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An ecological response index for simultaneous prediction of eutrophication and metal pollution in Domat Al-Gandal lake, Saudi Arabia.

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ABSTRACT
Man-made lakes are landscape modifications that can help the ecology. Artificial lakes may support several ecosystems. New plants and animals alter ecosystems. Humans constructed Domat Al-Gandal Lake which is located between 29°49'12.08N and 29°48'23.54N and 39°54'9.33E and 39°54'57.19E in northern Saudi Arabia. Eutrophication affects the water quality in many lakes worldwide by encouraging the growth of planktonic algae. Natural and man-made sources add heavy metals to lakes .Most heavy metals are low in concentrations. Summer temperatures reached 28.9 °C and winter temperatures 10.8 °C. Maximum turbidity occurred in winter (5.53 NTU) and minimum in autumn (4.15 NTU). The regional transparency averaged 2.48 m. Autumn and spring pH was 7.60 to 8.28, respectively. Total phosphorus ranged from 101.48 to 88.85 µg/L. Regional heavy metal averages fluctuated little. Four phytoplankton communities groups were identified. Chlorophyceae, Cyanophyceae, Bacillariophyceae, and Dinophyceae. Seasonal changes in phytoplankton populations were narrow. Chlorophyta and Cyanophyta had the highest-standing crops. Maximum phytoplankton density was in the north (84.045 X 10^3 Cell/L) and the south (71.370 X 10^3 Cell/L). This research examined the numerous approaches used to evaluate lake water quality and eutrophication, showed, and analyzed eutrophication sources, nutrient transformations, and eutrophication mechanisms, and proposed complete management options for watershed development.

INTRODUCTION

Damming rivers create artificial lakes, which can be used for water storage and agriculture. Hydropower dam, can be considered as the outcome benefit from the ma-made lakes. A lacustrine ecosystem is formed, which may help with the propagation of fish populations for commercial aquaculture and subsistence fishing. The construction of dams, the formation of man-made lakes, and the development of irrigation projects in general introduce significant changes in the environment and, simultanously, produce several risks to ecosystem. In terms of environmental changes, water resources development projects typically lead to the degradation of the environment through the elimination of vegtation, the acceleration of soil erosion, and the creation of biotopes more hospitable than before to intermediate hosts or vectors of parasitic or infectious diseases (Hunter *et al.*, 1982; Araoye, 2002).

Domat Al-Gandal Lake is one of the artificial lakes created due to human endeavors. Domat Al-Gandal Lake is an oval-shaped body of water found in northern Saudi Arabia between the coordinates of 29°49'12.08N and 29°48'23.54N and 39°54'9.33E and 39°54'57.19E. The lake got its name from the town it was situated in (Domat Al-Jandal governorate in Al-Jouf). Since agriculture plays a significant role in the economy, the Emirate of Al-Jouf is home to many agricultural businesses. Several underground wells in the Al-Jouf region help the region's considerable agriculture and other human activities. Domat Al-Gandal, is an artificial lake,which was created to be as a astorage reservoir of flodding water in the Emirate of Al-Jouf. In light of this, it is safe to say that this lake is the largest man-made lake in the whole of the Arabian Peninsula. The irrigation project's water flow, which started in 1987, explains why Lake Domat Al-Gandal exists in a desert which receiving the agricultural runoff from the nearby the agricultural fields.

Eutrophication, it is an ecological phenomenon which is occurred by the increasing of nutrients, particularly phosphorus and nitrogen that encourage the growth of planktonic algae to bloom. The rapid growth of phytoplankton and other microorganisms and a decline in water quality are two negative consequences of water eutrophication, which has a negative impact on aquatic ecology and the proper functioning of water bodies (Xiang *et al.*, 2015; Touliabah, H. e Elbassat, R., 2017; May *et al.*, 2020; Hu *et al.*, 2022; Lin *et al.*, 2022a; Wang *et al.*, 2022; Yudhistira *et al.*, 2022).

Water quality declines and cyanobacterial blooms are inevitable results of eutrophication, which has become a global problem for lakes and reservoirs (Ke *et al.*, 2018; Srichandan e Rastogi, 2020). One of the most significant challenges to long-term economic growth is the eutrophication of lakes (Le *et al.*, 2010).

Algae biomass in any waterbodies grows with increasing eutrophication rates (Camargo *et al.*, 2005; Schindler *et al.*, 2016; Touliabah, H. e Elbassat, R., 2017; Ghashghaie *et al.*, 2018). Algal growth and Chlorophyll a are most sensitive to the to the elements nitrogen (N) and phosphorus (P). Unfortunately, these fertilizer inputs can severely impact the quality of receiving waterways (Smith, 2003; Rastogi *et al.*, 2015).

Recent years have seen much public and scholarly attention focused on the rapidly declining water quality in many of the country's lakes, primarily due to accelerated eutrophication brought on by growing human usage and contamination of natural waters. The ultimate goal of the National Eutrophication Program is to develop methods and techniques to monitor and trying to reduce the accelerated eutrophication of the lakes (Malueg *et al.*, 1973).

Lake heavy metals are introduced by natural and man-made sources (Bem et al., 2003; Reza and Singh, 2010). The primary natural source is typically the natural weathering of rocks and soil exposed to surface waters (Hou et al., 2013; Cheng et al., 2021). Most heavy metals are typically present in low concentrations in natural environments.

There is an insufficient number of scientific studies dealing with the ecological, biological, and eutrophication of Lake Domat Al-Gandal. The number that does not exceed the fingers of the hand. Elbassat did the first study dealing with zooplankton and their related bacteria in 2011 (El-Bassat R.A. *et al.*, 2011). The only research dealing with the preliminary study of the physico-chemical properties of Domat Al-Gandal was done by Rabigh 2014 (Rabeh e El-Boray, 2014). The rest research dealing with bird migration was done by Heezik, 1999 and Almansour 2013 (Van Heezik e Seddon, 1999; Almansour e Jarrar, 2013).

The goals of this research were to examine the various techniques used to evaluate lake water quality and eutrophication; (ii) show and analyze the various eutrophication sources, nutrient transformations, and eutrophication mechanisms; and (iii) propose comprehensive management strategies for sustaining watershed development. Lake eutrophication and water quality are evaluated and discussed in this study. Moreover, a few strategies for controlling water pollution are outlined.

MATERIALS AND METHODS

Study Site

The lake, developed in a valley surrounded by high hills, has an oval shape. Groundwater and the farmers' surplus water flow into the lake's central basin. Installation of a fountain and the completion of other projects, such as the asphalting, paving, lighting, and iron fencing of the neighborhood's streets, began in 2006, ushering in a period of development for the lakeside area. The elevation of Domat Al-Jandal Lake is 585 meters (1,928 ft). From its northern to southern extremities, the lake reaches a maximum of 1.93 kilometers in length, and its breadth is roughly 1 kilometer at its widest point. The diameter is around 5.79 km, and the depth varies from very shallow to quite deep (6.53 m and 17.66 m). Domat Al-Jandal Lake was sampled throughout 2019 according to the seasons. Table 1 and Fig. 1 show samples were obtained from the northern, middle, and southern sections.

Table (1): A table showing the latitude and longitude of the section under study

	Latitude	Longitude
Northern Section (NS)	29°49'3.97N	39°54'25.24E
Middle Section (MS)	29°48'50.50N	39°54'38.58E
Southern Section (SS)	29°48'36.14N	39°54'52.88E

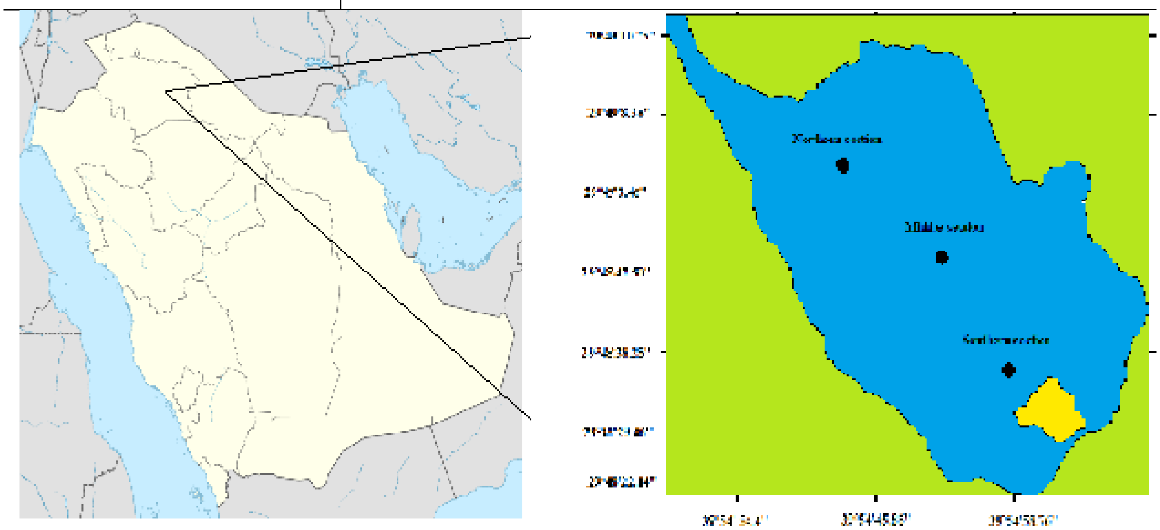

Fig. 1: Location map of Domat Al-Gandal lake

Water Quality

Temperature, Turbidity, salinity, and pH, measurements were taken on-site using Ecosounder-UWTEC depth, YSI 556 MPS Meter. To measure the degree of transparency (SD), we dropped a black-and-white Secchi disc (25 cm in diameter).

Standard water analysis methods were used to estimate physicochemical characteristics (APHA, 2005). Nitrite nitrogen (NO_2-N), Nitrate nitrogen (NO_3-N), Ammonia nitrogen (NH_4-N), Reactive phosphate (PO_4-P), and Total Phosphorus (TP) were measured corresponding to standard methods (APHA, 2005). Polyvinyl chloride samplers were used to gather seasonal samples from the subsurface seasonally at each section in 2019.

The concentration of heavy metals (Cu, Fe, Ni, Mn, Pb, Co, Cr, Zn, Cd) in water samples was measured by the atomic absorption spectrophotometer (AAS), GBC-93, Australian Model at the National Institute of Oceanography and Fisheries, Hurghada, Egypt (APHA, 2005).

Preparation of Phytoplankton for estimation of Standing Crop

Phytoplankton in the water sample were quickly preserved in a 5% formalin solution and sent to the laboratory of phycology at King Abdulaziz University's Rabigh Branch, Faculty of Science and Arts, Saudi Arabia. We used sedimentation methods for estimation the standing crop (quantitative analysis) and the species composition (qualitative analysis) of the phytoplankton communities. Sedimentation was used to estimate the standing crop (quantitative analysis) and the species composition (qualitative analysis) of the phytoplankton communities (Ultermöhl, 1958; EPA, 1979; APHA, 2005).

One-liter samples filtered onto Whatman GF/F filters, chlorophyll-a concentration was calculated spectrophotometrically. 90% acetone was used to extract the pigments overnight at 4°C in the dark. Lorenzen's formula for calculating chlorophyll-a was used (1967).

Trophic Status Index (TSI)

The lake's trophic state is evaluated using the TSI equation by (Carlson, 1977; Liu *et al.*, 2010; Devi Prasad e Siddaraju, 2012). TSI, was determined according to Total Phosphorus, Secchi Disc, and Chlorophyll a. The equation used in this article is as follows:

$$\mathrm{TSI}\ (\mathrm{TP}, \mu g\ L^{-1}) = 10\ X \left(6 - \frac{\ln\left(\frac{48}{TP}\right)}{\ln 2}\right) \qquad \text{------------------ (1)}$$

$$\mathrm{TSI}\ (\mathrm{SD}, m) = 10\ X \left(6 - \frac{\ln(SD)}{\ln 2}\right) \qquad \text{------------------ (2)}$$

$$\mathrm{TSI}\ (\mathrm{CHL}, \mu g\ L^{-1}) = 10\ X \left(6 - \frac{2.04 - 0.68\ x\ \mathrm{Ln}\,(\mathrm{CHL})}{\ln 2}\right) \qquad \text{------------------ (3)}$$

Where

TSI: Trophic Status Index.

SD: Secci Disc Readings by meters.

TP: Total phosphorus readings by µg/l.

Chl.: Chlorophyll a by µg/l.

Statistical Analysis

The relationships between the various parameters analyzed were allocated by computing the correlation coefficients (r) with the Statistical program Ver 7 (Statsoft, 2007).

RESULTS & DISCUSSION

The artificial lakes and reservoirs discussed here represent a wide range of sizes and climates. To comprehend the limnology of artificial lakes, we believe it is necessary to be familiar with their temperature and pH ranges (Allanson, 1973). Water temperature is an essential indicator of water quality that regulates many biological processes in a waterbodies system. Temperature affects all biological systems in waterbodies (Harvey *et al.*, 2011). The water temperature follows the usual trend in the investigated area (Table 1). The maximum water temperature was recorded in summer, 28.9 °C, and the lowest during winter, 10.8 °C. The same trend was recorded by El-Bassat as well as Rabeh in Dumat Al-Jandal (El-Bassat R.A. *et al.*, 2011; Rabeh S.A. e K.F. 2014). There is an inverse relationship between water temperature and total phytoplankton (r= -0.90) and direct proportional with the trophic status index depending on Secchi Disc (r = 0.86). The obtained finding was like those obtained by Dallas (Dallas e Rivers-Moore, 2012). They reported there is a direct relation between eutrophication and water temperature in Kowie/Bloukrans waterbody of South Africa.

The state of turbidity is a function of nutrients laden into the lake. The turbidity increased southwards, and the maximum turbidity was recorded during winter (5.53 NTU), while the minimum was in Autumn (4.15 NTU) (Table 1). The turbidity was directly proportional with Cyanophyta (r = 0.67), and Bacillariophyta phytoplanktonic group (r = 0.72) and inversely related with the trophic status index calculated according to transparency and Chlorophyll a (r = -0.72 and -0.76 respectively). The data here was twice those recorded by Saleh 2014may be due to the high influx of agricultural waste during the sampling time. This is agreed by the data obtained by Hellström in shallow lakes (Hellström, 2012). On the other hand, our data agreed with those obtained by El-Bassat et al., 2011.

The seasonal average of transparency measured by the Secchi disc was nearly 2.48 m. Transparency can be decreased due to the intensive growth of phytoplankton, increasing turbidity, increasing the site and suspended matters, and increasing the agricultural waste from the agricultural land beside the lake (Table 1). This is confirmed by the obtained data and those recorded by Rabeh & El-Boray, 2014 and El-Bassat et al., 2011. However, transparency has a direct relationship with the community of Bacillariophyta and dinoflagellates phytoplanktonic group (r = 0.76 & 0.73, respectively). These relationships were similar to those obtained by Touliabah and El-Bassat, 2017 in the Rabigh Lagoon (Touliabah, H. E. e Elbassat, R. A., 2017).

Lake water's acidity or alkalinity can be measured by its pH level. pH readings fluctuated between 7.60 and 8.28 during autumn and spring, respectively (Table 1). These data agree somewhat with Rabeh & El-Boray, 2014 and El-Bassat et al., 2011. Lakes with a pH of more than 7.00 are called alkaline or basic. The causes of acidic lakes might be either natural or man-made. Most natural acid lakes can be found in the Arctic, namely peat bogs (Hellström, 2012; Vahatalo *et al.*, 2021). The pH level is an essential indicator of water quality since it affects how soluble minerals are. Growth cycles of photosynthesis and respiration in plankton in eutrophic waters can affect pH levels. This indicates that pH levels may indicate phytoplankton growth and water eutrophication (Touliabah and Elbassat, 2017). The Secchi disc eutrophication index negatively correlates with pH (r= -0.68).

Eutrophication and an overall decline in water quality can result from a lake's nutrient burden increasing (El-Serehy *et al.*, 2018; Yan *et al.*, 2019; Damar *et al.*, 2021; Acuña-Alonso *et al.*, 2022; Chen *et al.*, 2022; Hu *et al.*, 2022; Lin *et al.*, 2022a; b; Zahedi *et al.*, 2022). The seasonal fluctuations of nitrite in the studied area were nearly similar between 10 and 11 µg/L. On the other hand, the regional average of nitrite showed the Northern section of the lake higher than the rest section (12.88 µg/L). The seasonal average of nitrate ranged between 149.48µg/L in winter and 85.63 µg/L during autumn (Table 2). In the investigated area, dissolved nutrient contents and seasonal fluctuations are controlled by several factors: drainage water input and biogeochemical cycles. This view was agreed upon by Rabeh & El-Boray, 2014 and El-Bassat *et al.*, 2011. At the same time, the seasonal variation of ammonia was high in Winter (111.23 µg/L) and decreased to 49.28 µg/L during Autumn. According to Chapman and Kimstach (1992), the obtained data shows that ammonia content in clean water is typically less than 0.2 mg/l as nitrogen (Chapman e Kimstach, 1992).

To describe a specific kind of lake as Eutrophy, you can only do so if the water is abundant in phytoplankton, displaying the typical coloration of the vegetation from spring to autumn, and if there is a high production of phytoplankton for a relatively long period during summer. When describing waters lacking in phytoplankton,(The oligotrophic water is not lacking phytoplankton). The oligotrophic water has certain characteristics: algal biomass in term of Chlorophyll a concentration is less than 2 microgramm/l, dissolved oxygen is greater than 8 mg/l. the terms oligotrophy and dystrophy are used instead. The former refers to blue waters, the latter to murky ones (Allanson, 1973; Abdel-Raouf *et al.*, 2012; Abdulhasan *et al.*, 2022; Acuña-Alonso *et al.*, 2022).

The total phosphorus ranged between 101.48 µg/ during summer and 88.85 µg/L during winter (Table 1). Rabeh and El-Boray (2014) didn’t take total phosphorus in their limnological studies on Duma Al-Jandal Lake, while El-Bassat et al. (2011) just recorded the orthophosphate only. The present result showed a direct relationship between Chlorophyll and total phosphorus (r= 0.79), as shown in Fig. (2). These results agree with the data obtained by Dodds et al. 2006 in Kansas lakes, USA, and Nurnberg, 1966 in Hardwater Lakes (Nurnberg, 1996; Dodds *et al.*, 2006). They calculated hypolimnetic anoxia and eutrophication based on relationships of the data on many water bodies. As a general rule, it is believed that eutrophication processes cause an increase in the N, P, and Si concentrations of water bodies (Vollenweider, 1968; Caspers, 1984; Jin *et al.*, 1990; Lau e Lane, 2002; Saetang e Jakmunee, 2021; Xin e Ren, 2021). Nitrogen and phosphorus restrict the development of terrestrial plants, phytoplankton, macroalgae, and vascular plants in aquatic habitats, whereas silicon does the same for diatoms (Rabalais, 2002; Camargo e Alonso, 2006; Schindler *et al.*, 2016; Deng *et al.*, 2022). ???? Nitrogen and phosphorus eutrophication are stimulating the growth of phytoplankton not restrict its development. The eutrophication index according to Secchdisc, Total Phosphorus, and Chlorophyll a were represented in Table (3).

Table 2: The Seasonal average of some physicochemical Parameters.

	Water Temp. °C	Depth m	Secchi Disc m	Turbidity NTU	pH	NO_2-N µg/L	NO_3-N µg/L	NH_3-N µg/L	T.P µg/L
Winter	10.8	11.7	2.7	5.4	8.3	10.4	149.5	111.1	88.9
Spring	25.9	10.3	2.5	5.0	8.1	10.8	127.9	87.0	94.4
Summer	28.9	9.0	2.4	4.5	7.8	10.8	106.1	67.7	98.3
Autumn	22.8	7.6	2.3	3.9	7.6	10.8	85.6	49.3	101.5

Throughout history, heavy metals have always been a part of aquatic environments. It's been found that several of these components play crucial roles in living organisms. Human actions that release trace metals into aquatic habitats can be broken down by deposits and incorporated into sediments. When it comes to metals, sediments are the most concentrated physical pool (Pourang, 1996; Amini Ranjbar, 1998; Ferraro *et al.*, 2006; Al-Wesabi *et al.*, 2015; Birch *et al.*, 2015; Saeed e Zaki, 2017; Al-Hasawi *et al.*, 2018; Cyriac *et al.*, 2021).

Table 3: The Seasonal average of Eutrophication index.

	TSI (TP)	TSI (SD)	TSI (CHL)	TSI (TP)
Winter	68.9	45.6	47.2	68.9
Spring	69.7	46.7	50.1	69.7
Summer	70.3	47.3	51.2	70.3
Autumn	70.8	48.3	51.6	70.8

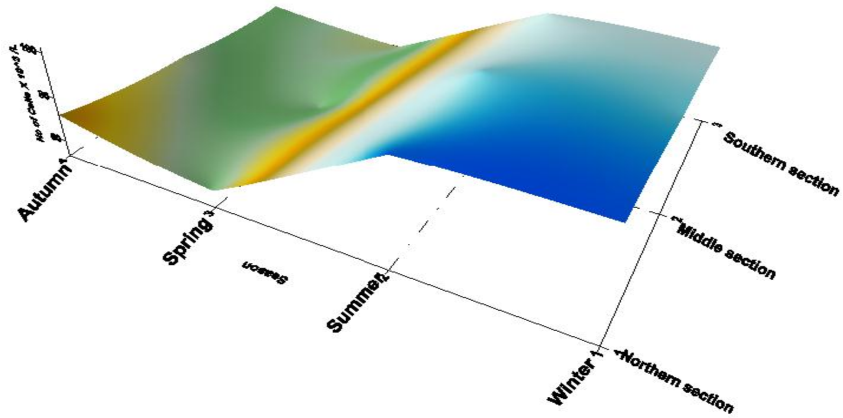

Fig. 2: Scatter plot correlation between total phosphorus and Chlorophyll a during the period of study.

This is the first time to determine heavy metals in Domat Al-Gandal lake. We measured nine heavy metals in the water lake in this study. The fluctuations in the regional average of heavy metals were very narrow. The regional and seasonal averages of nine heavy metals are represented in Tables (4 & 5). Ni has an inverse relation with the standing crops of blue-green algae (r = -.75), where is the readings of seasonal average of standing crops of blue-green algae (33.47 X 10^3 cells/L). This result was confirmed by the data obtained by Spencer and Nichols (Van Baalen e O'donnell, 1978; Spencer e Nichols, 1983; Awasthi e Rai, 2004; Kaamoush *et al.*, 2022). They reported Nickel toxicity to algae. The same trend about indirectly proportional between Chromium and diatoms and total phytoplankton in the investigated area (r = -0.83 and -0.61, respectively). Most studies indicate how toxic chromium is to algae, and this confirmed our data recorded (Hervey, 1949; Wium-Andersen, 1974; Hedayatkhah *et al.*, 2018)

Table 4: The regional average of heavy metals in the investigated area (µg/L).

	Cu	Fe	Ni	Mn	Pb	Co	Cr	Zn	Cd
Northern Section	18.5	667.8	223.9	20.8	17.4	50.5	19.8	11.2	11.7
Middle Section	19.3	564.7	237.2	21.3	19.0	52.1	19.2	16.8	10.9
Southern Section	19.9	495.9	246.1	21.6	20.1	53.2	18.9	20.6	10.3

Table 5: The Seasonal average of heavy metals in the investigated area (µg/L).

	Cu	Fe	Ni	Mn	Pb	Co	Cr	Zn	Cd
Winter	12.2	442.6	52.5	38.6	29.1	53.9	9.9	15.9	6.3
Spring	16.5	422.0	146.8	21.7	22.1	51.0	11.1	12.7	7.6
Summer	23.4	487.0	246.5	16.8	16.5	49.2	14.4	13.3	10.4
Autumn	32.2	609.3	349.9	19.7	11.9	48.1	19.2	16.3	14.1

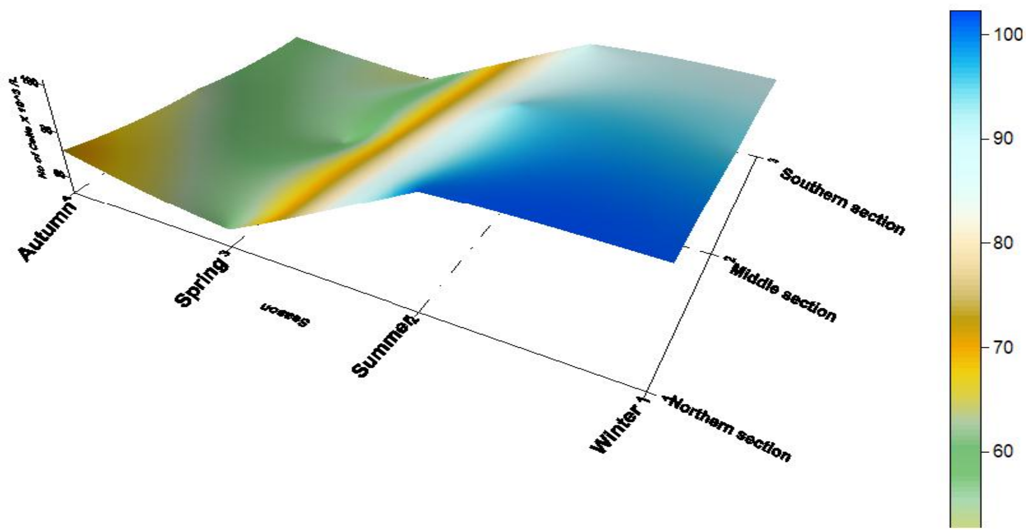

Fig. 3: Total of phytoplankton standing crop during the period of study.

Figure 3 displays the overall phytoplankton composition of the Doma Al-Jandal lake during the investigation period. Four phytoplankton groupings associated phytoplankton communities were recognized. Chlorophyceae, Cyanophyceae, Bacillariophyceae, and Dinophyceae were the phytoplanktonic groups. It is noticed that there are only very modest seasonal variations in the phytoplankton populations.

The regional average of phytoplankton standing crop is clear. The highest standing crops were Chlorophyta and Cyanophyta, and there is a slight difference between them in the standing crop. The third group from the dominant view was Bacillariophyta. On the other hand, the Dinoflagellate represented the rare group of the total phytoplankton. According to the regional average, we find that there is a gradient in standing crops decreases from north to south of the lake. The maximum density of total phytoplankton was recorded in the northern section (84.045 X 10^3 Cell/L) and the lowest standing crop in the southern site (71.370 X 10^3 Cell/L). Figure 4 showed the regional average of standing crop of phytoplankton during the period of investigation. The maximum percentage was Chlorophyceae (40.3%) followed by Cyanophyta (39.5%).

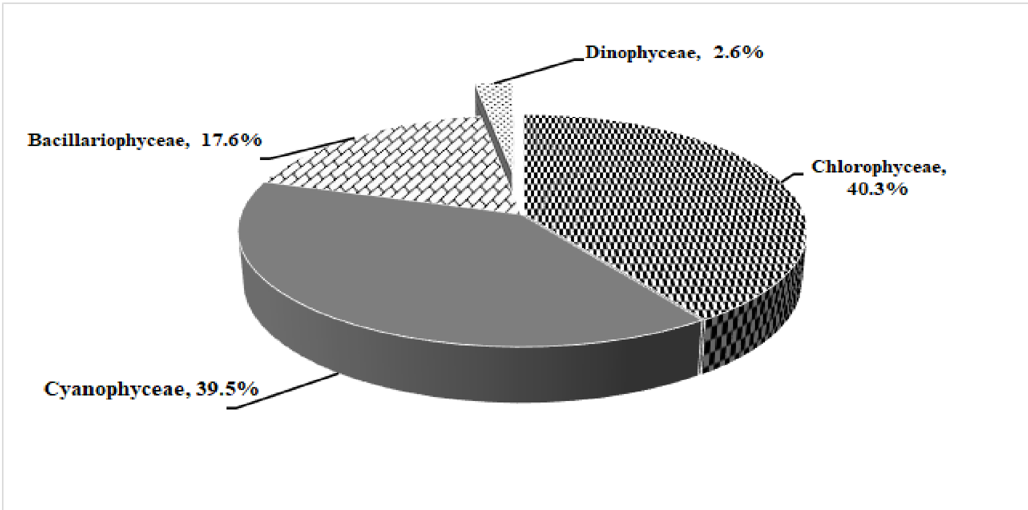

Fig (4): Regional average showing the percentage of standing crop of phytoplankton during the period of investigation.

The phytoplankton composition is affected by environmental factors. The first one is related to physical and chemical such as water temperature and Zinc with indirect relation to total phytoplankton crop (r = -0.90 and r = -.061, respectively). The total phytoplankton standing crop correlated with the total phosphorus (r = 0.92). The present data agree with those obtained by Paerl (Paerl, 1988). He reported both inorganic and organic nutrient enrichment play integral roles in stimulating and supporting the bloom formation of phytoplankton.

The seasonal average of Chlorophyll a showed that the maximum Chlorophyll a was recorded during Autumn (8.572 µg/L), and the minimum value (5.675 µg/L) was recorded during Winter. The relationship between chlorophyll a's concentration and Bacillariophyceae standing crop was an indirect correlation (r= -0.66). This result agreed with those Shoo obtained (Sahoo *et al.*, 2017). They recorded negative relation between chl-a and diatom in the Chilika Lagoon, east coast of India.

CONCLUSION

1. Domat Al-Gandal lake is considered one of the new artificial lakes, which may lead to significant environmental changes in the Domat Al-Gandal region.
2. Due to the many huge agricultural projects in the region, this lake is also considered a resort for people and tourists. This may lead to a positive or negative impact

due to the human factor. Therefore, more environmental studies must be done, including abiotic and biotic factors are required.

3. The lake is considered one of the critical routes for bird migration, which impacts the lake.

4. Further studies on the estimation of heavy elements in water and sediments, as well as the organisms that live in the waters of Domat Al-Gandal lake.

Further laboratory studies on the effect of heavy metals on some types of algae isolated from Domat Al-Gandal lake.

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