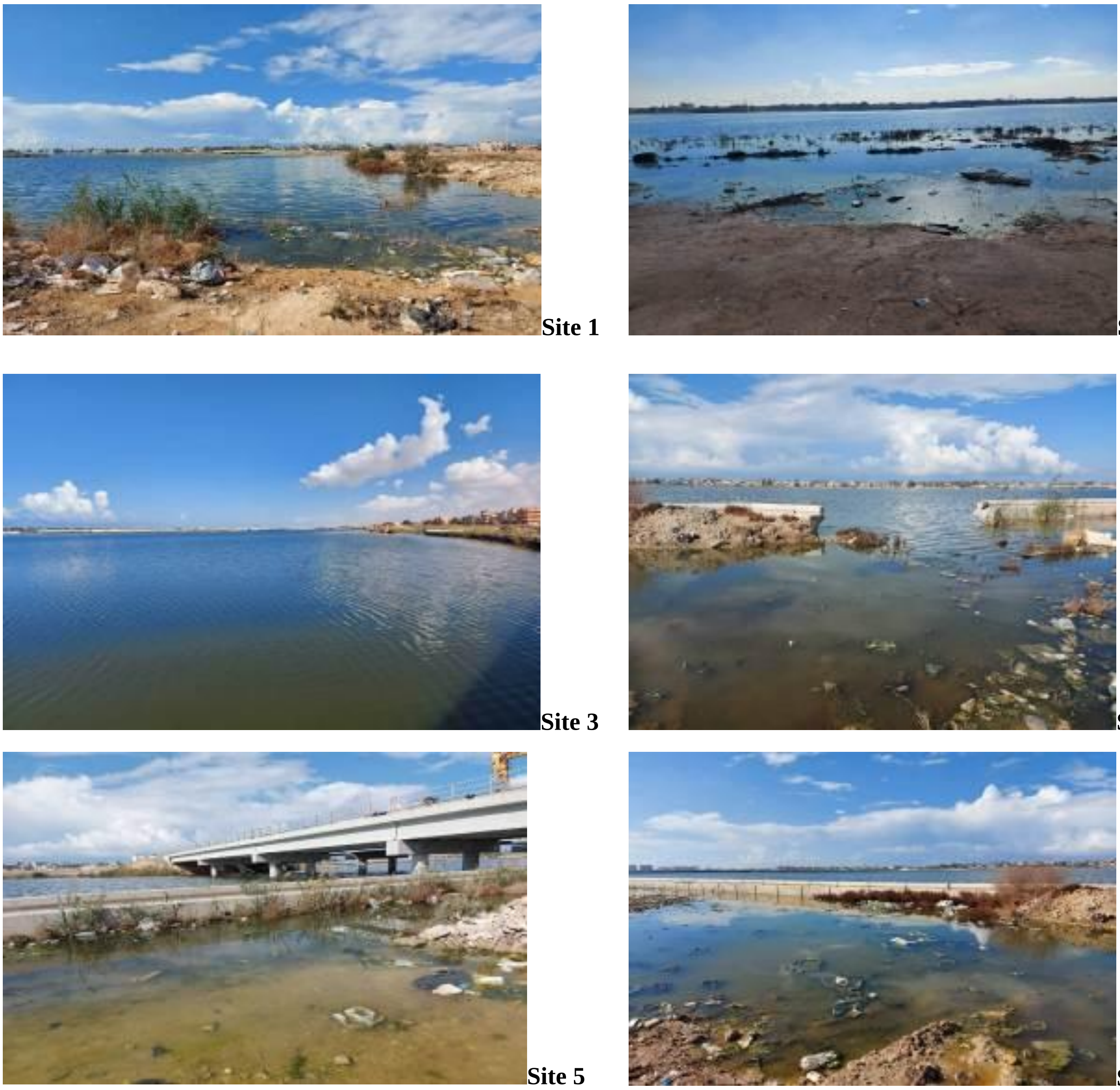
Site 1 Site 2 Site 3 Site 4 Site 5 Site 6

Figure 2: Sampling sites.

Palmer's algae pollution index

Palmer Species Index was calculated based on 20 genera of algae that are known to be indicative of organic pollution (Palmer, 1969). Each of these genera is assigned a pollution tolerance score, ranging from 1 to 5, where higher scores indicate more tolerance to pollution as showed in Table (1). The pollution index score was calculated by adding the scores of the algae present in the sample. If the total score is ≥20, the water is considered to be significantly polluted by organic matter. If the total Score <15, the water is likely unpolluted or has low organic pollution.

Table 1: Common Algal Genera in Palmer's Index

Genus	Index	Genus	Index
Anacystis	1	*Phormidium*	1
Closterium	1	*Ankistrodesmus*	2
Cyclotella	1	*Synedra*	2
Gomphonema	1	*Phacus*	2
Melosira	1	*Stigeoclonium*	2
Micractinium	1	*Chorella*	3
Pandorina	1	*Navicula*	3
Nitzschia	3	*Euglena*	5
Chlamydomonas	4	*Oscillatoria*	5
Scenedesmus	4	Other filamentous Blue green algae	5

Trophic Diatoms index

The Trophic Diatoms index (TDI) is a method used to assess the trophic status and water quality of aquatic environments based on Diatoms abundance and their sensitivity to pollution.

TDI = $$index = \frac{\sum_{j=1}^{n} a_j s_j v_j}{\sum_{j=1}^{n} a_j v_j}$$

(s) nutrient sensitivities (1-5)

(v) indicator values for taxa (1-3)

a: abundance (number of cells for each species / total number of algae

the range of value (0 - 100)

"Diatoms Quality index" DQI= 100 - TDI.

RESULTS AND DISCUSSION

During the four seasons from October 2022 to July 2023, 33 species following to 27 genera and 5 divisions (Figure 3) were recorded from in the seven lakes north of Benghazi. The most diverse group was Chlorophyta (49%), followed by Cyanobacteria (21%), Bacillariophyta (12%), Euglenophyta (9%) and Dinophyta (9%) as well.

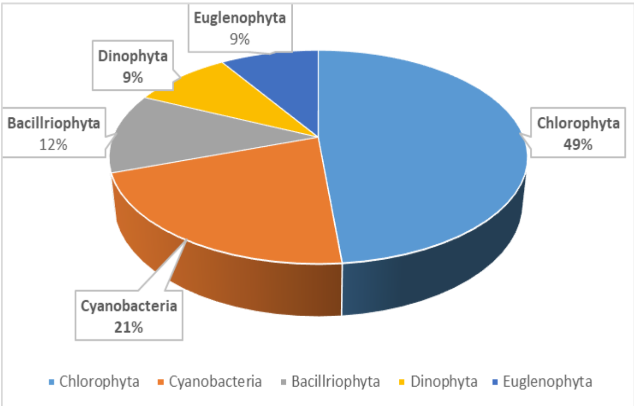

Figure 3: Microalgae composition in the study area.

Evaluation of lakes trophic state by Nygaard index

Nygaard's indices for the different algal groups (Cyanophycean, Chlorophycean, Bacillariophycean, Euglenophycean and Compound Quotient (CQ)) are used to provide a meaningful evaluation of pollution and trophic status in water bodies. The Cyanophycean group score in the seven lakes indicated an oligotrophic nature. The Chlorophycean group score also indicated an oligotrophic nature. The Bacillariophycean group score indicated to oligotrophic nature of water. The Euglenophycean group score indicated to oligotrophic nature. The compound index indicated the eutrophic level of a lake (Nygaard, 1949). If the ratio is less than 1, the lake is considered as being oligotrophic, whereas if it is greater than 3, the lake is considered as being eutrophic. Compound index value (Cyanophyceae +Chlorococcales + Centrales + Euglenales / pennales) has been found to be 9 for the study area, which indicating that it is eutrophic (Table 2).

Table 2: Nygaard's Status indices for microalgae in the seven lakes.

Index	Trophic Status Indices Oligotrophic/ Eutrophic (Nygaard, 1949)	The study area
Index 1 (Cyanophycean)	0.0 – 0.40 / 1 - 3.0	0.21
Index 2 (Chlorophyll)	0.0 – 0.70 / 2 – 9.0	0.48
Index3 (Bacillariophycean)	0.0 – 0.30 / 0 – 1.75	0.33
Index4 (Euglenophycean	0.0 – 0.70 / 0 – 1.0	0.21
Index 5(Compound Quotient (CQ)	0.0 – 1.0 / 2 – 2.5	9.00

Evaluation of organic pollution by Palmer's algal genera

A Palmer Pollution Index Factor ranging from 1 to 5 has been assigned to each of the twenty most tolerant species of algae.

The types of algae that were most tolerant of organic pollution were assigned a value of 5. Those that were less tolerant were assigned a lower number. If the pollution index score is 20 or more, the score is evidence of high organic pollution. A score of 15-19 indicates probable organic pollution. Lower scores usually indicate less organic pollution. In present study, Palmer index was calculated for the seven lakes and it is found that out of 20 genera, 11 genera were found with total index value of 36. That indicates to high organic pollution in the seven lakes and clearly indicated that the water body was eutrophic nature. Detailed results of the Palmer Index are summarized in Table 3.

Table 3: Palmer Pollution Index for the study area.

Genus	Pollution index	The study area
Anacystis	1	-
Closterium	1	-
Cyclotella	1	1
Gomphonema	1	-

Melosira	1	-
Micractinium	1	-
Pandorina	1	1
Phormidium	1	-
Ankistrodesmus	2	-
Synedra	2	-
Phacus	2	-
Stigeoclonium	2	2
Chorella	3	3
Navicula	3	3
Nitzschia	3	3
Chlamydomonas	4	4
Scenedesmus	4	4
Euglena	5	5
Oscillatoria	5	5
Other filamentous Blue green algae	5	5 (Stigonema)
Total score		**36**

Trophic Diatoms index

As presented in Table 4, a Trophic Diatom Index (TDI) score of between 4 and 4.5 indicates generally good water quality, but suggests slight pollution or eutrophication due to changes in the diatom community. This range indicates shifts in the diatom community and a decrease in sensitive species, as well as moderate levels of pollution.

AT autumn season *Cyclotella meneghiniana* has a low abundance (0.07), and no sensitivity value. At winter *Cyclotella meneghiniana* increased in abundance (0.3), but no av or asv. *Gyrosigma acuminatum* appeared with small values (asv = 0.5) while *Navicula subtilissima* and Nitzschia *palea* and have moderate values. At spring season *Navicula subtilissima* showed the highest asv (1.0), indicating a strong presence, while at summer the distribution of diatoms was similar to that at autumn.

Table 4: Data used in calculation of TDI and DQI in different seasons in the seven lakes, North of Benghazi, Cyclo: *Cyclotella meneghiniana*; Gyr: *Gyrosigma acuminatum* Nav: *Navicula subtilissima*; Nitz: *Nitzschia palea*

	Autumn			Winter			Spring			Summer		
	a	av	asv	a	av	asv	a	av	asv	a	av	asv
Cycl	0.07	0	0	0.3	0	0	0.15	0	0	0.16	0	0
Gyr	0	0	0	0.05	0.1	0.5	0	0	0	0	0	0
Nav	0.08	0.08	0.32	0.18	0.18	0.72	0.25	1	4	0.07	0.07	0.28
Nitz	0.07	0.07	0.35	0.02	0.02	0.1	0	0	0	0.06	0.06	0.3
Σ		0.15	0.67		0.3	1.32		1	4		0.13	0.58
TDI	4.5			4.4			4			4.5		
DQI	95.5			95.6			96			95.5		

The over status of the seven brackish lakes, North of Benghazi based on the all used algae indices

Nygaard's indices classify lakes based on their nutrient levels and productivity, ranging from oligotrophic (low nutrients and productivity) to eutrophic (high nutrients and productivity). Each index assesses a different aspect of microalgal communities. Higher values of Chlorophycean Index suggest lower nutrient levels (oligotrophic conditions). Higher values of Cyanophycean Index indicate higher nutrient levels, possibly due to eutrophication. In the current study, the trophic state index of Cyanophycean, Chlorophycean, Bacillariophycean, Euglenophycean indicated to oligotrophic nature, but the compound index value which was 9 indicated to the eutrophic level of the seven lakes. These results were agreed with Hamaidi-Chergui *et al.,* (2014) who recorded that the compound index, which encompassed the widest range and was highly sensitive, remains a valuable tool for assessing the eutrophication of the lake. Palmer index was calculated for the seven lakes by 11 genera, with total index value of 36. That indicates to high organic pollution in the seven lakes and clearly indicated that the water body was eutrophic nature. This value is higher than that found by Mishra *et al.,* (2017) who mentioned that (Palmer index = 16 and 24) of a lake are indicate to high organic pollution.

Palmer's pollution indices of microalgae and Nygaard's microalgae quotient values were clearly indicated a high degree of pollution in the seven lakes north of Benghazi.

The TDI score (4.0–4.5) and seasonal diatom shifts confirm that the aquatic environment is under moderate ecological pressure but not yet severely degraded. The increase in tolerant taxa such as *Nitzschia*, *Navicula*, *Cyclotella* and fluctuations in sensitive species suggest that nutrient inputs are influencing community structure, particularly in winter and spring. Monitoring these trends over time is crucial, as continued nutrient enrichment could escalate eutrophication and reduce biodiversity (Hasan *et al.,* 2023).

CONCLUSION

This study highlights the effectiveness of microalgae as bioindicators for evaluating the trophic status and levels of organic pollution in the Seven Lakes region, north of Benghazi. The diversity, abundance, and community composition of microalgal species exhibited clear spatial variations that corresponded with differing nutrient loads and anthropogenic pressures across the lakes. This approach reinforces the value of microalgae as reliable, cost-effective indicators in long-term monitoring and environmental management strategies. Given the vulnerability of the Seven Lakes to nutrient enrichment and urban runoff, continuous surveillance using microalgal bioassessment is essential for early detection of ecological degradation and for guiding appropriate remediation efforts.

In conclusion, microalgae serve not only as sensitive indicators of trophic shifts and organic pollution but also as essential tools in the development of sustainable lake management policies in the Benghazi region.

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