Alfarama Journal of Basic & Applied Sciences
https://ajbas.journals.ekb.eg
ajbas@sci.psu.edu.eg

Faculty of Science Port Said University
http://sci.psu.edu.eg/en/

April 2023, Volume 4 , Issue II
DOI:https://doi.org/10.21608/ajbas.2022.169528.1130

ISSN 2682-275X

Submitted: 18/10/2022
Accepted: 30/11/2022
Pages: 378 - 390

Assessment of Water Quality and Bacteriological Indicators of Sewage Pollution in Bahr El-Baqar Drain, Eastern Nile Delta, Egypt

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ABSTRACT

This study assessed the seasonal and spatial variation of the water quality physicochemical parameters, major dissolved ions, and the bacteriological indicators of sewage pollution in Bahr El-Baqar drain, Eastern Nile Delta, Egypt, in the summer and winter seasons of 2018. Results showed that the drain water contained higher values of the physicochemical parameters: pH, Total dissolved salts (TDS), Electrical conductivity (EC), Dissolved oxygen (DO), Biological oxygen demand (BOD), and Chemical oxygen demand (COD), which are typical for domestic and industrial wastewater. The concentrations of dissolved salts (mg/L) in the drain water followed the decreasing order: Cl^- (743.5) > NO_3^- (30.26) > NH_4^+ (18.22) > PO_4^{3-} (2.63). Additionally, the bacteriological indicators; Total Viable Bacteria (TVC), and Total Coliform (TC) groups in the investigated drain water samples. Results of TVC, which counted by standard plate method (SPC) and the TC showed high seasonal levels of sewage pollution in the water of the Bahr El-Baqar drain, particularly in the summer samples. The TVC ranged from 3.8×10^4 (winter) to 6.4×10^5 CFU/ml (summer), which highly exceeds (≤ 1000 CFU/ml) the recommended limit set by Egyptian Law No. 48/1982 for protection of the River Nile and waterways from pollution. Similarly, the TC ranged from 1.3×10^6 (winter) to 9.3×10^7 CFU/ml (summer), which highly exceeds the World Health Organization (WHO) safe limit (≤1000 CFU/100 ml) for wastewater use in irrigation. This study provides the current pollution status of Bahr El-Baqar drain to find sustainable solutions for the national water vulnerability crisis.

Key Words:

Water quality, Major ions, Total Viable Bacteria, Total Coliform, Bahr El-Baqar drain

1. INTRODUCTION

Water is the most important natural resource which is used by humans to meet their needs and it is a valuable source for agricultural and industrial operations [1, 2]. Water pollution originates from both natural and manmade sources, which gives rise to a variety of water pollutants. To keep people healthy and protect them from numerous diseases, these toxins in the water must be eliminated [3]. Polluted drains in the Nile Delta such as Bahr El-Baqar are considered one of the most important dangerous elements for the nearby aquatic environment. Various polluting sources such as mining, industrial operations, non-point sources, especially vehicle exhaust, and the use of metal-enriched materials, including chemical fertilizers, plant manures, sewage sludge, and wastewater drainage are involved [4]. Furthermore, the use of polluted water from drains outfalls in fish farms and agricultural lands has very dangerous environmental impacts on plants, and soil [5]. In the last few decades, the increase in municipal and domestic waste discharge with infrequent primary and secondary treatment isn't sufficient anymore to prevent contamination and harming water resources [6]. Abdel-Azeem et al. [7] reported that using wastewater for irrigation will raise the concentration of heavy metal content in soil and plant in southern Port-Said city. The biggest worries to preserving our future are water quality management, water pollution control, and environmental protection [6]. Assessment of water quality resulting in the efficient management of water resources using monitoring networks [1].

Pathogenic organisms are revealed by microbial indicators of fecal contamination [2]. The presence of pathogenic microbes in the water supply may cause waterborne diseases such are salmonellosis, tuberculosis, typhoid, paratyphoid, cholera, amoebic dysentery, poliomyelitis, aseptic meningitis, and infectious hepatitis [8]. *Escherichia coli* and the Coliform group are significant bacterial indicators used to identify the water quality and assess its health risk. The Coliform bacteria have often been recognized as a sign of fecal contamination in water, which threatens both crops and people's health [9]. Standard plate count is helpful for monitoring the potential for bacterial growth in the wastewater [5]. Water pollutants can affect both the populations of higher and lower plants and animals. Therefore, biological indicators can show the extent of water pollution [10]. The procedure applied in this study used a multi-level decision support scheme including a detailed geochemical analysis based on collecting representative samples of surface water of Bahr El-Baqar drain, in addition to the site selection along the drain's course according to the EuroGeoSurveys Geochemistry Expert Group Sampling Protocol.

Objectives of the present research study is to develop, test and verify a novel combination of state-of-the-art geochemical contamination risk assessment by evaluating and integrating the seasonal and spatial variation of the water quality physico-chemical parameters, major dissolved ions, and bacteriological indicators in the surface water of Bahr El-Baqar drain, Eastern Nile Delta, Egypt.

2. Materials and Methods

2.1 Study area

Bahr El-Baqar drain is one of the most polluted drains in Egypt [6]. The drain is located in the eastern part of the Nile Delta with a length of about 170 Km starting from north Cairo, where Belbeis (east) and Qalubiya (west) secondary drains meet together near Zagazig, Sharqiya Governate and ending into Lake Manzala south of Port Said city [1, 11] (Fig. 1). Lake Manzala was estimated to be an important resource of the Egyptian fishing receives about 60 m^3/s of wastewater from Bahr El-Baqar drain [5, 12]. The main contamination sources which spoil the Bahr El-Baqar drain are industries in Shoubra El-Khema, north Cairo such ad metal industries, food processing, disinfectant and soap, paper and textile manufacturing, industries near Zagazig city, and municipal wastewater discharged into Belbeis and Qalubiya drains [13]. The study area includes five sampling sites along Bahr El-Baqar drain, Eastern Nile Delta, Egypt, starting from the upstream site S1 (south near Zagazig) to the downstream site S5 (north, near Lake Manzala) as shown in Fig. 1 and Table 1.

2.2. Water sampling

A total of 20 water samples were collected from 5 main sites along Bahr El-Baqar drain starting from S1 (Qalubiya drain) and S2 (Belbeis drain) in Saft Elhinna village, south Zagazig, Sharqiya Governate about 80 Km north Cairo to Lake Manzala about 2 km south of Port Said city (Fig. 1 and Table 1). The water samples were collected in 1 L HDPE bottles during the summer and winter seasons of 2018, then the samples were transported to the lab in an icebox for further analysis.

2.3 Physico-chemical parameters and major ions' analysis

Physicochemical parameters such as temperature, pH, total dissolved salts (TDS), electrical conductivity (EC), dissolved oxygen (DO), were measured in the field by Multi-probe Aqua-Read AP 5000 (water monitoring instruments, Kent, England), as well as biological oxygen demand (BOD), and chemical oxygen demand (COD) were measured in the lab using the standard methods: APHA 5210 & 5220, respectively [14]. Additionally, some important major dissolved ions (e.g., Ammonium, NH_4^+; Chlorine, Cl^-; Nitrate, NO_3^-; and Phosphate, PO_4^{3-}) were measured and analyzed in the water samples from Bahr El-Baqar drain using the standard methods: APHA 4500-F [14]. Accuracy and precision of the measurements were optimized and confirmed using external reference standards and quality control samples.

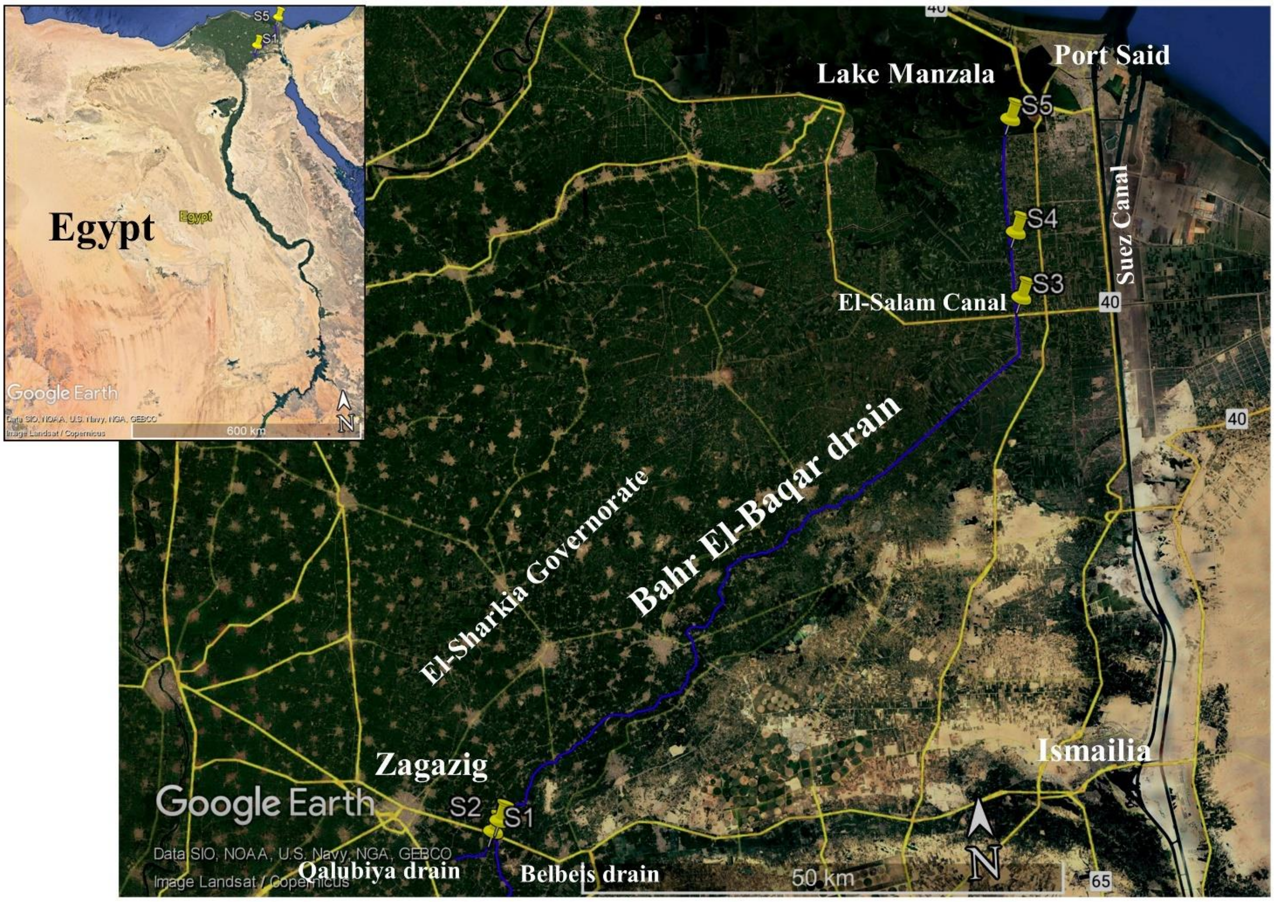


Fig. 1. Location map of the study area and sampling sites (S1-5) in Bahr El-Baqar drain, Eastern Nile Delta, Egypt.

Table 1. Coordinates of the sampling sites of water in Bahr El-Baqar drain.

Site	Location	Lat.	Long.
S1	Qalubiya drain	30° 33′ 37.8″ N	31° 36′ 03.8″ E
S2	Belbeis drain	30° 33′ 32.4″ N	31° 36′ 12.3″ E
S3	Near Bahr El-Baqar village	31° 01′ 01.4″ N	32° 12′ 12.7″ E

S4	North Bahr El-Baqar drain	31^o 04′ 41.6″ N	32^o 12′ 06.4″ E
S5	Outlet of Bahr El-Baqar drain into Lake Manzala	31^o 11′ 03″ N	32^o 12′ 11.8″ E

2.4 Bacteriological analysis

Total viable bacterial count (TVC) was conducted according to the method of [14] using the dilution plate method. TVC was determined using plate count agar medium, while Total Coliform (TC) was estimated using Eosin Methylene Blue Agar medium [14].

2.5 Statistical analysis

Univariate (min, max, mean and standard deviation, (SD)), and bivariate correlation were carried out to show the normal distribution of data and the relationship between the physicochemical parameters, bacteriological indicators, and major ions in the drain water samples using Statgraphics software [15].

3. Results and Discussion

3.1 Seasonal and spatial variation of physicochemical parameters of Bahr El-Baqar drain water

The measured physicochemical parameters (e.g., temperature, pH, TDS, EC, DO, BOD, and COD) and selected dissolved major ions (e.g., NH_4^+, Cl^-, NO_3^-, and PO_4^{3-}) of Bahr El-Baqar drain water were reported in Table 2. The spatiotemporal variation of the parameters in the study sites was shown in Fig. 2. Because temperature directly affects the majority of physical, biological, and chemical characteristics, the water temperature in canals and drains is crucial for water quality [12]. The average temperature of the drain water was 20 ^oC and varied from 14.5 ^oC (winter) to 27.8 ^oC (summer) (Table 2). While the temperature of the drain water shows a decreasing pattern from upstream sites (e.g., site-S1: Qalubiya drain) towards downstream sites (e.g., S5) near Lake Manzala, south of Port Said city (Fig. 1 and 2a). The drainage of sewage water might be referred to as the high temperature at upstream sites (S1: 27.8 ^oC) compared to 23 ^oC [12].

The pH of the drain water, which ranges from 6.54 to 7.7 and indicates slightly alkaline water, is 7.48 (Table 2), which is within the typical pH range (6.0-8.5) recommended for irrigation water. The drain's water pH in this study is comparable to that in earlier studies [11, 12], and more alkaline water (pH: 7.35-9.10) was also observed [5, 7, 16]. The pH of the drain water has almost no seasonal variation along the study sites (S1-5) (Table 2 and Fig. 2b). The water quality, the solubility of metals, alkalinity, and hardness of water are all significantly influenced by pH [11]. The increase in pH could be related to the photosynthesis, growth of aquatic plants, and high vegetation.

The TDS in Bahr El-Baqar drain water varied from 700 to 2550 mg/L (Table 2). These TDS values are higher than those (700-1104 mg/L) previously reported in the drain water [5, 12], but lower than the range (1202-4096 mg/L) reported by Badawy et al. [16]. Water with high TDS is toxic to plants and poses a salinity hazard [12].

The EC measures the ionic strength of water [11, 12]. The EC in Bahr El-Baqar drain water ranges from 1390 to 4670 μS/cm (Table 2), which is higher than the range of 1080-1670 μS/cm [5, 12], and the range of 1050-1950 μS/cm [11], and falls within the range of 2800-6400 μS/cm [16]. Both TDS and EC have a close relationship and exhibit a rising seasonal pattern at the study sites: S1 to S5 (Fig. 2 c and d).

The DO is essential in water bodies because it is necessary for the respiration of aquatic organisms and the photosynthetic activity of the primary producers [12, 17]. The DO in the water of Bahr El-Baqar drain has a range of 1.90-8.90 mg/L and an average of 5.16 mg/L (Table 2), compared to the low DO ranges of 0.3-0.7

mg/L [12], 0.07-0.34 mg/L [18], 0.1-0.35 mg/L [7], and 0.24 mg/L [5] that were previously reported in the drain water. While low DO could hinder plant growth, high DO can harm aquatic life and degrade water quality [18]. The decrease of DO is mainly related to the decomposition of free oxygen by bacteria. Regarding the spatiotemporal variation, the DO in winter samples is decreasing from site-S1 northward to S5 (Fig. 2e), which may be referred to as the inflow of domestic, industrial, and agricultural wastewater [12]. In contrast, S5 has the highest DO value (8.90 mg/L) in summer samples (Fig. 2e), which may be referred to as the inflow of fresh water to this site.

Table 2. Statistical summary of the physicochemical parameters of Bahr El-Baqar drain water.

	Temp (C^o)	pH	TDS (mg/L)	EC (μS/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NH_4^+ (mg/L)	NO_3^- (mg/L)	PO_4^{-3} (mg/L)	Cl^- (mg/L)
Mean	20.07	7.48	1685.8	2864.5	5.16	6.83	57.78	18.22	30.26	2.63	743.5
Min	14.50	6.54	700	1390	1.90	1	37	2.80	2.80	2.18	234
Max	27.80	7.7	2550	4670	8.90	14	82.20	44.80	64.40	3.79	1177
Median	20.65	7.61	2080	3215	5.15	6.75	53.25	11.20	25.20	2.53	966.5
SD	4.51	0.33	708.18	1205.8	2.23	4.95	18.13	15.93	23.43	0.45	383.88

A reliable indicator of water quality, BOD is frequently used to measure the level of organic contamination in wastewater-treatment facilities [17]. The BOD levels in the drain water samples ranged from 1 to 14 mg/L with an average of 6.83 mg/L (Table 2), which is lower than higher BOD levels previously recorded in the drain: 168-206 mg/L [12], 72-303 mg/L [18], and 61 mg/L [5]. Notably, the BOD levels of the winter water samples are higher than those of the summer samples (Fig. 2f). Bacterial decomposition of organic matter affect the DO in water leading to an increase of the BOD [5].

The COD indicates the amount of oxygen required to oxidize the organic and inorganic matter in wastewater. In this study, COD in the drain water ranges from 37 to 82.20 mg/L (Table 2), which is significantly higher than 22-45 mg/L [12], and 79 mg/L [5]. Typical COD values are in the range of 5-20 mg/L for open watercourses, and 20-100 mg/L for domestic and municipal wastewater [12]. Seasonally, the COD of the summer water samples is higher than that of winter samples throughout the study sites (Fig. 2g). The DO, BOD, and COD represent the contamination brought on by domestic and industrial effluents [19]. According to earlier studies [20, 21], an element's release from the solid soil phase to the liquid phase may be impacted by seasonal changes in environmental parameters including temperature and pH.

The abundance of dissolved major ions is determined based on cation and anion properties [16]. The concentrations of dissolved major ions (mg/L) in the drain water were distributed in the following order: Cl^- (743.5) > NO_3^- (30.26) > NH_4^+ (18.22) > PO_4^{3-} (2.63), which highly exceed their maximum contaminant levels (MCL): 250, 10, 0.5, and 0.1, respectively [22] (Table 2 and Fig. 2). The NH_4^+ is environmentally hazardous because of its toxicity to fish, ease of oxidation and quick depletion of DO, however, Ammonia (NH_3) is extremely toxic, and both NH_3 and NH_4^+ are grouped as total ammonia [5]. The range of NH_4^+ in this study is 2.8-44.8 mg/L (Table 2), compared to lower levels (10-14) mg/L reported before in the drain water [12]. The NH_4^+ shows an increase in all study sites towards the drain's end (Fig. 2h). Additionally, sewage effluent from treatment plants is a major source of ammonia in the drain's water [12].

The NO_3^- shows a range of 2.8-64 mg/L (Table 2), which is almost similar to the range of 1-70 mg/L reported before in the drain water [12], and higher than 17.2 mg/L [5]. The NO_3^- showed a spatiotemporal increase at the southern part of the drain, followed by a gradual decrease towards the drain end to the north, particularly in winter samples (Fig. 2i). High-nitrate and low-ammonia nitrogen levels indicate that pollution occurred earlier [12, 17].

The range of PO_4^{-3} in the drain water is 2.18-3.79 mg/L (Table 2), which is nearly equivalent to (1-4 mg/L) [12]. The overuse of fertilizers in agricultural activities near the drain could be the source of phosphate. Even the beginning of the drain's shallow groundwater aquifer was contaminated by the fertilizer discharge [23]. The PO_4^{-3} levels varied along the study sites, but they were somewhat higher in winter samples (Fig. 2j). Fertilizers and wastewater contain high amounts of nitrates which are the most serious persistent pollutants. The use of organo-chloro-pesticides (highly toxic) is now prohibited as they may accumulate in the food chain [24].

The Cl^- is the dominant anion in the drain water in this study and ranges from 234 to 1177 mg/L with an average of 743.5 mg/L (Table 2), compared to low Cl^- levels previously reported in the drain water; 97-184 mg/L [12], 54-110 mg/L [11], and higher levels 2048 mg/L [5]. Like TDS and EC, the Cl^- exhibits a seasonal tendency, with a particular increase from the downstream S3 toward the drain's end (Fig. 2k).

The comparison of water quality physico-chemical parameters and major dissolved ions in this study and those of previous studies in Bahr El-Baqar drain, Lake Manzala and the River Nile are reported in Table 3. It is concluded that the average value of pH (7.48) in this study is higher than (6.6-7.35) previously reported in the water of Bahr El-Bagar and Kitchener drains [12, 18, 20], while it is lower than those of [1, 5, 7, 11, 16, 25, 27-31, 33] (Table 3). The average TDS (1685.8 mg/L) in the drain water is higher than (2.8-1485 mg/L) repored before [5, 12, 29-30, 33], however, it is below those of [1, 16, 27-28] (Table 3). The average EC (2864 μS/cm) in the drain water is much higher than (276-2500 μS/cm) in most previous studies [1, 5, 12, 18, 20, 29, 32-33], while it is lower than those of [11, 16, 31]. The average DO (5.16 mg/L) in the drain water exceeds (0.002-4 mg/L) [5, 7, 12, 18, 27, 29, 32] and is below those of [28, 30-31, 33] (Table 3). The average BOD in the drain water exceeds (3.2 mg/L) of the Nile River water [33], while it is much lower than (11-140 mg/L) reported before in water of the drain and Lake Manzala [1, 5, 7, 18, 25-27, 32] (Table 3). The average COD (57.78 mg/L) is higher than (9.7-50 mg/L) in the water of Bahr El-Baqar drain, Lake Manzala and the River Nile [1, 12, 26, 33], and is lower than those of [5, 7, 25, 27] (Table 3). The average NH_4^+ (18.22 mg/L) in the drain water exceeds (0.27-17.5 mg/L) [1, 28, 30] and is lower than (20-28 mg/L) [12, 18] (Table 3). The average NO_3^- (30.26 mg/L) in this study exceeds (1.34-20 mg/L) [1, 5, 7, 26, 28, 30] and is below (42-237 mg/L) previously dectected in the water of BahrEl-Baqar drain, Kitchener drain and the River Nile [12, 18, 20, 33] (Table 3). The average PO_4^{-3} (2.63 mg/L) only exceeds (0.37 mg/L) [28], however, it is below most reported values (2.37-29 mg/L) in the water of Bahr El-Baqar, Kitchener drain, Northern Nile Delta, Lake Manzala and the River Nile [7, 12, 18, 20, 30, 33] (Table 3). The average Cl^- in the drain water (743.5 mg/L) exceeds most chloride values (5.37-180 mg/L) previously detected in the water of Bahr El-Baqar, Kitchener drain and the River Nile [1, 11-12, 18, 20, 26, 33], however, it is lower than (2048 mg/L) reported before in the water of Bahr El-Baqar drain [5].

Table 3. Comparison of the physico-chemical parameters and major dissolved ions (mg/L) in the studied drain water and those of previous studies in Bahr El-Baqar drain, Lake Manzala and the River Nile, Egypt.

Ref.	Location	Temp (C^o)	pH	TDS (mg/L)	EC (μS/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NH_4^+ (mg/L)	NO_3^- (mg/L)	PO_4^{-3} (mg/L)	Cl^- (mg/L)
This study	Bahr El-Baqar	20	7.48	1685.8	2864.5	5.16	6.83	57.78	18.22	30.26	2.63	743.5
[1]	Bahr El-	22	7.5	1898	2500		18	22	4	13.5		32.6

	Baqar											
[5]	Bahr El-Baqar	28	9.1	1104	1670	0.24	61	79		17.2		2048
[7]	Bahr El-Baqar		8.09			0.21	51	145		6.45	7.63	
[11]	Bahr El-Baqar		7.5		7500							5.37
[12]	Bahr El-Baqar	23	6.6	1200	1500	0.45		38	20	70	4	180
[16]	Bahr El-Baqar		7.55	2664	3000							
[18]	Bahr El-Baqar		7.2		1540	0.15	140		28	199.4	14.5	137.2
[20]	Kitchener Drain		7.35		2480					42	3.65	10.5
[25]	Bahr El-Baqar	22.3	8.45				51	145				
[26]	Bahr El-Baqar				3665		25	50		20		50
[27]	Bahr El-Baqar	27	7.6	3520		0.16	48.75	60.78				
[28]	Bahr El-Baqar	23	7.8	4150		8.5			0.27	1.34	0.37	
[29]	Bahr El-Baqar	23	7.48	2.8	436	0.002						
[30]	Lake Manzala	22.7	8.5	1485		7.6			17.5	4	2.37	
[31]	Lake Manzala	20	7.46		4010	6.5						
[32]	Lake Manzala	20			1800	4	11					
[33]	Nile River	27.4	8.1	179	276	5.9	3.2	9.7		237	29	11.2

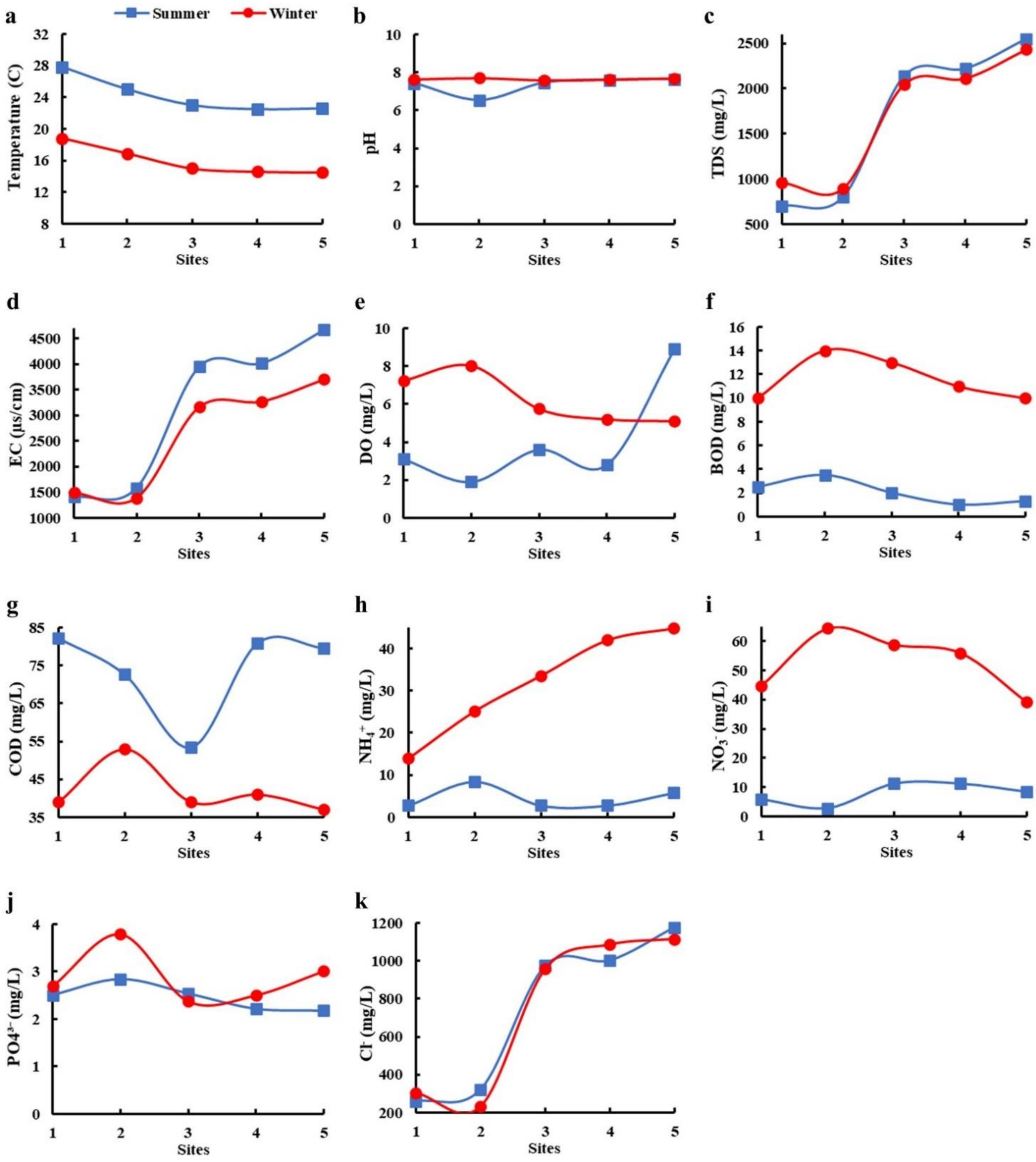
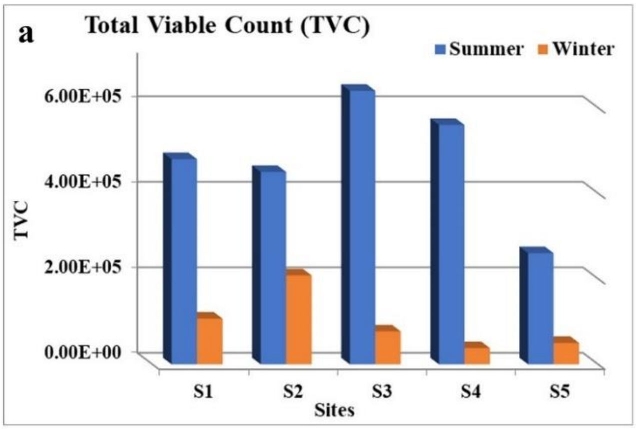


Fig. 2. Spatial and temporal distribution plots of physicochemical parameters of water samples collected during the summer and winter of 2018 from Bahr El-Baqar drain: temperature (a), pH (b), TDS (c), EC (d), DO (e), BOD (f), COD (g); and selected dissolved ions: NH^{4+} (h), NO^{3-} (i), PO_4^{2+} (j), and Cl^- (k).

3.2. Seasonal and spatial variation of bacteriological indicators in Bahr El-Baqar drain water

The study results showed seasonal and spatial variations of both the Total Viable Count (TVC) and Total Coliform (TC) group in the drain water samples (Fig. 3). The TVC counts along the study sites have the following decreasing order: S3 > S4 > S1 > S2 > S5 in the summer samples, while S2 > S1 > S3 > S5 > S4 in the winter samples (Fig. 3a). The highest count of TVC was recorded in site S3 (near Bahr El-Baqar village) with a value of 6.4 $\times 10^5$ CFU/ml in summer samples, while the lowest TVC was in S5 (south Lake Manzala) with a value of 0.38 $\times 10^5$ CFU/ml in winter samples (Fig. 3a). The TC group counts along the study sites have the following decreasing order: S2 > S1 > S3-5 in the winter samples, while in the summer samples all sites (S1-5) have almost same low counts (Fig. 3b). The highest count of TC group was 9.3 $\times 10^7$ CFU/ml in S2 (Belbeis drain near Zagazig city) in summer samples, while the lowest value was 1.3 $\times 10^6$ CFU/ml in S5 (south Lake Manzala) in winter samples (Fig. 3b). The World Health Organization (WHO) set a limit of less than 1000 CFU/100 mL of Fecal coliforms, which is considered safe for wastewater use in irrigation [34].



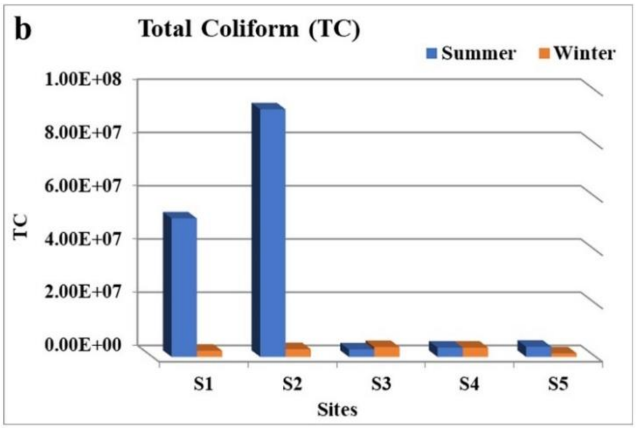


Fig. 3. Seasonal variation of the bacteriological indicators; TVC (a) and TC (b) in Bahr El-Baqar drain water during the summer and winter of 2018.

In comparison to previous studies in Bahr El-Baqar drain and Lake Manzala, Soliman et al. [5] reported high pollution levels of TVC (144 x 105 CFU/ml), and lower TC (43 x 105 CFU/100 ml) in the drain outlet near Lake Manzala. Elkorashy [1] showed less contamination than the present study where TC ranged from 12-45 × 104 CFU /ml in summer, to 24-93 × 104 CFU /ml in winter. Moreover, Hamed et al. [25] reported significant levels of total viable bacteria (TVB) and fecal coliform bacteria (FCB) in the water of Bahr El-Baqar and Lake Manzala, due to untreated wastewater leaked into the drain either directly or indirectly [25]. These results could be explained by the fact that the increasing rate of sewage and municipal discharge of wastewater into the Bahr El-Baqar drain from the surrounding cultivated lands and village houses, and the increased human activity in the summer season.

3.3 Statistical analysis

3.3.1 Correlation between physicochemical parameters and major dissolved ions in the drain water

The significant bivariate relationships between the physico-chemical parameters and major dissolved ions in water samples from the Bahr El-Baqar drain are shown in Fig. 4. In the drain water samples, the pH shows negative significant ($p < 0.05$) relationships with BOD (r= -0.93; Fig. 4a), and PO_4^{3-} (r= -0.91). The TDS has a positive and significant relationship with EC (r= 0.99, $p < 0.01$ (Fig. 4b), and with Cl^- (r= 0.99,

$p < 0.01$). Additionally, the temperature exhibits negative significant ($p < 0.05$) relationships with other physicochemical parameters; TDS (r= -0.9), EC (r= -0.9); dissolved ions: NH_4^+ (r= -0.94), Cl^- (r= -0.91; $p < 0.05$) (Fig. 4c).

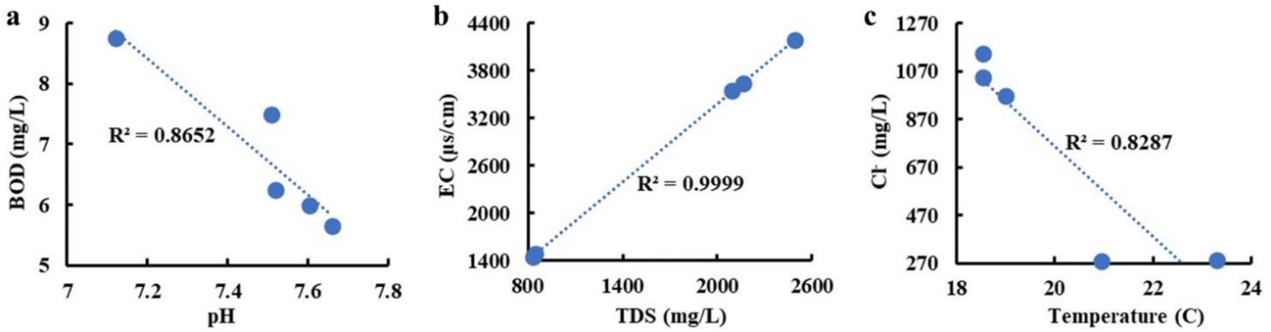


Fig. 4. Bivariate correlation between the physicochemical parameters and dissolved ions concentrations (mg/L) in the water of Bahr El-Baqar drain: BOD versus pH (a), EC versus TDS (b), and Cl^- versus Temperature (c).

3.3.2 Correlation between physicochemical parameters and bacteriological indicators in the drain water

In the winter samples, the TVC showed positive medium correlations with temperature (R^2= 0.35; $p < 0.05$; Fig. 5a), pH (R^2= 0.23; $p < 0.05$; Fig. 5b), and BOD (R^2= 0.45; $p < 0.05$; Fig. 5d), however, the TVC showed positive significant correlations with DO (R^2= 0.88; $p < 0.05$; Fig. 5c), and COD (R^2= 0.78; $p < 0.05$; Fig. 5e). In the summer samples, the TVC was negatively correlated with DO (R^2= 0.55; $p < 0.05$; Fig. 5c) and COD (R^2= 0.33; $p < 0.05$; Fig. 5e). It is noted that the amount of oxygen consumed by either biological or chemical forms has a great effect on the TVC as shown in Fig. 5.

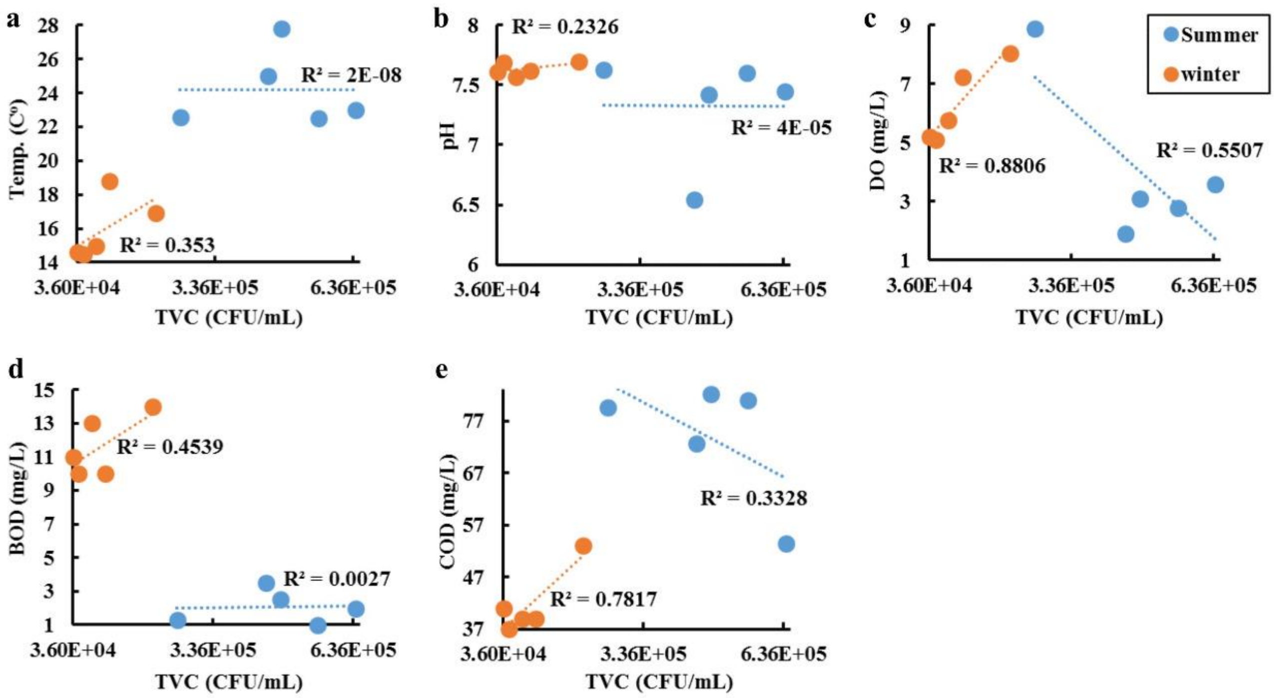


Fig. 5. Bivariate correlation between Total Viable Count (TVC) and the physico-chemical parameters: temperature (a), pH (b), DO (c), COD (d), and BOD (e) in the investigated drain water.

In contrast, Total Coliform (TC) in the summer samples was positively correlated with temperature (R^2= 0.46; $p < 0.05$; Fig. 6a), BOD (R^2= 0.86; $p < 0.05$; Fig. 6d), and with weak positive correlation with COD (R^2= 0.027; $p < 0.05$; Fig. 6e). However, the TC was negatively correlated with pH (R^2= 0.81; $p < 0.05$; Fig. 6b), and DO (R^2= 0.27; $p < 0.05$; Fig. 6c). In the winter samples, the TC has almost very weak correlations with the physico-chemical parameters, except for, a negative correlation with pH (R^2= 0.44; $p < 0.05$; Fig. 6b), and a positive correlation with BOD (R^2= 0.366; $p < 0.05$; Fig. 6d).

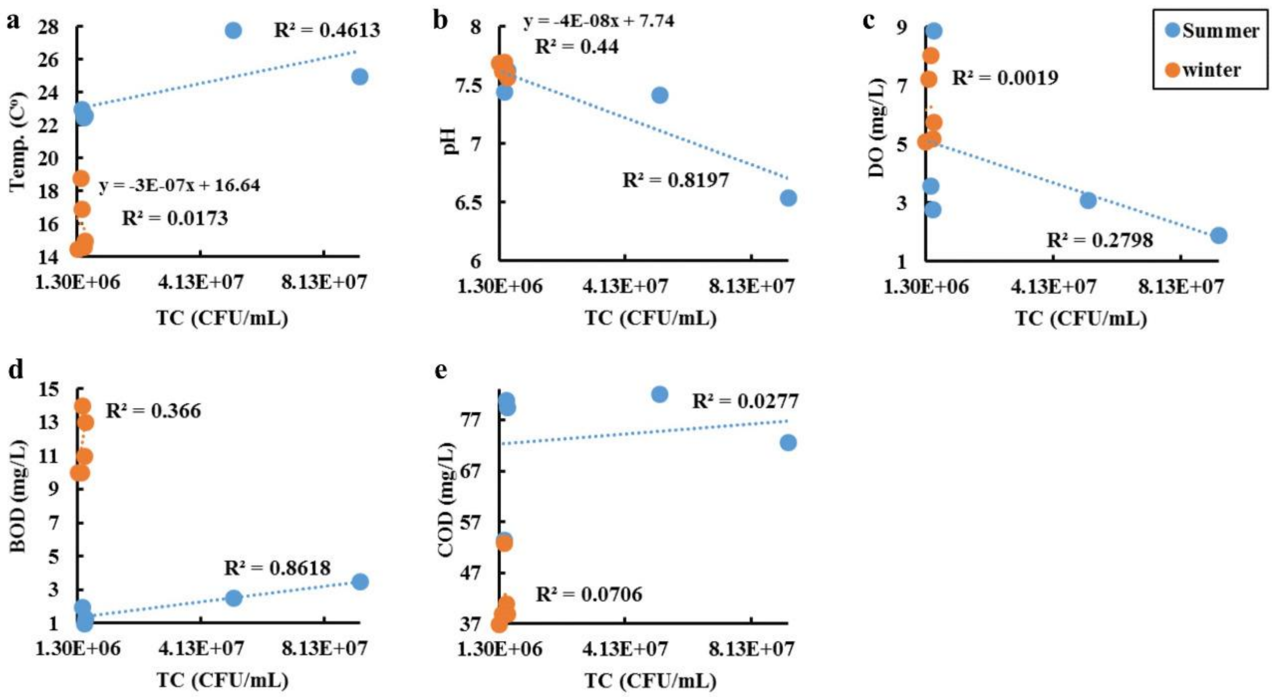


Fig. 6. Correlation between the Total Coliform (TC) group and the physicochemical parameters: temperature (a), pH (b), DO (c), COD (d), and BOD (e) in the investigated drain water.

4. Conclusion

This study assessed the spatial and seasonal variation of the water quality physicochemical parameters, major dissolved ions, and bacteriological indicators in the water of Bahr El-Baqar drain, Eastern Nile Delta, Egypt by integrating geochemical and statistical analyses. Results showed that the physico-chemical parameters; temperature (14.5-27.8 ^oC), pH (6.54 to 7.7), TDS (700-2,550 mg/L), EC (1,390-4,670 µS/cm), DO (1.90-8.90 mg/L), BOD (1-14 mg/L), and higher COD (37-82.20 mg/L) are aberrant water quality physico-chemical values for the drain water, which are typical for domestic and industrial wastewater. Additionally, the concentrations of the major dissolved ions (mg/L) in Bahr El-Baqar drain water followed the decreasing order: Cl^- (743.5) > NO_3^- (30.26) > NH_4^+ (18.22) > PO_4^{3-} (2.63). Regarding the statistical correlation between the physico-chemical parameters and major dissolved ions in the drain water samples, temperature was negatively correlated with TDS, EC, NH_4^+ and Cl^-. Similarly, pH was negatively correlated with BOD and PO_4^{3-}, while TDS was positively correlated with EC and Cl.

The total viable count was carried out using the standard plate method. Results showed high contamination in Site S3 which is the meeting point between the two branches of Bahr El-Baqar drain. It is worth mentioning that the TVC of all the monitored sites exceeded (1000 CFU/ml) the recommended limit by Egyptian Law No. 48/1982 for protection of the River Nile and waterways from pollution. The total coliform group ranged from 2.80 $\times 10^6$ CFU/ml to 9.3×10^7 CFU/ml during the summer season, while it ranged from 1.30$\times 10^6$ CFU/ml to 3.70$\times 10^6$ CFU/ml during winter. Statistically, the TVC was positively correlated with temperature, pH, DO, BOD, and COD, while the TC was positively correlated with temperature, BOD, and negatively with pH, and DO. In this study, the TC showed high pollution levels of sewage and municipal wastewater drainage that highly exceed the World Health Organization (WHO) safe limit (≤1000 CFU/100 ml) for wastewater use in irrigation.

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