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Impacts of Climate Change on Water Quality using GIS Technique in Water Courses at Egyptian Delta Governorates

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ABSTRACT

The present work aimed to study the water quality of six Delta Egyptian governorates using ArcGIS maps. Compared to winter, water temperature was higher during summer in all selected governorates. Dissolved oxygen (D.O.) was higher than in summer during winter in all selected governorates. The maximum atmospheric temperature (Tmax) was higher in current work than that recorded throughout the past ten years in Damietta and Beheria governorates during spring, while it was high at Kafr El-Sheikh in autumn and summer. Tmax was directly proportional to the observed water temperature and inversely proportional to D.O. Water temperature showed negative correlations with all physicochemical parameters. Cd levels were relatively high in winter in all examined governorates. Pb level raised at Gharbia, Dakahila, and Monfia in winter and spring. Cu and Fe levels were moderately high during all seasons, while Zn levels were high and moderate in Kafr El-Seikh and Damietta in spring. The spatial distribution gave a visual picture of the main parameters affecting the water quality in the examined governorates.

INTRODUCTION

Water quality changes combined with rising atmospheric temperatures due to climate change may affect freshwater ecosystems. Thus, projected changes in global air temperature and rainfall could affect river flows inducing mobility and dilution of contaminants. On the other hand, the increasing water temperatures may affect chemical reaction kinetics, causing impairment in water quality and freshwater ecological status (**Whitehead *et al.*, 2009**). Many authors studied the impacts of the climate change on environmental chemical pollutants (**Whitehead *et al.*, 2009; Balbus *et al.*, 2013; Gouin**

***et al.*, 2013; Kibria *et al.*, 2021)**. Climate change stressors influence the responses, fate, and bioaccumulation of environmental contaminants, besides the persistence and movement of chemical pollutants in the environment. Toxic chemical pollutants may be released, degraded, transported, and mobilized at higher rates due to rising temperatures, which might increase their environmental and human exposure. **Dallas and Rivers-Moore (2014)** discussed the global climate change drivers and ecological consequences in freshwater ecosystems. They stated that the primary climate change drivers are precipitation and air temperature. They added that the ecological consequences of global climate change on freshwater ecosystems may be classified according to the impacts on biological assemblages, habitat, and water quantity and quality.

In their Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) reported that *"The interaction of (i) increased temperature, (ii) increased sediment, nutrient, and pollutant loadings from heavy rainfall, (iii) increased concentrations of pollutants during droughts, and (iv) disruption of treatment facilities during floods will reduce raw water quality and pose risks to drinking water quality"* **(Pachauri *et al.*, 2014)**. Furthermore, **Bates *et al.* (2008)** indicated that based on observational records and climate projections, freshwater resources have the potential to be strongly impacted by climate change and are more vulnerable, with wide-ranging consequences for human societies and ecosystems. Some evidence indicated that in Switzerland there was a considerable temperature increase reported for water courses at all altitudes, and the small streams have shown an increase in winter temperature maxima in Scotland **(Langan *et al.*, 2001; Hari *et al.*, 2006)**.

In UK, **Whitehead *et al.* (2009)** stated that in 1988 and 2002, there have been two sudden shifts in water temperatures, following changes in air temperature. As a result, most chemical reactions and bacteriological processes may be run faster at higher water temperatures, in addition to having a negative impact on some aquatic organisms if species are unable to adapt to the new conditions. Thus, there is a need for providing climate model scenarios of the best available information for assessing future impacts of climate change on the water quality and the ecology of surface water bodies.

Many authors have widely used the Geographic Information System (GIS) technique in their research studies to assess water quality in some regions worldwide **(El-Zeiny & Elbeih, 2019; Al-Shaibah *et al.*, 2021; Oseke *et al.*, 2021)**, it is considered a significant tool in treating environmental problems, and applying the geo-statistical analysis approach in GIS applications enables the interpolation technique to expect the value of attributes at un-sampled sites from measurements taken at locations within the same station. Moreover, it is a set of approaches or tools for predicting the values of variables distributed in space or time. This helps investigate the sample data and create interpolated maps.

Thus, this work aimed to study the relationship between meteorological variations and the quality of freshwater ecosystem (physicochemical parameters and the spatial distribution of heavy metals) in six Delta Egyptian governorates (Kafer EL-Sheikh, Damietta, Beheira, Dakahlia, Gharbia, and Menofia Governorates). This investigation spanned four successive seasons and utilized GIS mapping applications.

MATERIALS AND METHODS

Study area

In the present study, visits (two visits/ season) during the summer, autumn, winter, and spring of 2019 and 2020 in different water courses of the six selected delta governorates (Kafer EL-Sheikh, Damietta, Beheira, Dakahlia, Gharbia, and Menofia Governorates) were carried out (Fig. 1). A total number of 41 sites were selected for the study with the aid of the Ministry of Public Health and Population.

Kafr El-Sheikh Governorate lies in the far North of Egypt, bordered by the Mediterranean Sea in the North and the Rosetta branch in the West, it extends for 85km until reaching its mouth in the Mediterranean Sea. The yearly temperature is 23.78ºC. Nine sites were selected in six villages in two centers named: Qillin (Minyat Qillin, Al-Monshaah, Al-Sughra, and Al Minshilayn villages) and Sidi-Ghazy (Om-Gaafar and Saqr villages).

Damietta Governorate is located in the northern part of the country in the Nile Delta, surrounded by the Mediterranean in the north and Manzala Lake in the east. Its climate is hot, dry in the summer, and mild rainy in the winter. The yearly temperature is 22.28ºC. Seven sites were investigated in five villages in two centers, namely Kafr Saad and Kafr Al-Bateekh.

Beheira Governorate lies in the northern part of the country in the Nile Delta, bordered in the North by the Mediterranean Sea and in the East by the Rosetta branch. It is characterized by long, hot, and humid summer seasons, while the winter seasons are cool, dry, and mostly clear. The annual air temperature typically varies from 7 to 35°C and is rarely below 4 or above 39°C. Eight sites were selected in seven villages in two centers, including Shobra (Ezbet Israf and Ezbet Beshara villages) and Damanhour (Damatuoh, Alwusta, Zarkon, Hassan Khair, and Iflaka villages).

Dakahlia Governorate is located in the northeastern part of Egypt; it includes 18 cities, and is bounded by Sharkia Governorate in the East, Gharbia and Kafr el-Sheikh Governorates in the West, the Mediterranean in the North, Damietta in the North-east and Qalyobia in the South. It has a mild climate that tends to be warm in winter, with some rain that increases on the coasts. The summer is hot, and the average annual temperatures range from 14- 28°C. Five sites were examined in two centers, namely Al-Mansoura and Mit Ghamr.

Gharbia Governorate lies in the North of the country, south of Kafr El Sheikh Governorate, and north of Monufia Governorate. It consists of 8 cities. Despite being near the Nile, it generally has a very hot desert climate. The annual high temperature of

Gharbia Governorate is 29.2ºC. Six sites were examined in two centers, namely Tanta and El-Mahalla El-Kubra.

Monufia Governorate is located in the northern part of the country in the Nile Delta, bounded by the south of Gharbia Governorate and from the north of Cairo Governorate. The mean monthly temperature ranges from 13.7 to 27.8ºC. Eight sites were examined in three centers named: Ashmon - Gress village (Rosetta branch, Abo-Elawally, El-Noqrasheia, and El-Nagar ponds), Shibin Al-Kom (Al-Maslk and Al-zeraa ponds), and Menof (Shbsher tamaly and Zawia Razen Dbrokee).

Fig. 1. Map of the study area showing the selective Egyptian governorates

Ecological survey

Seasonal survey of the water banks was carried out for the selected tested sites in the six governorates covering four successive seasons during 2019 and 2020. Field sheets were designed for information for each site of water bodies under study.

Physical characterization of water

The main ecological parameters were recorded in the all sampling sites at the 6 selective governorates during the study period. Thus, the water temperature, electrical conductivity (µmhos) and TDS (Total dissolved salts) using a portable conductivity meter (HI 9635), pH using a portable pH meter (HI 9024) and dissolved oxygen (D.O) using a portable D.O meter (HI 8543) were measured on spot at midday, at 20cm under the water surface. All these parameters were recorded in the field sheets, following the procedures outlined in APHA (American Public Health Association) (**Clesceri *et al.*, 1989**).

Chemical analysis of water

For chemical assessment, water samples were collected in 1liter polyethylene bottles from each examined site at the six selective governorates. In the laboratory, water samples were filtered to determine the levels of cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), and iron (Fe). Water samples (200ml) were digested with 5ml of di-acid mixture (9 HNO_3: 4 $HClO_4$) on a hot plate and filtered by Whatman No. 42 filter paper, and double distilled water was added to bring the volume up to 50ml, following the method outlined by **Abd El-Kader *et al.* (2016)**. Determination of heavy metals in water samples were performed by atomic absorption spectrophotometer, according to the guidelines of **A.O.A.C. (1995)**. The mean value of each element was seasonally calculated for each site.

Meteorological data

Ground-based monitoring stations

In this study, we used daily meteorological data on temperature collected from a selection of the Egyptian Meteorological Authority (EMA)'s ground-based monitoring stations (Al-Mansoura, Tanta, Quessna, Sakh, Damietta and Rashid stations) for the past ten years (2006 to 2016) and for the period of our study (2019- 2020). These data are currently available at the EMA's electronic database. The selection of the monitoring stations was selected based on our areas of study. Each station covers an area of a diameter of 50 Kilo. The climate data were analyzed to extract indactors of extreme weather events, focusing on extreme air temperature. The correlation between climate extremes and current data was studied.

GIS mapping

In the current study, the coordinates of each sampling location were converted into a GIS layer attributed with the measured water quality parameters during the four seasons using ArcGIS. All the spatial data are registered to the Universal Transverse Mercator (UTM), Zone 36 projection coordinate system. The used mapping approach in GIS shows the spatial variation in water quality parameters in the study area, including the physicochemical parameters (temperature, electrical conductivity, dissolved oxygen, Total Dissolved solids, and pH) and heavy metals (Cd, Pb, Cu, Fe, and Zn). This technique helps produce spatial variability maps to determine the contributory variables to pollution accumulation and nutrient loading in the study area.

Statistical analysis

All the relationships between the meteorological data (the maximum (Tmax) and minimum (Tmin) temperatures), the physicochemical parameters, and heavy metal concentrations were done through the Pearson correlation coefficient using SPSS version 23 for Windows. The non-parametric Kruskal-Wallis H test with the Mann-Whitney U test was used for the skewness results to detect the differences in the distribution of heavy metals in six examined governorates. The spatial variations for each physicochemical parameter and heavy metals during different seasons in the six examined governorates were performed using ArcGIS software 10.5.

RESULTS

The present results of physicochemical measurements at different sites located in the six selected governorates are displayed in Table (1) during the four seasons. All parameters were varied from lower to higher among the examined sites in all governorates. Water temperature ranged between 25 and 28ºC in summer, while in autumn, it was varied from 19± 1.7ºC in Dakahlia to 24.25± 0.5ºC in Damietta. The lowest mean value of water temperature was recorded during winter in Gharbia (11.5± 1.7ºC) and in Kafr el-Sheikh (24.5± 1.2ºC) during spring.

The values of water pH were varied from 6.9± 0.48 in Gharbia to 7.8± 18 in Beheria during summer and from 7.4 in Menofia andDakahlia to 7.8± 0.24 in Kafr El-Sheikh during autumn. All pH values were approximately around the normal range during spring. However, the highest mean value of pH was 8.13± 0.19 in Kafr El-Sheikh during winter.

Regarding the mean values of dissolved oxygen (D.O.), it was observed that these values were most higher during winter and spring than those recorded during summer and autumn at all sites representing the selected governorates, whereas the highest mean value of D.O. was found in Damietta (4.77± 2.5mg/ L), followed by Dakahlia (4.7± 2.2mg/ L) in winter and in Gharbia (4.7± 1.8mg/ L) during spring. Additionally, the highest mean value of electrical conductivity (EC) was recorded in Beheria (2384.5± 2283.3µ/ cm) and that for total dissolved salts (TDS) was recorded in Damietta (1554± 418.3mg/ L) during winter.

Results in Fig. (2) show the mean meteorological data about the maximum (Tmax) temperatures recorded from a selection of the Egyptian Meteorological Authority (EMA)'s ground-based monitoring stations (Al-Mansoura, Tanta, Quessna, Sagha, Damietta and Rashid stations) for the past ten years (2006 to 2016) and for the period of our study (2019- 2020) during the four seasons. It was observed that the highest increases in Tmax (2.1- 2.6ºC) between the past ten years and those during the current study (2019-2020) were recorded in Damietta and Rashid stations (Damietta and Beheria Governorates) during spring. These increases reached 1.7 and 1.9ºC in Sagha and Rashid stations (Kafr El-Sheikh) during autumn and summer, respectively.

Regarding the annual atmospheric temperatures and their role in change of the physical characteristics of water, the results in Table (2) present the correlation between the atmospheric temperatures and different physical parameters of water. The maximum and minimum atmospheric temperatures (Tmax and Tmin) were positively correlated with water temperature, indicating that atmospheric temperature was directly proportional to the observed water temperature. On the other hand, atmospheric temperature (Tmax and Tmin) was negatively correlated with dissolved oxygen (D.O.), indicating that atmospheric temperature was inversely proportional to water D.O. level. Meanwhile, water temperature was negatively correlated with electrical conductivity (EC) (r= - 0.2), total dissolved solids (TDS) (r= - 0.1), D.O. (r= - 0.5), and pH (r= - 0.4).

Table 1. Physicochemical parameters of water samples collected from different sites representing the selected governorates during summer, autumn, winter and spring (2019- 2020)

Governorate	**Season**	**Mean values ±SD**				
		Temp. (ºC)	**PH**	**Electrical conductivity (µ/ cm)**	**TDS (mg/ L)**	**D.O (mg/ L)**
Damietta	**Summer**	28.13±2.02	7.5±0.49	1236.75±946.4	838±671.7	0.82±0.57
Beheria		25.1±1.6	7.8±.18	814.75±346.3	520.9±198.7	0.65±0.58
Kafr El-Sheikh		25.96±2.2	7.22±0.13	1572.14±406.9	1110.57±358.08	1.75±1.78
Menofia		25.5±1.6	7.3±0.2	580.7±165.5	360.7±133.7	1.7±0.9
Dakahalia		26.75±1.5	7.2±0.46	1466±776.4	970±591.2	1.27±1.09
Gharbia		28±2.45	6.9±0.48	495.25±142.6	305.25±133.0	1.78±1.84
Damietta	**Autumn**	24.25±0.5	7.7±0.64	752.75±379.7	330.75±145.8	2.79±2.54
Beheria		20.2±0.99	7.70±0.18	1118.14±545.9	761.43±359.5	1.09±0.66
Kafr El-Sheikh		20±0.89	7.8±0.24	1429.7±800.9	1021.4±617.2	2.6±2.2
Menofia		21.1±2.2	7.4±0.1	776.2±469.8	492.6±340.2	1.98±1.6
Dakahalia		19±1.7	7.4±0.4	743±305.8	518.6±214.4	3.15±1.32
Gharbia		20.6±0.6	7.57±0.2	646.25±242.4	361.75±109.5	2.27±2.6
Damietta	**Winter**	13.7±0.6	7.44±0.6	2240±565.6	1554±418.3	4.77±2.5
Beheria		14.7±1.2	7.68±0.33	2384.5±2283.3	996.88±418.6	2.4±1.9
Kafr El-Sheikh		14.14±1.86	8.13±0.19	1070±488.1	703.7±327.9	3.86±1.85
Menofia		14.75±1.3	7.47±0.38	576.7±121.3	404±85.9	3.59±2.59
Dakahalia		12±2.24	7.54±0.5	517±122.3	323.7±85	4.7±2.2
Gharbia		11.5±1.7	7.16±0.15	649.75±371.4	453.25±257.3	2.47±2.13
Damietta	**Spring**	27.2±1.3	7.6±0.18	1053±570	713.8±368.7	4.3±1.8
Beheria		26.4±1.3	7.24±0.5	799.3±356.9	527±237.9	2.5±3.86
Kafr El-Sheikh		24.5±1.2	7.4±0.2	959.5±705.8	650.8±464.4	3.7±0.67
Menofia		27±1.15	7.16±0.18	459±44.97	298±57.06	1.6±1.1
Dakahalia		27.8±0.76	7.4±0.44	672.3±183.4	467.3±132.3	2.23±2.8
Gharbia		25.5±0.58	7.05±0.4	449.75±87.2	286±26.2	4.7±1.8

Temp.: temperature, TDS: Total dissolved solids, and DO: Dissolved oxygen.

Table 2. Relationships between physical parameters of water with the annual atmospheric temperatures (2006-2020)

Physical parameters of water	**Tmax (˚C)**	**Tmin (˚C)**	**Water Temperature (˚C)**	**EC. (µ cm)**	**TDS (mg/ L)**	**DO (mg/ L)**
Tmax (˚C)	1					
Tmin (˚C)	0.8***	1				
Water temperature (˚C)	0.5***	0.4***	1			
EC. (µ cm)	-0.1**	0.2***	-0.2***	1		
TDS (mg/L)	-0.1**	0.2***	-0.1**	0.9***	1	
DO (mg/L)	-0.7***	-0.7***	-0.5***	0.01	0.05^{ns}	1
pH	-0.2***	-0.01^{ns}	-0.4***	0.5***	0.4***	0.1**

Tmax: Maximum air temperature, Tmin: Minimum air temperature, EC: Electrical conductivity, TDS: Total dissolved solids, and DO: Dissolved oxygen. ** symbol refers to significant correlation at $P< 0.01$, while *** refers to significant at $P< 0.001$. ns: Insignificant correlation.

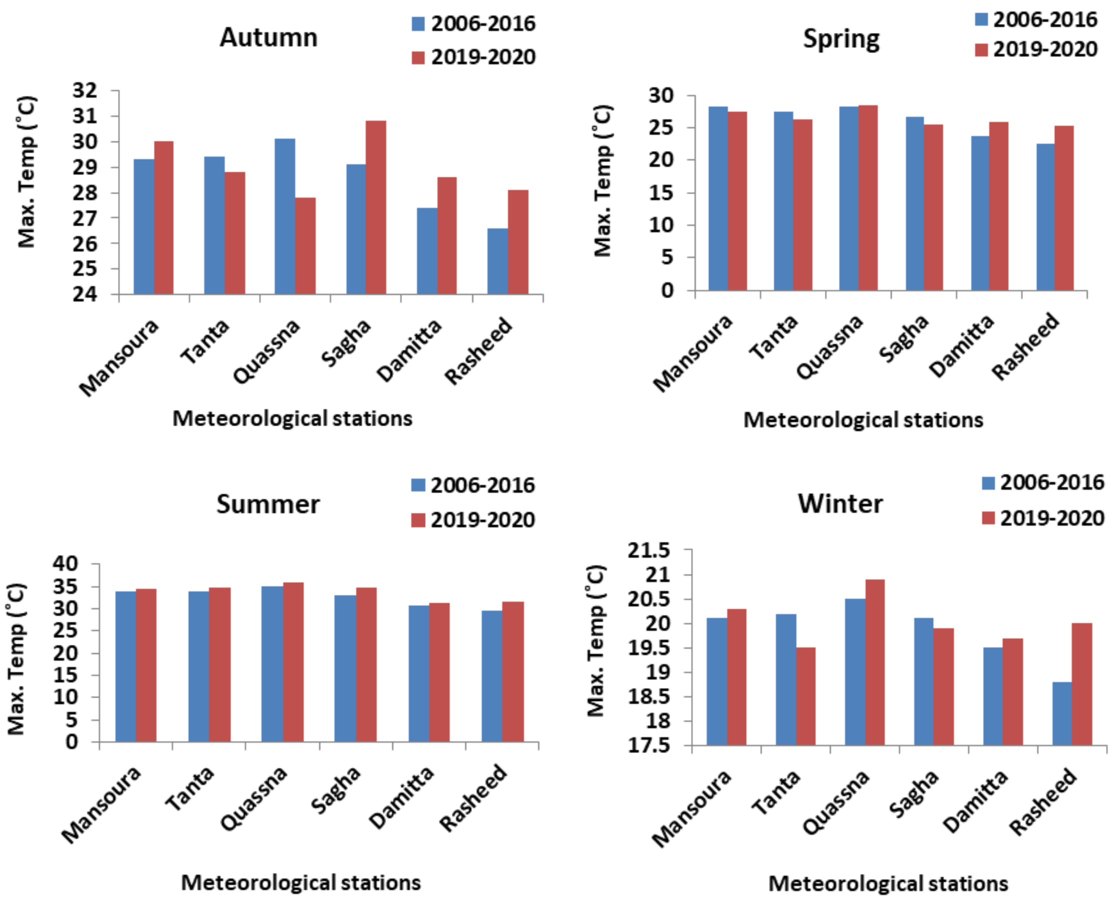


Fig. 2. Seasonal differences in mean maximum atmospheric air temperature between 2006- 2016 and 2019- 2020 recorded in six meteorological stations covering the six selected governorates in Egypt

Results of the chemical analysis of heavy metals (Cd, Pb, Cu, Zn, and Fe) in water samples from different sites located in the six selected governorates during four seasons (2019- 2020) are given in Table (3). During spring, Cd and Pb concentrations were significantly high in Menofia, Gharbia, and Dakahila. Moreover, Zn was significantly higher in Kafer El Shiekh and Damietta, while Cu was higher in Menofia and Gharbia, compared to that in the other governorates, while, Fe showed no significant differences between the different governorates. During winter, Cd and Cu concentrations were significantly higher in Gharbia and Dakahila than in the other governorates, while Pb was higher in the same two governorates but not to the levels of significance. During autumn, there were variations in the concentrations of the examined heavy metals but not to the level of significance.

Relationships between water metals levels and atmospheric temperature are presented in Table (4). Cadmium (Cd) concentrations in water samples of Gharbia and Dakahlia were negatively associated with the atmospheric temperatures (Tmax and Tmin), and with the Tmin in Menofia.

Table 3. Comparison of the different heavy metals between the six governorates in the four seasons

Heavy metal	**Dakahlia**	**Damietta**	**El Beheira**	**Gharbia**	**Kafer El Shiekh**	**Menofia**	**Test of significance**	
	Median (Range)	Median (Range)	Median (Range)	Median (Range)	Median (Range)	Median (Range)	**KS**	***P*-value**
Autumn								
Cd (µg/L)	0.075 (0.001-0.368)	0.1035 (0-0.111)	0.097 (0.022-0.111)	0.152 (0.005-0.307)	0.07 (0.017-1.541)	0.083 (0.032-0.245)	1.42	0.922
Pb (µg/L)	6.18 (3.25-16.56)	4.59 (2.39-8.31)	4.31 (0.51-12.99)	7.27 (4.48-11.19)	3.52 (0.8-7.44)	2.342 (0.672-5.578)	7.68	0.175
Zn (mg/L)	0.073 (0.006-0.106)	0.081 (0.012-0.18)	0.089 (0.001-0.152)	0.0925 (0.077-0.111)	0.028 (0.006-0.164)	0.092 (0.019-0.111)	2.80	0.731
Fe (mg/L)	0.118 (0.024-0.305)	0.199 (0.0438-0.372)	0.21 (0.0314-0.246)	0.253 (0.2405-0.258)	0.071 (0.025-0.2407)	0.218 (0.0348-0.2657)	7.89	0.162
Cu (µg/L)	11.67 (4.43-16.76)	17.25 (6.54-29.83)	15.23 (0.45-24.54)	17.67 (12.2-30.03)	8.64 (1.24-37.59)	8.26 (2.08-13.26)	6.31	0.277
Summer								
Cd (µg/L)	0.085 (0.044-0.145)	0.122 (0-0.541)	0.299 (0.023-5.636)	0.102 (0.033-0.509)	0.071 (0.039-0.271)	0.133 (0.05-0.285)	7.92	0.161
Pb (µg/L)	1.549 (0.959-1.668)	0.79 (0.46-6.84)	5.325 (1.285-9.328)	5.274 (2.782-6.097)	1.758 (0.366-6.1)	5.12 (0.8-19.21)	10.59	0.060
Zn (mg/L)	0.126 (0.058-0.559)	0.023 (0.01-0.06)	0.021 (0.013-0.027)	0.188 (0.055-0.469)	0.019 (0.004-0.038)	0.031 (0.027-0.047)	21.28	0.001*
Fe (mg/L)	0.333 (0.167-0.431)	0.316 (0.177-0.443)	0.454 (0.312-0.618)	0.36 (0.255-0.607)	0.246 (0.029-0.302)	0.357 (0.185-0.567)	13.26	0.021*
Cu (µg/L)	5.31 (2.56-13.82)	7.64 (0.1-12.68)	4.83 (0.2-12.47)	5.65 (2.3-9.06)	3.96 (2.45-11.68)	6.32 (1.52-11.75)	0.84	0.975
Spring								
Cd (µg/L)	0.567 (0.523-0.932)	0.044 (0.021-0.267)	0.047 (0.011-0.081)	0.863 (0.126-0.984)	0.033 (0.013-0.071)	1.103 (0.56-2.732)	20.22	0.001*
Pb (µg/L)	18.2 (14.5-65)	4.56 (2.75-11.04)	2.7 (1.632-5.139)	41.76 (19.66-57.51)	3.68 (0.98-11.14)	64.57 (31-77.32)	20.77	0.001*
Zn (mg/L)	0.083 (0.077-0.103)	0.21 (0.159-2.932)	0.029 (0-0.159)	0.066 (0.048-0.086)	0.44 (0.06-7.33)	0.055 (0.045-0.068)	15.07	0.010*
Fe (mg/L)	0.121 (0.106-0.146)	0.126 (0.039-0.175)	0.276 (0.086-0.482)	0.434 (0.122-0.847)	0.088 (0.05-1.357)	0.1598 (0.1301-0.1789)	5.78	0.328
Cu (µg/L)	85.2 (80.6-132.3)	13.68 (8.88-30.74)	13.63 (2.94-51.74)	125.02 (121.55-128.49)	16.12 (2.09-23.91)	142.3 (98.8-239.8)	17.92	0.003*
Winter								
Cd (µg/L)	0.696 (0.306-1.221)	0.105 (0.058-0.142)	0.312 (0.201-1.403)	0.641 (0.163-0.854)	0.447 (0.136-1.138)	0.38 (0.137-0.926)	12.45	0.029*
Pb (µg/L)	20.8 (6.9-118.8)	6.1 (4.04-11.36)	8.36 (5.43-26.56)	39.7 (11.9-68.2)	12.63 (7.14-27.72)	10.7 (3.56-50.95)	8.96	0.111
Zn (mg/L)	0.062 (0.03-0.142)	0.079 (0.02-0.114)	0.023 (0.001-0.078)	0.0535 (0.019-0.119)	0.026 (0.003-0.055)	0.031 (0.005-0.114)	7.18	0.207
Fe (mg/L)	0.126 (0.0275-0.2306)	0.124 (0.0142-0.216)	0.143 (0.0469-0.206)	0.186 (0.055-0.246)	0.054 (0.0265-0.0924)	0.133 (0.018-0.2669)	6.83	0.234
Cu (µg/L)	86.8 (27.4-169.3)	7.23 (4.02-18.62)	76.28 (42.2-94.63)	83.1 (43.2-113.9)	39.9 (8.8-96.8)	69.7 (16.6-117.2)	11.25	0.047*

(*) asterisk refers to significant differences between governorates at $P < 0.05$

Meanwhile, they were negatively correlated between the lead (Pb) concentrations in water samples collected from all investigated governorates, except with Tmx in

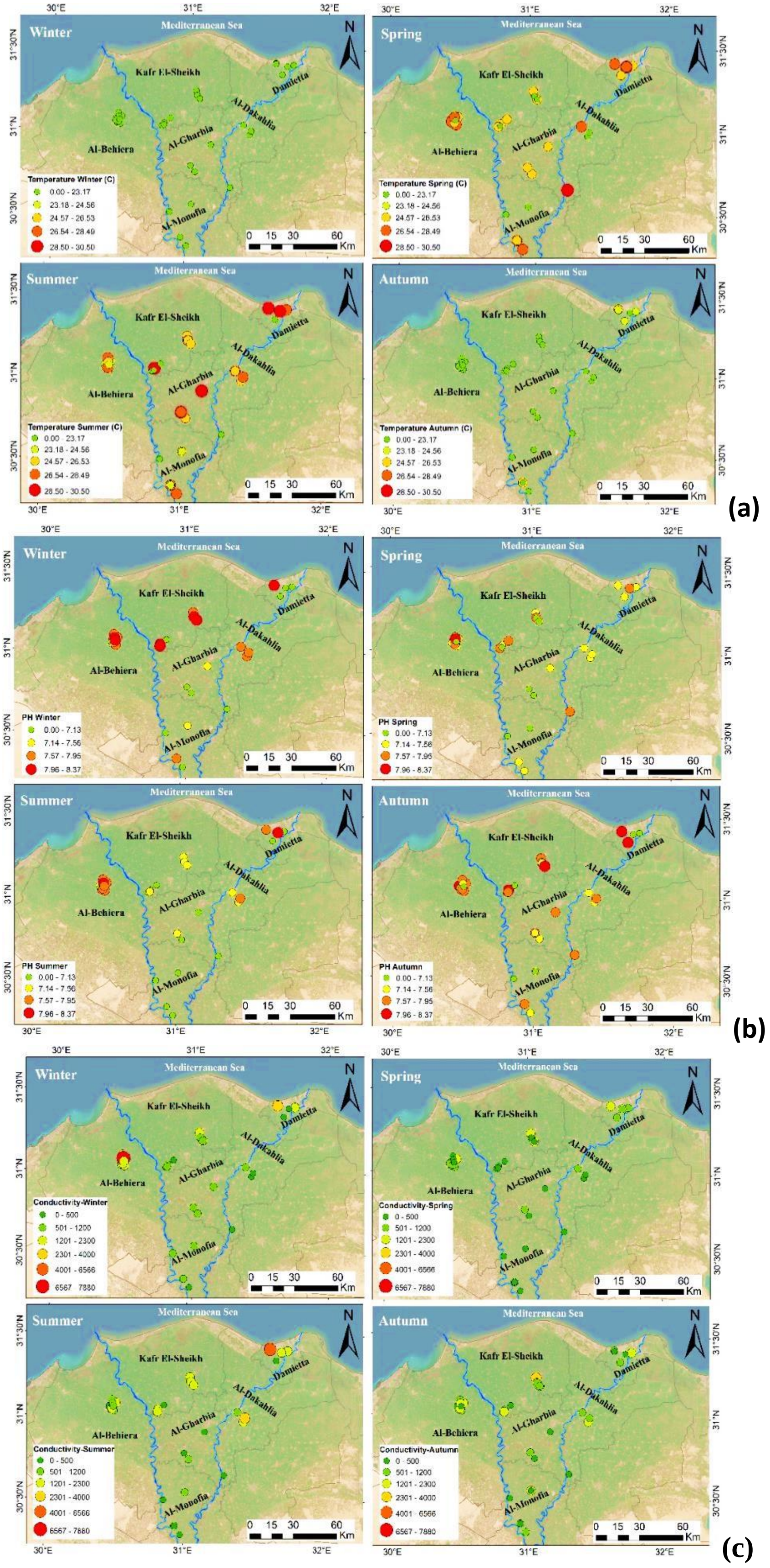
Menofia, Zinc (Zn) concentrations was positively correlated with both atmospheric temperatures in Gharbia, and with Tmin in Dakahlia. Whereas, iron (Fe) concentrations were positively associated with atmospheric temperatures in Damietta, El-Beheria, Dakahlia, and Menofia. Additionally, the copper (Cu) concentrations were negatively correlated with atmospheric temperatures in Kafer El- Shiekh, El-Beheria, Gharbia, and Dakahlia, and it showed a significant negative correlation with Tmin in Menofia.

Table 4. Relationships of heavy metals with atmospheric maximum and minimum temperatures in each governorate

		Cd	**Pb**	**Zn**	**Fe**	**Cu**
Kafer El-Shiekh	Tmax	-0.229	-0.583**	-0.067	0.071	-0.518**
	Tmin	-0.25	-0.556**	-0.176	0.06	-0.514**
Damietta	Tmax	0.152	-0.460**	-0.105	0.553**	-0.081
	Tmin	0.183	-0.436**	-0.293	0.607**	-0.239
El-Beheira	Tmax	0.247	-0.416**	-0.056	0.605**	-0.825**
	Tmin	0.244	-0.374**	-0.043	0.540**	-0.779**
Gharbia	Tmax	-0.501**	-0.644**	0.556**	0.303	-0.711**
	Tmin	-0.638**	-0.741**	0.528**	0.131	-0.849**
Dakahlia	Tmax	-0.726**	-0.582**	0.313	0.524**	-0.685**
	Tmin	-0.744**	-0.563**	0.376*	0.610**	-0.728**
Menofia	Tmax	- 0.116	-0.213	-0.141	0.642**	-0.279
	Tmin	-0.436**	-0.601**	0.1	0.531**	-0.639**

The level of significant at *: $P < 0.05$ and **: $P < 0.01$.

The results showed that, by using ArcGIS, each water sampling site was illustrated in its corresponding map attributed to each physicochemical parameter during different seasons for temperature, pH, EC, TDS, and D.O., as shown in Fig. (3a, b, c, d, and e), respectively. It was found that the maximum temperature values were distributed in Damietta, Kafr El-Sheikh, and Gharbia during summer, whereas it was recorded in Menofia during spring. Winter and autumn showed a normal distribution of lower temperatures at all examined sites along the selected governorates (Fig. 3a). In summer, D.O. levels were the lowest in most studied governorates (Fig. 3e).


Winter
Spring
Summer
Autumn
Mediterranean Sea
Kafr El-Sheikh
Al-Behiera
Al-Gharbia
Al-Dakahlia
Damietta
Al-Monofia
30°E
31°E
32°E
31°30'N
31°N
30°30'N
0 15 30 60 Km
N
Temperature Winter (C)
Temperature Spring (C)
Temperature Summer (C)
Temperature Autumn (C)
0.00 - 23.17
23.18 - 24.56
24.57 - 26.53
26.54 - 28.49
28.50 - 30.50
(a)
PH Winter
PH Spring
PH Summer
PH Autumn
0.00 - 7.13
7.14 - 7.56
7.57 - 7.95
7.96 - 8.37
(b)
Conductivity-Winter
Conductivity-Spring
Conductivity-Summer
Conductivity-Autumn
0 - 500
501 - 1200
1201 - 2300
2301 - 4000
4001 - 6566
6567 - 7880
(c)

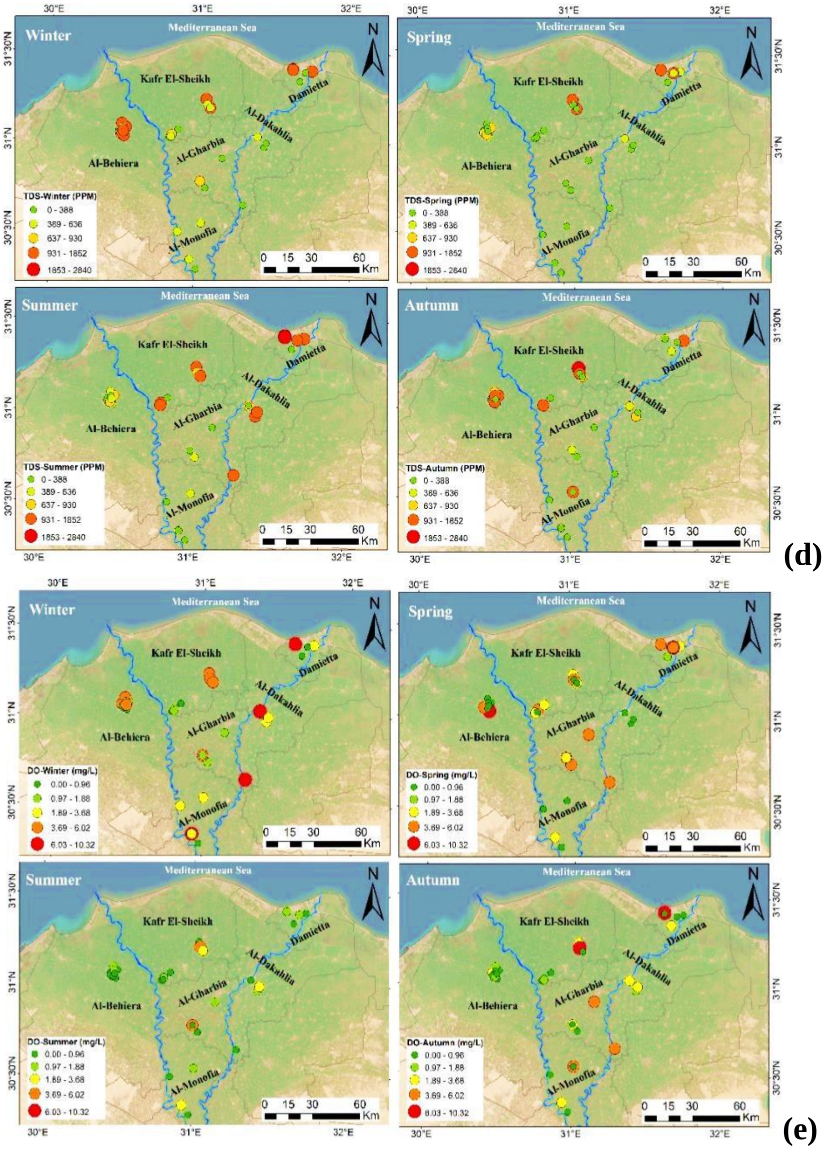
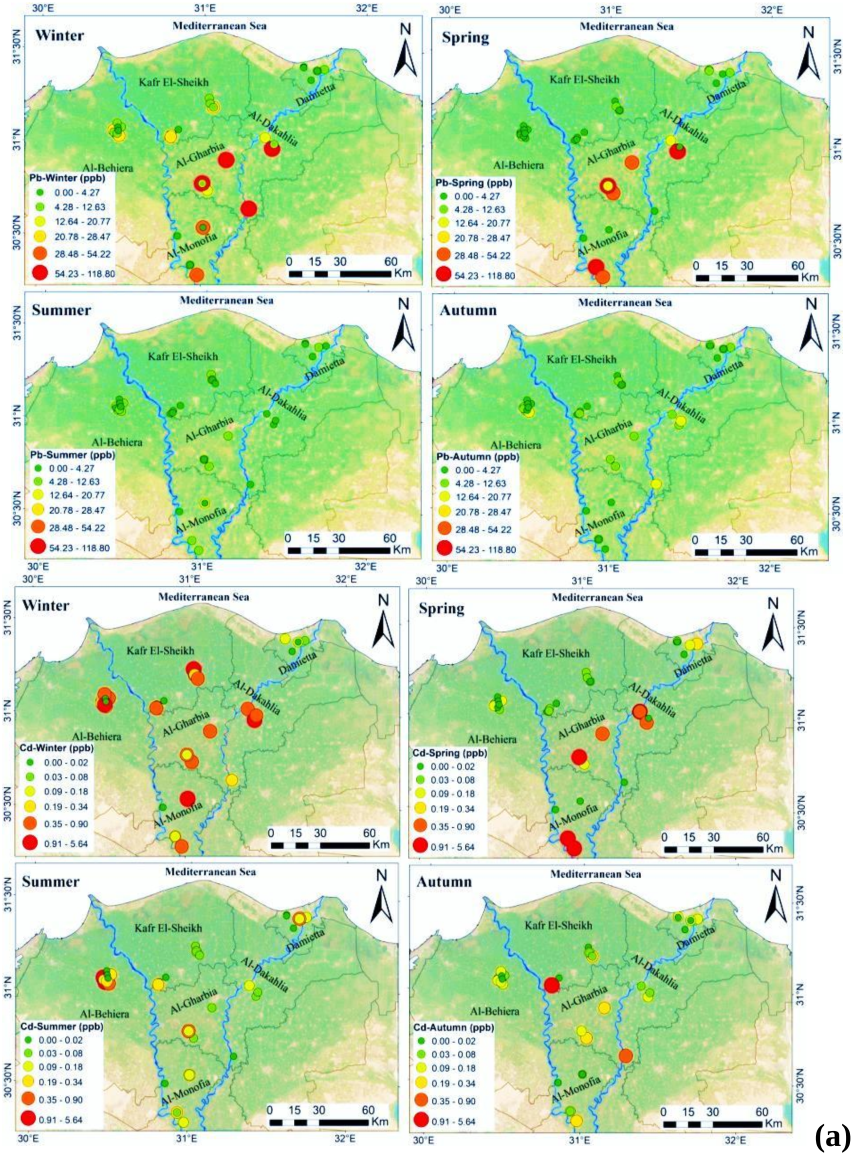


Fig. 3. The spatial variations for each physicochemical parameter showing: Temperature **(a)**, pH **(b)**, EC **(c)**, TDS **(d)**, and D.O. **(e)** during different seasons in six studied governorates using ArcGIS software.

The results, when visualized using ArcGIS, illustrate the concentrations of heavy metal in different governorates according to seasons (Fig. 4). In winter, cadmium (Cd) concentration was moderately high in all examined governorates, while in the spring, it reached high levels in Monfia, Dakahila, and Gharbia (Fig. 4a). Lead (Pb) level was moderately high in winter and spring in Gharbia, Dakahila, and Monfia, while it was low during summer and autumn in all examined governorates (Fig. 4b). Furthermore, copper (Cu) concentration was high during winter and spring in most of the governorates, while it was low during summer and autumn in all examined governorates (Fig. 4c). Meanwhile, iron (Fe) levels were moderately high during all seasons at most of examined governorates (Fig. 4d). On the other hand, zinc (Zn) levels were low in all governorates during all seasons, except for spring, it recorded high and moderate levels in Kafr El-Seikh and Damietta, respectively (Fig. 4e).



(a)

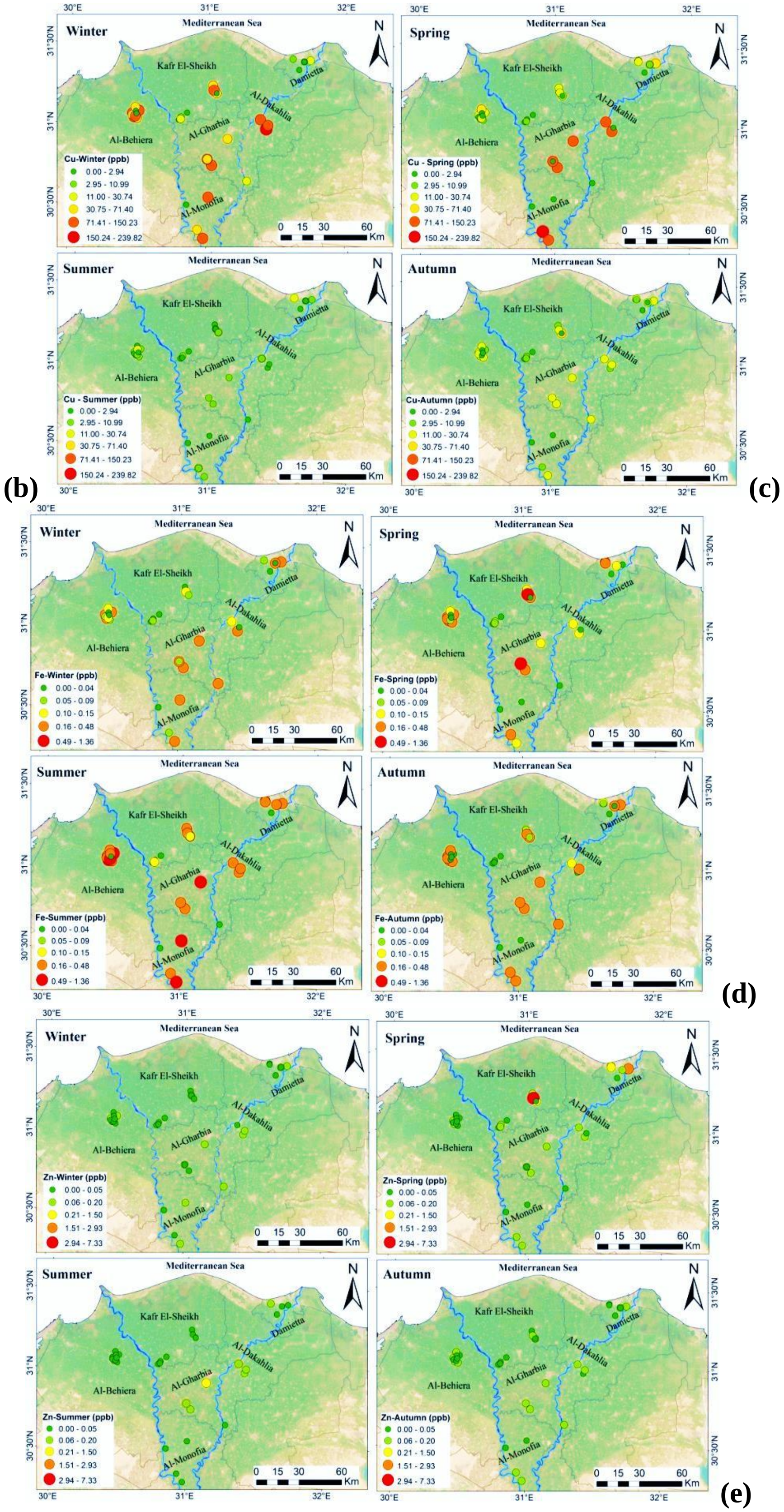


Fig. 4. The spatial variability of metals concentrations showing: **(a)** Cadmium: Cd, **(b)** Lead: Pb, **(c)** Copper: Cu, **(d)** Iron: Fe, and **(e)** Zinc: Zn along the different sites in the selected

DISCUSSION

Water quality parameters were defined as i) physicochemical basic parameters (temperature, pH, dissolved oxygen, dissolved organic matter) and nutrients, ii) micropollutants (inorganic and organic) including metals, pesticides and pharmaceuticals, and iii) biological parameters with pathogens microorganisms, cyanobacteria **(Delpla *et al*., 2009)**. The consequences of global climate change for freshwater ecosystems were reviewed by **Dallas and Moore (2014)** who summarized the ecological consequences on water quality as it caused an increase in water temperature, increase in organic matter decomposition, decrease in the concentration of dissolved oxygen, changes in nutrient cycles (and carbon cycling) and loads, increase in sedimentation and turbidity, and mobilization of adsorbed pollutants, such as metals and phosphorus from the riverbed.

In the current work, the highest water temperature degrees were in summer and spring, which ranged between 25 and 28ºC at all sites of the examined governorates. Higher maximums of temperature ranges indicated poorer aquatic system health **(Sheldon *et al.*, 2019)**. This result was parallel to the dissolved oxygen (D.O.) values that ranged from 0.65 to 1.75mg /L during summer at all sites representing the selected governorates. **Ji *et al.* (2017)** reported in their study that water hypoxia occurs when the D.O. concentration is below 2mg/ L, and this is an urgent warning for the ecosystem's health. In the present study, in summer, D.O. levels were the lowest in most studied governorates, and this result may be related to the increase in water temperature during this season.

It is difficult to estimate the future freshwater temperature by climate predictions since data collection on water temperature is rarely present. Therefore, the air temperature has been used as a proxy for the water temperature in the climatic models due to the similarity of the shallow water temperature to ambient air temperature. Thus, the major determinant of water temperature in lakes is air temperature as it keeps the radiative balance between the lake surface and the atmosphere. However, comparisons between air temperature and water temperature in various water bodies suggest that unadjusted air temperature is often not a reliable proxy, and the surface water temperature is 2ºC higher than water temperature in many cases **(Peeters *et al.*, 2002; Paaijmans *et al.*, 2008)**. In their study, **O'Reilly *et al.* (2015)** stated that after the increases of air temperature, most lakes in the world are currently becoming warmer. The surface water temperature of lake has been observed to increase at a mean worldwide rate of 0.34 °C/ decade from 1985 to 2009. Projections suggest that by the end of the 21st century, lake water temperatures could increase by up to 4°C compared to the current levels. This will be most pronounced near the surface during spring and early summer **(Lepori & Roberts, 2015)**.

In the present study, it was observed that the atmospheric temperature was directly proportional to the observed water temperature, while the atmospheric temperature was inversely proportional to the water D.O. level. Oxygen has limited solubility in water directly related to atmospheric pressure and inversely related to water temperature and salinity **(Trick *et al.*, 2008)**. **Cox and Whitehead (2009)** declared that higher water temperatures increase the rate of biological activity and chemical reactions in streams This phenomenon results in a reduced saturation of dissolved oxygen (D.O.) concentration in the river. Thus, with the increasing water temperature, the saturated dissolved oxygen decreases, and the re-oxygenation effect in the river decreases accordingly **(Zhong *et al.*, 2021)**.

Depending on the Egyptian meteorological data, it was observed that, the highest increases in Tmax (2.1- 2.6ºC) between the past (10 years) and those during the current study (2019- 2020) were recorded in Damietta and Rashid stations (Damietta and Beheria governorates) during spring. These increases reached 1.7 and 1.9ºC in Sagha stations (Kafr El-Sheikh) during autumn and summer, respectively. According to the World Meteorological Organization **(WMO)**, the decade of 2011- 2020 was the warmest on record. The 2015- 2020 were the warmest six years recorded, with the hottest top three years being 2016, 2019, and 2020. The average global temperature in 2020 was above the preindustrial (1850- 1900) **(Canton, 2021)**. This evidence coincides with our present study that 2019- 2020 was the period of our collection of samples during which the Tmax showed an increase compared with the past (10 years) in Damietta, Beheria, and Kafr el-Sheikh governorates during spring, autumn, and summer.

The current results of the chemical analysis showed that during spring, Cd and Pb concentrations were significantly high in Menofia, Gharbia, and Dakahila, as well as Zn was more elevated in Kafer El Shiekh and Damietta, while Cu was higher in Menofia and Gharbia, compared to its values in the other governorates. During winter, Cd, Pb, and Cu concentrations were high in Gharbia and Dakahila. However, these results are below the recommended maximum acceptable concentration for cadmium (5µg/ L), copper (1.5mg/ L), lead (0.01mg/ L), and zinc (15mg/ L), according to **WHO (2008)** and **Griffiths *et al.* (2012).**

In the current results, Tmax and Tmin showed a negative correlation with Cd, Pb, and Cu in most of the examined different governorates. Zn showed a significant positive correlation with atmospheric temperature in Gharbia and Dakahlia, while iron (Fe) showed positive correlations in Damietta, Beheria, Dakahlia, and Menofia. Our data showed that the atmospheric temperature was directly proportional to the observed water temperature. Water temperature is considered the main factor that controls multiple chemical reactions **(Iordache *et al.*, 2022)**. The exchanges in water flow are fundamental in the interaction between various chemical elements in the river body, such as the intake and reduction of physicochemical parameters in water and vertical redox gradients in sediments **(Byrne *et al.*, 2014)**. The present results of negative correlations may be due to the most polluted materials being deposited in the bottom layers, reaching up to 90% in the case of Pb, Cd, and Cu **(Frémion *et al.*, 2016)**. Therefore, it is necessary to amplify investigations concerning the effect of temperature rises on the action of heavy metals, especially aluminum, chromium, lead, iron, manganese, and nickel that can enter aquatic systems via direct or indirect ways **(Nin & Rodgher, 2021)**. On the contrary, the positive correlations of Zn and Fe may be attributed to their essentials for different aquatic organisms.

Regarding the association between water temperature and dissolved oxygen in the current work, the spatial variations for temperature and dissolved oxygen (D.O.) illustrated by ArcGIS showed that the maximum temperature values were distributed in Damietta, Kafr El-Sheikh, and Gharbia during summer, whereas it was the highest in Menofia during spring. The lowest levels of D.O. were during summer at most studied governorates. This result confirms that the atmospheric temperature is inversely proportional to water D.O.

Similarly, **Karami *et al.* (2019)** used ArcGIS to investigate the spatial effects of different climatic factors, including temperature, precipitation, evaporation, and transpiration on the quality of groundwater resources in Varamin Plain, Iran. The water quality was assessed using pH, electrical conductivity, total dissolved solids, anions, cations concentrations, and total hardness. All parameters (except pH) along the plain were highly variable, and the spatial distribution of the data was not regular. They attributed their results to the effect of climatic factors on water quality, with the maximum temperature identified as the most impactful factor. Additionally, **Rasouli and Jabari (2013)** investigated the effect of climatic and geological factors on the quality and quantity of groundwater resources in Mahvelat Plain (Iran) using geostatistical methods in ArcGIS software. They evaluated the data about the water level, electric conductivity, and the total concentration of soluble salts within three statistical periods related to 2001, 2007, and 2012.

Regarding the spatial variation of metals at different examined governorates, present results showed that cadmium (Cd) concentration was high in Gharbia, Dakahila, and Monfia during spring. While, lead (Pb) level was moderately elevated in winter and spring in Gharbia, Dakahila, and Monfia, and copper (Cu) concentration was high during winter and spring in most governorates. Meanwhile, iron (Fe) levels were moderately high during all seasons in most of the examined governorates. Zinc (Zn) levels were high and moderate during spring in Kafr El-Seikh and Damietta, respectively. These results may be attributed to seasonal variations, besides different climatic and anthropogenic factors, which vary in each governorate.

Correspondingly, the present results go well with those carried out in Egypt by **Salaah *et al.* (2022)**, who detected the spatial allocation of heavy metals in Lake Qarun surface water using the GIS technique. They used the inverse distance weighting (IDW) technique from GIS to map the spatial distribution of the heavy metals in the lake during summer and winter. Results revealed that the highest metal contents were recorded in surface water during summer compared to winter. Moreover, the highest metal concentrations were reported in the eastern section of the lake.

In addition, other studies have widely documented the effects of water quality variables and climatic conditions on aquatic ecosystems. **Dallas and Moore (2014)** stated that in South Africa, water quality in many rivers and wetlands, together with climatic factors which act as additional stresses on these ecosystems, is widely complicated. These represented the water quality changes including water temperature, affecting the solubility of oxygen and other gases, chemical reaction rates, toxicity, and microbial activity.

Moreover, the combined effects of high temperature and low flows, and dissolved oxygen decrease form a high risk to aquatic organisms **(Dallas & Day, 2004; Dallas, 2008)**. In addition, many studies connected experimental laboratory work with field-based studies on the link between air and water temperature. They found that the effect of elevated water temperature on aquatic organisms has allowed for the development of tools for assessing water temperature in river ecosystems and scenarios prediction for elevated temperatures **(Dallas & Ketley, 2011; Dallas & Rivers-Moore, 2011; Dallas *et al.*, 2012; Dallas & Rivers-Moore, 2012; Rivers-Moore *et al.*, 2013a; Rivers-Moore *et al.*, 2013b)**.

CONCLUSION

The correlation analysis of our results showed that the water quality of the examined sites at the selected delta governorates is influenced by climatic factors represented in atmospheric temperature. The maximum temperature has the highest impact on different water parameters, such as water temperature, dissolved oxygen, and heavy metals. Based on geostatistical methods, the spatial distribution gives a visual picture of the main parameters affecting the water sources in a region. Continuous study of factors affecting water quality could be helpful in the management and sustainability of water sources. Furthermore, it is possible to predict the climatic factors' impacts on water quality to plan for the future.

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