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Some Environmental Characteristics of Lake Nasser, Aswan Reservoir and the River Nile at Aswan, Egypt and Their Impacts on the Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758)

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ABSTRACT

In this study, the effects of heavy metal pollution on three aquatic habitats in the Aswan Governorate of Egypt - Lake Nasser, Aswan Reservoir, and the River Nile - were evaluated for the Nile tilapia (*Oreochromis niloticus*). 36 water and 90 fish tissue samples were tested for the presence of Cu, Fe, Pb, Cd, and Zn, among other heavy metals. Significant regional and seasonal variations were noted, with the River Nile exhibiting the highest levels of contamination, particularly for lead (Pb), beyond permissible limits in summer. Particular accumulation showed that the largest concentrations of metals were found in the liver and gills, highlighting their roles as the primary organs for detoxification and filtration. Hematological testing showed that exposure to heavy metals significantly changed blood parameters. Significant changes in hemoglobin concentrations, mean corpuscular volume, and red blood cell count point to potential anemia and physiological stress in fish. Seasonal variations were evident, with the greatest changes in hematological indicators occurring in summer and fall. Significant site-specific changes were found by biochemical tests. Higher concentrations of uric acid, creatinine, and liver enzymes such as glutamic pyruvic transaminase (GPT) and glutamic-oxaloacetic transaminase (GOT) in fish from the River Nile suggested compromised kidney and liver function, but higher amounts of these biomarkers were also found in Lake Nasser and the Aswan Reservoir, albeit to a lesser extent, highlighting the problem's pervasive nature and the pressing need for action. These results highlight how vital it is to continue monitoring heavy metal contamination in these aquatic habitats and to control it effectively. In order to lower heavy metal concentrations, the report fervently supports the installation of sophisticated wastewater treatment facilities and strict pollution control measures. Public awareness campaigns are equally vital since they play a critical role in informing the local community about the health concerns associated with eating fish from contaminated streams. This study emphasises the serious risks that heavy metal deposition poses to public health and the environment in freshwater ecosystems, underscoring the significance of sustainable management practices.

INTRODUCTION

One of Egypt's national priorities for sustainable progress is water quality monitoring **(ElBagoury *et al*., 2023)**. Aquatic life is shielded from the harmful effects of short- or long-term exposure to toxins in water ecosystems by water quality standards **(Hong *et al*. 2022)**. Heavy metals are among the most common pollutants since they can linger in the environment, build up in food chains, and induce toxicity in a range of tissues and organs, **(Briffa *et al.*, 2020)**.

Pesticides, mining operations, sewage disposal waste, and industrial and agricultural discharges are the main sources of heavy metal contamination in water **(Said *et al.*, 2021)**.

Tilapia are being utilized as a model for studying environmental contaminants, such as heavy metal accumulation in aquatic bodies **(Abdel-Kader & Mourad, 2020)**.
Measuring the amounts of heavy metals in fish can provide an accurate indicator of heavy metal contamination in aquatic environments **(El-Sappah *et al.*, 2022)**. Integrating water quality measures with biological monitoring (biomonitoring) provide an accurate picture of the state and any dangers to aquatic environments.

Many variables influence differences in heavy metals concentrations among fish tissues, including their levels in water and food, water chemistry, fish species, size, age, gender, eating patterns, environment, and physiological health **(Kaçar, 2024)**. Both acute and chronic toxicity from heavy metal exposure can result in abnormal foetal growth, infertility, immunodeficiency, cancer, organ failure, and neurological disorders. Studies by **Mohamed *et al*. (2020)** and **Salcedo Sánchez *et al*. (2022)** have found that even minor exposure to heavy metals can pose serious health hazards.

Hematological and biochemical characteristics are essential measures in fish that provide substantial information on the metal's toxicity, either dietary or water-borne **(Fazio *et al*., 2022)**.

The Aswan Governorate in Egypt is renowned for its diverse freshwater environments, including Lake Nasser, Aswan Reservoir, and the River Nile. Lake Nasser is one of the largest artificial lakes on Earth, accounts for 95% of Egypt's freshwater budget, and is the world's largest embankment dam. Its high-water storage capacity and flow make it a vital resource for the country's economy. Aswan Reservoir, the second-largest artificial reservoir in the world, extends from southern Egypt to northern Sudan. Its strategic importance lies in water storage, hydroelectric power production, and river flow control, providing Egypt with the potential for further agricultural and industrial development. The second-longest river in the world played a vital role in shaping ancient and modern Egyptian civilization.

In order to better understand the effects of water quality and heavy metals on fish health, the study examined the effects of these variables on fish samples taken from various aquatic settings in Aswan Governorate. The fish samples were examined in terms of their hematological and biochemical parameters.

MATERIALS AND METHODS

1. Study area

The study area includes three different geographical locations along Aswan City (Fig. 1): Lake Nasser located between latitudes 22° 00' and 23° 58' N and Longitudes 30° 35' and 33° 15' E.; Aswan Reservoir situated at 21°02′–23° 58′ N and longitudes 30°37′–32°55′ E and River Nile located at 24° 07` 05.14" N and 32° 53` 50.33" E after the El-Sail drain disposal point of waste water.

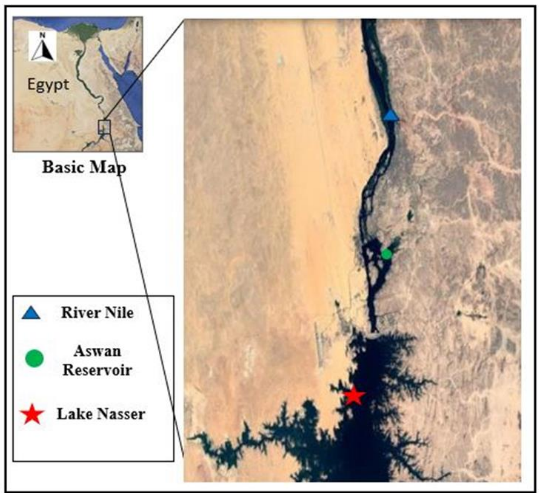

Fig. 1. The locations from which samples were collected: River Nile (RN), Aswan Reservoir (AR), and Lake Nasser (LN)

2. Water and fish sampling

36 water samples were collected from the selected sites during the four seasons of 2021 (3 samples of water for each site in a single season) gathered in two-liter (HDPE) bottles. These water samples were taken from the central region of each location at a depth of two meters. 90 fresh tissue samples of *Oreochromis niloticus* for the three aquatic sites during summer and winter were collected (Three per season per site) during the same period of water sampling. Fish samples were transferred to the laboratory of the Faculty of Fish and Fisheries Technology at Aswan University for dissecting to obtain organs (liver, gills, gonads, muscles, and kidneys). 15 fish tissue samples from each site per season were placed in polyethylene bags, and then frozen for analysis.

3. Water analysis

pH, water temperature (°C) and dissolved oxygen (DO) were recorded using the water checker (U-10 Horiba Ltd.). Chemical oxygen demand (COD) was measured by using closed reflux, titrimetric method (5220 B). Total dissolved solids (TDS), alkalinity (ALK), total gardness, ammonia as NH_3-N , soluble anions (CL, F, NO_3 and SO_4), total nitrogen (N) and total phosphorus (P) were measured using gravimetry method (2540 C), titration method (2320 B), EDTA titrimetric method (2340 C), phenate method (4500–NH_3F) and high performance liquid chromatography HPLC (Model Shimadzu -SCL-10ASB), Macro-Kjeldahl Method (4500B) and UV/Persulfate Digestion (4500-P I) method. respectively. Total Cu, Fe, Pb, Cd and Zn were measured by Atomic Absorption Spectrophotometer (Perkin Elmer 3110 USA, with graphite atomizer HGA-600). Sampling and assessment of water quality were done according to **APHA (2017)**, chemical analysis of water samples were carried out in the Ministry of Irrigation Laboratory at Aswan.

4. Fish tissue analysis

Heavy Metals (Cu2+, Fe2+, Pb2+, Cd2+ and Zn2+) concentrations in fish samples were measured by Unicam SOLAR Atomic Absorption Spectrometer (Solar 969) (United Kingdom) using the wet digestion method according to **Tiimub and Afua (2013)**. The results were calculated in milligram per kilogram wet weight conducting according to the Egyptian Health Law No. 7163 / 2010. Determination of trace elements in fish tissues was carried out in the laboratories of the Lake Nasser Development Authority for Fisheries Research in Aswan

5. Hematological and biochemical analyses

Two peripheral blood samples were taken via cardiac puncture, as described by **Osman *et al*. (2011)**. Four samples were collected for hematology and four samples for biochemical analysis of site per season. White blood cells count (WBCs), lymphocytes, monocytes, neutrophils, eosinophils, hemoglobin concentration (Hb), red blood cells count (RBCs), hematocrit value (Hct), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC) and platelet count (PLT) were measured directly by using the Mindray® automatic hematology analyzer (BC-2800, Shenzhen, China).

The biochemical parameters studied include uric acid, urea, creatinine, albumin, alkaline phosphatase, cholesterol, triglycerides, glutamic pyruvic transaminase (GPT), glutamic-oxaloacetic transaminase (GOT) and sugar. These parameters were measured by a commercially reagent kits (Erba Mannheim Chem -7, Germany). These kits are Erba Uric Acid Reagent Kit - Code 120248, Erba Urea BUN Test Kit - Code 120214, Erba Creatinine Test Kit- Code 120246, Erba Albumin kit - Code 120223, Erba Alkaline Phosphatase Kit -Code 120238, Erba Cholesterol Kit - Code 120194, Erba triglyceride kit - Code 120211, Erba SGPT kit - Code 120207, Erba SGOT Kit - Code 120204, Erba Glucose Reagent Kit - Code 120235. Prothrombin time (PT) was determined by using a semi-automated coagulation analyzer (CoaDATA 504, Labitec GMBH, Germany). All hematological and biochemical analysis were conducted in El-Masah Laboratory, Aswan.

6. Statistical analysis

The basic statistics were given in terms of means, standard deviations and ranges. Homogeneity of variance was evident, and all data were subjected to one-way, two-way and three- way ANOVA to study the main effects of different factors considered in each analysis. Site and seasonal variations and their interactions in physical and chemical characteristics of water were considered. Such variations in addition to organ factors were considered evaluating the pattern of variations in these organs. Tukey HSD Multiple Range's Test was used as a post-hoc test to compare means at $P< 0.05$. Further, the parameters considered were treated in multivariate sense. All statistical calculations were carried out using SPSS package version 26 for windows. PAST statistical software was also used.

RESULTS

1. Physical and chemical water characteristics

The variations in water quality with respect to locality and seasons were summarized in Table (1). The two-way ANOVA analysis revealed significant site main effect variations in all physical and chemical characters except PH, TEMP, TDS, ALK and NH_3.

On the other hand, seasonal main effect was insignificant in all characters except COND and TEMP. The interaction between site and season factors was only significant for TEMP.

In Lake Nasser, seasonal variations were only significant in TEMP, ALK, and TP, these seasonal variations are significant only in TEMP and TP for Aswan Reservoir and in TEMP only in the River Nile site. Geographical variations in each season were insignificant in all physical and chemical characteristics.

2. Heavy metals in water samples

The pattern of variations in water heavy metals concentration in Lake Nasser, Aswan Reservoir, and the Nile River in different seasons of 2021 are shown in Table (2). The two-way ANOVA revealed significant site main effect for Cu, Fe and Zn. The main effect of season factor and the site-season interaction were insignificant for all studied heavy metals.

No significant seasonal variations were observed for all heavy metals in all sites whereas site variations were only significant in summer for Cu, Cd and Zn, in autumn for Fe, Cd and Zn, in winter for Cd and Zn and in spring for Zn. These significant variations are in the order: RN > AR > LN except for Fe in autumn and Zn in winter (RN > LN > AR). Only, Pb was higher than the permissible limits (0.064ppm) at Lake Nasser in summer according to the Egyptian Law No. 48 of 1982.

Table 1. Effect of site and season on physical and chemical characteristics of water samples from lake Nasser (LN), Aswan Reservoir (AR) and River Nile (RN) during 2021

Parameter	Site	Seasons				Site Effect
		Summer	Autumn	Winter	Spring	
PH (unit)	LN	8.1 ± 0.26 Aa (7.8 -8.3)	8.06 ± 0.15 Aa (7.9-8.2)	7.9 ± 0.26 Aa (7.7 - 8.2)	8 ± 0.26 Aa (7.8 - 8.3)	**8.01 ± 0.22 A (7.7 - 8.3)**
	AR	8.11 ± 0.18 Aa (7.9 -8.2)	7.93 ± 0.35 Aa (7.6- 8.3)	8.03 ± 0.20 Aa (7.8 - 8.2)	8.06 ± 0.25 Aa (7.8 - 8.3)	**8.03 ± 0.23 A (7.6 - 8.3)**
	RN	8.17 ± 0.05 Aa (8.11 - 8.20)	8.21 ± 0.11 Aa (8.1- 8.3)	8.13 ± 0.15 Aa (7.9 - 8.3)	8.18 ± 0.16 Aa (8 - 8.3)	**8.17 ± 0.11 A (7.9 - 8.3)**
	Season Effect	**8.12 ± 0.16 a (7.8 - 8.3)**	**8.07 ± 0.23 a (7.6 - 8.3)**	**8.02 ± 0.21 a (7.7 - 8.3)**	**8.08 ± 0.21 a (7.8 - 8.3)**	
DO (ppm)	LN	7.4 ± 0.1 Aa (7.3- 7.5)	6.9 ± 0.10 Aa (6.8 - 7)	6.7 ± 0.40 Aa (6.5 - 7.2)	7.16 ± 0.35 Aa (6.8 - 7.5)	**7.05 ± 0.35 A (6.5 - 7.5)**
	AR	6.8 ± 0.3 Aa (6.5- 7.1)	6.23 ± 0.25 Aa (6 - 6.5)	6.20 ± 0.30 Aa (5.9 - 6.5)	6.13 ± 0.83 Aa (5.2 - 6.8)	**6.34 ± 0.49 B (5.2 - 7.1)**
	RN	6.56 ± 0.40 Aa (6.2 -7)	6.30 ± 0.70 Aa (5.8- 7.1)	5.90 ± 1.22 Aa (4.5 - 6.8)	6.23 ± 0.76 Aa (5.4 - 6.9)	**6.25 ± 0.74 B (4.5 - 7.1)**
	Season Effect	**6.9 ± 0.45 a (6.2- 7.5)**	**6.47 ± 0.49 a (5.8 - 7.10)**	**6.27 ± 0.75 a (4.5 - 7.2)**	**6.51 ± 0.77 a (5.2 - 7.5)**	
COND (ms/cm)	LN	256.6 ± 7.6 Aa (250 - 265)	270 ± 2 Aa (268 -272)	266 ± 8 Aa (258 - 274)	254.6 ± 7.50 Aa (247 - 262)	**261.8 ± 8.79 A (247 - 274)**
	AR	257.3 ± 15.27 Aa (244- 274)	276 ± 8.54 Aa (268 - 285)	267.6 ± 6.11 Aa (261 - 273)	253.33± 8.50 Aa (247 - 263)	**263.5 ± 12.7 A (244 - 285)**
	RN	275.6 ± 14.64 Aa (260 - 289)	284.3 ± 8.50 Aa (278 - 294)	267 .6 ± 5.50 Aa (264 - 274)	264.6 ± 9.50 Aa (255 - 274)	**273 ± 11.7 B (255 - 294)**
	Season Effect	**263.2 ± 14.6 a (244 - 289)**	**276.7 ± 8.72 b (268 - 294)**	**267.1 ± 5.79 ab (258 - 274)**	**257.5 ± 9.139 a (247 - 274)**	
TEMP (°C)	LN	28 ± 2 Aa (26 - 30)	22.3 ± 2.51 Ab (20 -25)	18.3 ± 1.527 Ab (17- 20)	20.6 ± 1.52 Ab (19 - 22)	**22.3 ± 4.07 A (17 - 30)**
	AR	18.93 ± 4.04 Aa (15.8 - 23.5)	22.43 ± 1.70 A ab (20.7- 24.1)	24.9 ± 2.35 A ab (22.5 - 27.2)	28.6 ± 2.62 Ab (25.8 - 31)	**23.7 ± 4.39 A (15.8 - 31)**
	RN	27.3 ± 1.52 Aa (26 -29)	24.33 ± 1.52 A ab (23 - 26)	20.66 ± 1.52 Ab (19 - 22)	21.6 ± 1.52 Ab (20 - 23)	**23.5 ± 3 A (19 -29)**
	Season Effect	**24.7 ± 4.9 a (15.8 - 30)**	**23.03 ± 1.96 ab (20 - 26)**	**21.30 ± 3.29 b (17 – 27.2)**	**23.64 ± 4.10 ab (19 - 31)**	
COD (ppm)	LN	7 ±1 Aa (6 -8)	6 ± 1 Aa (5 - 7)	7 ± 1 Aa (6 - 8)	7.66 ± 0.57 Aa (7- 8)	**6.9 ± 0.99 A (5 - 8)**
	AR	9 ±1 Aa (8 - 10)	8 ± 1 Aa (7- 9)	7 ± 1 Aa (6 - 8)	8 ± 2 Aa (6 - 10)	**8 ± 1.34 A (6 - 10)**
	RN	11 ± 1 Aa (10- 12)	11.66 ± 2.51 Aa (9 -14)	10.66 ± 3.05 Aa (8 - 14)	11.33 ± 2.08 Aa (9 - 13)	**11.16 ± 1.99 B (8 - 14)**
	Season Effect	**9 ± 1.93 a (6 - 12)**	**8.55 ± 2.87 a (5 - 14)**	**8.22 ± 2.48 a (6 - 14)**	**9 ± 2.29 a (6 - 13)**	
TDS (ppm)	LN	161.6 ± 7.6 Aa (155 -170)	161.3 ± 1.15 Aa (160 - 162)	170 ± 5 Aa (165 - 175)	163.3 ± 10 Aa (152 - 171)	**164 ± 6.8 A (152 -175)**
	AR	164.6 ±10.01 Aa (155 - 175)	162.6 ± 8.50 Aa (154 - 171)	166 ± 10.1 Aa (155 - 175)	166 ± 18.5 Aa (148 - 185)	**164.8 ± 10.7A (148 - 185)**
	RN	180 ± 11.13 Aa (170 - 192)	167.6 ± 5.50 Aa (164 - 174)	168 ± 6 Aa (162 - 174)	176.6 ± 9.07 Aa (167 - 185)	**173 ± 9 A (162 - 192)**

	Season Effect	**168.7 ± 11.96 a (155 - 192)**	**163.8 ± 5.86 a (154 - 174)**	**168 ± 6.63 a (155 - 175)**	**168.6 ± 12.9 a (148 - 185)**	
HARD (ppm)	LN	92 ± 10 Aa (82 - 102)	94.33 ± 1.15 Aa (93 - 95)	95.6 ± 8.50 Aa (86 - 102)	89.33 ± 1.52 Aa (88 - 91)	**92.8 ± 6.19 A (82 - 102)**
	AR	96 ± 5.29 Aa (90 -100)	95.66 ± 6.02 Aa (90 - 102)	96.3 ± 7.50 Aa (89 - 104)	92.33 ± 18.61Aa (75 - 112)	**95 ± 9.36 AB (75 - 112)**
	RN	103.6 ± 5.68 Aa (99 - 110)	102.33 ± 6.50 Aa (96 - 109)	103.6 ± 10.2 Aa (92 - 111)	100 ± 8.54 Aa (92 - 109)	**102.4 ± 6.94 B (92 - 111)**
	Season Effect	**97.2 ± 8.15 a (82 - 110)**	**97.4 ± 5.8 a (90 - 109)**	**98.5 ± 8.54 a (86 - 111)**	**93.8 ± 11.3 a (75 - 112)**	
ALK (ppm)	LN	101 ± 1 A ab (100 -102)	106 ± 1 A bc (105 -107)	110 ± 2 Ac (108- 112)	99.66 ± 3.78 Aa (97- 104)	**104 .1 ± 4.7 A (97 -112)**
	AR	103.6 ± 3.05 Aa (101-107)	105 ± 6.24 Aa (98 - 110)	108.33 ± 13.20 Aa (94- 120)	96 ± 12.7 Aa (82 - 107)	**103.2 ± 9.6 A (82- 120)**
	RN	105.6 ± 8.02 Aa (98-114)	105.33 ± 6.42 Aa (98 - 110)	105 ± 8.5 Aa (97 - 114)	104 ± 5.29 Aa (100 - 110)	**105 ± 6.16 A (97 - 114)**
	Season Effect	**103.4 ± 4.7 a (98 - 114)**	**105.4 ± 4.53 a (98 - 110)**	**107.7 ± 8.22 a (94 - 120)**	**99.8 ± 7.95 a (82 - 110)**	
CL (ppm)	LN	6.1 ± 0.1 Aa (6 - 6.2)	7 ± 1 Aa (6 - 8)	8 ± 1 Aa (7- 9)	7 ± 1 Aa (6 - 8)	**7.02 ± 1.01 A (6 - 9)**
	AR	6.8 ± 0.65 Aa (6.2 - 7.5)	7.33 ± 1.66 Aa (5.8- 9.1)	7.73 ± 0.56 Aa (7.1 - 8.2)	6.80 ± 0.30 Aa (6.5 - 7.1)	**7.16 ± 0.90 A (5.8 - 9.1)**
	RN	7.33 ± 0.68 Aa (6.8 - 8.1)	9.03 ± 1.38 Aa (7.5 - 10.2)	8.4 ± 1.15 Aa (7.2 - 9.5)	9.26 ± 2.05 Aa (7 - 11)	**8.5 ± 1.43 B (6.8 - 11)**
	Season Effect	**6.74 ± 0.71 a (6 - 8.1)**	**7.78 ± 1.52 a (5.8 – 10.2)**	**8.05 ± 0.87 a (7 - 9.5)**	**7.68 ± 1.65 a (6 - 11)**	
F (ppm)	LN	0.34 ± 0.01 Aa (0.33 - 0.35)	0.33 ± 0.02 Aa (0.31- 0.35)	0.35 ± 0.06 Aa (0.28 - 0.41)	0.32 ± 0.10 Aa (0.21 - 0.42)	**0.33 ± 0.05 A (0.21 - 0.42)**
	AR	0.35 ± 0.06 Aa (0.29 - 0.41)	0.33 ± 0.01 Aa (0.32 - 0.35)	0.34 ± 0.05 Aa (0.29 - 0.39)	0.35 ± 0.08 Aa (0.28 - 0.44)	**0.34 ± 0.04 A (0.28 - 0.44)**
	RN	0.44 ± 0.09 Aa (0.38 - 0.55)	0.41 ± 0.08 Aa (0.36 - 0.5)	0.39 ± 0.06 Aa (0.33 - 0.45)	0.43 ± 0.09 Aa (0.33 - 0.51)	**0.42 ± 0.07 B (0.33 - 0.51)**
	Season Effect	**0.38 ± 0.074 a (0.29 - 0.55)**	**0.36 ± 0.059 a (0.31- 0.51)**	**0.36 ± 0.057 a (0.28 - 0.45)**	**0.37 ± 0.096 a (0.21 - 0.51)**	
SO_4 (ppm)	LN	11.2 ± 2.16 Aa (8.9- 13.2)	11.76 ± 1.86 Aa (9.8 - 13.5)	11.3 ± 2.51 Aa (9 - 14)	11 ± 2 Aa (9 - 13)	**11.3 ± 1.85 A (8.9 - 14)**
	AR	12.16 ± 1.75 Aa (10.5-14)	11.96 ± 1.62 Aa (10.2 - 13.4)	11.70 ± 1.41 Aa (10.40 - 13.20)	12.53 ± 1.10 Aa (11.5 - 13.7)	**12.09 ± 1.31 A (10.2 - 14)**
	RN	14.33 ± 1.75 Aa (12.5 - 16)	13.83 ± 1.13 Aa (12.9 - 15.1)	14.76 ± 1.70 Aa (13 - 16.4)	12.66 ± 1.60 Aa (11.5 - 14.5)	**13.9 ± 1.57 B (11.5 - 16.4)**
	Season Effect	**12.56 ± 2.15 a (8.9 - 16)**	**12.52 ± 1.68 a (9.8 – 15.1)**	**12.60 ± 2.33 a (9 - 16.4)**	**12.06 ± 1.61 a (9 – 14.5)**	
NH_3 (ppm)	LN	0.04 ± 0.02 Aa (0.02 - 0.06)	0.05 ± 0.009 Aa (0.04 - 0.06)	0.05 ± 0.02 Aa (0.02 - 0.06)	0.04 ± 0.01 Aa (0.02 - 0.06)	**0.04 ± 0.01 A (0.02 - 0.06)**
	AR	0.04 ± 0.02 Aa (0.02 - 0.07)	0.03 ± 0.01 Aa (0.02 - 0.04)	0.03 ± 0.01 Aa (0.02 - 0.05)	0.035 ± 0.008 Aa (0.02 - 0.04)	**0.03 ± 0.01 A (0.02 - 0.07)**
	RN	0.08 ± 0.05 Aa (0.02 - 0.14)	0.06 ± 0.04 Aa (0.02 - 0.11)	0.08 ± 0.07 Aa (0.03 - 0.17)	0.33 ± 0.48 Aa (0.04 - 0.89)	**0.14 ± 0.24 A (0.02 - 0.8)**
	Season Effect	**0.058 ± 0.037 a (0.027 - 0.14)**	**0.052 ± 0.026 a (0.028 - 0.11)**	**0.057 ± 0.045 a (0.025 - 0.17)**	**0.136 ± 0.28 a (0.025 - 0.89)**	

NO_3 (ppm)	LN	0.42 ± 0.11 Aa (0.32 - 0.55)	0.39 ± 0.01 Aa (0.38 - 0.41)	0.53 ± 0.18 Aa (0.39 - 0.74)	0.52 ± 0.25 Aa (0.28 - 0.78)	**0.46 ± 0.15 A (0.2 - 0.7)**
	AR	0.54 ± 0.11 Aa (0.45 - 0.68)	0.47 ± 0.15 Aa (0.35 - 0.65)	0.47 ± 0.24 Aa (0.27 - 0.75)	0.55 ± 0.32 Aa (0.24 - 0.89)	**0.51 ± 0.19 A (0.2 - 0.8)**
	RN	0.66 ± 0.07 Aa (0.6 - 0.7)	0.71 ± 0.14 Aa (0.58 - 0.87)	0.73 ± 0.18 Aa (0.58 - 0.94)	0.74 ± 0.19 Aa (0.53 - 0.91)	**0.71 ± 0.13 B (0.5 - 0.9)**
	Season Effect	**0.54 ± 0.13 a (0.32 - 0.74)**	**0.52 ± 0.18 a (0.35 - 0.87)**	**0.58 ± 0.21 a (0.27 - 0.94)**	**0.60 ± 0.24 a (0.24 - 0.91)**	
TN (ppm)	LN	0.44 ± 0.10 Aa (0.35- 0.55)	0.45 ± 0.10 Aa (0.37 - 0.57)	0.46 ± 0.19 Aa (0.29 - 0.67)	0.46 ± 0.17 Aa (0.27 - 0.61)	**0.45 ± 0.12 A (0.2 - 0.6)**
	AR	0.49 ± 0.22 Aa (0.30 - 0.74)	0.41 ± 0.20 Aa (0.21 - 0.62)	0.45 ± 0.23 Aa (0.25 - 0.71)	0.50 ± 0.21 Aa (0.28 - 0.71)	**0.46 ± 0.19A (0.2 - 0.7)**
	RN	0.73 ± 0.11 Aa (0.6 - 0.8)	0.75 ± 0.21 Aa (0.56 - 0.98)	0.79 ± 0.18 Aa (0.61 - 0.98)	0.71 ± 0.33 Aa (0.4 - 1.1)	**0.74 ± 0.19 B (0.4 - 1.1)**
	Season Effect	**0.55 ± 0.18 a (0.30 - 0.81)**	**0.54 ± 0.22 a (0.21 - 0.98)**	**0.568 ± 0.242 a (0.25 - 0.98)**	**0.561 ± 0.247 a (0.27 – 1.1)**	
TP (ppm)	LN	0.05 ± 0.01 A ab (0.04 - 0.06)	0.04 ± 0.01 A ab (0.03 - 0.05)	0.03 ± 0.01 Aa (0.02 - 0.04)	0.07 ± 0.02 Ab (0.05 - 0.09)	**0.04 ± 0.02 A (0.02 - 0.09)**
	AR	0.06 ± 0.01A ab (0.06 - 0.08)	0.05 ± 0.01 A ab (0.04 - 0.07)	0.04 ± 0.02 Aa (0.02 - 0.07)	0.09 ± 0.009 Ab (0.08 - 0.09)	**0.06 ± 0.02 A (0.02 - 0.09)**
	RN	0.18 ± 0.06 Aa (0.14 - 0.25)	0.12 ± 0.05 Aa (0.08 - 0.18)	0.13 ± 0.05 Aa (0.09 - 0.19)	0.09 ± 0.01 Aa (0.08 - 0.11)	**0.13 ± 0.05 B (0.08 - 0.25)**
	Season Effect	**0.09 ± 0.06 a (0.04 - 0.24)**	**0.07 ± 0.046 a (0.03 - 0.18)**	**0.068 ± 0.055 a (0.02 - 0.19)**	**0.087 ± 0.017 a (0.05 – 0.11)**	

Capital letters in the vertical direction indicate the site significant while small letters refers to season significant ($P \leq 0.05$). Limits of law 48/1982 : PH (7 – 8.5) – DO (< 5) – COND (-) – TEMP (Over 5ºC) – COD (10) – TDS (500) – HARD (-) – ALK (-) – CL (-) – F (0.5) – SO_4 (200) – NH_3 (0.5) –NO_3 (2) – TN (3.5) – TP (2).

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In multivariate sense of physical water characters, the main effect of site was significant (P = 0.0001) whereas season and interaction effects were insignificant (P> 0.69). By one-way ANOVA, site variations were significant (P=0.0001), and in terms of DFA, the three sites were clearly separated on CVI (95.6%); the physicals of LN were closer to those of AR than to those of RN (Fig. 1a). On CVII which explain small variations (4.4%), LN and AR physicals were slightly overlapped.

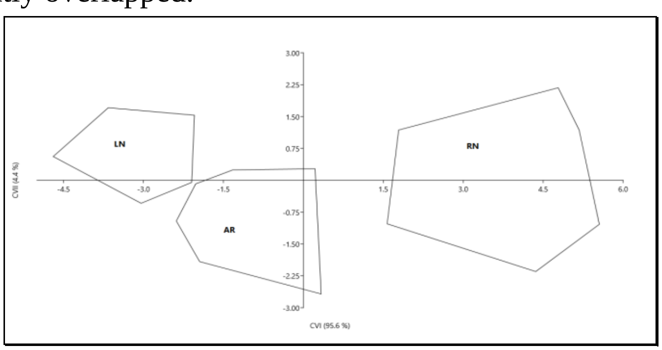

Fig. 1a . An analytical drawing from the past statistical program showing the significant variations of the physical and chemical properties of water samples of (Lake Nasser, Aswan Reservoir and the River Nile during 2021

Table 2. Effect of site and season on heavy metal concentrations of water samples from Lake Nasser (LN), Aswan Reservoir (AR) and River Nile (RN) during 2021

Heavy Metal	Site	Seasons				Site Effect
		Summer	Autumn	Winter	Spring	
Cu (ppm)	LN	0.0072 ± 0.0008 Aa (0.006 - 0.008)	0.0062 ± 0.001 Aa (0.004 - 0.007)	0.0097 ± 0.002 Aa (0.007 - 0.12)	0.0063 ± 0.001 Aa (0.005 - 0.007)	**0.0074 ± 0.001 A (0.004 - 0.012)**
	AR	0.0095 ± 0.001 ABa (0.007 - 0.01)	0.0092 ± 0.003 Aa (0.006 - 0.012)	0.0099 ± 0.002 Aa (0.007 - 0.013)	0.0099 ± 0.001 Aa (0.008 - 0.01)	**0.0096 ± 0.002 A (0.006 - 0.01)**
	RN	0.012 ± 0.002 Ba (0.009 - 0.01)	0.014 ± 0.004 Aa (0.008 - 0.01)	0.016 ± 0.005 Aa (0.009 - 0.02)	0.015 ± 0.006 Aa (0.007 - 0.02)	**0.0146 ± 0.004 B (0.007 - 0.02)**
	Season Effect	**0.0098 ± 0.002 a (0.006 -0.01)**	**0.0099 ± 0.004 a (0.004 - 0.01)**	**0.011 ± 0.004 a (0.007 - 0.02)**	**0.010 ± 0.005 a (0.005 - 0.02)**	
Fe (ppm)	LN	0.053 ± 0.008 Aa (0.04 - 0.06)	0.066 ± 0.01Aa (0.04 - 0.08)	0.077 ± 0.007 Aa (0.06 - 0.08)	0.063 ± 0.01 Aa (0.05 - 0.07)	**0.064 ± 0.013 A (0.04 - 0.08)**
	AR	0.083 ± 0.011 Aa (0.07 - 0.09)	0.050 ± 0.033 Aa (0.01 - 0.07)	0.088 ± 0.033 Aa (0.05 - 0.12)	0.091 ± 0.01 Aa (0.07 - 0.09)	**0.078 ± 0.027 A (0.01 - 0.12)**
	RN	0.138 ± 0.06 Aa (0.08 - 0.2)	0.14 ± 0.02 Ba (0.13 -0.17)	0.14 ± 0.06 Aa (0.07 - 0.2)	0.16 ± 0.06 Aa (0.07 - 0.2)	**0.148 ± 0.05 B (0.07 - 0.22)**
	Season Effect	**0.091 ± 0.05 a (0.04 - 0.21)**	**0.087 ± 0.04 a (0.01 - 0.17)**	**0.103 ± 0.04 a (0.05 - 0.2)**	**0.105 ± 0.05 a (0.05 - 0.2)**	
Pb (ppm)	LN	0.064 ± 0.04 Aa (0.01 - 0.09)	0.007 ± 0.002 Aa (0.005 - 0.009)	0.009 ± 0.004 Aa (0.006 - 0.01)	0.0064 ± 0.003 Aa (0.003 - 0.009)	**0.022 ± 0.032 A (0.003 - 0.098)**
	AR	0.0096 ± 0.002 Aa (0.006 - 0.01)	0.006 ± 0.001 Aa (0.004 - 0.008)	0.007 ± 0.002 Aa (0.004 - 0.009)	0.010 ± 0.004 Aa (0.005 - 0.01)	**0.008 ± 0.003 A (0.004 - 0.01)**
	RN	0.010 ± 0.001 Aa (0.008 - 0.01)	0.042 ± 0.06 Aa (0.007 - 0.11)	0.044 ± 0.06 Aa (0.008 - 0.11)	0.008 ± 0.001Aa (0.007 - 0.009)	**0.026 ± 0.04 A (0.007 - 0.11)**
	Season Effect	**0.028 ± 0.03 a (0.006 - 0.09)**	**0.019 ± 0.03 a (0.004 - 0.11)**	**0.020 ± 0.03 a (0.004 - 0.11)**	**0.008 ± 0.003 a (0.003 - 0.01)**	
Cd (ppm)	LN	0.00046 ± 0.0002 Aa (0.0002 - 0.0006)	0.00048 ± 0.00005 Aa (0.0004 - 0.0005)	0.00037 ± 0.00003 Aa (0.0003 - 0.0004)	0.00042 ± 0.0002 Aa (0.0002 - 0.0006)	**0.0004 ± 0.0001 A (0.0002 - 0.0006)**
	AR	0.0007 ± 0.001 AB a (0.0006 - 0.0008)	0.00064 ± 0.00009Aa (0.0005 - 0.0007)	0.0006 ± 0.0002 AB a (0.0004 - 0.0008)	0.0007 ± 0.0002 Aa (0.0005 - 0.0009)	**0.0007 ± 0.0001 A (0.0004 - 0.0009)**
	RN	0.001 ± 0.0002 Ba (0.0008 - 0.001)	0.0008 ± 0.00009 Ba (0.0007 - 0.0009)	0.001 ± 0.0001 B a (0.0008 - 0.001)	0.003 ± 0.005 Aa (0.0008 - 0.009)	**0.0017 ± 0.002 A (0.0007 - 0.009)**
	Season Effect	0.00074 ± 0.0002 a (0.0002 - 0.001)	0.00069 ± 0.0001 a (0.0004 - 0.0009)	0.00067 ± 0.0003 a (0.0003 - 0.001)	0.0017 ± 0.003 a (0.0002 - 0.009)	
Zn (ppm)	LN	0.0030 ± 0.001 Aa (0.001- 0.005)	0.0031 ± 0.002 Aa (0.001 - 0.005)	0.0051 ± 0.002 AB a (0.002 - 0.006)	0.0029 ± 0.001 Aa (0.001- 0.004)	**0.0035 ± 0.0019 A (0.0012 - 0.006)**
	AR	0.0065 ± 0.0008 Ba (0.005 - 0.007)	0.0046 ± 0.0001 Aa (0.004 - 0.00009)	0.0038 ± 0.0031 A a (0.001 - 0.007)	0.0055 ± 0.001 AB a (0.004 - 0.006)	**0.0051 ± 0.001 A (0.001 - 0.007)**
	RN	0.00816 ± 0.001 Ba (0.006 - 0.009)	0.0101 ± 0.002 Ba (0.008 - 0.012)	0.0103 ± 0.001 B a (0.008 - 0.01)	0.00813 ± 0.001 Ba (0.006 - 0.009)	**0.0091 ± 0.001 B (0.006 - 0.012)**
	Season Effect	**0.0059 ± 0.002 a (0.001 - 0.009)**	**0.0059 ± 0.003 a (0.001 - 0.01)**	**0.0064 ± 0.003 a (0.001 - 0.01)**	**0.0055 ± 0.002 a (0.001 - 0.009)**	

Capital letters in the vertical direction indicate the site significant while small letters refers to season significant, Permissible limit of law No 48 of 1982 : Cu (1) – Fe (1) – Pb (0.05) – Cd (0.01) – Zn (1).

In multivariate sense of heavy metal water characters, the main effect of site was significant (*P*=0.0001) whereas season and interaction effects were insignificant (*P*> 0.52). By one-way ANOVA, site variations were significant (*P* = 0.0001) and in terms of DFA, the LN and AR were separated as one cluster vs RN on CVI (98%) whereas the heavy metals of LN were separated with overlapping from those of AR on CVII (2%) (Fig. 1b).

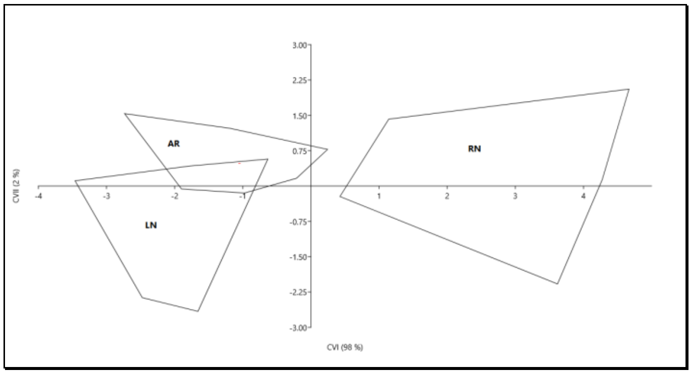

Fig. 1b. An analytical drawing from the past statistical program showing the significant variations of heavy metal concentrations in the water samples of Lake Nasser, Aswan Reservoir and the River Nile during 2021

3. Heavy metals in fish organs

The variations in the concentration of heavy metals in different organs of *Oreochromis niloticus* collected from Lake Nasser, Aswan Reservoir, and the Nile River during summer and winter are shown in Tables (3, 4). The three-way ANOVA reflects highly significant variations for the site, season and organ and their interactions.

In univariate sense, the heavy elemental differences between organs in summer are only significant for Fe (liver > gills > kidney > muscles> gonads), Cd (liver> kidney> gills> gonads > muscles) and Zn (gills> liver> gonads> muscles> kidney) in LN, Cu (liver> kidney> gills> gonads> muscles), Fe (gills > liver > kidney> muscles > gonads) and Zn (gills > kidney > muscles > liver > gonads) in AR and Cu (kidney > gonads > muscles> liver> gills), Fe (liver > kidney > gonads > gills > muscles), Pb (liver>gills> gonads> muscles> kidney), Cd (gonads> liver > gills> muscles> kidney) and Zn (kidney > gills > liver> gonads> muscles) in RN.

The heavy elemental differences between organs in winter are only significant for Cu (liver> muscles> gills> kidney > gonads) and Fe (gonads> muscles> liver> gills> kidney) in LN, Cu (liver> gills> muscles> gonads> kidney), Pb (gills > liver> gonads> kidney> muscles), Cd (kidney> gills> liver> muscles> gonads) and Zn (gonads> liver> gills> kidney > muscles) in AR and Cu (liver> muscles> gills> gonads > kidney), Fe (liver> gills> gonads> kidney> muscles), Pb (muscles> gonads> liver > kidney> gills), and Cd (muscles > gonads> kidney> gills> liver) in RN. In comparison, seasonal pattern of variations were evident as regard residue magnitude and ordering among organs.

Site variations for each organ

In summer, site variations for all organs were significant in all heavy metals, except for Pb in gonads and muscles and for Cd and Zn in kidney. The site order of all metal residues for each organ of the Nile Tilapia was as follows: In liver and gills, RN > LN >AR for all heavy metals; In gonads, RN> AR> LN for Cu, RN > LN > AR for Fe, Cd and Zn; In muscles, RN > LN >AR for Cu, LN > AR >RN for Fe, RN>AR>LN for Cd; In kidney: RN > LN > AR for Cu and Fe, LN >AR>RN for Cd and RN >AR>LN for Zn.

In winter, variations between sites in heavy metal residues of different fish organs were evident with exceptions. The site order of all variations in metal residues for each organ of the Nile tilapia was as follows: In liver, RN > AR >LN for Cu, RN > LN >AR for Fe and Zn, AR > RN >LN for Pb; In gills, RN >LN>AR for Cu and Fe, AR > LN >RN for Pb; In gonads, RN > LN > AR for Cu and Fe, LN > RN >AR for Cd; In muscles, RN > LN >AR for Cu, Fe, Pb and Zn; In kidney, LN >RN >AR for Cu, RN >AR > LN for Fe, LN >AR>RN for Pb. In comparison between the two seasons, patterns of variations were evident as regard to the residue magnitude and ordering among sites studied.

The main effects of site, organ and their interactions of all heavy metal residues in multivariate sense were highly significant ($P= 0.0001$). Moreover, site variations irrespective of organ and organ irrespective of site were significant ($P < 0.0028$).

Table 3. Heavy metal concentrations mg/kg wet weight in different fish organs of *O. niloticus* collected from Lake Nasser (LN), Aswan Reservoir (AR) and River Nile (RN) during summer

HM	Organ	Sites		
		LN	AR	RN
Cu	Liver	0.135 ± 0.13 Aa (0.05 - 0.28)	0.128 ± 0.009 Aa (0.11 - 0.13)	8.00 ± 2.34 B ab (5.5 - 10.2)
	Gills	0.123 ± 0.01 Aa (0.11 - 0.13)	0.066 ± 0.019 Ab (0.05 - 0.08)	4.26 ± 0.13 Ba (4.1 - 4.3)
	Gonads	0.047 ± 0.02Aa (0.03 - 0.07)	0.054 ± 0.001 Ab (0.052- 0.055)	9.99 ± 2.5 Bb (7.5 - 12.5)
	Muscles	0.066 ± 0.02 Aa (0.04 - 0.08)	0.015 ± 0.005 Ac (0.01 - 0.02)	9.42 ± 0.70 Bb (8.6 - 9.9)
	Kidney	0.107 ± 0.07 Aa (0.04 - 0.19)	0.095 ± 0.002 Ad (0.093- 0.097)	22 ±1.26 Bc (20.6 - 23.1)
Fe	Liver	1.36 ± 0.09 Aa (1.2 - 1.4)	0.558 ± 0.05 A ab (0.4 - 0.6)	12.57 ± 0.98 Ba (11.8 - 13.6)
	Gills	1.21 ± 0.05 Aa (1.1 - 1.2)	0.667 ± 0.25 Ab (0.4 - 0.9)	4.07 ± 1.38 Bb (2.8 - 5.6)
	Gonads	0.638 ± 0.10 Ab (0.5 - 0.7)	0.253 ± 0.09 Aa (0.1 - 0.3)	9.24 ± 1.14 Bc (7.9 - 10.2)
	Muscles	0.678 ± 0.32 Ab (0.3 - 0.9)	0.295 ± 0.16 AB ab (0.1 - 0.4)	0.005 ± 0.003 Bd (0.002 - 0.008)
	Kidney	1.14 ± 0.01 Aa (1.13 - 1.15)	0.362 ± 0.08 A ab (0.2 - 0.4)	12.14 ± 1.15 Ba (10.8 - 13.06)
Pb	Liver	0.260 ± 0.10 Aa (0.1 - 0.3)	0.097 ± 0.092 Aa (0.02 - 0.2)	10.54 ± 0.75 Ba (9.8 - 11.3)
	Gills	0.137 ± 0.04 Aa (0.09 - 0.18)	0.011 ± 0.002 Aa (0.009 - 0.01)	1.49 ± 0.19 Bb (1.2 - 1.6)
	Gonads	0.043 ± 0.002 Aa (0.041 - 0.046)	0.111 ± 0.002 Aa (0.10 - 0.11)	0.107 ± 0.09 Ac (0.02 - 0.20)
	Muscles	0.076 ± 0.008 Aa (0.06 - 0.08)	0.025 ± 0.03 Aa (0.001 - 0.07)	0.067 ± 0.02 Ac (0.04 - 0.09)
	Kidney	0.337 ± 0.40 Aa (0.07 - 0.8)	0.022 ± 0.01 Aa (0.01 - 0.03)	0.003 ± 0.003 Ac (0.0009- 0.007)
Cd	Liver	0.260 ± 0.18 Aa (0.08 - 0.4)	0.073 ± 0.02 Aa (0.05 - 0.10)	3.79 ± 0.47 Ba (3.3 - 4.2)
	Gills	0.157 ± 0.07 Aa (0.09 - 0.24)	0.257 ± 0.22 Aa (0.07 - 0.50)	0.742 ± 0.17 Bb (0.5 - 0.8)
	Gonads	0.046 ± 0.03 Aa (0.009 - 0.08)	0.034 ± 0.04 Aa (0.005 - 0.09)	4.64 ± 0.87 Ba (3.6 - 5.3)
	Muscles	0.004 ±0.002 Aa (0.002- 0.006)	0.024 ± 0.003 Aa (0.021 - 0.027)	0.700 ± 0.20 Bb (0.5 - 0.9)
	Kidney	0.207 ± 0.06 Aa (0.15 - 0.28)	0.023 ± 0.002 Ba (0.021- 0.025)	0.004 ± 0.002 Bb (0.002- 0.007)
Zn	Liver	0.620 ± 0.32 Aa (0.25 - 0.85)	0.207 ± 0.007 Aab (0.1 - 0.2)	8.27 ± 1.81 B ab (6.2 - 9.8)
	Gills	1.25 ± 0.05 Ab (1.2 - 1.3)	0.542 ± 0.01 Ac (0.52 - 0.55)	9.43 ± 4.51 B ab (5.8 - 14.5)
	Gonads	0.367 ± 0.16 Aac (0.2 - 0.5)	0.116 ± 0.04 Aa (0.08 - 0.16)	4.68 ± 2.97 Ba (2.1 - 7.9)
	Muscles	0.182 ± 0.01 Ac (0.16 - 0.19)	0.326 ± 0.01 Ab (0.31 - 0.34)	3.45 ± 2.45 Aa (1.05 - 5.9)
	Kidney	0.144 ± 0.002 Ac (0.142- 0.146)	0.528 ± 0.16 Ac (0.38 - 0.70)	12.83 ± 0.93 Bb (11.7 - 13.5)

Capital letters in the horizontal direction indicate the site significant while small letters in the vertical direction refers to organ significant ($P \leq 0.05$). The permissible limits of the Egyptian Health Law No. 7163 / 2010: Cu (-), Fe (-), Pb (0.3), Cd (0.05), Zn (-) mg/kg, wet weight.

Table 4. Heavy metal concentrations in different fish organs of *O. niloticus* mg/ kg wet weight collected from Lake Nasser (LN), Aswan Reservoir (AR) and the River Nile (RN) during winter

HM	Organ	Sites		
		LN	AR	RN
Cu	Liver	0.132 ± 0.001 Aa (0.130 - 0.133)	0.255 ± 0.002 Aa (0.253- 0.257)	8.90 ± 1.45 Ba (7.2 - 9.8)
	Gills	0.082 ± 0.003 A bc (0.07 - 0.08)	0.077 ± 0.01 Ab (0.06 - 0.09)	0.21 ± 0.01 Bb (0.1 - 0.2)
	Gonads	0.055 ± 0.02 Ab (0.02 - 0.08)	0.038 ± 0.002 A cd (0.035 - 0.039)	0.151 ± 0.01 Bb (0.13 - 0.16)
	Muscles	0.092 ± 0.001 Ac (0.091- 0.094)	0.063 ± 0.02 A db (0.03 - 0.08)	0.285 ± 0.08 Bb (0.1 - 0.3)
	Kidney	0.078± 0.003 Abc (0.07 - 0.08)	0.011± 0.001 Bc (0.010 - 0.012)	0.051 ± 0.01Cb (0.03 - 0.06)
Fe	Liver	0.645 ± 0.10 A ab (0.5 - 0.7)	0.314 ± 0.10 Aa (0.2 - 0.4)	4.68 ± 1.11 Ba (3.4 - 5.6)
	Gills	0.495 ± 0.15 A ab (0.3 - 0.6)	0.457 ± 0.15 Aa (0.3 - 0.6)	1.36 ± 0.08 Bb (1.2 - 1.4)
	Gonads	0.692 ± 0.16 Ab (0.5 - 0.8)	0.584 ± 0.19 Aa (0.3 - 0.7)	1.31 ± 0.12 Bb (1.1 - 1.4)
	Muscles	0.647 ± 0.04 A a (0.61 - 0.69)	0.246 ± 0.23 Ba (0 - 0.4)	0.666 ± 0.14 Ab (0.5 - 0.8)
	Kidney	0.383 ± 0.002 Aa (0.381 - 0.386)	0.506 ± 0.04 Ba (0.4 - 0.5)	0.751 ± 0.05 Cb (0.6 - 0.7)
Pb	Liver	0.024 ± 0.003 Aa (0.021 - 0.027)	0.700 ± 0.22 Ba (0.4 - 0.8)	0.052 ± 0.02 Aa (0.03 - 0.07)
	Gills	0.025 ± 0.002 Aa (0.022 - 0.027)	0.737 ± 0.16 Ba (0.5 - 0.8)	0.002 ±0.001 Aa (0.001- 0.004)
	Gonads	0.088 ± 0.06 Aa (0.01 - 0.1)	0.383 ± 0.21 Aab (0.1 - 0.5)	0.100 ± 0.09 Aa (0.01 - 0.02)
	Muscles	0.064 ± 0.003 Aa (0.061 - 0.067)	0.012 ± 0.001 Bb (0.011 - 0.014)	0.107 ± 0.01 Ca (0.09 - 0.12)
	Kidney	0.056 ± 0.004 Aa (0.051 - 0.059)	0.029 ± 0.008 Bb (0.02 - 0.03)	0.003 ± 0.001 Ca (0.001- 0.004)
Cd	Liver	0.016 ± 0.003 Aa (0.013 - 0.019)	0.050 ± 0.06 Aa (0.01 - 0.13)	0.003 ± 0.002 Aa (0.001- 0.005)
	Gills	0.046 ± 0.06 Aa (0.01 - 0.1)	0.070 ± 0.01Aa (0.05 - 0.08)	0.006 ± 0.001 Aa (0.005- 0.008)
	Gonads	0.034 ± 0.003 Aa (0.031 - 0.037)	0.019 ± 0.002 Ba (0.01 - 0.02)	0.032 ± 0.001 Aa (0.031 - 0.034)
	Muscles	0.032 ± 0.02 Aa (0.007 - 0.05)	0.025 ± 0.003 Aa (0.021- 0.028)	0.330 ± 0.21 Ab (0.09 - 0.50)
	Kidney	0.028 ± 0.003 Aa (0.02 -0.03)	0.284 ± 0.21 Aa (0.05 - 0.48)	0.009 ± 0.002 Aa (0.007- 0.012)
Zn	Liver	0.662 ± 0.44 Aa (0.14 - 0.97)	0.217 ± 0.01 Aa (0.20 - 0.23)	2.16 ± 0.89 Ba (1.3 - 3.1)
	Gills	0.675 ± 0.11 Aa (0.5 - 0.7)	0.194 ± 0.01 Aa (0.17 - 0.20)	3.23 ± 2.23 Aa (1.4 - 5.7)
	Gonads	0.440 ± 0.12 Aa (0.3 - 0.5)	0.507 ± 0.18 Ab (0.3 - 0.7)	3.13 ± 2.02 Aa (1.6 - 5.4)
	Muscles	0.270 ± 0.03 Aa (0.2 - 0.3)	0.034 ± 0.002 Ba (0.032-0.036)	0.287 ± 0.03 Aa (0.2 - 0.3)
	Kidney	0.164 ± 0.002 Aa (0.162 - 0.166)	0.074 ± 0.02 Aa (0.05 - 0.09)	1.19 ± 1 Aa (0.5 - 2.3)

Capital letters in the horizontal direction indicate the site significant while small letters in the vertical direction refers to organ significant ($P \leq 0.05$). The permissible limits of the Egyptian Health Law No. 7163/2010: Cu (-), Fe (-), Pb (0.3), Cd (0.05), Zn (-) mg/kg wet weight.

In Lake Nasser, significant inter- organ variations of heavy metal residues in multivariate sense (*P* = 0.0013) were evident since these residues were separated on both CVI (74.5%) and CVII (20.1%) of DFA (Fig. 2a). Significant pattern of variations was also evident in Aswan Reservoir (*P* = 0.0218) with liver residues separated on CVI (77.5%) vs the remaining organs which were separated on CVII (17.9%) with overlapping (Fig. 2b). In the River Nile, heavy metal residues reflected significant variation between organs (*P*= 0.04) with clustering of organs on both CVI (53.3%) and CVII (27.4%) with overlapping or obvious separation in different cases (Fig. 2c). For each organ, multivariate site variations in heavy metal residues were significant (*P*≤ 0.0001) with RN vs. LN and AR separated on CVI (79.4%); LN and AR were separated on CVII (20.6%) with little overlapping (Fig. 2d as representative of organs).

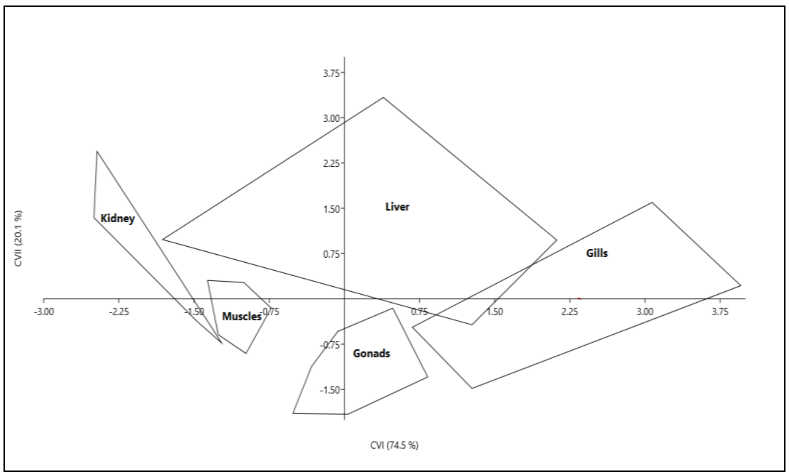

Fig. 2a. An analytical drawing from the past statistical program showing the significant differences of the heavy metals concentration between the different organs of the Nile tilapia at the Lake Nasser site during summer and winter

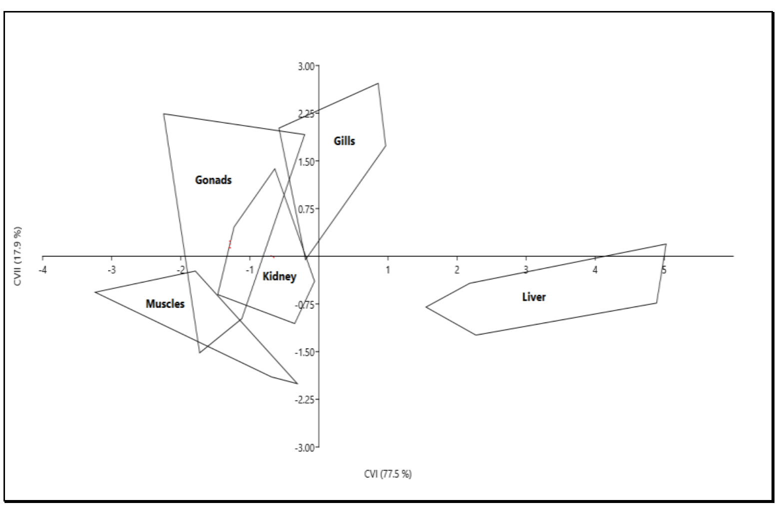

Fig. 2b. An analytical drawing from the past statistical program showing the significant differences of the heavy metals concentration between the different organs of the Nile tilapia at the Aswan reservoir site during summer and winter

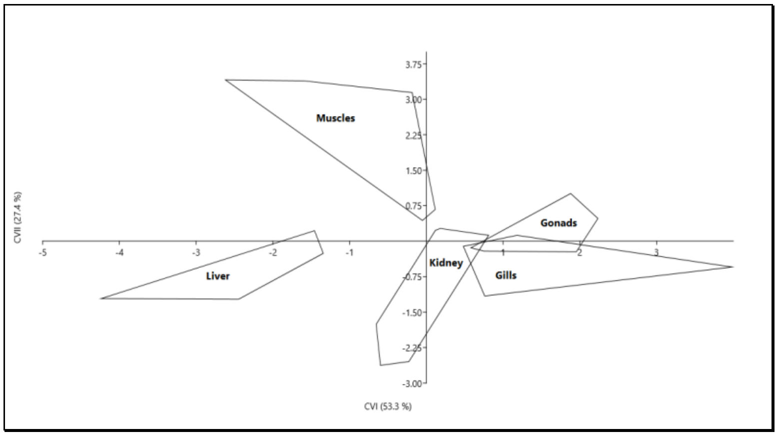

Fig. 2c. An analytical drawing from the past statistical program showing the significant differences of the heavy metals concentration between the different organs of the Nile tilapia at the River Nile site during summer and winter

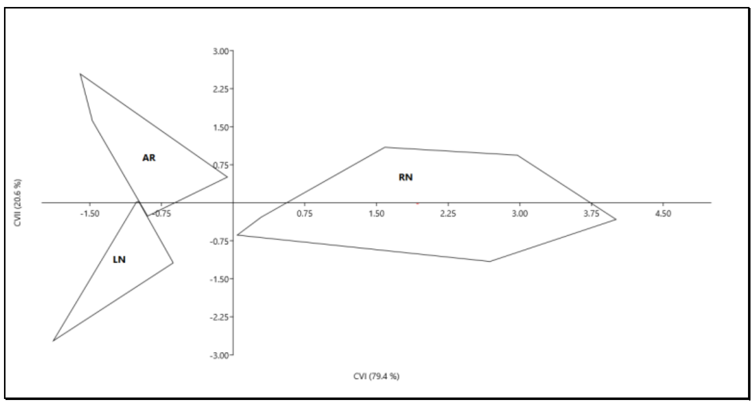

Fig. 2d. An analytical drawing from the past statistical program showing the significant differences in the heavy metals concentration in the kidney of *O. niloticus* between different sites during the summer and winter

4. Bio-concentration factor (BCF)

The pattern of high values and variations in the BCF of Cu, Fe, Pb, Cd and Zn in different organs of *O. niloticus* collected from Lake Nasser, Aswan Reservoir and the River Nile are presented in Table (5). The three-way ANOVA analysis reflects strong significant main effects for the site, season and organ and their interactions. Bioaccumulation factors of different organs were significantly different for Zn (gills> liver> gonads > muscles > kidney) in LN, Cu (liver > gills > kidney > gonads > muscles) in AR and Pb (liver > gills > gonads > muscles > kidney) and Fe (liver > kidney > gonads > gills > muscles) in RN. On the other hand, organ bioaccumulation factors of different sites were significantly different for liver in Cu and Pb (RN > AR > LN) and Fe and Zn (RN > LN > AR); for gills in Cu and Zn (RN > LN > AR); for gonads in Cu, Fe and Cd (RN > LN> AR), Pb (AR > RN> LN) and Zn (RN > AR > LN); for muscles in Cu, Pb and Cd (RN > LN >AR) and in Fe (LN > AR > RN) ; for kidney in Cu (RN > LN > AR), Pb (LN > AR > RN) and Zn (RN > AR > LN).

Table 5. Bio concentrationfFactor of heavy metals in different fish organs of *O. niloticus* mg/ kg wet weight collected from Lake Nasser (LN), Aswan Reservoir (AR) and the River Nile (RN) during summer and winter

HM	**Site**	**Organs**				
		liver	gills	Gonads	muscles	kidney
Cu BCF	**LN**	15.9 ± 10.3 Aa (6.8 - 35.8)	12.7 ± 4.67 Aa (6.8 -17.5)	6.25 ± 3.17 Aa (2.6 - 10.8)	9.47 ± 2.50 Aa (5.7- 12.7)	11.9 ± 9.03 ABa (5.4 - 29.6)
	AR	20.3 ± 8.5 Aa (11.2 - 32.6)	7.62 ± 2.36 Ab (4.7 - 11.4)	4.91 ± 1.4 Ab (2.7 - 7.05)	4.05 ± 3.10 Ab (1.14 - 9.31)	5.68 ± 5.14 Ab (0.76 -12.4)
	RN	636.9 ± 246.8 Ba (397.1- 985.1)	180.7 ±188.7 Ba (10.6 - 436.3)	411.2 ± 466.5 Ba (7.6 -1020)	395.3 ± 433.5 Ba (11.2 - 1013.06)	902.4 ± 1032.8 Ba (1.8 - 2365.6)
Fe BCF	**LN**	17.2 ±10.3 Aa (7.02 - 30.2)	14.7 ± 9.4 Aa (4.7-25.5)	10.49 ± 2.3 ABa (7.3 - 14.2)	10.40 ± 3.79 Aa (6.8 - 15.7)	13.42 ± 9.48 Aa (4.5 - 25.1)
	AR	5.48 ± 2.38 Aa (2.4 -7.7)	7.07 ± 3.3 Aa (2.6 - 11.6)	5.5 ± 4.6 Aa (2.2 -14.5)	4.17 ± 2.76 Ba (1.8 - 8.5)	5.42 ± 2.39 Aa (3.7 - 10.03)
	RN	71.04 ± 52.3 Ba (23.7-163.02)	22.8 ± 17.9 Aab (6.9 - 46.6)	43.02 ± 39.19 Bab (5.59 - 95.14)	2.71 ± 3.39 Bb (0.01- 8)	52.45 ± 55.86 Aab (3.6 - 129.05)
Pb BCF	**LN**	4.78 ± 3.8 Aa (1.4 -12.3)	3.97 ± 3.8 Aa (1.06 - 11.5)	5.85 ± 7.45 Aa (0.4 - 19.6)	5.48 ± 4.21 ABa (0.7 - 10.6)	6.22 ± 3.10 Aa (1.6 - 9.3)
	AR	56.6 ± 64.5 ABa (2.03 - 169.9)	56.6 ± 75.3 Aa (0.8 - 191.7)	29.49 ± 20.8 Ba (8.7 - 54.6)	1.91 ± 1.97 Aa (0.15 - 5.6)	3.13 ± 1.24 Ba (1.6 - 5)
	RN	540.3 ± 610.2 Ba (0.27-1329.5)	76.5 ± 87.6 Aab (0 - 178.2)	8.16± 8.70 Ab (1.04 - 23.4)	7.68 ± 4.73 Bb (0.78 – 13)	0.23 ± 0.22 Cb (0.02 - 0.5)
Cd BCF	**LN**	419.2 ±707.2 Aa (30.8 - 1836.7)	226.7 ± 156.6 Aa (31.07 - 372.09)	88.8 ± 28.8 Aa (36.7 - 124.03)	50.08 ± 60.5 Aa (4.04 -141.2)	277.42 ± 234.9 Aa (70.6 - 620.4)
	AR	81.9 ± 60.5 Aa (15.3 - 155.03)	217.8 ±192.7 Aa (63.01 - 585.4)	36.6 ± 36.8 Aa (6.3 - 105.3)	36.6 ± 13.3 Aa (26.7 - 61.6)	219.2 ± 285.9 Aa (26.9 - 736.1)
	RN	1899.9 ± 2117.1 Aa (1.04 - 4536.9)	371.4 ± 412.08 Aa (5.2 - 917.5)	2412.6 ± 2803.5 Aa (28.3 - 5900)	502.9 ± 256.2 Ba (106.2 -833.3)	6.69 ± 3.06 Aa (2.08 – 10)
Zn BCF	**LN**	195.4 ± 121.7 Aab (22.9 - 353.06)	345.3 ± 292.9 ABb (100.6 - 858.4)	117.03 ± 44.5 Aab (50.7 - 171.4)	68.11 ± 30.3 Aa (36.4 - 108.4)	50.18 ± 29.03 Aa (24.9 - 94.8)
	AR	59.7 ± 50.18 Aa (26.7 - 153.3)	79.03 ± 30.8 Aa (27.3 - 119.3)	124.7 ± 183.3 Aa (11.6 – 480)	31.7 ± 21.9 Aa (4.8 - 59.8)	53.11 ± 34.51 Aa (12.2 -107.8)
	RN	616.3 ± 450.3 Ba (141.05 - 1169.4)	724.3 ± 572.3 Ba (148.8 - 1726.3)	460.7 ± 313.3 Ba (128.7 - 946.9)	217.8 ± 272.2 Aa (25.3 - 708.6)	859.5 ± 854.8 Ba (58.9 - 2016.8)

Capital letters in the vertical direction indicate the site significant while small letters in the horizontal direction refers to organ significant.

3.5 Hematological characters

The variations of the hematological parameters of *O. niloticus* from the studied sites in different seasons are summarized in Table (6). The main effect of site factor was significant for all hematological characters except WBCs, MCV, NET, MCH and ESO whereas, the main effect of season factor was insignificant for WBCs, LYMPH, NET, HB, RBCs, HCt and MCH. Site-season interaction was only significant for MCV, RBCs, MCHC and HCt. Seasonal variations were only significant for MCHC at Lake Nasser, MONO, ESO, RBC, HCt, MCV, MCH, MCHC and PLT at Aswan Reservoir and MONO, HCt, MCV and MCHC at the River Nile. Site variations were significant for LYMPH and MONO in summer, WBC, RBC, HCt and MCHC in autumn, MONO, ESO, HB, RBC, HCt, MCV and PLT in winter and RBC, HCt, MCHC and PLT in spring.

Table 6. Effect of site and season on hematological parameters in the blood of *Oreochromis niloticus* at Lake Nasser (LN), Aswan Reservoir (AR) and River Nile (RN) in different seasons

Parameter	**Site**	**Season**				**Site effect**
		Summer	Autumn	Winter	Spring	
WBCs (x10^9/L)	LN	107.87 ± 25.83 Aa (75.5 - 132)	97.25± 10.62 ABa (89 - 112)	79.97 ± 35.62 Aa (27.4 - 104.4)	109.62 ± 14.80 Aa (90.2 - 122.1)	**98.68 ± 24.53 A (27.4 - 132)**
	AR	105.25 ± 22.96 Aa (78 - 128)	76.8 ± 20.45 Aa (55 - 97.1)	90.25 ± 20.89 Aa (75 - 120)	116.45 ± 29.99 Aa (89 - 156)	**97.18 ± 26.38 A (55 - 156)**
	RN	107.62 ± 36.99 Aa (72 - 158)	119.6 ± 12.41 Ba (107 - 136.4)	101.17 ± 56.84 Aa (20.8 - 142.8)	135.22 ± 44.20 Aa (88.7 - 184.7)	**115.9 ± 38.99 A (20.8 - 184.7)**
	Season Effect	**106.91 ± 26.47 a (72 - 158)**	**97.88 ± 22.80 a (55 - 136.4)**	**90.46 ± 37.79 a (20.8 - 142.8)**	**120.43 ± 31.07 a (88.7 - 184.7)**	
Lymphocytes %	LN	52 ± 2.16 Aa (50 - 55)	53.5 ± 5.80 Aa (48 - 61)	53.5 ± 5 Aa (48 - 60)	53.25 ± 4.42 Aa (49 - 58)	**53.06 ± 4.12 A (48 - 61)**
	AR	55 ± 1.82 AB a (53 - 57)	51.25 ± 2.98 Aa (48 - 55)	51 ± 2.94 Aa (48 - 55)	52.25 ± 3.09 Aa (48 - 55)	**52.37 ± 2.96 A (48 - 57)**
	RN	58.5 ± 3.10 B a (55 - 62)	55.25 ± 3.40 Aa (52 - 60)	55.25 ± 5.37 Aa (50 - 62)	56.75 ± 4.99 Aa (52 - 62)	**56.43 ± 4.11 B (50 - 62)**
	Season Effect	55.16 ± 3.53 a (50 - 62)	53.33 ± 4.20 a (48 - 61)	53.25 ± 4.51 a (48 - 62)	54.08 ± 4.33 a (48 - 62)	
Monocytes %	LN	18.5 ± 1.29 Aa (17 - 20)	20.5 ± 2.38 Aa (18 - 23)	17.75 ± 1.25 Aa (16 - 19)	19 ± 1.41 Aa (17 - 20)	**18.93 ± 1.80 A (16 - 23)**
	AR	16 ± 1.82 ABa (14 - 18)	20.25 ± 1.70 Ab (18 - 22)	21.75 ± 1.70 Bb (20 - 24)	21.25 ± 2.21 Ab (19 - 24)	**19.81 ± 2.88 A (14 - 24)**
	RN	13.75 ± 1.70 Ba (12 - 16)	16.75 ± 2.75 A ab (14 - 20)	18.25 ± 1.25 Ab (17 - 20)	19.25 ± 1.89 Ab (18 - 22)	**17 ± 2.78 B (12 - 22)**
	Season Effect	**16.08 ± 2.50 a (12 - 20)**	**19.16 ± 2.75 b (14 - 23)**	**19.25 ± 2.26 b (16 - 24)**	**19.83 ± 1.99 b (17 - 24)**	

Neutrophils %	LN	27.5 ± 2.08 Aa (25 - 30)	24.5 ± 3.1 Aa (20 - 27)	27.25 ± 5.12 Aa (20 - 32)	27 ± 3.55 Aa (22 - 30)	**26.56 ± 3.48 A (20 - 32)**
	AR	26.5 ± 1.29 Aa (25 - 28)	27 ± 1.82 Aa (25 - 29)	26.50 ± 2.08 Aa (24 -29)	25.5 ± 1.29 Aa (24 - 27)	**26.37 ± 1.58 A (24 - 29)**
	RN	25.75 ± 2.98 Aa (23 - 30)	26.5 ± 2.08 Aa (24 - 29)	24.25 ± 3.86 Aa (20 - 28)	22.75 ± 3.86 Aa (19 - 28)	**24.81 ± 3.29 A (19 - 30)**
	Season Effect	**26.58 ± 2.15 a (23 - 30)**	**26 ± 2.44 a (20 - 29)**	**26 ± 3.76 a (20 - 32)**	**25.08 ± 3.36 a (19 - 30)**	
Eosinophils %	LN	2 ± 1.41 Aa (0 - 3)	1.5 ± 0.57 Aa (1 - 2)	1.5 ± 0.57 AB a (1 - 2)	1 ± 0.81 Aa (0 - 2)	**1.5 ± 0.89 A (0 - 3)**
	AR	2.50 ± 0.57 Aa (2 - 3)	1.5 ± 0.57 A ab (1 - 2)	0.75 ± 0.5 Ab (0 - 1)	1 ± 0.81 Ab (0 - 2)	**1.43 ± 0.89 A (0 - 3)**
	RN	2 ± 0.81 Aa (1 - 3)	1.5 ± 0.57 Aa (1 - 2)	2.25 ± 0.95 B a (1 - 3)	1.50 ± 0.57 Aa (1 - 2)	**1.81 ± 0.75 A (1 - 3)**
	Season Effect	**2.16 ± 0.93 a (0 - 3)**	**1.5 ± 0.52 ab (1 - 2)**	**1.5 ± 0.90 ab (0 - 3)**	**1.16 ± 0.71 b (0 - 2)**	
Hemoglobin g/ dl	LN	10.4 ± 1.82 Aa (8.5 - 12.4)	11.22 ± 1.42 Aa (10.3 - 13.3)	11.85 ± 0.42 Aa (11.3 - 12.3)	11.62 ± 1.15 Aa (10.3 - 13)	**11.29 ± 1.29 A (8.5 - 13.3)**
	AR	8.95 ± 0.98 Aa (7.9 - 10.2)	9.7 ± 0.81 Aa (8.9 - 10.7)	9.42 ± 1.04 Ba (7.9 - 10.2)	10.92 ± 2.02 Aa (8.9 - 13)	**9.75 ± 1.39 B (7.9 - 13)**
	RN	9.75 ± 0.68 Aa (8.8 - 10.4)	9.47 ± 0.58 Aa (8.8 - 10.1)	8.52 ± 0.90 Ba (7.3 - 9.3)	8.85 ± 2.49 Aa (6.8 - 12.1)	**9.15 ± 1.34 B (6.8 - 12.1)**
	Season Effect	**9.72 ± 1.31 a (7.9 - 12.4)**	**10.13 ± 1.21 a (8.8 - 13.3)**	**9.93 ± 1.64 a (7.3 - 12.3)**	**10.46 ± 2.16 a (6.8 - 13)**	
RBCs ($x10^{12}$/L)	LN	2.08 ± 0.82 Aa (1.3 - 3.1)	2.36 ± 0.54 Aa (1.8 - 3.1)	2.31 ± 0.71 Aa (1.4 - 3.2)	1.83 ± 0.31 Aa (1.6 - 2.3)	**2.14 ± 0.60 A (1.3 - 3.2)**
	AR	1.45 ± 0.12 Aa (1.3 - 1.6)	1.43 ± 0.24 Ba (1.2 - 1.7)	1.23 ± 0.20 Ba (1.02 - 1.52)	2.17 ± 0.43 Ab (1.7 - 2.6)	**1.57 ± 0.44 B (1 - 2.6)**
	RN	1.42 ± 0.52 Aa (1.1 - 2.2)	1.36 ± 0.34 Ba (1.1 - 1.8)	1.67 ± 0.47 AB a (1.06 - 2.14)	1.22 ± 0.15 Ba (1.1 - 1.4)	**1.42 ± 0.39 B (1 - 2.2)**
	Season Effect	**1.65 ± 0.60 a (1.1 - 3.1)**	**1.71 ± 0.59 a (1.1 - 3.1)**	**1.73 ± 0.65 a (1 - 3.2)**	**1.74 ± 0.50 a (1.1 - 2.6)**	
Hematocrit (Hct)%	LN	35 ± 8.48 Aa (27 - 45)	35.25 ± 7.63 Aa (28 - 46)	36.25 ± 5.31Aa (32 - 44)	29.27 ± 6.14 ABa (23.6 - 38)	**33.94 ± 6.87 A (23.6 - 46)**
	AR	26.75 ± 3.86 Aa (23 - 32)	29.25 ± 2.21 ABa (27 - 32)	27 ± 4.24 Aa (22 - 31)	35.55 ± 1.99 Bb (33.3 - 38)	**29.63 ± 4.66 A (22 - 38)**
	RN	25.42 ± 7.42 A ab (18.5 - 35.2)	24.20 ± 4.68 B ab (20.3 - 30.5)	13.97 ± 7.19 Ba (6.6 - 20.3)	26.67 ± 3.96 Ab (22.9 - 32)	**22.56 ± 7.48 B (6.6 - 35.2)**
	Season Effect	**29.05 ± 7.63 a (18.5 - 45)**	**29.56 ± 6.74 a (20.3 - 46)**	**25.74 ± 10.85 a (6.6 - 44)**	**30.5 ± 5.55 a (22.9 - 38)**	
Mean corpuscular volume (MCV/ fL)	LN	176.8 ± 31.91 Aa (145.1 - 219.6)	151.39 ± 26.48 Aa (127.2 - 188.8)	166.22 ± 47.04 Aa (137.5 - 236.1)	164.68 ± 51.05 Aa (102.6 - 227.5)	**164.78 ± 37.35 A (102.60 - 236.1)**
	AR	185.22 ± 29.23 Aa (166.6 - 228.5)	209.08 ± 40.30 Aa (168.5 - 262.2)	106.97 ± 15.06 Bb (87.6 - 120.7)	180.35 ± 21.77 Aa (148.3 - 194.9)	**170.41 ± 46.82 A (87.6 - 262.29)**
	RN	184.66 ± 45.22 Aa (142.3 - 245.4)	189.50 ± 71.57 Aa (109.1 - 277.2)	81.46 ± 27.39 Bb (42.3 - 105.)	223.19 ± 57.21Aa (162.4 - 290.9)	**169.7 ± 72.40 A (42.3 - 290.9)**
	Season Effect	**182.24 ± 32.93 a (142.3 - 245.4)**	**183.33 ± 51.55 a (109.1 - 277.2)**	**118.22 ± 47.38 b (42.3 - 236.1)**	**189.4 ± 48.99 a (102.6 - 290.9)**	
Mean corpuscular	LN	54.05 ± 13.3 Aa	48.71 ± 8.42 Aa	55.42 ± 18.63 Aa	64.97 ± 14.14 Aa	**55.78 ± 13.99 A**

hemoglobin (MCH /pg)		(40 - 71.2)	(42.9 - 61.1)	(38.4 - 81.9)	(44.7 - 77.8)	**(38.4 - 81.9)**
	AR	62. 02 ± 8.13 A ab (53.12 - 72.85)	69.33 ± 13.62 Ab (56.1 - 87.7)	42.75 ± 8.91 Ac (31.5 - 51.9)	50.37 ± 0.90 A ac (49.2 - 51.4)	**56.11 ± 13.36 A (31.5 - 87.7)**
	RN	73.74 ± 20.55 Aa (47.2 - 90.9)	73.06 ± 19.20 Aa (47.3 - 91.8)	55.14 ± 21.80 Aa (42.5 - 87.7)	74.81 ± 28.77 Aa (48.2 - 110)	**69.19 ± 22.12 A (42.52 - 110)**
	Season Effect	**63.27 ± 15.90 a (40 - 90.9)**	**63.7 ± 17.19 a (42.9 - 91.8)**	**51.1 ± 16.85 a (31.5 - 87.7)**	**63.38 ± 19.76 a (44.7 - 110)**	
Mean corpuscular hemoglobin concentration (MCHC g/dl)	LN	30.29 ± 2.13 Aa (27.5 - 32.4)	32.31 ± 3.30 Aa (28.9 - 36.7)	33.06 ± 3.43 Aa (27.9 - 35.3)	40.35 ± 4.25 Ab (34.2 - 43.6)	**34 ± 4.95 A (27.5 - 43.6)**
	AR	33.62 ± 2.46 A ab (31.4 - 36.8)	33.14 ± 0.28 A ab (32.8 - 33.4)	39.95 ± 5.55 Ab (34.6 - 46.2)	28.27 ± 3.91 Ba (25.2 - 34)	**33.74 ± 5.36 A (25.2 - 46.2)**
	RN	40.20 ± 8.55 Aab (29.5 - 47.5)	39.86 ± 4.95 B ab (33.1 - 43.8)	75.20 ± 36.83 Ab (41.3 - 110.6)	32.72 ± 4.40 Ba (28.4 - 37.8)	**46.99 ± 24.23 B (28.4 - 110.6)**
	Season Effect	**34.7 ± 6.43 a (27.5 - 47.5)**	**35.11 ± 4.70 a (28.9 - 43.8)**	**49.4 ± 27.44 b (27.9 - 110.6)**	**33.78 ± 6.44 a (25.2 - 43.6)**	
Platelet count PLT($\times 10^9$/L)	LN	110.5 ± 21.73 Aa (87 - 134)	103.25 ± 16.07 Aa (89 - 120)	145.25 ± 64.22 Aa (97 - 239)	102.75 ± 19.41 Aa (78 - 123)	**115.43 ± 37.04 A (78 - 239)**
	AR	156.25 ± 77.34 A ab (111 - 272)	243.5 ± 70.65 Ab (180 - 325)	181 ± 49.87 AB ab (123 - 231)	99.75 ± 17.55 Aa (86 - 125)	**170.12 ± 74.79A (86 - 325)**
	RN	288.75 ± 164.23 Aa (135 - 520)	226.75 ± 121.96 Aa (118 - 344)	390.25 ± 198.21 Ba (120 - 597)	145 ± 27.97 Ba (108 - 176)	**262.68 ± 157.93 B (108 - 597)**
	Season Effect	**185.16 ± 123.89 ab (87 - 520)**	**191.16 ± 98.77 ab (89 - 344)**	**238.83 ± 158.92 b (97 - 597)**	**115.83 ± 29.42 a (78 - 176)**	

Capital letters in the vertical direction indicate the site significant while small letters in the horizontal direction refers to season significant $P \leq 0.05$.

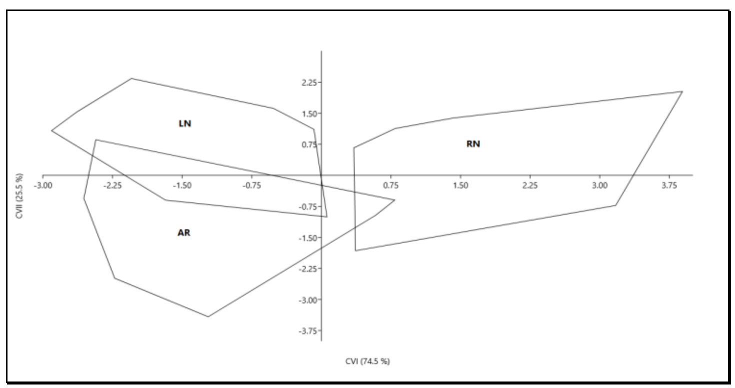

Fig. 3a. An analytical drawing from the past statistical program showing the spatial variations of hematological characters in different seasons.

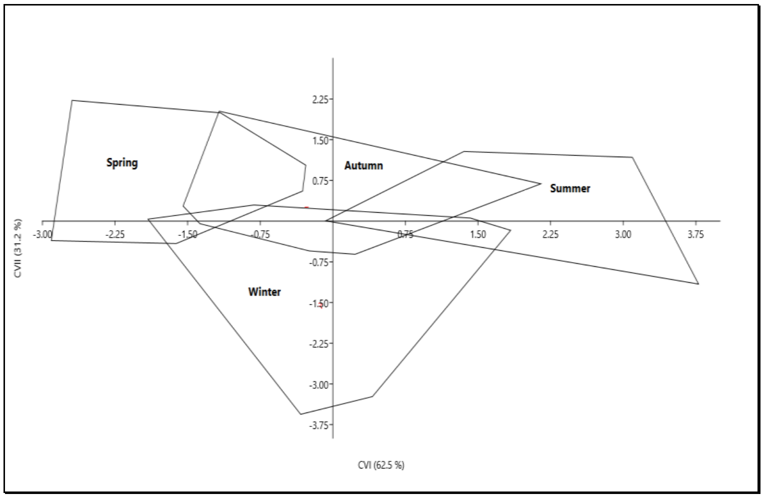

Fig. 3b. An analytical drawing from the past statistical program showing the seasonal variations of hematological characters in different sites.

3.6 Biochemical characters

The variations of the biochemical characters of *O. niloticus* from the studied sites in different seasons are summarized in Table (7). The main effect of site factor was significant for all biochemical characters except UREA,TRI and SUGAR whereas, the main effect of season factor was significant for all characters. Site-season interaction was only insignificant for PT, TRI, GOT and sugar. Seasonal variations were only insignificant for UA, PT, TRI, CHLEST and GPT at Lake Nasser, creatinin, TRI, GPT and sugar at Aswan Reservoir and PT, GOT and sugar at the River Nile. Site variations were insignificant for ALK, TRI, GOT and sugar in summer, albumin, PT, chlest, TRI and sugar in autumn, UA, urea, creatinin, albumin, PT, ALK, chlest, and sugar in winter and UA, creatinin, PT, chlest, TRI and sugar in spring.

Table 7. Effect of site and season on biochemical parameters in the blood of *Oreochromis niloticus* at Lake Nasser (LN), Aswan Reservoir (AR) and River Nile (RN) in different seasons

Parameter	Site	season				Site effect
		Summer	Autumn	Winter	Spring	
Uric Acid UA (mg/dl)	LN	5.07 ± 1.27 Aa (3.7 - 6.7)	4.75 ± 1.07 Aa (3.8 - 6.3)	3.07 ± 0.91Aa (2.5 - 4.4)	4.61 ± 2.91 Aa (2.6 - 8.9)	**4.37 ± 1.75 A (2.5 - 8.9)**
	AR	6.38 ± 1.35 Aa (4.9 -7.9)	5.85 ± 1.67 Aa (4.3 - 8.2)	2.57 ± 0.42 Ab (2.1 - 3.1)	2.88 ± 0.35 Ab (2.3 - 3.1)	**4.42 ± 2.02 A (2.17 - 8.2)**
	RN	16.4 ± 3.93 Ba (10.9 - 19.3)	24.75 ± 6.79 Bb (14.6 - 28.7)	2.38 ± 0.28 Ac (2.02 - 2.69)	3.75 ± 0.46 Ac (3.1 - 4.1)	**11.82 ± 10.18 B (2 - 28.7)**
	Season Effect	**9.28 ± 5.75 a (3.7 - 19.3)**	**11.78 ± 10.27 a (3.8 - 28.7)**	**2.67 ± 0.62 b (2 - 4.4)**	**3.75 ± 1.72 b (2.3 - 8.9)**	
Urea (mg/dl)	LN	9.08 ± 1.24 Aa (7.2 - 10)	7.35 ± 2.18 Aa (5.5 - 10.5)	12.25 ± 2.75 Aa (9 - 15)	24 ± 10.29 Ab (16 - 39)	**13.17 ± 8.30 A (5.5 - 39)**
	AR	10.25 ± 2.21Aa (8 - 13)	14 ± 2.16 B ab (12 - 17)	20.8 ± 9.59 Ab (14.2 - 35)	8.32 ± 0.54 Ba (7.9 - 9.1)	**13.34 ± 6.67 A (7.9 - 35)**

	RN	17.95 ± 3.61 Bab (13.5 - 22.3)	17.97 ± 2.83 Bab (15.8 - 22.1)	20.4 ± 4 Ab (16.3 - 25.2)	12.25 ± 3.5 Ba (8 - 16)	**17.14 ± 4.41 A (8 - 25.2)**
	Season Effect	**12.42 ± 4.71 a (7.2 - 22.3)**	**13.1 ± 5.07 ab (5.5 - 22.1)**	**17.81 ± 6.96 b (9 - 35)**	**14.85 ± 8.98 ab (7.9 - 39)**	
Creatinine (mg/dl)	LN	0.22 ± 0.09 Aa (0.1 - 0.3)	0.29 ± 0.13 Aa (0.1 - 0.4)	0.74 ± 0.19 Ab (0.5 - 0.9)	0.56 ± 0.25 Aab (0.3 - 0.9)	**0.45 ± 0.26 A (0.1 - 0.9)**
	AR	0.47 ± 0.32 Aa (0.1 - 0.8)	1.02 ± 0.54 Ba (0.5 - 1.8)	0.69 ± 0.20 Aa (0.4 - 0.9)	0.43 ± 0.03 Aa (0.3 - 0.4)	**0.65 ± 0.38 B (0.1 - 1.8)**
	RN	1.37 ± 0.14 Ba (1.1 - 1.5)	1.1 ± 0.08 Ba (1.1 - 1.2)	0.70 ± 0.13 Ab (0.5 - 0.8)	0.48 ± 0.12 Ac (0.3 - 0.5)	**0.93 ± 0.38 C (0.3 - 1.5)**
	Season Effect	**0.69 ± 0.55 ab (0.1 - 1.5)**	**0.83 ± 0.50 b (0.1 - 1.8)**	**0.71 ± 0.16 ab (0.4 - 0.9)**	**0.49 ± 0.15 a (0.3 - 0.9)**	
Albumin ALB (g/dl)	LN	3.55 ± 0.63 Aa (2.7 - 4.2)	2.9 ± 0.64 Aab (2.2 - 3.5)	1.5 ± 0.24 Ab (1.2 - 1.8)	2.63 ± 1.11 Aab (1.4 - 3.7)	**2.64 ± 1 AB (1.2 - 4.2)**
	AR	3.17 ± 0.66 Aa (2.4 - 3.9)	2.7 ± 0.89 Aa (1.6 - 3.7)	1.41 ± 0.15 Ab (1.1 - 1.5)	1.24 ± 0.08 Bb (1.1 - 1.3)	**2.13 ± 0.98 A (1.1 - 3.9)**
	RN	5.38 ± 1.47 Ba (3.7 - 7.3)	3.18 ± 0.68 Ab (2.5 - 4.1)	1.51 ± 0.22 Ac (1.2 - 1.2)	1.36 ± 0.16 Bc (1.1 - 1.5)	**2.86 ± 1.82 B (1.1 - 7.3)**
	Season Effect	**4.03 ± 1.35 a (2.4 - 7.3)**	**2.92 ± 0.70 b (1.6 - 4.1)**	**1.47 ± 0.19 c (1.1 - 1.8)**	**1.74 ± 0.88 c (1.1 - 3.7)**	
Prothrombin time PT(seconds)	LN	6.12 ± 0.33 Aa (5.7 - 6.5)	5.7 ± 0.87 Aa (5.2 - 7)	6.02 ± 0.48 Aa (5.4 - 6.5)	6.47 ± 0.69 Aa (5.7 - 7.2)	**6.08 ± 0.63 A (5.2 - 7.2)**
	AR	7.35 ± 0.42 ABa (6.8 - 7.8)	6.55 ± 0.73 Aab (5.7 - 7.5)	6.02 ± 0.88 Aab (5.3 - 7.2)	5.72 ± 0.55 Ab (5.2 - 6.3)	**6.41 ± 0.87 AB (5.2 - 7.8)**
	RN	8.37 ± 1.63 Ba (6.4 - 10.4)	6.45 ± 0.71 Aa (5.7 - 7.4)	6.92 ± 0.55 Aa (6.3 - 7.6)	6.47 ± 0.86 Aa (5.4 - 7.5)	**7.05 ± 1.22 B (5.4 - 10.4)**
	Season Effect	**7.28 ± 1.31 a (5.7 - 10.4)**	**6.23 ± 0.80 b (5.2 - 7.5)**	**6.32 ± 0.74 b (5.3 - 7.6)**	**6.22 ± 0.74 b (5.2 - 7.5)**	
Alkaline phosphatase ALK (U/L)	LN	104.75 ± 12.84 Aa (91 - 120)	107 ± 9.12 Aa (97 - 117)	115 ± 14.14 Aa (97 - 131)	332.25 ± 125.07 Ab (198 - 499)	**164.75 ± 114.93 A (91 - 499)**
	AR	116.5 ± 13.17 Aa (100 - 129)	66.62 ± 33.63 Bb (19.8 - 99.2)	97.25 ± 14.24 Aab (85 - 117)	69.75 ± 12.80 Bb (56.4 - 87.2)	**87.53 ± 28 B (19.8 - 129)**
	RN	126 ± 28.10 Aa (109 - 168)	121 ± 14.65 Aa (110 - 142)	105 ± 10.42 Aa (97 - 120)	60.15 ± 17.23 Bb (38.6 - 79.2)	**103.03 ± 31.62 B (38.6 - 168)**
	Season Effect	**115.75 ± 19.75 ab (91 - 168)**	**98.2 ± 31.13 a (19.8 - 142)**	**105.75 ± 14.03 a (85 - 131)**	**154.05 ± 147.41b (38.6 - 499)**	
Cholesterol (mg/dl)	LN	122.5 ± 14.79 Aa (104 - 139)	126.5 ± 29.17 Aa (100 - 167)	87.5 ± 5.74 Aa (79 - 91)	102 ± 46.31 Aa (48 - 159)	**109.62 ± 30.26 A (48 - 167)**
	AR	114.75 ± 9.46 Aa (101 - 121)	101.25 ± 20.07 Aa (82 - 129)	89.02 ± 36.92 Aab (54.1 - 141)	56.62 ± 7.38 Ab (49.1 - 65.3)	**90.41 ± 29.60 A (49.1 - 141)**
	RN	210 ± 45.61 Ba (148 - 249)	201.5 ± 95.96 Aa (129 - 339)	81.25 ± 28.80 Ab (59 - 122)	107.25 ± 10.96 Aab (95 - 117)	**150 ± 76.56 B (59 - 339)**
	Season Effect	**149.08 ± 51.83 a (101 - 249)**	**143.08 ± 69.50 a (82 - 339)**	**85.92 ± 24.88 b (54.1 - 141)**	**88.62 ± 34.58 b (48 - 159)**	
Triglycerides TRI (mg/dl)	LN	167.25 ± 57.37 Aa (118 - 239)	158.5 ± 32.15 Aa (114 - 187)	71 ± 8.12 Aa (63 - 81)	184 ± 92.05 Aa (95 - 303)	**145.18 ± 67.96 A (63 - 303)**
	AR	184.5 ± 17.99 Aa (162 - 200)	330.25 ± 224.93 Aa (165 - 652)	121 ± 29.56 Ba (97 - 162)	179.25 ± 25.25 Aa (143 - 197)	**203.75 ± 129.76 A (97 - 652)**
	RN	207.25 ± 38.87 Aa (158 - 249)	194.75 ± 8.95 Aab (186 - 207)	98.5 ± 15.69 ABc (78 - 116)	159.75 ± 16.52 Ab (141 - 181)	**165.06 ± 48.17 A (78 - 249)**
	Season Effect	**186.33 ± 41.12 a (118 - 249)**	**227.83 ± 141.64 a (114 - 652)**	**96.83 ± 27.92 b (63 - 162)**	**174.33 ±51.76 ab (95 - 303)**	
Glutamic pyruvic transaminase GPT (U/L)	LN	97.25 ± 11.23 Aa (85 - 112)	110 ± 21.02 Aa (87 - 132)	129.25 ± 28.07 Aa (97 - 165)	130.5 ± 54.68 Aa (98 - 212)	**116.75 ± 32.78 A (85 - 212)**
	AR	207.5 ± 79.38 Aa (109 - 297)	292.75 ± 127.94 Ba (133 - 425)	177.75 ± 57.33 Aa (123 - 234)	170 ± 60.79 AB a (112 - 232)	**212 ± 91.97 B (109 - 425)**
	RN	560.75 ± 205.07 Ba (332 - 820)	327.5 ± 91.57 Bb (251 - 460)	299.5 ± 84.06 Bb (220 - 412)	259.25 ± 51.16 Bb (213 - 324)	**361.75±163.50 C (213 - 820)**
	Season	**288.5 ± 236.35 a**	**243.41 ± 129.61 ab**	**202.16 ± 92.92 ab**	**186.58 ± 75.50 b**	

	Effect	**(85 - 820)**	**(87 - 460)**	**(97 - 412)**	**(98 - 324)**	
Glutamic-oxaloacetic transaminase GOT (U/L)	LN	158 ± 18.81 Aa (137 - 178)	103.25 ± 14.38 Ab (87 - 121)	103.75 ± 19.97 Ab (85 - 132)	105.5 ± 20.07 Ab (88 - 131)	**117.625 ± 29.20 A (85 - 178)**
	AR	291.75 ± 132.86 Aa (153 - 428)	102.75 ± 45.30 Ab (66 - 168)	107.25 ± 17.17 Ab (87 - 122)	108.25 ± 11.02 Ab (98 - 123)	**152.5 ± 104.51 A (66 - 428)**
	RN	263.25 ± 105.66 Aa (198 - 420)	231 ± 63.25 Ba (189 - 325)	235.75 ± 68.10 Ba (154 - 312)	217.5 ± 65.84 Ba (123 - 276)	**236.87 ± 71.57 B (123 - 420)**
	Season Effect	**237.66 ± 107.54 a (137 - 428)**	**145.66 ± 75.36 b (66 - 325)**	**148.91 ± 74.62 b (85 - 312)**	**143.75 ± 65.52 b (88 - 276)**	
Sugar (mg/dl)	LN	131.75 ± 17.55 Aa (110 - 152)	108.25 ± 22.09 Aab (76 - 124)	99 ± 9.01 Ab (88 - 110)	95.25 ± 13.52 Ab (81 - 113)	**108.56 ± 20.66 A (76 - 152)**
	AR	117 ± 23.25 Aa (92 - 147)	91.5 ± 31.71 Aa (67 - 138)	118 ± 14.89 Aa (97 - 132)	102.5 ± 16.62 Aa (87 - 121)	**107.25 ± 23.17 A (67 - 147)**
	RN	119.25 ± 22.91 Aa (98 - 145)	104.75 ± 28.22 Aa (80 - 140)	113.25 ± 19.15 Aa (87 - 132)	100 ± 21.02 Aa (78 - 123)	**109.31 ± 22.02 A (78 - 145)**
	Effect	**122.66 ± 20.50 a (92 - 152)**	**101.5 ± 26.10 ab (67 - 140)**	**110.08 ± 15.93 ab (87 - 132)**	**99.25 ± 15.98 b (78 - 123)**	

Capital letters in the vertical direction indicate the site significant while small letters in the horizontal direction refers to season significant ($P \leq 0.05$).

In the multivariate analysis of biochemical characters, the main effects of site, season, and their interaction were all statistically significant ($P \leq 0.0001$). Based on the canonical variate analysis, biochemical traits of AR exhibited an intermediate position between LN and RN on CVI (88.5% of variation), while on CVII (11.5% of variation), AR characters showed distinct differences compared to LN and RN. Seasonal variations in biochemical characters were evident mainly on CVI (77.8%) and CVII (16.1%) (Fig. 3c, d).

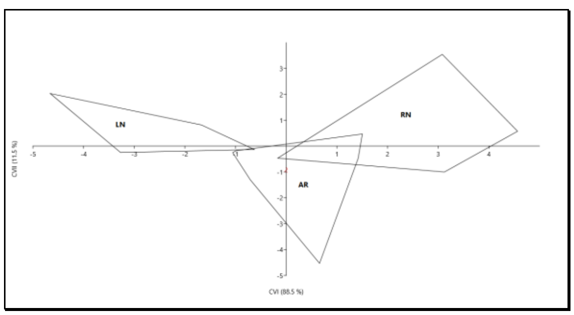

Fig. 3c. An analytical drawing from the past statistical program showing the site variations of biochemical characters in different seasons

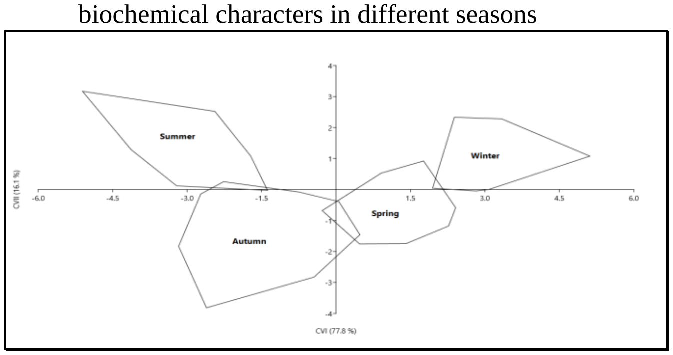

Fig. 3d. An analytical drawing from the past statistical program showing the seasonal variations of biochemical characters in different sites

DISCUSSION

Water quality

Surface water quality is vital in preserving human health and aquatic flora and fauna **(Döndü *et al*., 2022)**. The present study highlighted the significance of site-specific factors in determining water quality. There were significant differences in most physical and chemical parameters, except for PH, temperature (TEMP), total dissolved solids (TDS), alkalinity (ALK), and ammonia (NH3). These findings align with **Zaghloul *et al*. (2023)** and **Abdel-Satar *et al*. (2024a)**, who emphasize the importance of geographic location in shaping water characteristics.

There were significant differences in the location of the River Nile throughout the year in terms of electrical conductivity (COND), chemical oxygen demand (COD), hardness, chloride (CL), fluoride (F), sulfate (SO4), nitrate (NO3), total nitrogen (TN), and total phosphorus (TP). There were also big differences in the location of Lake Nasser in terms of dissolved oxygen (DO) and hardness. Only the hardness of the Aswan reservoir showed significant site variation (Table 1). Multivariate analysis confirmed the site's significant influence on physical water characteristics, with a clear separation of the three sites based on discriminant function analysis (Fig. 1a). This indicates site-specific solid characteristics, particularly distinguishing Lake Nasser and Aswan Reservoir from the River Nile, reflecting unique hydrological and environmental conditions **(Goher *et al*., 2021)**. The slight overlap between Lake Nasser and Aswan Reservoir suggested minor regional influences shared between these two sites **(Abdel-Satar *et al*,. 2024b)**.
COD in the Nile was higher than the permissible limits of Law 48/1982, which indicated organic pollution and negative effects on water quality due to high loads of all forms of organic matter.

The present study agree with the results of **Ali *et al.* (2014)** and **Mekawey *et al*. (2023)**, who suggested the high levels of organic pollutants resulted from untreated wastewater. The increase in DO in Lake Nasser indicates that the lake is healthy and can support aquatic organisms' needs **(Al-Afify *et al*., 2023)**.

Seasonal effects were less pronounced, with only conductivity (COND) and TEMP showing significant variations at all sites; COND recorded a high significance in autumn. This finding is opposite to **Rahman *et al*. (2021)**, who suggested that the electrical conductivity of water declined during the rainy and pre-winter seasons due to water dilution by rainfall. The water temperature following the normal seasonal cycles reported in Egypt is high in summer and low in winter, which agrees with **Taher *et al*. (2021)**.

According to **Abdel-Satar *et al.* (2024b)**, the significant seasonal variations in Lake Nasser's temperature, alkalinity, and total phosphorus demonstrate how vulnerable these variables are to variations. This is most likely due to variations in temperature and nutrient loading, which have an impact on the ecosystem health of the lake. Similarly, Aswan Reservoir displayed significant seasonal variations in TEMP and TP, highlighting the role of seasonal dynamics in influencing nutrient levels **(Rizk *et al.*, 2020)**. In contrast, the River Nile only showed significant seasonal variation in TEMP, indicating a more stable nutrient regime, possibly due to different hydrological or anthropogenic factors.

Heavy metals in water

Heavy metals in aquatic ecosystems are a serious global issue because of their negative features, such as toxicity, persistence, non-biodegradability, and bioaccumulation **(Batapola *et al.*, 2024)**. The location factor's main effect is evident in the highly significant differences in the concentrations of most Cu, Fe, and Zn elements in the River Nile water during the year (Table 2). These findings are consistent with **Imam *et al.* (2020)** and **Abdel-Satar *et al*. (2024b)**. According to **Goher *et al*. (2019)** and **Elmagd *et al*. (2020)**, iron was the most abundant metal at all sites, with a higher level in the River Nile water. Due to the abundance of metals in the earth's crust, water flowing from neighboring coastlines frequently carries soil with it, increasing the concentration of Fe in the water **(El-Degwy *et al*., 2023)**.

In the present study, significant spatial differences were observed in Cu, Cd, and Zn concentrations in the summer, Cd and Zn in the winter, and Zn in the spring. These findings are consistent with other studies conducted by various researchers, including **Elnazer *et al*. (2018)**, **Abdelhafiz *et al.* (2021)** and **El-Khayat *et al*. (2022)**. All these elements were essential at the River Nile site but not so important at the sites of Lake Nasser and Aswan Reservoir (Fig. 1b). Numerous factors, such as the weathering environment, soil type, pH, redox potential, and ability to dilute, contributed to the variances between these sites.

According to **Abdel-Satar *et al*. (2017)**, it is clear that the location factor has a major impact on the concentration of heavy metals in metal-laden urban and agricultural runoff **(Al-Afify & Abdel-Satar, 2022)**. Pb was higher than the permissible limits at Lake Nasser in summer according to Egyptian Law No. 48 of 1982, which could be attributed to the metal getting out from the bottom sediment into the upper water column due to high temperatures and the fermentation process **(El-Degwy *et al*., 2023)**.

This research did not show significant seasonal changes for all trace elements in all locations. These results disagree with those of **El-Tohamy *et al.* (2018)** and **Ghannam (2021)**, who found seasonal variations of heavy metals in different seasons due to temperature and water level differences, which affect the concentrations of heavy metals in water.

Heavy metals in fish

The accumulation of heavy metals in fish organs presents serious health risks, with effects that are potentially carcinogenic, teratogenic, or mutagenic **(Shaalan, 2024)**. In this study, the analysis of heavy metal residues in the Nile tilapia organs from various sites demonstrated significant spatial and seasonal variations. Consistent with the findings of **Elsharkasy *et al.* (2023)**, the concentrations of metals in fish organs were notably higher than in water samples, underscoring the importance of biomonitoring using fish tissues.

Organ-specific differences were observed, as reported by previous studies **(El-Kader *et al*., 2022; Abass, 2024)**. The liver displayed the highest levels of Cu, Fe, and Cd, with the gills primarily concentrating Zn and the gonads, especially in Lake Nasser, abundantly containing Fe (Fig. 2a). We can link these variations to the metabolic roles of the organs. For instance, the liver, a critical detoxifying organ, tends to accumulate higher levels of heavy metals.

The seasonal trends showed that Fe concentrations in the liver of the Nile tilapia were elevated during summer, likely due to increased levels of Fe in the water, in line with **Ahmed *et al.* (2020)**. Conversely, Cu levels were lowest in the gonads during winter, reflecting reduced metal uptake from feeding and environmental sources, as **Ghanem *et al*. (2016)** noted.

The Aswan Reservoir exhibited distinct patterns of metal accumulation, with Cu being more concentrated in the liver than in other organs. At the same time, Zn concentrations were comparable in the gills and kidneys (Fig. 2b). Lead (Pb) accumulation in the gills during winter might be due to leaded petrol spills from fishing boats and agricultural runoff. Additionally, Cu concentrations were lower in the kidneys **(Ghanem, 2019)**.

A distinct pattern of metal distribution was observed in the River Nile, with significant differences among organs. The liver was a primary site for the accumulation of Cu, Fe, and Pb, while the gills and kidneys showed similarities in Zn accumulation, and the gills and gonads in Pb (Fig. 2c). Elevated Cu levels in the kidney during summer, likely due to sewage effluents, matched the findings of **Abdel-Halim *et al*. (2022)**. On the other hand, Cd concentrations were lower in the liver during winter, possibly due to reduced pollutant input, as reported by **Elsayed *et al*. (2019)**. These findings align with **Mohamed (2019)** and **Mohammady *et al*. (2021)**, who highlighted that pollutant accumulation in fish organs is influenced by feeding patterns, species-specific differences, and the organs' physiological roles. In particular, the liver and kidney serve as primary detoxification sites, which may explain their higher metal concentrations.

Spatial variations across sites were also significant. In the River Nile, metal accumulation in the liver and gills was particularly pronounced during summer, with differences in Cu and Fe persisting into winter. Similarly, the gonads exhibited significant differences in all metals except Pb in summer, while the kidney showed marked differences in Cu, Fe, and Zn during summer and Fe in winter (Fig. 2d). In contrast, Lake Nasser showed fewer organ-specific differences, with Cd accumulation in the gonads during winter and Fe in the muscles during summer. The Aswan Reservoir displayed spatial differences primarily for Pb in the liver and gills during winter, with some overlap with Lake Nasser in the kidney (Fig. 2d).

In agreement with **Ghanem (2019)** and **Elwasify *et al.* (2021)**, the kidney was identified as a primary target organ for Cu and Zn, while the liver followed for Fe and Pb. These findings reflect the detoxifying and excretory functions of these organs. On the other hand, muscles were not significant sites of metal accumulation, which is consistent with their physiological roles.

The concentrations of Pb and Cd exceeded permissible limits set by Egyptian Health Law No. 7163/2010 during specific seasons. Elevated Pb levels were detected in the liver tissue of the Nile tilapia from the River Nile during summer and in the liver and gills from the Aswan Reservoir during winter. Similarly, Cd levels were above permissible limits in multiple organs across all study sites, particularly during winter. These exceedances underscore the critical need for monitoring and mitigating pollution in aquatic ecosystems. Seasonal influences were evident, with higher metal concentrations during summer, likely driven by increased evaporation and agricultural runoff, as noted by **Darweesh *et al.* (2019)** and **Ghannam (2021)**. These seasonal patterns highlight the importance of considering temporal factors in environmental monitoring programs.

Bioconcentration factor (BCF)

The bioconcentration factor (BCF) is an essential measure in evaluating the environmental risk of chemicals relevant to academic research **(Zhao *et al.*, 2022)**. It is defined as the ratio of metal concentrations in water and fish **(Komala *et al*., 2022)**.

During the research periods, we identified highly significant variations in the output data of BCF, which linked metal transfer from water to different organs of *O. niloticus* fish. The present study confirmed that the gill tissue collected from Lake Nasser bioaccumulated higher amounts of zinc (Table 5). This observation is compatible with **El-Agri *et al*. (2021)** and **Elowa *et al.* (2022)**, which is attributed to MTs-binding proteins formed due to metal interactions in gill uptake sites, which are involved in biotransformation and defense pathways. This mechanism shields tissues from the harmful effects of heavy metal toxicants. The liver tissue from the Aswan reservoir site bioaccumulates higher levels of copper (Table 5). This finding matches with **Elwasify *et al*. (2021)**, who discovered that Cu exhibited high levels in the liver, which may be related to its ability to retain Cu. The liver is the selective organ for the stock of copper. On the other hand, the liver from the River Nile showed high Pb-BCF and Fe-BCF, possibly due to more detoxification of these metals in the liver **(Girgis *et al.*, 2019)**.

The available information indicated that the physiological function of edible organs, with their capacity for regulation, and the organism's feeding behavior, which plays a significant role in the variations of bioaccumulation in those organs, may be the cause of the differences in the levels of bioaccumulation in the various fish organs **(Ghanem, 2019)**.

The present study highlighted the strong effect of the site and showed its highly significant differences in the bioaccumulation factor of heavy metals in fish organs. Some studies by **Ghannam (2021)** and **Abdel-Halim *et al.* (2022)** corroborate with our findings. The River Nile site showed highly significant site differences in the bioaccumulation factor of all elements for each organ of the Nile tilapia compared to the sites of Lake Nasser and Aswan Reservoir, which had lower values for those elements. The liver and gonads had considerable differences in Cu, Pb, Fe, and Zn levels. The gills had differences in Cu and Zn levels, the muscles had differences in Cu, Fe, Pb, and Cd, and the kidneys had differences in Cu, Pb, and Zn levels (Table 5).

Abdel-Halim *et al.* (2022) agree that the discharge of liquid waste into the water can introduce large quantities of heavy metals (HMs) into the River Nile. However, Cd-BCF recorded the maximum value in the gonads tissue, where fish absorb Cd directly from exposure to contaminated media or by consuming food containing the toxin. According to the United States Environmental Protection Agency **(USEPA, 2008)**, the kidney had higher Cu and zinc BCF levels. This finding was similar to **Tayel *et al.* (2018)**, who found high Cu and Zn BCF in the kidney of *O. niloticus* inhabiting the water of the Damietta branch of the River Nile, followed by Pb and FeBCF in the liver and lower BCF for Fe in the River Nile muscle tissue. The present study agrees with **El-Shenawy *et al*. (2021)**, who reported that heavy metals were significantly higher in fish viscera, including kidney and liver, than in muscle tissue. The liver and kidney showed increasing levels, possibly due to their functional roles as detoxification and excretion **(Elwasify *et al*., 2021)**.

Elwasify *et al*. (2021) and **El-Degwy *et al*. (2023)** have previously shown an apparent seasonal effect, demonstrating an increase in the average values of BCF in the summer and a decrease in the winter for all studied metals in all organs of the Nile tilapia across all sites (Table 5) due to an increase in negative human activities.

Hematology analysis

The hematological examination is one of the most popular methods for assessing fish's physiological state and health **(Witeska *et al*., 2022)**.

The site's impact on the Nile tilapia's hematological parameters throughout the year was evident, particularly at the River Nile site, where there were highly significant spatial differences in lymphocytes, MCHC, and PLT parameters (Table 6). Lymphocytes are a crucial type of white blood cells that play an essential role in fish defensive mechanisms. According to **Segner *et al.* (2022)** and **Ibrahim and ElSayed (2023)**, this elevation suggests that the fish may have immunological responses to the dangerous substances in the water. Most likely, the swelling of red blood cells due to increased carbon dioxide in the blood, hypoxia, or stress led to an increase in MCHC. A platelet increase may occur due to myeloproliferative disease, infections, or anemia caused by iron deficiency or bleeding. There were high differences in the amounts of hemoglobin and red blood cells in Lake Nasser throughout the year, and the lake had a high hematocrit level. On the other hand, the River Nile (El-Sail drain) had low Hb, RBCs, and Hct levels (Table 6).

These results are similar with **Ali *et al*. (2019)**. Environmental conditions directly affect fish red cells, causing a drop in hemoglobin, hematocrit, and RBC count due to pollution **(Guerra *et al*., 2021)**. The spatial variations in each season are illustrated in Fig. (3a), which shows the degree of spatial differences in the location of the River Nile compared to Lake Nasser and Aswan Reservoir. HCT showed a significant decrease at the River Nile site in the autumn, winter, and spring seasons, while it was highly significant in the spring at the Lake Nasser and Aswan Reservoir sites.

The River Nile exhibited a significant decrease in RBCS during the spring, whereas Lake Nasser experienced an increase in it during the autumn and winter seasons. Additionally, there was a significant increase in the values of HCT in the autumn, HB, RBCs, and MCV in the winter, and MCHC in the spring. The observed reduction in RBCs and HCT values of fish in the River Nile due to exposure to different pollutants agrees with **Mohamed *et al*. (2020)**. Generally, fish with high values for these hematological markers (HB, HCT, RBC, MCV, and MCHC) are considered very active, according to **Ahmed *et al*. (2020)**.

Our results agree with several studies indicating location's effect on fish hematology parameters **(Omar *et al*., 2021; Aly *et al*., 2023)**.

All the sites' hematological parameters were affected by the season in a big way. For example, Table (6) shows high seasonal differences in eosinophils during summer because of the higher body metabolic rate caused by the high temperature and reproductive activities **(Fallah *et al*., 2014)**. The significant decrease in monocytes during summer may indicate an ongoing infection, metal-induced cell or tissue damage leading to aberrant hematopoiesis, or direct stimulation of immunological responses by the presence of pollutants **(Sueiro & Palacios, 2016)**. The study also revealed significant seasonal variations in MCHC during winter, which aligns with the findings of **Abduljalil *et al*. (2022)**. According to **Misra *et al*. (2020)**, this increase induced shrinkage of the red cell, causing anemic conditions, and PLT significantly increased during winter. However, this finding does not align with the findings of **Osman *et al.* (2018)** and **Gouda *et al.* (2022)**, who found a significant reduction in the platelet count in *Oreochromis niloticus* exposed to contaminants. **Eissa *et al*. (2015)** agreed with this finding and **Al-Zahaby *et al*. (2017)** suggested that this may lead to a type of anemia known as microcytic.

In the present study, characteristics varied between sites in all seasons (Fig. 3b). Summer recorded high significant seasonal differences in eosinophils at Aswan Reservoir and low monocyte variations at the River Nile and Aswan Reservoir. Autumn showed high MCH and PLT at Aswan Reservoir. At both the Aswan Reservoir and the River Nile sites, the MCHC was high in winter. Spring increased the parameters of MCHC at Lake Nasser, RBCs, and HCT at Aswan Reservoir and HCT at the River Nile, while decreasing the parameters of MCHC and PLT at Aswan Reservoir and MCHC at the River Nile. According to **Ahmed *et al*. (2020)**, fluctuations in ambient temperature and dissolved oxygen concentration associated with changing seasons lead to variability in piscine hematological parameters.

Biochemical analysis

The variations in biochemical parameters are used to determine physiological changes in aquatic ecosystems owing to stressful situations **(Afzal *et al.*, 2024)**. This study agrees with **Said *et al*. (2021)** and **Aly *et al*. (2023)** in the presence of an effect of location on the biochemical parameters of the Nile tilapia as a result of pollution. The results showed that there were highly significant spatial differences at the River Nile site in the criteria of uric acid, cholesterol, and GOT (Table 7). The increase of uric acid-supported environmental pollution in the River Nile causes kidney dysfunction **(Sabae & Mohamed, 2015)**. An increase in uric acid and urea may be due to sewage effluents **(Hassaan, 2011)**. Cholesterol increases may be due to renal and hepatic failure. Other studies support our results, showing an increase in cholesterol concentration in fish exposed to metal pollution **(Öner *et al.*, 2008; Jadán-Piedra *et al.*, 2018)**. Moreover, our results agree with the findings of **Mohamed *et al.* (2020)**, who reported the high level of cholesterol found in fish is affected by waste drainage water. Higher amounts of GOT and GPT in the blood may indicate damage to the Nile tilapia's liver and kidney tissues inhabiting the River Nile. Several studies found an increase in these enzymes following exposure to toxins **(Kavya *et al.*, 2016; El-matary *et al*., 2021)**.

Alkaline phosphatase (ALK) is regarded as a sensitive biological indicator for evaluating damage to the liver and other fish organs following environmental stress **(Kim *et al.*, 2016)**. Our result revealed that a high ALK was recorded in Lake Nasser, opposite to the outcomes of the study of **Osman *et al*. (2018)**, who observed an increase in ALK from the blood of the Nile Tilapia in the River Nile due to heavy metals. Aswan Reservoir exhibits significant spatial differences with the River Nile and Lake Nasser in certain biochemical characteristics—particularly in PT during summer and GPT during spring. The River Nile site had the highest site variations in summer in uric acid, urea, creatinine, albumin, cholesterol, and GPT, followed by Lake Nasser in urea, albumin, and ALK in spring. In contrast, Aswan Reservoir had the highest difference in Triglycerides during winter (Fig. 3c).

Multivariate analysis showed significant seasonal variations of biochemical parameters in sugar, GOT, GPT, cholesterol, PT, and albumin (Table 7) at all sites during summer. This could be attributed to the fish's increased metabolic activity and feeding habits during this season **(Ahmed & Sheikh, 2019)**. Uric acid and creatinine are highly significant in autumn because the land runoff brings terrestrial pollutants and bacteria to the fish habitat **(Abduljalil *et al.*, 2022)**. Urea levels were significantly elevated during winter. This response may be associated with impaired renal function, potentially leading to necrosis of the renal tubules due to reduced urea excretion. This finding is consistent with the results of **Salaah (2018)**. Elevated blood urea levels can occur during liver disease, impaired kidney function, and cardiac arrest **(Hamdy *et al.*, 2018)**.

ALK showed significant variation in spring, likely due to increased catabolic activity associated with heightened metabolic and anabolic processes during this season **(Abduljalil *et al.*, 2022)**.

Seasonal changes had varying effects on biochemical parameters across different locations. The most pronounced seasonal variations were observed in summer, possibly due to increased energy demands, higher feed intake, elevated metabolic rates, and higher temperatures **(Jan & Ahmed, 2021; Reshi & Ahmed, 2022)**. In contrast, winter was associated with a general decrease in most parameters.

Highly significant seasonal differences were noted in several parameters: uric acid and albumin levels varied in summer and autumn at the Aswan Reservoir and the Nile River sites, while sugar levels fluctuated in Lake Nasser. Triglycerides showed a significant increase in the Nile River during autumn and spring. Marked seasonal differences were also recorded for uric acid and cholesterol in the Aswan Reservoir and Nile River, creatinine in Lake Nasser and the Nile River, and albumin in Aswan Reservoir during winter and spring (Fig. 3d).

Alterations in serum biochemical parameters in fish are generally influenced by several factors, including age, season, environmental conditions, stress, diet, and disease **(Kumar *et al.*, 2019; Jan & Ahmed, 2021)**.

CONCLUSION

The current study demonstrated that the Nile tilapia fish inhabiting the River Nile were more affected by poor water quality. Metal pollution has induced changes in the blood profile of *Oreochromis niloticus* followed by the fish inhabiting the Aswan Reservoir and Lake Nasser according to pollution levels due to human, urbanization touristic, agricultural activities, fishing practices, and untreated wastewater. The possible negative health consequences of heavy metals on locals living close to these locations are brought to the attention of this study. Reducing aquatic loss can result in less heavy metal contamination in the environment when new technologies are used properly. In rural areas, it is advised to create a strategic plan for sewage treatment with a specific goal. Furthermore, establishing more programs for enhancing the environmental and health awareness of individuals living on the banks of the River Nile must be promoted.

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