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Bioassessment and Biomonitoring of Wadi El-Rayan Protectorate Lakes (Egypt) Using the Recommended Water Framework Directive (WFD) Indices Based on Zooplankton and Macrobenthic Invertebrates

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ABSTRACT

The present study was carried out with the purpose of monitoring the recent zooplankton and benthic macroinvertebrate assemblage and evaluating the ecological state of Wadi El-Rayan Lakes, which are solely dependent on waste and agricultural discharging water through the El-Wadi drain. The study commenced in November 2018 and ended in July 2019, during which water samples were collected to measure environmental parameters. The Shanon-Wiener diversity index (H`) and Bray-Curtiz similarity index were applied. The Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT) were also applied to the upper and lower Wadi El-Rayan Lakes for the first time. In the upper lake, forty adult zooplankton taxa were identified, while in the lower lake, the number of species declined dramatically to nineteen adult species and three immature stages. Rotifera dominated the upper lake, whereas Copepoda dominated the lower lake. A total of ten macro-invertebrate taxa were identified in the upper lake, whereas thirteen were identified in the lower lake. The benthic communities of the upper lake consist of Mollusca, Annelida, and Arthropoda, while those of the lower lake comprise Arthropoda, Mollusca, Annelida, and Coelentrata. Although the upper lake displayed a poor to medium ecological status, the lower lake exhibited diverse populations, indicating a better ecological condition. The BMWP score of the upper lake was 41, suggesting a moderate status, while the lower lake's score was 59, indicating a moderate ecological status as well. The ASPT values indicated a moderate ecosystem status for both the upper and lower lakes. This study established a baseline reference for future monitoring, and calls for stakeholders to take special care of this crucial protectorate to mitigate uncontrolled activities.

INTRODUCTION

Rivers, reservoirs, and lakes are essential constituents of the global water system, supplying water for various purposes such as drinking, irrigation, and power generation, as well as serving as habitats for all plant and animal species (**Ayres *et al.*, 1997**). Lakes are incredibly fertile and diverse ecosystems that support a wide range of life cycles for numerous species. The Wadi El-Rayan Depression (WRD) was chosen as a wastewater reservoir for Fayoum

Governorate, where water streamed into the first lake, the Upper Wadi El-Rayan Lake (UWRL), in 1976 and the second lake, the Lower Wadi El-Rayan Lake (LWRL), in 1980 (**Khedr *et al.*, 2023**). Both lakes were designated as protected wetland areas. Wadi El-Rayan Depression stands in the Egyptian Western Deserts, approximately 42 km southwest the governorate of EL-Fayoum and 125 km southwest of Cairo government. Its two artificial lakes, UWRL and LWRL, are essential to the life cycles of a wide range of species, which include 38 species of wild plants, 68 species of zooplankton, 214 species of phytoplankton, 25 species of macrobenthos (**El-Shabrawy and Hussien, 2015**). Aquatic ecosystems are vulnerable to various contaminants specially the anthropogenic activities **(Bashir *et al.*, 2020)**. The water in the two lakes is well-oxygenated all the year-round, with levels ranging between 7.29–12.58 mg/l in the UWRL and 5.22–11.75 mg/l in the LWRL. Several studies have investigated the water quality, pollution, and physicochemical properties of Wadi EL-Rayan Lakes (**Abdou, 2005; Shama *et al.*, 2011; Abdou *et al.*, 2016; Goher *et al.*, 2019; Sabae, 2021; Abd El-Mageed *et al.*, 2022**).

The role of zooplankton in aquatic ecosystems is of paramount importance. As consumers of phytoplankton, they effectively recycle essential nutrients, such as carbon, nitrogen, and phosphorus. Zooplankton acts as a crucial intermediary, linking primary producers to higher trophic levels. Additionally, fluctuations in zooplankton populations can serve as indicators of changes in water quality, pollution levels, and overall ecosystem health **(Nassif, 2012)**. **Mageed (2000)** focused on the vertical migration of zooplankton in Wadi El-Rayan lakes, while **Khalifa and Abd El-Hady (2010)** specifically delved into the community structure of zooplankton.

Currently, pollution is the ecological hazard which leads water quality to decline and changes the quantitative arrangement of organisms that live there. An ecological platform's accumulation of biological and physicochemical reactions is referred to as a bioindicator. Accordingly, benthic organisms are frequently used as bioindicators to evaluate how pollution affects aquatic ecosystems (**Roy *et al.*, 2022**). Because they mineralize, encourage, and mix the oxygen flux into the sediment, macrobenthos play a crucial role in aquatic ecosystems by recycling organic matter. Physical and chemical factors, such as contamination of the sediment ecosystem, the organic matter of the deposits, the depths, fast deposition, and sediment toxicity, influence the distribution and abundance of benthic communities, causing shifts of macrobenthic communities towards lower abundance (**Sarker *et al.*, 2016)**.

The benthic fauna of Wadi EL-Rayan was first studied by **Aboul-Ela and Khalil (1989)**. The lower Wadi El-Rayan Lake's benthic macrofauna was investigated by **Al-Assiuty *et al.* (2007)**. In his survey of the macrobenthos of Wadi El Rayan, **Khalil (1984)** listed ten species, with Physa acuta, *Melanoides tuberculate*, and *Gammarus* sp. being the most prevalent. According to **Fouda and Saleh (1988)**, Wadi El Rayan's coarse sand bottom supports a poor fauna in terms of both species and individuals. With two species of bivalve and six gastropods, mollusca were the most prevalent. Fourteen species were listed by **El-Shabrawy (1993)**, the most common being *Echinogammarus veneris, Palaemon elegans, Chironomus larvae, Melanoides tuberculata, Theodoxus niloticus, Semisalsa* sp., and tubificidae. **El-Shabrawy (1996)** found eleven benthic invertebrates species in the lower lake; however, **El-Shabrawy (2007)** found 23 species in three phyla: nine Mollusca, eight Annelida, and six Arthropoda species. The density of macrobenthos was higher in the upper lake (960 ind/m^2) than those found in the lower lake (350 ind/m^2). The temporal variations of macrobenthic communities in the lower lake, the area impacted by fish farms, were studied from June 2003 to May 2004 by **Al-Assiuty *et al.* (2007)**. Thirteen species made up the community structure, grouped into four major groups: the Mollusca, the Annelida, the Crustacea, and the Insecta.

In contrast to spot measurements and field observations of water chemistry, which offer a narrow perspective for understanding or contextualizing disturbance, biological indicators incorporate exposure over time, enabling evaluation over time from various stressors (**Carignan and Villard, 2002**). Traditionally, macroinvertebrate communities' taxonomic makeup has been used by biomonitoring as a gauge of ecological change **(Culp *et al.*, 2010).** Rapid bioassessment programmes frequently rely on basic metrics of diversity and abundance to draw conclusions (**Reynoldson and Metcalfe-Smith, 1992**); Aquatic organisms can be impacted by a variety of factors, including unknown or undetected pollutants, changes to water levels, or deterioration of the surrounding environment. Biomonitoring can supplement, and in some cases replace, traditional assessments based on water chemistry **(Yoder and Rankin, 1998)**. Biomonitoring has been scientifically shown to be useful in systems with a low number of small, shallow freshwater pond ecological systems as shown by **Jacks *et al.* (2021)**. Long-term environmental changes will be better understood if these ecosystems are monitored in the years to come.

The Water Framework Directive (WFD) used the macrobenthic invertebrates as an obligatory tool in assessing the water quality in the European countries. At least 60% of the biological indicators created over the previous 20 years are based on macroinvertebrate species or communities, according to literature reviews of the indicators used for lentic and lotic system water quality assessments (**Czerniawska-Kusza, 2005**). The Biological Monitoring Working Party (BMWP) and BMWP-ASPT indices were applied to the River Nile by **Fishar and Williams (2008)** and **Nassif** (**2020**), while **Fishar *et al.* (2015)** used the biotic indices on Lake Manzala.

The few available references indicated that there is no clear idea about the zooplankton and macrobenthic fauna in Wadi El-Rayan lakes. Therefore, our research sheds light on current resident zooplankton and macrobenthic assemblages in the upper and lower Wadi El-Rayan Lakes. In addition, it investigates the recommended biotic indices (BMWP and ASPT) to study their ecological status and gives the stakeholders the recommendations in order to conserve the biota living in one of the most crucial protectorates in Egypt.

MATERIALS AND METHODS

Studied Area:

Wadi El-Rayan has an area of 352.15 km^2 and is linked to two artificial bodies of water connected by a channel (**Hereher, 2015**). **El-Shabrawy (2007)** states that each year, 200 million cubic meters of water from farm drainage are moved to the lakes. There are a pair of lakes in Wadi El Rayan, joined by a channel (Fig. 1). The combined surface of the two lakes is 50.9 km^2 for the higher and 62.0 km^2 for the one below. Between 30° 20'–30° 25' E and 29° 05'–29° 20' N are where they are located. There is permanent shallow water with emergent aquatic macrophytes in the connecting area, creating a swamp. The upper lake is 25 meters deep at its deepest point and is encircled by thick vegetation (**Saleh, 1984**). The southwest is constantly adding new flooded areas, causing the lower lake to change constantly. Its deepest point is 33 meters. Water from the El-Wadi Drain supplies the Wadi El Rayan lakes, with discharges of $11 \times 106\ m^3$ in January and $24 \times 106\ m^3$ in November, for a total of $220 \times 106\ m^3$ y−1 **(Abd Ellah, 1999)**. The second lake receives an inflow of $127 \times 106\ m^3$ y−1 that varies from $3.6 \times 106\ m^3$ in July to $17 \times 106\ m^3$ in March. The physical and chemical characteristics of the lakes differ. The salinity of the higher one increases from north to south. According to several studies (**Aboul-Ela and Khalil, 1989; Saleh *et al.*, 1988**), there are more nutrients in the upper lake than in the lower one.

To cover the investigation area, exactly ten stations were carefully selected. The upper and lower lakes are accurately represented by stations 1 to 5 and stations 6 to 10, respectively, as shown in Figure 1. Station 1 was in front of El-Wadi Drain. Stations 2, 3, and 4 represented the eastern, middle, and western sectors of the upper lake, respectively, while station 5 was situated prior to the connecting canal. Station 6 was located down the connection canal, and station 7 was a mixing point of fish farm drainage water. Stations 8, 9, and 10 represented the western, middle, and southern sectors of the lower lake, respectively.

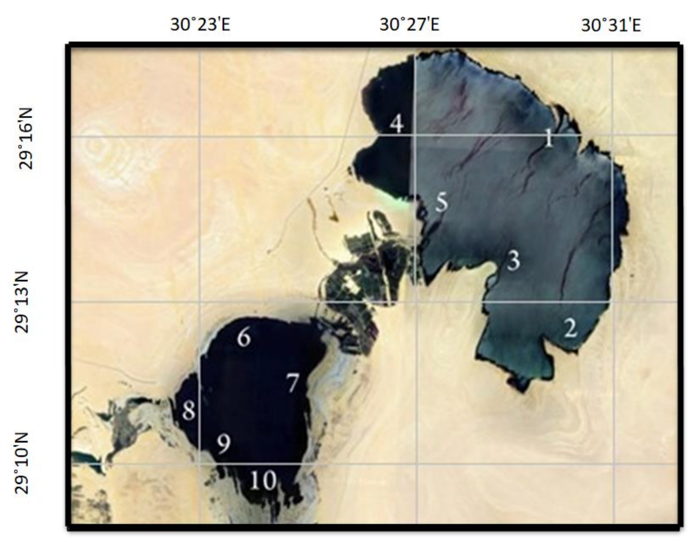

Fig. 1 A demonstrative map of the sampling sites from Wadi EL-Rayan Lakes

Collection and Analyses:

Multiprob meters have been utilized in the field to take measurements of the main variables: water temperature, transparency, pH, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO). In the Lab., BOD, COD, SO_4, and PO_4 were measured and examined. Zooplankton samples were collected via a 55-micron plankton net by filtering 30 liters of each station. Samples were preserved by formaldehyde in the field. In Lab., species were identified, sorted, and counted. Samples of macrobenthos were periodically taken from Wadi El-Rayan Lakes during November 2018 to July 2019 by a square grab sampler with a surface area of 225 cm^2. Every sample was taken from the surface of the lake's bottom, immediately cleaned through a 500µm mesh net to remove any remaining mud or sediments, and then preserved in plastic containers containing 5% formalin. The samples were cleaned in the lab and then sieved once more through a 500 µm mesh net. Using a zoom stereomicroscope, benthic animals were identified and categorized to species and genera. Each group was preserved in a glass bottle containing 4% formalin after counting. The species that were gathered were identified using the methods recommended by **Bishai *et al.* (2000) and Mancini and Andreani (2008).**

Data treatment:

Shanon-Wiener diversity index (H`):

The macrobenthic fauna diversity index was calculated to assess the pollution consequences on the diversity and equitability at each station, and consequently on the ecosystem using the computer software Primer 5.

Biological Monitoring Working Party (BMWP):

It is a technique used to measure the quality of any water stream using the macroinvertebrates' families as biological indicators. The BMWP score was calculated as the sum of the tolerance scores of all macroinvertebrate families in each station.

Average Score Per Taxon (ASPT):

The average score per taxa (ASPT) was calculated for each station by dividing the BMWP score by the total number of the recorded families in the station.

Similarity Index:

By using the Bray-Curtiz similarity index, it was possible to ascertain how similar the benthic communities were in each of the ten lakes' stations. Primer 5 computed the similarity dendrogram.

RESULTS AND DISCUSSION

Water quality properties:

One of the most significant ecological variables that affects an organism's distribution and physiological behavior is its temperature. The upper lake experienced minimum and maximum temperatures that varied from 17.5˚ C in winter to 30.4˚ C in summer. The lowest and maximum temperatures in the lower lake were 16.8˚C and 31.5˚C, respectively. The two lakes did not significantly differ from one another. However, there is a noticeable seasonal variance in the data.

As shown in Table (1), the average transparency was higher in the upper lake than in the lower lake with no significant temporal variation. Conductivity and TDS values are correlated with one another. For the higher and deeper lakes, respectively, the EC ranged from 2.3 to 2.8 ms/cm and from 21.3 to 29.8 ms/cm, with a summer maximum and a winter minimum. Between the two lakes, there are notable differences. In the lower lake, there were also notable variations in some sites. The TDS values peaked in the winter and decreased in the summer. In the upper and lower lakes, it varied from (1.7-1.9 g/l) to (18.7-24.9 g/l), respectively. There were both spatially and significantly different between the two lakes. Wadi El Rayan Lakes' pH ranges from 8.2 to 8.8, with the alkaline side. Between the two lakes, there was little variation. Dissolved oxygen content provides information about the waterbody's health and capacity for its own purification through biological processes. DO varied between (7.4–11.2 mg/l) and (5.2-10.5 mg/l) in the higher and deeper lakes respectively, with seasonally significant difference and no spatial variations. Similar results were recorded by **Shama *et al*. (2011**). According to numerous authors (**Amer, 2007, Ibrahim *et al.*, 2008, and Nassif, 2012**), summertime recorded the lowest value, while autumn recorded the highest. High BOD values indicate the level of pollution in the habitat under study because, according to **Hassan (2008)**, BOD is directly correlated with the breakdown of organic matter in water. Based on Egyptian law 48/1982, the BOD values were therefore within allowable limits, specifically 6 mg/l. It ranged between (3.8-5.5 mg/l) and (2.5-5.4 mg/l) in the upper and lower lake, respectively. **Shama *et al.* (2011)** confirmed that the upper lake has higher BOD values than the lower one. In the upper and lower lakes, respectively, COD ranged from 5.6 mg/l to 12.4 mg/l and 4.0 mg/l to 10.4 mg/l, with a clear variation during the cold seasons. Springtime recorded the highest value, while wintertime recorded the lowest. The annual averages of COD values in the upper and lower lakes are illustrated in Table (1). These results revealed that the upper lake is more polluted than the lower lake.

SO_4 was investigated as well and there was a great substantial difference between the two lakes. The lower lake revealed higher values than the upper lake. This result was in coincidence with those recorded by **Shama *et al.* (2011)**. High concentrations of phosphate are indicators of the presence of pollution and this in turn responsible for eutrophication **(Peavy *et at.*, 1986)**. There was no significant variation between the two lakes, however, the upper lake showed higher annual average (20.1 mg/l).

Table (1). Average of physical and chemical recorded parameters in the upper and lower Wadi El-Rayan Lakes.

Parameters	Upper lake	Lower Lake
Temperature (˚C)	23.9	24.1
Transparency (cm)	89.25	48
EC (µs/cm)	2.5	25.5
TDS (gm/L)	1.8	21.8
pH	8.5	8.3
DO (mg/L)	9.3	7.8
BOD (mg/L)	4.6	3.9
COD (mg/L)	9	7.2
SO_4 (mg/L)	0.5	5.1
PO_4-P (µg/L)	20.1	15.5

Zooplankton assemblage features:

The Upper Lake:

In the upper lake, a total of forty adult zooplankton species, three immature stages, and free-living nematodes were identified. The zooplankton community comprised four principal groups: Rotifera, Copepoda, Cladocera, and Protozoa, with Rotifera constituting approximately 72% of the total zooplankton community (Figure 2). During the investigation, twenty-one rotifer species were cataloged, with *Trichocerca cylindrica*, *Keratella cochlearis*, and *Polyarthra vulgaris* emerging as the dominant species. These findings are consistent with the research conducted by **El-Shabrawy and Dumont (2009)**. The survey revealed the presence of five adult copepod species along with two immature stages, indicating an average density of 16786 individuals /m^3. Additionally, seven species of Cladocera were identified, with an annual average density of 3666 individuals /m^3. *Diaphanosoma excisum* emerged as the most predominant Cladoceran species, with an annual average density of 1636 individuals/m^3, followed by *Daphnia longispina* at 1117 individuals/m^3. In contrast, Protozoa displayed the lowest density, averaging 1688 individuals/m^3 and comprising seven species. Notably, *Centropyxis oculeata*, *Arcella vulgaris*, and *Tintinopsis beroidae* were found to be the prevailing protozoan species.

It is worth noting that Rotifera, Copepoda, and Nematoda exhibited a similar distribution trend, as depicted in Figure (3). Station 1 recorded the highest number of zooplankton individuals, followed by station 4, with respective average counts of 105643 individuals/m^3 and 82805 individuals/m^3.

The Lower Lake:

In the lower lake, nineteen adult zooplankton species and three immature stages were identified. The composition of the zooplankton community consisted of four primary groups: Copepoda, Rotifera, Cladocera, and Protozoa, with Copepoda emerging as the predominant group, representing approximately 70.77% of the total zooplankton community (Figure 4).

Notably, the investigation revealed four adult copepod species and two immature stages in the lower lake, with Nauplius larvae constituting the primary bulk with an average of 3920 ind./m^3. These findings diverge from the conclusions drawn by **El-Shabrawy and Dumont (2009)**, who asserted that Rotifera accounted for 65% of the total zooplankton abundance. However, both the study mentioned earlier and the present investigation concur that *Thermodiaptomus galebi* stands as the most prevalent copepod species in the lower lake.

In Figure 5, it is obvious that station 8 had the highest total zooplankton individual count (16370 ind./m^3) due to the prevalence of Rotifera, particularly *Keratella tropica* and *Brachionus plicatilis*. Consistent with findings presented by **El-Shabrawy and Dumont (2009)**, it is noted that *B. plicatilis* experienced peak density during the summer season in the lower lake. Conversely, Copepoda demonstrated its maximum density in station 6. Meanwhile, station 10 had the lowest total density at 9373 ind./m^3.

Zooplankton biodiversity index:

The results showed that stations 2, 3, and 1 in Table 2 displayed the highest Shannon index values (H`= 3.07, 3.06, and 3.05, respectively), with stations 2 and 3 having the highest species diversity, each with 36 species. This indicates the excellent ecosystem status in this sector of the upper lake. Conversely, stations 10 and 9 had the lowest diversity values (H`= 1.84 and 1.89, respectively), with station 9 having the lowest species count, which illustrates the unstable ecosystem status of this sector.

The overall trend indicated that the upper lake had higher species and diversity index values than the lower lake. Additionally, it was noteworthy that the upper sector of the lower lake exhibited higher biodiversity than the lower sector, potentially reflecting the impact of increasing salinity in the lower lake. These findings provide valuable insights that contribute to our understanding of the ecosystem dynamics in the upper and lower lake sectors.

The similarity index:

The dendrogram (Figure 6) illustrates the presence of two primary clusters of stations, indicating distinct zooplankton community structures within the two lakes. Specifically, for the upper Wadi El-Rayan Lake (UWRL), stations 2 and 3 demonstrated the highest degree of similarity. Conversely, in the LWRL, stations 6 and 8 exhibited the highest similarity. This finding highlights the unique zooplankton community compositions present within the respective lakes.

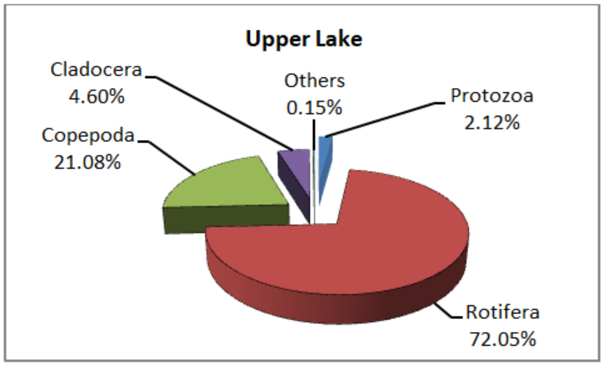

Figure 2. Zooplankton assemblage of the upper lake.

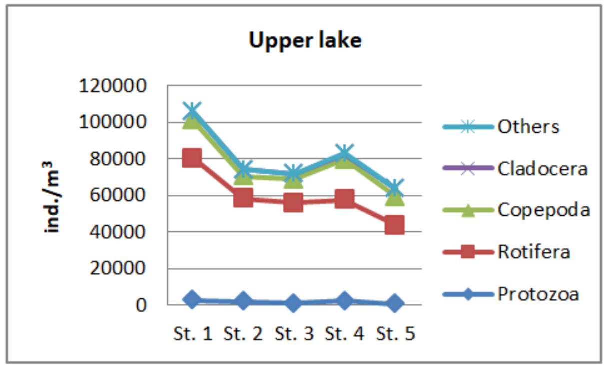

Figure 3. Zooplankton spatial distribution in the upper lake.

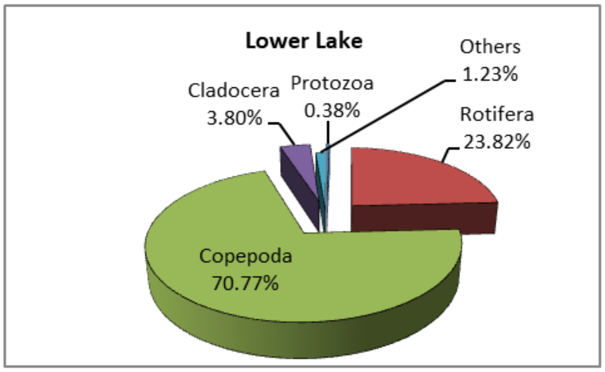

Figure 4. Zooplankton assemblage of the lower lake.

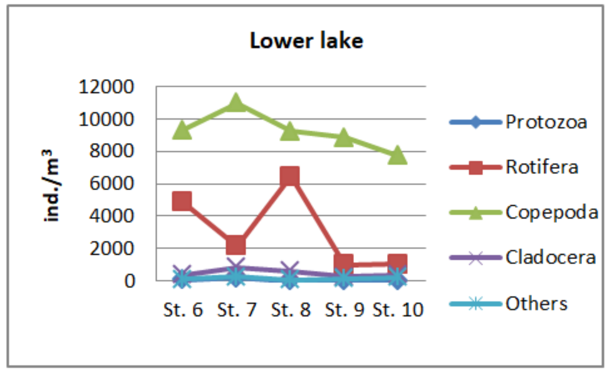

Figure 5. Zooplankton spatial distribution in the lower lake.

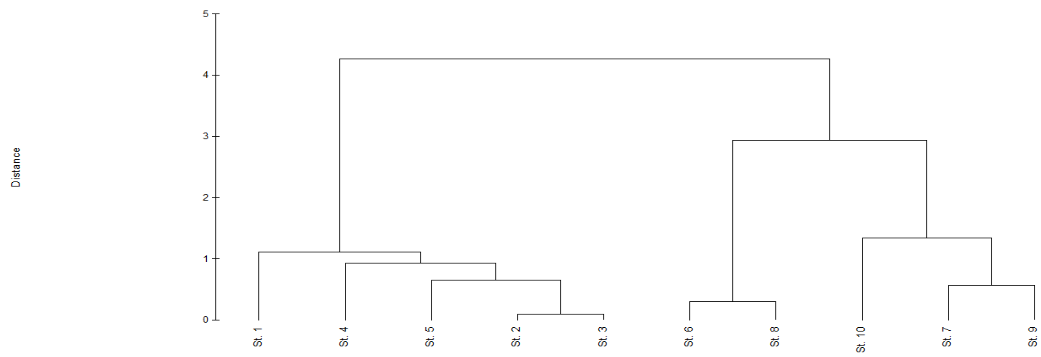

Figure 6. Similarity dendrogram according to zooplankton assemblage in Wadi El Rayan Lakes

Table 2. Diversity indices of zooplankton assemblage in Wadi El Rayan Lakes.

Station	No. of species	Richness	Evenness	Shannon	Simpson
St. 1	35	3.11	0.84	3.05	0.94
St. 2	36	3.39	0.84	3.07	0.94
St. 3	36	3.40	0.84	3.06	0.94
St. 4	33	3.09	0.81	2.89	0.93
St. 5	32	3.07	0.83	2.94	0.93
St. 6	14	1.67	0.86	2.42	0.90
St. 7	12	1.36	0.78	2.05	0.80
St. 8	13	1.55	0.85	2.37	0.88
St. 9	9	1.08	0.79	1.89	0.80
St. 10	10	1.20	0.74	1.84	0.75

Macrobenthic fauna assemblage features:

Macrofaunal richness and abundance have been used in many studies to identify environmental responses because of their variable susceptibility to different perturbations **(Rasifudi *et al.*, 2018)**. Consequently, it is possible to identify environmental changes in lakes by observing alterations in the macroinvertebrate community composition and structure. Biological monitoring is one method used in evaluating the harmful effects of activity by humans on the quality of water. According to **Merritt *et al.* (2017)**, it is thought to be a helpful tool for determining the quality of water as well as acquiring knowledge about the ecology of rivers.

The Upper Lake:

During the current investigation, Mollusca, Annelida, and Arthropoda were the groups that made up the macrobenthic fauna with percentages of 94.52%, 4.51%, and 0.98%, respectively (Fig.7). The total recorded species were ten species with a total density of 5735 ind./m^2. *Melanoides tuberculate*, *Gyraulus ehrenbergi*, and *Limnodrillus* Spp. were the predominant species existing in the upper Wadi El-Rayan Lake with percentage of 63%, 25.58%, and 4.5%, respectively.

Figure (8) illustrates that station 1 had the highest density with an average of 10749 ind./m^2 due to the dominance of *Melanoides tuberculate*, *Gyraulus ehrenbergi*, and *Limnodrillus* Spp., while 969 ind./m^2 were the lowest benthic population density recorded in station three. According to **Abejo and Jumawan (2023**), the upstream station's greater abundance supports speculation that the area's rocky substrates and swiftly moving water make perfect habitat conditions for these types of organisms.

With an average density of 4479 ind./m^2, autumn had the least density. On the contrary, winter exhibited the highest density due to the dominance of *Melanoides tuberculate* and *Gyraulus ehrenbergi*, with an average of 7182 ind./m^2 (Figure 9). Similar to cyclic trends in diversity and taxonomic richness; seasonal fluctuations frequently cause macroinvertebrate densities to rise from low in spring to high in autumn and then fall in winter (**Christman and Voshell, 1993; Linke *et al.*, 1999; and Brown, 2007**). Temperature and calcium combined had a major impact on the temporal macrobenthos variability **(Al-Assiuty *et al*., 2007)**.

With averages of 70.84% and 45.9% in the UWRL and 20.96% and 47.24% in the LWRL, respectively, the sand and mud comprised the majority of the lake sediment fraction. The UWRL and LWRL had varying organic materials contents, ranging from 1.17–6.45 and 4.3–13.6%, respectively (**Khedr *et al.*, 2023**).

The community structure was not significantly impacted by the size of the sediment grains (**Al-Assiuty *et al*., 2007**), although, the findings of **Hauer *et al.* (2018)** that sediments serve as critical for the integrity of habitat because they are varied and well-composed. This is especially beneficial for the medium- to long-term evolution of habitat features. Aquatic species losses and mortality may result from high loads of mostly fine sediments, which also cause high turbidity concentrations **(Espa *et al.*, 2015)**.

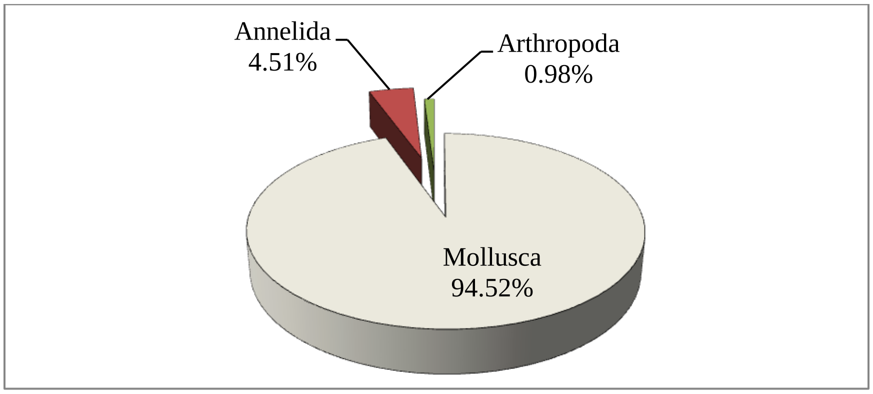

Figure 7. Macrobenthic assemblage of the upper lake.

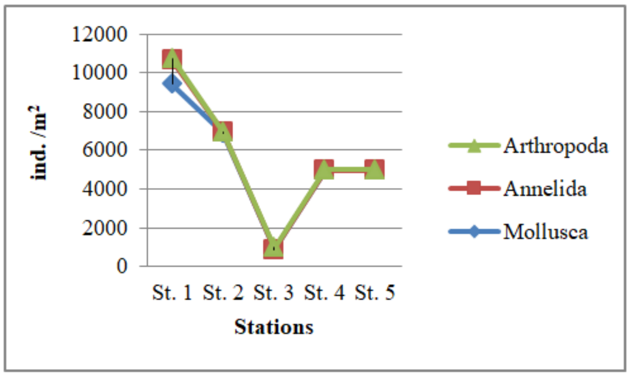

Figure 8. Different macrobenthic groups spatial distribution in the upper lake.

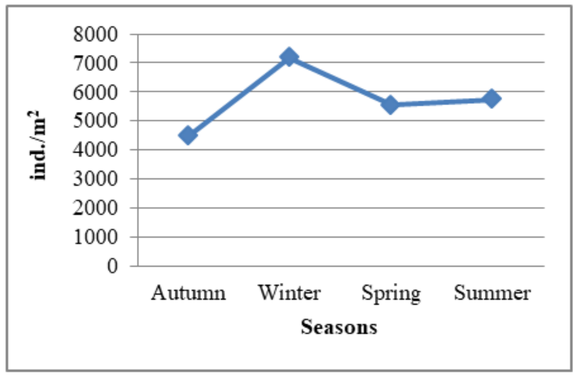

Figure 9. Total macrobenthic community temporal distribution in the upper lake.

The Lower Lake:

During the current investigation, Arthropoda, Mollusca, Annelida, and Coelentrata were the groups that made up the macrobenthic fauna with percentages of 43.46%, 31.82%, 24.05% and 0.67%, respectively (Figure 10). The total recorded species were thirteen species with a total density of 2267 ind./m^2. **El-Assiuty *et al.* (2007)** also recorded thirteen benthic species in the lower lake during the period of 2003-2004.

Figure (11) illustrates that station 7 had the highest density with an average of 3178 ind./m^2, while 1313 ind./m^2 were the lowest benthic population density recorded in station 9. With an average density of 600 ind./m^2, summer had the least density. On contrary, winter exhibited the highest density due to the dominance of *Corophium acherusicum* and *Gammarus aequicauda* an average of 3292 ind./m^2 (Figure 12). These results disagreed with those recoded by **El-Assiuty *et al.* (2007)** who recorded the lowest density in winter.

Corophium acherusicum, *Melanoides tuberculate*, *Nereis diversicolor*, *Gammarus aequicauda*, *Ficopomatus enigmaticus*, and *Cerastoderma glaucum* were the predominant living species in the lower lake with percentage of 28.75%, 22.69%, 13.87%, 12.61%, 8.34%, and 8.30%, respectively. Sea aneamone exists only in the lower lake especially in stations 9 and 6 with an average of 29 ind./m^2 and 24 ind./m^2, respectively. **El-Assiuty *et al.*, (2007)** confirmed that *Corophium* sp. was the most abundant species representing 51% of the total abundance referring this result to the presence of aquatic plants. However, **Neal and Avant (2006)** stated that *Corophium* sp. densities vary with the geographical region and it prefers the mudflats.

It is obvious that the benthic assemblage in the lower lake dominated by brackish and marine species. This result is confirmed by **Shama *et al.* (2011)** who found that the lower Wadi EL-Rayan Lake underwent progressive salinity increase. Chironomus larvae disappeared from all stations in the lower lake. This may be an indication to algae and plants availability as **Abejo and Jumawan (2023)** mentioned that most of the insect larvae feed on algae and plants. As a typical benthic community for pond ecosystems, chironomids accounted for more than half of the recorded taxa (15/27 taxa), according to **Campbell *et al.*, (2009)**. Typical representatives of grazed grassland ponds are Tanytarsus, Glyptotendipes, Cricotopus, and Chironomus (**Campbell *et al.*, 2009**). Furthermore, Chironomus and Glyptotendipes are widely recognised markers of eutrophication and sedimentation (**Rasmussen, 1984; Lindegaard, 1995; Broderson *et al.*, 2001**).

For the long-term changes, although **Al-Assuity *et al.* (2007)** recorded new species such as *Hydrobia* sp., *Rhyacophila* sp., *Isotoma* sp., and *Orchestia gammarella*, they were not recorded in the current study. Furthermore, they did not record *Bellamya unicolar*, *Valvata nilotica*, *Semisalsa* sp., *Physa acuta*, *Corbicula flumina*, *Cypridus torosa*, and *Palaemon longirostris*. This may indicate significant differences in water quality and human activities.

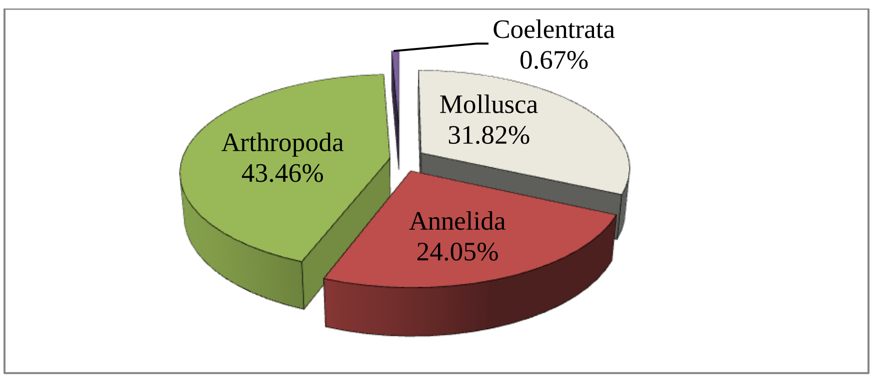

Figure 10. Macrobenthic assemblage of the lower lake.

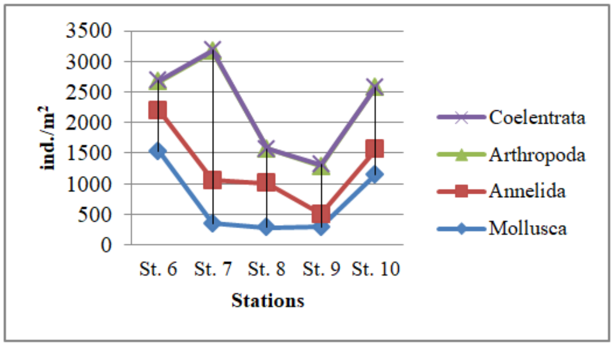

Figure 11. Spatial distribution of different macrobenthic groups in the lower lake.

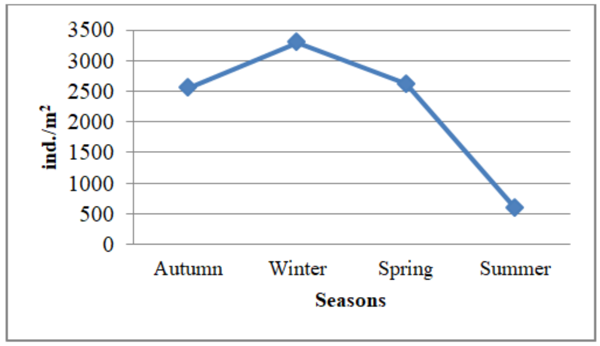

Figure 12. Temporal distribution of total macrobenthic community in the lower lake.

Macroinvertebrates biodiversity index:

Biodiversity gives avital roles to the water system due to the function done by different organisms in the community. One of the biggest risks to the lake's ecosystems and biodiversity is thought to be the dropping water levels brought on by a reduced water supply **(Afefe, 2020)**. The investigators discovered that, although diversity is probably a reliable metric for comparison, there can be significant temporal variations in invertebrate abundance for some systems.

Therefore, in contaminated ecosystems where disturbance of habitat results, the decline in species diversity is regarded as a loss of biodiversity. Regarding the present investigation, the highest biodiversity values have seen in the lower lake where stations 10, 9, and 8 revealed H`= 1.87, 1.69, and 1.66, respectively. That means that these stations are considered to be moderately polluted according to **Wilhm and Dorris (1968)** and **Mason (2002)**. As shown in Table 3, station 4 exhibited the lowest diversity index (H`= 0.76). Furthermore, stations 2, 3, 4, and 5 showed diversity values lower than 1. According to **Mason (2002)**, this result explicit that this community is affected by heavy organic pollution. Obviously, the lower lake exhibited higher diversity values and numbers of species than the upper lake as shown in Tables (3 and 4). Regarding the upper lake, station 1 was made up the best number of species, density, and diversity indices. For the lower lake, station 10 revealed the greatest diversity index, however, station 6 made up the highest species number (N=12). These results may be useful in evaluating the stream's ecological integrity and informing management plans for the preservation of aquatic environments.

Table 3. Diversity indices of the upper lake.

Station	No. of Sp.	Density	Richness	Evennes	Shannon	Simpson
St. 1	9	10749	0.86	0.51	1.12	0.55
St. 2	7	6968	0.68	0.48	0.94	0.54
St. 3	4	969	0.44	0.70	0.97	0.57
St. 4	7	4982	0.70	0.39	0.76	0.42
St. 5	6	5007	0.59	0.54	0.97	0.53

The similarity index:

In Figure (13), the similarity dendrogram exhibited two main clusters of the upper lake stations. The first cluster showed station 3 which reveals its especial community assemblage. In the second cluster, stations 4 and 5 revealed the highest similarity percentage indicating similar benthic assemblages. The similarities and differences between the sampling sites may be related to the various pollutants, the presence of organic matter, and the amount of trash present, all of which have an impact on the abundance of macroinvertebrates.

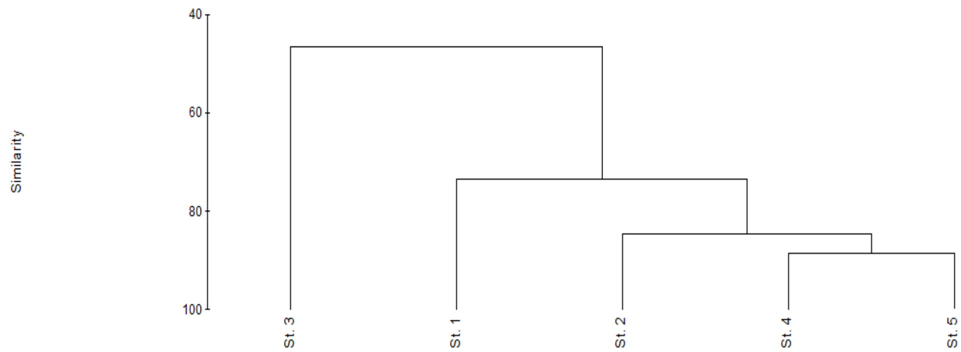

Figure 13. Similarity dendrogram of the upper lake according to macrobenthic invertebrates

Table 4. Diversity indices of the lower lake.

Station	No. of Sp.	Density	Richness	Evenness	Shannon	Simpson
St. 6	12	2689	1.39	0.59	1.46	0.67
St. 7	9	3178	0.99	0.66	1.45	0.67
St. 8	9	1573	1.09	0.76	1.66	0.78
St. 9	8	1313	0.97	0.81	1.69	0.78
St. 10	9	2584	1.02	0.85	1.87	0.82

In the lower lake similarity chart (Figure 14), two clusters were found. The first cluster consists of stations 6 and 10. The second cluster consists of stations 7, 8, and 9; whereas stations 7 and 8 were the most similar stations in the benthic assemblage.

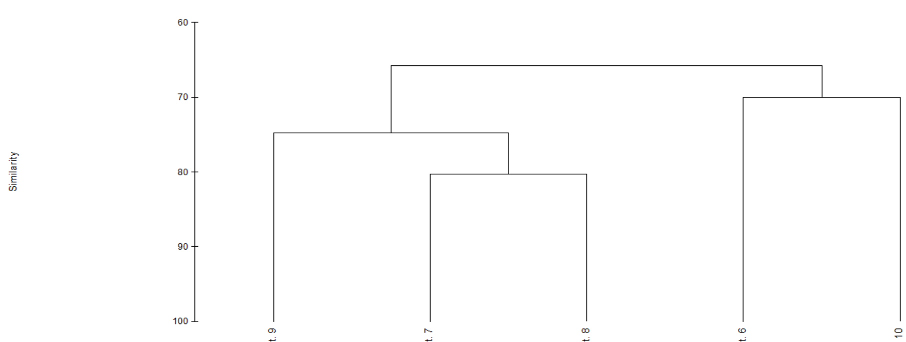

Figure 14. Similarity dendrogram of the lower lake according to macrobenthic invertebrates

Table 5. Comparison between different biological indices (ASPT, BMWP, and H`) in the studied stations along the upper and lower Wadi EL-Rayan Lakes.

Station	ASPT	BMWP	H`
1	3.66	33	1.12
2	3.85	27	0.94
3	2.75	11	0.97
4	3.85	27	0.76
5	3.33	20	0.97
6	4.41	53	1.46
7	4.55	41	1.45
8	4.55	41	1.66
9	4.37	35	1.69
10	4.66	42	1.87

Table 6. Scheme illustrates the different ecological categories regarding BMWP scores

BMWP score	Category	Interpretation
0-10	Very poor	Heavily polluted
11-40	Poor	Polluted or impacted
41-70	Moderate	Moderately impacted
71-100	Good	Clean but slightly impacted
>100	Very good	Unpolluted, unimpacted

Table 7. Bio-classification of water quality according to the ASPT values by Friedrich *et al.*, (1996)

ASPT	Assessment
>5	Excellent ecological quality
4-5	Good ecological quality
3-4	Moderate ecological quality
2-3	Poor ecological quality
1-2	Very poor ecological quality

Biological Monitoring Working Party (BMWP):

The Biological Monitoring Working Party (BMWP) was calculated for the average species of the upper lake stations to give a general ecological status of the lake. The overall BMWP score was 41 which mean that the lake is moderately impacted by pollution according to the Table (6). As shown in Table (5), the highest BMWP score was in station 1 (BMWP = 33), followed by stations 2 and 4 (BMWP = 27), followed by station 5 (BMWP = 20). The lowest score was in station 3 (BMWP =11). These results indicate that all stations in the upper lake have poor benthic community and this could be attributed to the sediment nature, food availability, and / or unsuitable water quality. According to **Shama *et al.* (2011)**, who concluded that the upper lake is more polluted than the lower one, the low benthic density may be due to the high nutrient and heavy metals content. On the other hand, **Hauer *et al.* (2018)** pointed out that macroinvertebrates are impacted by the loss of interstitial volume and morphological heterogeneity. **Khedr *et al.* (2023)** confirmed these results as they concluded that the El-Rayan Lakes' sands may have a negative impact on the organisms that inhabit the bottom, according to toxicological indices, which stated that all sites in the two lakes were at moderate to low risk.

Regarding the lower lake, the calculated overall BMWP of the lake was 59 which reflect its moderate ecological status. Station 6 gave the highest score (BMWP = 53), which means it has moderate ecological status. For stations 7 and 8, the BMWP score was 41 indicating a moderate status. On the other side, station 9 gave the least score (BMWP = 35) indicating that this station has poor community where it may be impacted by certain source of pollution.

Average Score Per Taxon (ASPT):

Although the overall ASPT in the upper lake gave score of 4.1 (moderate status), station 3 showed ASPT of 2.75 which reflect its poor ecological status (Table 7).

For the lower lake, ASPT score of the whole lake was 4.5 revealing its good status. Furthermore, there is no significant variation between stations giving the same moderate status of each station. This result may be in agreement with **Al-Assuity *et al.* (2007)** who concluded that the fish farm effluent has no strong effect on the macrofaunal community structure.

CONCLUSION

In conclusion, the zooplankton results revealed that the upper lake had four times higher population density and greater biodiversity than the lower lake, indicating a more stable ecosystem. Furthermore, this study revealed obvious changes in the macrobenthic invertebrate assemblages with time; however, the recommended biological indices (both BMWP and ASPT) gave the same results indicating that both lakes have an overall moderate ecological status. Agricultural activities, tourism, urbanization, and climate change are the main reasons of lowering the habitat quality. While this work of assessment of zooplankton and benthic macroinvertebrate composition was a genuinely new application on Wadi EL-Rayan Lakes, the outcomes can effectively be used as a preliminary comparison and a benchmark for upcoming biomonitoring. Further biomonitoring and bioassessment programs are recommended to know if these changes were nature-induced or human-induced. As part of their efforts to preserve these valuable resources, decision-makers must apply planning procedures to the ecosystem of the WRLs.

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