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Effect of Environmental Variables on Zooplankton in Various Habitats of the Nile River

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Abstract: The present study investigated the effect of environmental variables on the abundance and distribution of zooplankton in different habitats along the Nile River in Shattura Village. Zooplankton samples were collected from three distinct sites along the Nile River in Shattura Village, each exhibiting different environmental characteristics: Site 1 with vegetation, site 2 lacking vegetation, and site 3 being a drain canal. The study spanned from spring 2020 to winter 2021, during which the physico-chemical parameters of the water were analyzed. Rotifera constituted the majority of the zooplankton (54.73%), followed by Cladocera (20.59%), Copepoda (13.1%), and Ostracoda (8.9%). Among the 52 identified zooplankton species, Rotifera comprised 18 species, Cladocera 13 species, Copepoda 10 species, and Ostracoda 11 species. Site 1 exhibited the highest zooplankton density (44.08%), attributed to the presence of vegetation, followed by site 3 (37.18%), influenced by agricultural drains, and site 2 had the lowest density (18.73%). Zooplankton abundance peaked in summer and declined in winter. Notably, Rotifera abundance increased in populated sites (site 3), whereas other zooplankton groups thrived in less populated areas. Correlation analyses revealed positive associations between Rotifera and Cladocera with electric conductivity, total dissolved solids (TDS), chloride (Cl), calcium (Ca), and sulfate (SO_4). Conversely, Copepoda showed positive correlations with water transparency, pH, dissolved oxygen, and biological oxygen demand (BOD). Overall, seasonal variations significantly impacted the zooplankton community, with Rotifera dominating and Ostracoda being the least abundant. High values of the Shannon–Weaver diversity index, richness, and evenness suggested ample food resources and favorable growth conditions. Transparency, conductivity, pH, dissolved oxygen, and BOD were identified as the key influencing parameters on zooplankton abundance. Additionally, vegetation and agricultural drains strongly influenced total zooplankton levels.

Keywords: Rotifera; Cladocera; Copepoda; Ostracoda; River Nile; physico-chemical factors; zooplankton; nutrient salts; CCA

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1. Introduction

The Nile River serves as Egypt's primary source of freshwater, crucial for both drinking and agricultural purposes, earning it the status of the country's lifeblood [1]. The presence of riparian vegetation plays a pivotal role in regulating mineral and organic compound cycles within water habitats. Furthermore, macrophytes form an integral part of aquatic ecosystems, contributing significantly to biogeochemical cycles [2]. However, along the Nile, numerous drains act as conduits for pollutants originating from sewage, agricultural runoff, and industrial discharge [3]. These drains receive water from various sources, including surface runoff from irrigated fields, deep percolation from agricultural lands, and releases from canals, leading to seepage losses [4].

The El-Murra drain, a prominent feature of Sohag City, gathers excess irrigation water from smaller drains and releases it into the Nile River. Pollution primarily stems from agricultural practices and untreated domestic waste from settlements along the drain, exacerbating water quality degradation. Zooplankton density stands out as a critical indicator in aquatic ecosystems [5]. Zooplankton, comprising small, weak-swimming organisms, inhabit diverse aquatic environments and play multifaceted roles in food chains, energy transfer, and nutrient cycling. Protozoa, Rotifera, Copepoda, and Cladocera typically constitute a significant portion of zooplankton communities in aquatic ecosystems [6]. The distribution of zooplankton populations is influenced by a myriad of factors, including changes in physico-chemical water properties, drainage patterns, sewage inputs, and vegetation [2].

In developing nations such as Egypt, rivers face severe ecological challenges due to chemical and organic contamination resulting from agricultural runoff, and inadequate sewage treatment. Consequently, water quality deteriorates, rendering habitats unsuitable for aquatic species [7].

While previous studies have examined various zooplankton components in the Nile, our study stands out as the first to focus environmental variables on zooplankton groups in the vicinity of Shattura Village. Therefore, it is imperative that our research provide insight into the diversity and abundance of some zooplankton groups in the study area.

The primary objective of the present research is to elucidate seasonal variations in zooplankton diversity and abundance in the River Nile near Shattura Village. Additionally, we aim to investigate the influence of environmental variables on the distribution of the dominant zooplankton species groups within the selected sites.

2. Materials and Methods

The study was conducted in Shattura Village, situated approximately 40 km north of Sohag Governorate, along the banks of the Nile River in Sohag. Three distinct sampling stations were established along the shoreline of Shattura Village (Figure 1), each characterized as follows: Site 1 (26°49′19.09′′ N, 31°31′13.12′′ E) featured abundant vegetation. Site 2 (26°49′19.09′′ N, 31°31′13.12′′ E) was devoid of vegetation and agricultural drainage. Site 3 (26°49′19.09′′ N, 31°31′13.12′′ E) represented an agricultural drainage canal known as the El-Murra Canal, which traverses approximately 2 km through Shattura Village, conveying agricultural drainage to the Nile River.

Seasonal water samples were thoroughly collected from the designated sites between spring 2020 and winter 2021, as per the methodology outlined by Sameoto et al. [8]. 20 L of subsurface water, located approximately 50 cm deep and characterized by relatively stagnant conditions, were filtered using a zooplankton net with a mesh size of 55 µm and a mouth diameter of 0.35 m. Each sample was replicated three times and preserved in a 4% formalin solution before being stored in plastic containers.

Field measurements encompassed a range of parameters, including water temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), and water transparency, utilizing a portable multi-probe meter. Additionally, chemical parameters such as ammonia (NH_4), nitrate (NO_3), nitrite (NO_2), sulfate (SO_4^{2-}), phosphate (PO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl) were analyzed following standard methods outlined in APHA [9].

In the laboratory, zooplankton samples were sorted into distinct groups and enumerated using an Olympus Stereo-Zoom Dissecting Microscope MOD-AZM 100. Identification of zooplankton groups was facilitated using various taxonomic keys, Refs. [10–16] for Rotifera; Ref. [17] for Cladocera; and Refs. [10,18–20] for Ostracoda.

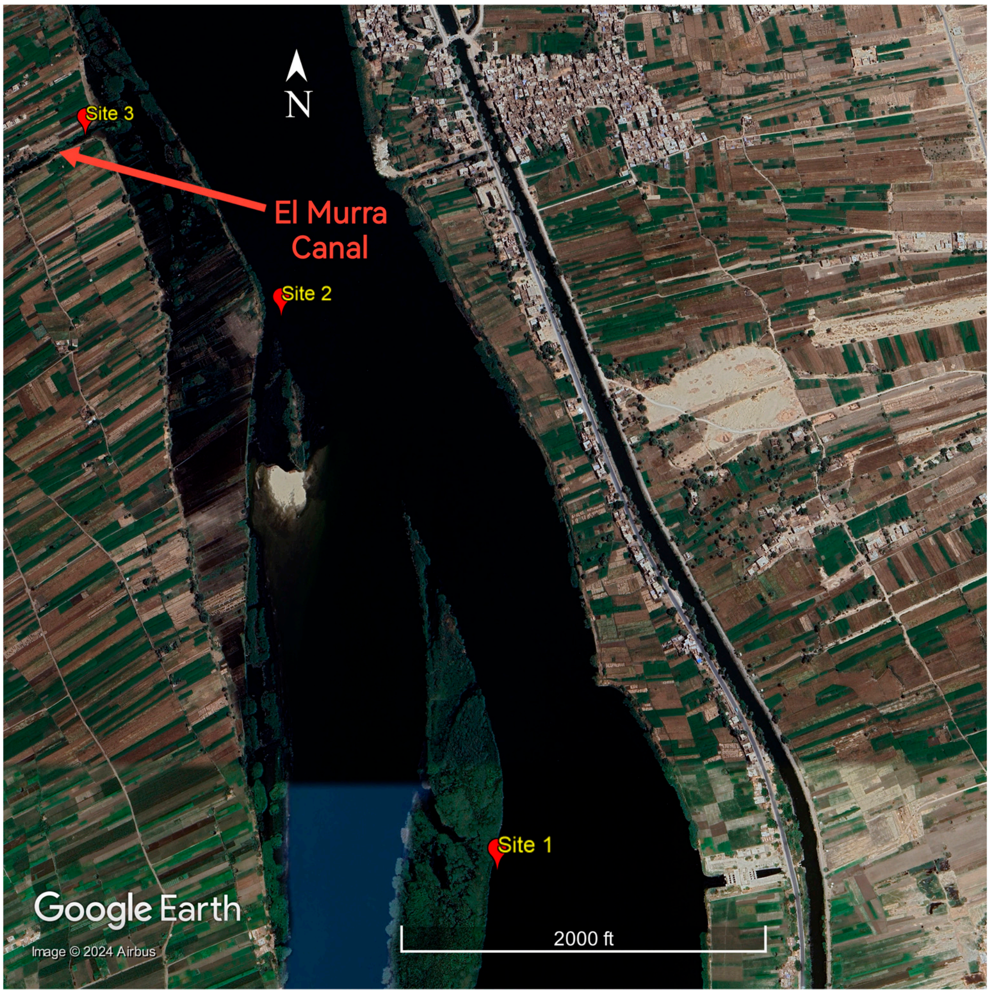

Figure 1. Map of River Nile at Shattura Village showing the selected sampling sites during the present study.

Statistical analyses were performed to explore the relationships between zooplankton and physico-chemical factors. The Spearman correlation coefficient was computed using SPSS version 22 to assess these relationships. The Kruskal–Wallis test was used to explain the difference between ecological variables between sites and seasons. Canonical correspondence analysis (CCA) was employed with PAST 4.03 to elucidate the associations between zooplankton and environmental parameters. Furthermore, the Shannon–Weaver diversity index was calculated for zooplankton species based on the equation proposed by Shannon and Weaver [21].

$$H' = -\Sigma pi\ lnpi$$

where pi is the relative abundance of each species (ni/N).

Evenness index (E) returns to the next equation: E = H′/ln S. Where S is the richness.

3. Results and Discussion

3.1. Physico-Chemical Parameters in Water

The physico-chemical factors of water serve as fundamental indicators for assessing its nature, quality, and typology [22]. Table 1 presents the recorded physico-chemical parameters of water samples collected from spring (2020) to winter (2021). Notably, the maximum temperature was observed at site 3 during summer (30 °C), while the lowest temperature was documented at site 1 in winter (17 °C) (Figure 2). Temperature variations are influenced by several factors, such as geographic location, shading, water source, thermal inputs, water body size, and depth, resulting in significant fluctuations [23]. Temperature plays a critical role as it dictates the types of organisms capable of coexisting within aquatic ecosystems, including the planktonic community in the River Nile near Shattura Village. Additionally, ambient temperature is influenced by various factors, including dissolved oxygen levels, the rate of aquatic plant photosynthesis, and the metabolic activities of aquatic organisms [23,24].

Table 1. Seasonal variations of some physico-chemical parameters in the three selected sites of Nile River in Shattura Village during the period of collection.

Season	Spring			Summer			Autumn			Winter		
Site	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**
Temp (°C)	20.45	20.6	21.4	29.5	29.1	30	20.5	21.4	21.2	17	17.5	17.3
Transparency (cm)	64	74	18	60	70	16	67	71	13	53	69	11
pH	8.62	6.38	6.45	8.89	7.45	6.71	7.87	6.47	6.83	8.05	6.30	7.29
DO (mg/L)	8.93	7.52	3.36	8.60	5.23	3.94	8.81	4.95	4.19	7.19	5.85	3.09
EC (µS/cm)	359.7	367.5	488.2	331.5	317.8	347.4	499	540	578	603	590	512
TDS (mg/L)	200	210	266	195	207	190	270	290.5	297.5	310	282.5	289
BOD (mg/L)	8.66	8.12	6.75	7.15	6.67	5.22	9.96	8.48	5.92	7.81	6.18	4.99
NO_3 (µg/L)	53.6	49.9	67.6	33.8	57.8	88.2	74.1	37.9	94.7	70.4	69.2	78.3
NO_2 (µg/L)	17.5	17.7	21.6	15.9	14.3	22.7	18.3	20.4	22.6	16.4	18.4	23.9
NH_4 (µg/L)	354.6	378.4	405.7	278.3	259.6	318.2	247.3	422.5	447.1	322.7	238.1	491.4
SO_4^{2-} (mg/L)	32.75	34.05	38.45	32.35	31.21	38.67	39.96	36.51	41.94	39.53	34.73	40.33
PO_4^{2-} (µg/L)	30	39	89	31	37	82	28	37	99	36	40	96
Ca^{2+} (mg/L)	28.8	20.9	33.8	27.25	22.5	29.4	39.5	35.6	38.9	40.2	34.5	41.6
Mg^{2+} (mg/L)	14.3	15.9	15.7	11.05	17.4	19.3	17.2	15.7	20.2	18.3	13.7	16.4
Cl^- (mg/L)	34	26.7	39.5	33.6	28	35.9	38	37	39.3	40	37.3	41.6

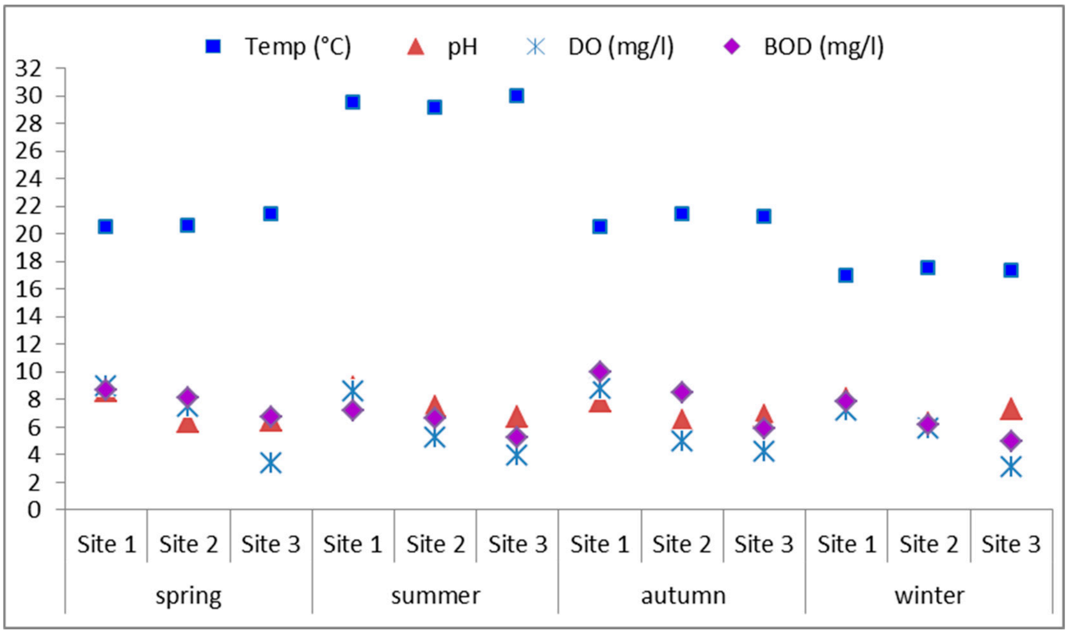

Figure 2. Seasonal variations of some physico-chemical parameters [Temp (°C), pH, DO (mg/L), and BOD (mg/L)] in the selected sites.

The turbidity and abundance of phytoplankton and zooplankton have a significant impact on the transparency of the water [25]. The highest value of transparency was 74 cm, which was recorded at site 2 during the spring. This may be explained by the low plankton abundance. The lowest value of transparency was 11cm, which was recorded at site 3 during the winter (Figure 3), this is due to the influence of agricultural drainage, which has a high concentration of organic matter and nutrients [26]. It is worth noting that site 3 (El-Murra drain) in the study area has the lowest number of transparency, ranging from 11 to 18 cm, which is attributable to agriculture drainage and probably anthropogenic activities [27].

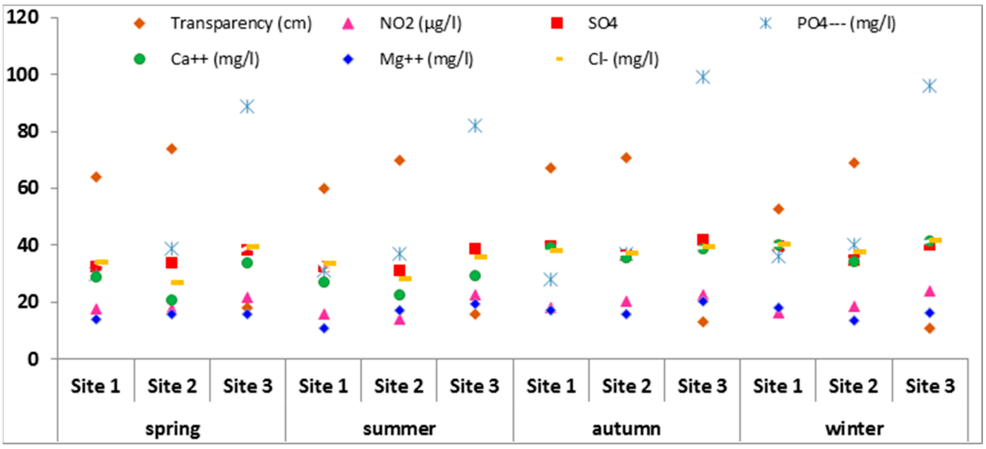

Figure 3. Seasonal variations of some physico-chemical factors [transparency (cm), NO_2 (µg/L), SO_4 (mg/L), PO_4 (µg/L), Ca (mg/L), Mg (mg/L), Cl (mg/L)] in the selected sites.

The highest pH value was 8.62, obtained at site 1 during spring, and the lowermost value was 6.30, noted at site 2 throughout the winter (Figure 2). The minimal value of dissolved oxygen (DO) found at site 3 during winter was 3.09 mg/L; this decrease was attributed to the impact of incoming agricultural drainage at this site, which consumed a significant quantity of DO during the oxidation process (Figure 2). The maximum reading of DO recorded at site 1 during spring was 8.93 mg/L, this was attributed to an increase in vegetation, which enhanced the ratio of oxygen in water via photosynthesis [28].

The lowest reading of BOD documented during the winter (El-Murra drain) at site 3 was 4.99 mg/L (Figure 2). Whereas, the highest value of BOD noted during autumn at site 1 was 9.96 mg/L. These findings concurred with those of Abdel-Satar et al. [27], who found that the BOD values varied from 1.2 to 8.0 mg/L.

Nitrate, nitrite, ammonia, sulphate, and phosphate levels were recorded at the studied sites (Figures 3 and 4). Nitrate ranged from 33.8 to 94.7 µg/L, nitrite varied from 14.3 to 23.9 µg/L, ammonia ranged from 238.1 to 491.4 µg/L, sulphate ranged from 31.21 to 41.94 (mg/L) and phosphate varied from 28 to 99 µg/L. According to earlier studies, the highest levels of nutrients were found at site 3 (El-Murra drain), which gets the greatest amounts of nutrient discharges and phosphate from agricultural drainages. Similarly, El-Enany [29] reported the highest levels of nutrients in Lake Manzala. Yadav and Kumar [30] attributed the increase in phosphate levels during the winter to agricultural runoff that contained phosphate fertilizers. The uptake of phosphate by aquatic plants, on the other hand, resulted in a low phosphate concentration at site 1. For calcium, magnesium, and chloride, the main salts (Figures 3 and 4) were in the range of 20.9–41.6 mg/L, 5–20.2 mg/L, and 26.7–41.6 mg/L, respectively. The major salts recorded increased along with the increase in nutrient salts. Our findings are consistent with those made by Mola and Shehata [31] and Abdel Satar [32], who reported a strong positive association between major salts and nutrient salts.

According to the Kruskal–Wallis test, there was a significant difference among ecological variables, sites, and seasons (p = 1.00, p = 0.05). The correlation matrix of physico-chemical parameters (Figure 5) revealed that EC and TDS had the highest positive correlation (r = 0.97), followed by dissolved oxygen and BOD (r = 0.76), and transparency and dissolved oxygen (r = 0.71). On the contrary, there is a strong negative correlation between EC and temperature (r = 0.768) and between TDS and temperature (r = 0.75). Furthermore, transparency is negatively correlated with ammonia (r = −0.589), nitrate (r = −0.709), nitrite (r = −0.815), sulphate (r = −0.69), and phosphate (r = −0.955). Similarly, Mola and Shehata [31] observed a positive relationship between dissolved oxygen and transparency (Figure 5). Correlation coefficient between some physico-chemical [Temp (°C), transparency (cm), pH, DO (mg/L), EC (μS/cm), TDS (mg/L), BOD (mg/L), NO_3 (μg/L), NO_2 (μg/L), NH_4 (μg/L), SO_4^{2-} (mg/L), PO_4^{2-} (μg/L), Ca^{2+} (mg/L), Mg^{2+} (mg/L), Cl (mg/L)] parameters and zooplankton groups during the collection.

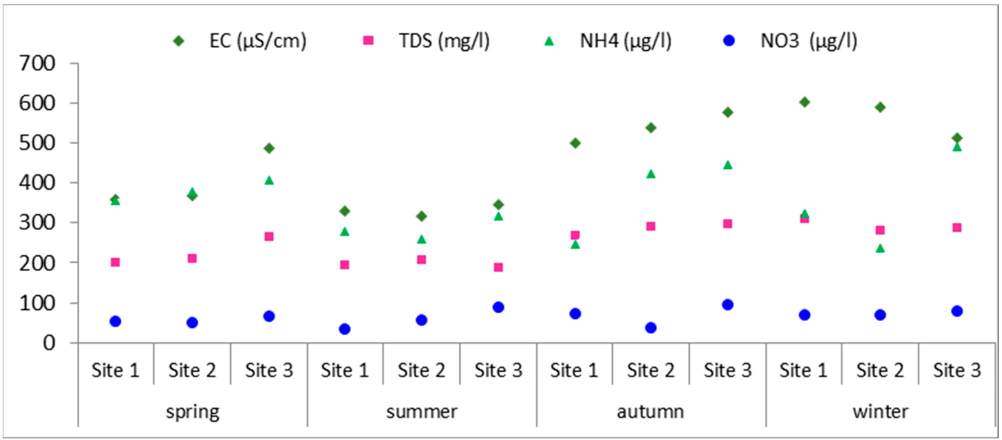

Figure 4. Seasonal variations of some physico-chemical parameters [EC (μS/cm, TDS (mg/L), NH_4 (μg/L), NO_3 (μg/L)] in the selected sites.

		T	Tra.	pH	DO	EC	TDS	BOD	NH4	NO3	NO2	SO4—	PO4—	Ca++	Mg++	Cl-	Roti.	Clad.	Cop
Tra.	r	-0.015																	
	Sig.	NS																	
pH	r	0.174	0.215																
	Sig.	NS	S																
DO	r	-0.016	0.714**	0.696*															
	Sig.	NS	S	S															
EC	r	-0.768	-0.191	-0.325	-0.25														
	Sig.	S	NS	S	S														
TDS	r	-0.75	-0.215	-0.292	-0.308	0.970**													
	Sig.	S	S	S	S	S													
BOD	r	-0.198	0.708**	0.341	0.761**	-0.022	-0.012												
	Sig.	NS	S	S	S	NS	NS												
NH4	r	-0.343	-0.589	-0.303	-0.574	0.263	0.355	-0.298											
	Sig.	S	S	S	S	S	S	S											
NO3	r	-0.183	-0.709	-0.292	-0.481	0.39	0.351	-0.489	0.177										
	Sig.	NS	S	S	S	S	S	S	NS										
NO2	r	-0.212	-0.815	-0.508	-0.721	0.357	0.354	-0.513	0.710**	0.592*									
	Sig.	S	S	S	S	S	S	S	S	S									
SO4—	r	-0.414	-0.69	-0.267	-0.438	0.668*	0.683*	-0.203	0.475	0.753**	0.734**								
	Sig.	S	S	S	S	S	S	S	S	S	S								
PO4—	r	-0.035	-0.955	-0.442	-0.838	0.227	0.258	-0.75	0.670*	0.691*	0.858**	0.648*							
	Sig.	NS	S	S	S	S	S	S	S	S	S	S							
Ca++	r	-0.616	-0.434	-0.017	-0.232	0.843**	0.859**	-0.063	0.328	0.508	0.519	0.822**	0.359						
	Sig.	S	S	NS	S	S	S	NS	S	S	S	S	S						
Mg++	r	-0.029	-0.474	-0.338	-0.454	0.266	0.304	-0.216	0.269	0.762**	0.399	.658*	0.491	0.308					
	Sig.	NS	S	S	S	S	S	S	S	S	S	S	S	S					
Cl-	r	-0.499	-0.598	-0.035	-0.343	0.754**	0.744**	-0.226	0.361	0.515	0.623*	0.793**	0.497	0.944**	0.221				
	Sig.	S	S	NS	S	S	S	S	S	S	S	S	S	S	S				
Rotifera	r	-0.666	-0.515	0.162	-0.165	0.581*	0.622*	-0.14	0.459	0.484	0.47	0.718**	0.399	0.812**	0.259	0.787**			
	Sig.	S	S	NS	NS	S	S	NS	S	S	S	S	S	S	S	S			
Cladocera	r	-0.59	0.391	0.145	0.475	0.582*	0.563	0.720**	-0.167	0.039	-0.131	0.352	-0.439	0.56	0.129	0.342	0.345		
	Sig.	S	S	NS	S	S	S	S	NS	NS	NS	S	S	S	SN	S	S		
Copepoda	r	0.072	0.493	0.694*	0.795**	-0.473	-0.513	0.593*	-0.214	-0.524	-0.526	-0.55	-0.608	-0.388	-0.455	-0.388	-0.18	0.143	
	Sig.	SN	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	NS	
Ostracoda	r	-0.49	0.084	0.193	0.259	0.55	0.593*	0.542	0.22	0.07	0.192	0.534	-0.14	0.701*	0.186	0.511	0.484	0.853**	0.075
	Sig.	S	NS	NS	S	S	S	S	S	NS	NS	S	NS	S	NS	S	S	S	NS

Figure 5. Heat map showing the correlation coefficient between some physico-chemical parameters and zooplankton groups during the collection. * Correlation is significant at $p < 0.05$; ** correlation is significant at $p = 0.01$.

3.2. Abundance and Seasonal Differences of Zooplankton

During the current study, a total of fifty-two zooplankton species were identified (Table 2), and classified into four taxonomic groups: Rotifera (18 species), Cladocera (13 species), Copepoda (10 species), and Ostracoda (11 species). The overall count of collected zooplankton amounted to 16,137 individuals, with Rotifera comprising the highest proportion (8774 ind./m^3), followed by Cladocera (3807 ind./m^3), Copepoda (2119 ind./m^3), and Ostracoda (1437 ind./m^3) (Figure 6). Rotifera constituted the largest percentage of zooplankton (54.73%), trailed by Cladocera (20.59%), Copepoda (13.13%), and Ostracoda forming the smallest portion (8.9%).

Table 2. The number of zooplankton taxa and species (ind./m^3) collected from the selected sites through the period of collection.

	Spring			Summer			Autumn			Winter			Total
Taxa	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**	**Site 1**	**Site 2**	**Site 3**	
Rotifera													
Anuraeopsis fissa	48	27	64	39	12	43	34	22	51	28	15	62	445
Brachionus angularis	100	49	171	78	30	93	158	90	189	266	99	287	1610
Brachionus calyciflorus	93	48	100	61	24	71	272	89	162	274	160	298	1652
Brachionus caudatus	25	19	37	18	8	45	16	7	39	9	8	44	275
Brachionus falcatus	11	8	6	4	0	2	7	4	13	9	0	11	75
Brachionus plicatilis	113	78	108	52	17	89	103	110	77	216	140	269	1372
Brachionus qudridentatus	19	9	22	6	3	6	2	0	6	11	3	15	102
Brachionus rubens	21	6	8	9	2	13	7	0	14	15	2	9	106
Brachionus urceolaris	14	4	6	2	0	6	5	1	8	0	4	11	61
Brachionus sp.	22	15	2	4	0	8	6	2	8	6	0	9	82
Cephalodella gibba	8	4	13	4	1	20	4	1	33	12	8	40	148
Collotheca ornata	5	0	13	15	4	3	9	0	11	3	5	12	80
Conochilus unicornis	3	0	2	4	2	12	11	5	4	10	2	5	60
Filinia longiseta	9	11	9	6	2	3	10	7	14	5	4	11	91
Keratella cochlearis	98	82	115	71	20	78	105	81	97	211	69	214	1241
Keratella tropica	164	51	99	52	14	79	136	79	80	216	60	218	1248
Philodina roseola	1	0	3	3	5	2	7	0	8	5	3	2	39
Polyarthra euryptera	7	0	15	7	0	12	9	0	11	7	0	19	87
Cladocera													
Alona intermedia	82	26	45	12	0	18	124	110	93	89	46	52	697
Alona rectangula	62	22	35	7	8	4	54	25	16	24	15	19	291
Bosmina longirostris	22	2	12	13	10	8	47	37	26	63	5	27	272
Ceriodaphnia reticulata	94	56	74	18	9	12	112	57	94	104	37	100	767
Chydorus sphaericus	4	0	2	0	3	2	6	0	3	3	0	1	24
Daphnia longispina	2	0	8	3	0	6	3	2	0	3	0	4	31
Diaphanosoma excisum	53	20	32	16	4	12	193	53	102	167	44	83	779
Macrothrix laticornis	7	3	0	4	0	0	67	16	39	19	8	14	177
Moina micrura	16	1	10	7	5	9	69	6	26	18	5	10	182
Pleuroxus aduncus	10	0	6	4	1	0	8	13	11	15	16	10	94
Pleuroxus letourneuxi	0	4	3	2	0	0	16	0	12	4	0	0	41
Simocephalus expinosus	5	0	2	11	6	3	28	19	59	26	18	19	196
Copepoda													
Afrocyclops gibsoni	17	0	0	23	5	15	0	6	8	11	2	0	87
Eucyclops serrulatus	37	0	20	16	0	0	7	0	0	6	5	0	91
Macrocyclops albidus	40	6	5	8	18	13	12	6	22	21	0	7	158
Mesocyclops ogunnus	17	12	12	13	33	11	26	7	18	8	4	4	165

Table 2. *Cont.*

Taxa	Spring			Summer			Autumn			Winter			Total
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
Microcylops linjanticus	61	0	27	58	4	0	19	0	0	13	3	7	192
Paracyclops fimbriatus	47	7	0	14	15	5	9	6	8	21	6	5	143
Shizopera nilotica	55	0	38	12	0	0	27	12	10	14	0	9	177
Thermodiaptomus galebi	54	10	0	20	6	7	18	6	11	17	2	11	162
Thermocyclops consimilis	69	6	26	15	1	25	11	9	10	29	8	8	217
Tropocyclops confinis	25	8	15	34	0	12	0	0	6	5	0	4	109
Copepodite stage	63	11	31	28	2	6	27	5	16	14	1	4	208
Nauplius stage	88	16	57	73	0	48	42	18	34	24	0	10	410
Ostracoda													
Candona neglecta	4	4	12	6	3	2	11	10	7	14	7	9	89
Candonocypris novaezelandiae	1	2	30	5	7	37	4	10	102	4	5	78	285
Cyprideis torosa	11	0	7	0	5	0	64	32	12	4	7	5	147
Cypridopsis vidua	27	6	9	23	7	9	28	36	6	49	21	9	230
Cyprideis littoralis	24	4	17	15	6	3	15	18	2	11	6	9	130
Gomphocythere sp.	3	0	4	0	1	5	12	8	4	9	1	0	47
Heterocypris salina	14	7	12	13	16	0	46	29	7	24	18	4	190
Heterocypris giesbrechtii	8	5	6	0	0	2	27	4	0	9	5	8	74
Limnocythere inopinata	17	0	2	12	0	0	17	22	8	16	8	11	113
Potamocypris variegata	9	1	6	4	0	2	0	23	0	5	0	3	53
Sclerocypris bicornis	11	3	4	15	0	7	4	6	9	9	4	7	79

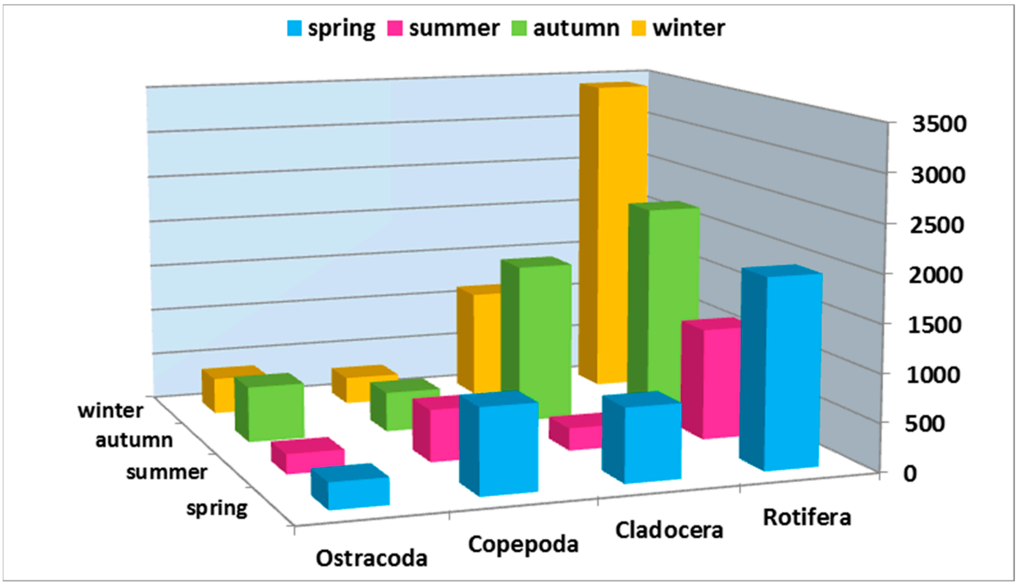

Figure 6. Seasonal variations of different zooplankton groups during period of collection.

According to Van Dijk and Van Zanten [33] and Galkovskaja [34], Rotifera dominate the Nile River due to their ability to reproduce across a wide range of temperature conditions and their short generation period compared to larger crustacean zooplankton. Similarly, Ramadan et al. [35] and Mageed [36] reported Rotifera accounting for 97% and 85.3% of all zooplankton, respectively, making it the most prevalent category. However, El-Serafy et al. (2009) [26] analyzed zooplankton distribution in Lake Nasser and found Copepoda to be the dominant group, followed by Cladocera. Furthermore, Mola and Shehata (2012) [31] demonstrated Ostracoda as the least dominant zooplankton group.

The greatest abundance of total zooplankton was documented at site 1 (7114 ind./m^3), with percentages of 44.08% owing to the influence of vegetation, which is used as food and shelter for zooplankton (Figure 7). Scheinin et al. [37] indicated that the density of zooplankton varies with the density of the surrounding vegetation. This relationship is frequently explained by the correlation between the density of the vegetation and its ability to serve as a shelter. In addition, site 3 contains a fairly large number of zooplankton (6000 ind./m^3) with ratios of 37.18% due to the impact of agriculture drains, which contain many nutrients. According to Abdel Mola and Shehata [31], agriculture drains that are rich in nutrients are responsible for the highest density of zooplankton. Conversely, the lowest number of total zooplankton was found at site 2 (3023 ind./m^3) with ratios of 18.73% due to the absence of vegetation and agriculture drains at this site. The varied distribution of zooplankton groups at different sites seems to be strongly influenced by numerous environmental parameters, such as water temperature, the existence of nutrients, and physico-chemical elements (Ahmed et al., 2011) [38].

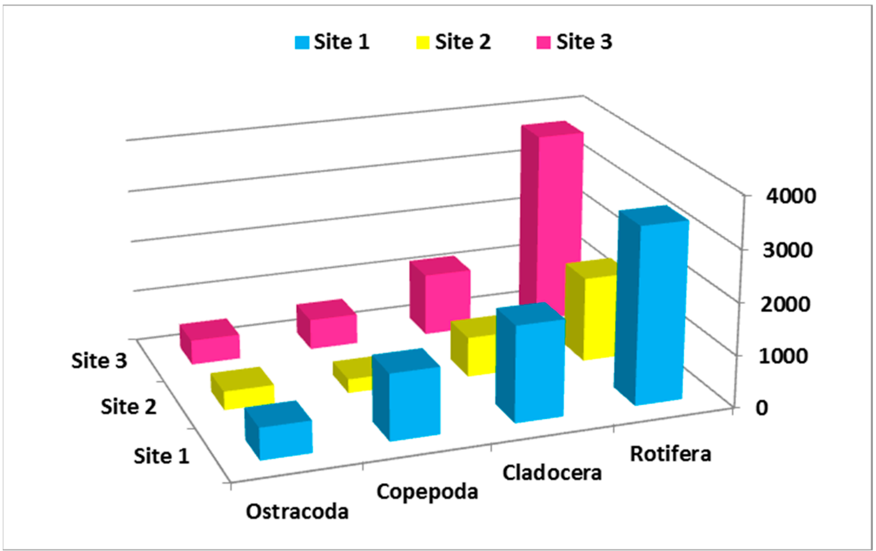

Figure 7. The abundance of different zooplankton groups in the three selected sites during the period of collection.

Brachionus was the most abundant genus of Rotifera in the present study, constituting 50% of all Rotifer species, represented by 9 species. This reveals the ability of the genus *Brachionus* to tolerate pollution, which is consistent with the findings of many studies [39–41]. *Brachionus calyciflorus*, *Brachionus angularis*, and *Brachionus plicatilis* were the most abundant Rotifera species, accounting for 18.82, 18.34, and 15.63% of the total number of Rotifera, respectively. According to Abdelmageed et al. [42], Mola [43], and Sharma et al. [44], the presence of previously abundant species indicates more eutrophication in the current studied area. Furthermore, according to Mola and Shehata [31], *Brachionus angularis* is the most prevalent species in Manzala Lake, accounting for 43.18% of all Rotifera. Additionally, Mageed [36] found that *B. angularis* represents 35% of total Rotifer species. Furthermore, Sladecek (1983) [45] noted that the genus *Brachionus* of Rotifera is diverse and has a wide distribution in the most eutrophicated streams. The maximum abundance of rotiferan species was noted at site 3 (3739 ind./m^3) due to the richness of the agriculture drainage, while the lowest number was found at site 2 (1856 ind./m^3) due to the absence of plants. The seasonal variations of the rotiferan species displayed that the highest value was observed in winter (3421 ind./m^3), and the lowest value (1164 ind./m^3) was reported in summer. El-Shabrawy et al. (2017) [46], contrary, reported that the species number and their richness were lowermost and maximum in summer and winter, respectively, and they attributed this to higher temperatures that accelerated the rate of population growth.

Cladocera emerged as the second most abundant zooplankton group, constituting 3807 ind./m^3 and encompassing 13 species (Table 2). Among them, *Diaphanosoma excisum* (779 ind./m^3, 20.46%) and *Ceriodaphnia reticulata* (767 ind./m^3, 20.14%) were the most abundant species, while *Daphnia longispina* (31 ind./m^3, 0.8%) and *Chydorus sphaericus* (24 ind./m^3, 0.6%) were the least abundant. Notably, Mola and Ahmed [47] identified *Bosmina longirostris* as the most abundant cladoceran species (83.77%). Furthermore, Mola and Shehata (2012) [31] observed *D. longispina* and *Chydorus sphaericus* as the least abundant cladoceran species, collectively accounting for 2.59% with a mean of 167 ind./m^3. Seasonal fluctuations in Cladocera numbers revealed the lowest count in summer (233 ind./m^3) and the highest in autumn (1678 ind./m^3) (Table 2), consistent with findings by Mola et al. and Mola and Ahmed) [47,48], attributing the decline in Cladocera abundance during summer to elevated water temperatures. The peak in Cladocera populations during autumn suggests favorable temperatures and ample food availability, such as bacteria and suspended debris [49]. Additionally, as suggested by Pandey et al. (2009) [50], heightened competition and fish predation with other groups may contribute to the reduced abundance of Cladocera during summer. Copepoda ranks as the third most prevalent zooplankton group, with an average density of 2119 ind./m^3 across 10 species (Table 2). The highest density of Copepoda was recorded in spring (880 ind./m^3), while the lowest was observed in winter (283 ind./m^3). Site 3 exhibited the lowest number of copepods, likely due to heightened pollution levels. Notably, nauplius larvae of copepods accounted for 19.34% of the total copepod population and were present across all investigated sites, indicating their resilience to pollution, consistent with findings by Emam [39]. Water temperature and transparency showed positive correlations with Copepoda, while nutritional salts exhibited negative correlations, aligning with the results of Mola and Shehata [31]. Site 1 boasted the highest copepod abundance (1268 ind./m^3) attributed to favorable environmental conditions, a conclusion supported by El-Enany (2009) [51].

Ostracoda emerged as the zooplankton group with the lowest abundance in our study (1437 ind./m^3), comprising 11 species (Table 2). The highest density of Ostracoda was observed in autumn (583 ind./m^3), with the lowest recorded in summer (205 ind./m^3). Interestingly, the relationship between ostracod density and temperature displayed a negative correlation, contrary to observations by Smol et al. [52], who noted higher ostracod numbers in spring and summer but lower counts in winter. Candonocypris novaezelandiae (285 ind./m^3) emerged as the most prevalent Ostracoda species at site 2, consistent with findings by Yousef [19]. Conversely, Ramadan et al. [53] reported *Cyprideis torosa* as the most abundant ostracod species.

Canonical correspondence analysis (CCA) was performed to investigate the relationship between zooplankton groups and physico-chemical parameters, and the results demonstrated that Copepoda had a favorable relationship with pH, DO, and transparency (Figure 8). Furthermore, Cladocera and Rotifera exhibited a significant association with electrical conductivity. In contrast, Ostracoda is unaffected by any field variables. As highlighted by Stahl and Ramadan [54], dissolved oxygen levels in water are essential for the survival of the majority of aquatic plants and animals, exerting a significant influence on the presence and abundance of plankton. Sharma and Sharma [55] further emphasize that seasonal fluctuations in dissolved oxygen concentrations can impact the activity and population levels of zooplankton. Additionally, Obuid-Allah et al. [49] noted that biological metabolism rates and the utilization of oxygen by organisms are directly influenced by water temperature, with higher temperatures leading to increased biological abundance, thereby underscoring the critical role of dissolved oxygen levels in aquatic ecosystems.

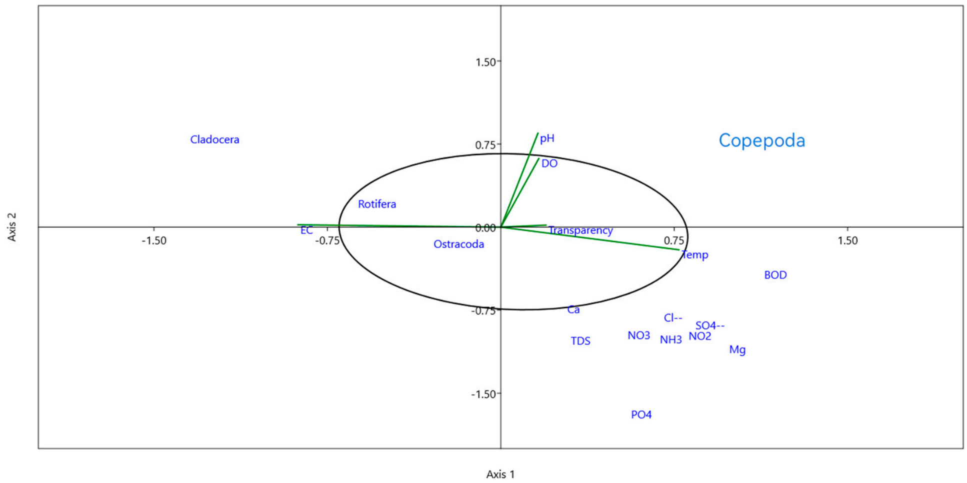

Figure 8. Canonical correspondence analysis (CCA) graph of physic-chemical parameters and four groups of zooplankton.

3.3. Correlation between Different Water Parameters and Zooplankton Groups

The correlation matrix revealed that Rotifera exhibited positive correlations with EC, TDS, NH_4, NO_3, and SO_4, while displaying negative correlations with temperature and transparency (Figure 5). Similarly, Cladocera showed positive correlations with DO, EC, TDS, BOD, Ca, and Rotifera, but negative correlations with temperature and transparency. These findings align with El-Shabrawy and Dumont's [56] observations, where they noted a significant positive correlation between Cladocera and dissolved oxygen. Copepoda exhibited a positive correlation with transparency, pH, DO, and BOD, while showing a negative correlation with EC, TDS, NH_4, NO_3, and SO_4. The findings suggest that environmental factors play a crucial role in influencing zooplankton density within aquatic ecosystems. By elucidating these correlations, we can gain valuable insights into the key drivers behind zooplankton abundance and distribution patterns.

3.4. Shannon–Weaver Diversity Indexes, Richness and Evenness

In our study, we observed the highest Shannon–Weaver diversity index for zooplankton groups during the summer at site 1, while site 3 exhibited the lowest values during the spring, summer, and winter (Figure 9). The maximum richness value of 52 was recorded at site 1 during spring and winter, while the lowest value of 38 was observed at site 2 during spring (Figure 9). Additionally, site 2 displayed the highest evenness value during spring, while site 3 recorded the lowest value during winter (Figure 9). These findings indicate that the sites examined in our study possess high species diversity and richness according to the Shannon–Weaver diversity index. This high diversity and richness of zooplankton species can be attributed to abundant food resources and favorable environmental conditions conducive to population growth and development [57].

In contrast, Meshram et al. [58] conducted a study on the diversity of Dal-Nigeen Lake and reported minimal zooplankton diversity. Our findings reveal higher diversity, richness, and evenness values for zooplankton, with evenness values exceeding 0.5 across all sites. This suggests that the presence of vegetation and agricultural drainage systems provides ample food resources and favorable conditions for zooplankton growth, consistent with the findings of Mohammad et al. [57] in Qena Governorate along the River Nile. The findings underscore the critical importance of comprehending the connections between zooplankton diversity indices and environmental factors. This understanding is pivotal for predicting how zooplankton communities will react to environmental shifts such as climate change, pollution, or habitat degradation. Through diligent monitoring of environmental variables and their impacts on zooplankton diversity, researchers can offer valuable insights to guide conservation and management efforts aimed at safeguarding aquatic ecosystems.

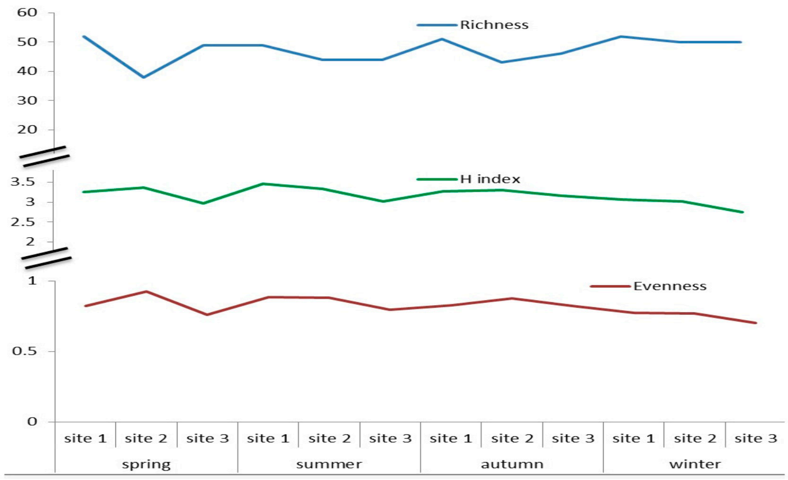

Figure 9. The Shannon–Weaver diversity index (H′), richness and evenness for the zooplankton categories throughout the study period.

In summary, the study revealed significant seasonal variations in the zooplankton population across the three investigated sites, with Rotifera dominating and Ostracoda representing the smallest proportion. High values of the Shannon–Weaver diversity index, richness, and evenness suggested favorable conditions for zooplankton growth and abundant food resources. Transparency, conductivity, pH, dissolved oxygen (DO), and biological oxygen demand (BOD) emerged as the key factors influencing the abundance of all zooplankton groups during the study period. Furthermore, the presence of vegetation and agricultural drains exerted a substantial influence on the overall abundance of zooplankton.

Author Contributions: Designed the study: E.A.Y., H.A.-T. and A.R.; collected the samples: E.A.Y.; analyzed the data: E.A.Y., H.A.-T. and A.R.; investigation: E.A.Y. and A.M.E.-M.; methodology: E.A.Y. and A.M.E.-M.; project administration: E.A.Y., H.A.-T. and A.M.E.-M.; wrote the manuscript: E.A.Y. and A.-A.S.A.-B.; read and approved the final version of the manuscript: E.A.Y. and A.-A.S.A.-B.; review and editing: E.A.Y. and A.R.; funding: S.A.-Q. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted under the roles of the ethical standards approved by Faculty of science, Sohag University, Egypt, Approval number (CSRE-5-23).

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Abbreviations

T: Temperature, Trans: Transparency, Do: Dissolved oxygen, EC: Electric Conductivity.

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