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Water Quality Assessment of River Nile at Rosetta Branch: Impact of Drains Discharge

[1]*Safaa M. Ezzat*, [2]*Hesham M. Mahdy*, [3]*Mervat A. Abo-State*,
[2]*Essam H. Abd El Shakour* and [2]*Mostafa A. El-Bahnasawy*

[1]Central Laboratory for Environmental Quality Monitoring (CLEQM),
National Water Research Center (NWRC), Cairo, Egypt
[2]Botany and Microbiology Department,
Faculty of Science (Boys), Al-Azhar University, Cairo, Egypt
[3]National Centre for Radiation Research and Technology (NCRRT),
Atomic Energy Authority, Cairo, Egypt

Abstract: River Nile is the main source of drinking water in Egypt. Unfortunately, it receives heavy load of industrial, agricultural and domestic wastes from several sources. The aim of the present study is to examine the water quality of about 120 km in River Nile at Rosetta branch and five main drains located on its sides, through several physico-chemical and bacteriological analyses. Results obtained from two seasons trips (summer 2010 and winter 2011) revealed that the water quality along studied area in Rosetta branch is obviously influenced by drains discharge. High concentrations of NH_3, total dissolved solids (TDS), electric conductivity (EC), biological oxygen demand (BOD), total alkalinity, turbidity and recognizable depletion in dissolved oxygen (DO) were recorded. Pollution from total and fecal coliforms as well as fecal streptococci exceeding permissible limits pointed out that agricultural and sewage wastes are the key factors in this environmental problem, particularly in winter season. The calculated water quality index (WQI) supported the analytical data and the correlation coefficient matrix between water quality pairs recorded several positive and negative significant relationships. The gradual improvement recognized at the end of the branch especially in summer season is attributed most probably to self-purification and dilution concepts. The study recommended treating wastewater prior to discharge or reuse as well as regular and constant monitoring for River Nile to mitigate health problems outbreaks or any aquatic ecosystem disorders.

Key words: River Nile · Rosetta branch · Delta region · Water quality · Drains discharge · Pollution · Physico-chemical and bacteriological analyses · Egypt

INTRODUCTION

River Nile travels along Egypt for about 950 km starting from downstream High Aswan Dam to upstream Delta Barrage, where it divides into two branches Rosetta and Damietta branches each of which runs separately to the Mediterranean Sea, forming the Delta region between both branches. Rosetta branch represents the main freshwater stream that extends northwards for about 239 km on the western boundary of the Nile Delta from Egypt's Delta Barrage [1]. Rosetta branch has an average width of 180 m and depth from 2 to 4 m. It ends at Edfina Barrage, 30 km upstream the sea, which releases excess water to the Mediterranean Sea. It is estimated that the aquatic environment of this branch receives more than 3 million cubic meters daily of untreated or partially treated domestic and industrial wastes and in addition to agricultural drainage water [2]. Rosetta branch water serves for a wide range of functions including agricultural, industrial and domestic water supply, fisheries and recreation. Unfortunately this branch is impacted by the agricultural drains located along its sides and by the industrial companies at Kafr El-Zayat city. The drains are EL-Rahawy, Sabal, El-Tahreer, Zaweit El-Bahr and

Corresponding Author: Safaa M. Ezzat, Central Laboratory for Environmental Quality Monitoring (CLEQM), National Water Research Center (NWRC), Cairo, Egypt.

Tala. These agricultural drains receive also domestic water from fifty five towns and villages distributed along the branch. The industrial outfalls are El-Maliya, Mobidat and Salt and Soda companies which are discharging directly at the east bank of the branch. These two sources of pollution potentially affect and deteriorate its quality of water [3, 4].

The aim of this study is to examine the water quality of River Nile at Rosetta branch through several physico-chemical and bacteriological analyses to evaluate how drains discharge may influence water quality. The correlations between different tested parameters were also discussed.

MATERIALS AND METHODS

Study Area: The area of our study extended about 120 km in Rosetta branch, starting from upstream El-Rahawy drain up to downstream of Tala drain as shown in Fig. 1. Fifteen sites were chosen, five at the drains outfalls (El-Rahawy, Sabal, El-Tahreer, Zawiet El-Bahr and Tala) and ten in Rosetta branch (five upstream and five downstream those drains) as shown in Table 1. Upstream drains sites are considered as reference points to evaluate deterioration impacts caused by drain discharge compared to the downstreams.

Sampling Procedure: Water sampling was carried out according to Standard Methods for Examination of Water and Wastewater [5]. Water samples were collected in two different seasons (summer 2010 and winter 2011) from Rosetta branch of the River Nile and five drains located on its side. The water samples were collected from the subsurface layer (at depth 50 cm) in stopper polyethylene plastic bottles. All samples collected for either physico-chemical or bacteriological examinations were stored in an iced cooler box and delivered immediately to the laboratory for analyses.

Physico-Chemical Analyses: Physical and chemical analyses were carried out according to Standard Methods for Examination of Water and Wastewater [5]. Field parameters (temperature, pH, electric conductivity (EC), dissolved oxygen (DO) and total dissolved solids (TDS)) were measured in-situ using multi-probe system, model Hydralab-Surveyor and rechecked in laboratory. Turbidity was measured by Nephelometric turbidity meter HACH, model 16800. Ammonia (NH_3) was measured by ammonia selective electrode, ORION model 95-12 attached to bench-top Ion analyser, ORION model 940. Biochemical oxygen demand (BOD) was determined by ORION BOD fast respiratory system, model 890. Major anions (chloride-Cl^-, nitrite-NO_2^-, nitrate-NO_3^-, phosphate-PO_4^{3-} and sulfate-SO_4^{2-}) were measured using Ion Chromatography (IC), model DX-500 chromatography system, while carbonates-CO_3^{2-} and bicarbonates-HCO_3^- were detected by Ion Chromatography (IC-METROHM). The concentrations of major cations (calcium-Ca^{2+}, potassium-K^+, magnesium-Mg^{2+} and sodium-Na^+) and trace metals including aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), vanadium (V) and zinc (Zn) were measured also using the Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES) with Ultra Sonic Nebulizer (USN), model Perkin Elmer optima 3000.

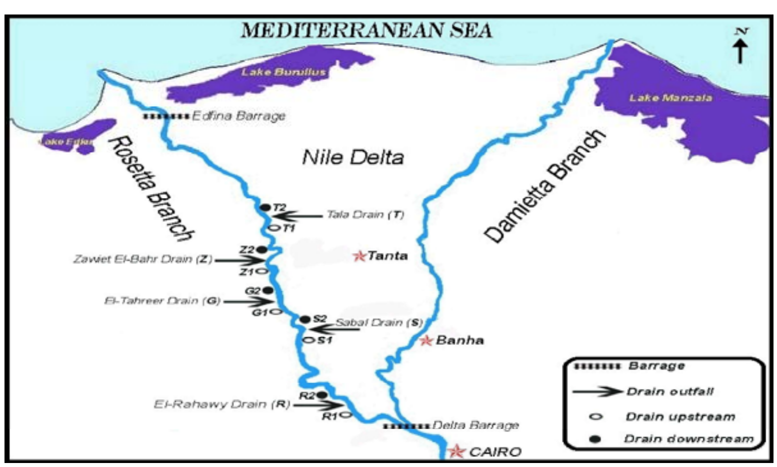

Fig. 1: Map of sampling locations (Drains and Rosetta branch)

Table 1: Location of the study sites in Rosetta branch, River Nile.

Site code	Description	Latitude (N)	Longitude (E)
R_1	Rosetta branch, upstream El-Rahawy drain	30°12'30.23"N	31° 2'02.21"E
R	El-Rahawy drain outlet (left bank)	30°12'26.21"N	31° 1'58.90"E
R_2	Rosetta branch, downstream El-Rahawy drain	30°12'25.41"N	31° 1'48.35"E
S_1	Rosetta branch, upstream Sabal drain	30°31'57.94"N	30°50'53.20"E
S	Sabal drain outlet (right bank)	30°32'13.47"N	30°51'07.09"E
S_2	Rosetta branch, downstream Sabal drain	30°32'29.05"N	30°51'01.27"E
G_1	Rosetta branch, upstream El-Tahreer drain	30°36'23.50"N	30°47'51.89"E
G	El-Tahreer drain outlet (left bank)	30°36'24.68"N	30°47'48.92"E
G_2	Rosetta branch, downstream El-Tahreer drain	30°36'28.90"N	30°47'47.49"E
Z_1	Rosetta branch, upstream Zawiet El-Bahr drain	30°42'51.10"N	30°45'55.23"E
Z	Zawiet El-Bahr drain outlet (left bank)	30°42'52.57"N	30°45'19.01"E
Z_2	Rosetta branch, downstream Zawiet El-Bahr drain	30°43'09.26"N	30°45'39.53"E
T_1	Rosetta branch, upstream Tala drain	30°48'58.19"N	30°48'37.60"E
T	Tala drain outlet (right bank)	30°49'01.74"N	30°48'47.77"E
T_2	Rosetta branch, downstream Tala drain	30°49'10.36"N	30°48'42.11"E

Bacteriological Analyses: All collected samples were examined within 6 hours after collection according to Standard Methods for Examination of Water and Wastewater [5]. Standard plate count (SPC) bacteria at 22°C and 37°C were determined by pour plate method No. 9215 B. For counting total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS), the membrane filter technique was applied using a filtration system completed with stainless steel autoclavable manifold and oil-free ''Millipore'' vacuum/pressure pump. Water samples were filtered through sterile, surface gridded ''Sartorious'' membrane of a pour size 0.45 µm and diameter 47 mm, according to standard method No. 9222 B, 9222 D and 9230 C on M-Endo agar LES, M-Fc agar and M-Enterococcus agar media, respectively. All media used were obtained in a dehydrated form, Difco-USA. Results were recorded as colony forming unit (CFU/100ml) using the following equation:

Total colonies /100 ml = (Counted colonies/ml of sample filtered) x 100

Water Quality Index: WQI is a 100 point scale that was used to summarize results from different physico-chemical and bacteriological measurements using computer program created by the National Sanitation Foundation, USA. The used parameters are: DO, FC, pH, BOD, temp., PO_4^{3-}, NO_3^- and turbidity. This index reduces huge amounts of data to a single number thus ranking water into one of five categories: very bad water (0-25), bad (25-50), medium (50-70), good (70-90) and excellent (90-100).

Statistical Analyses: Statistical analyses were established applying regression coefficient according to Challerjee and Machler [6].

RESULTS AND DISCUSSION

Results of physico-chemical and bacteriological analyses of water samples collected from drains and Rosetta branch during summer 2010 and winter 2011 were presented in Tables 2-8.

Physico-Chemical Characteristics of Water Samples

Temperature: Temperature affects the speed of chemical reactions, the metabolic rate of organisms, as well as how pollutants, parasites and other pathogens interact with aquatic residents. As given in Tables 2&3, temperatures changes ranged from 25.5°C to 27.7°C in drains outlets and between 25°C to 28.3°C along Rosetta branch sites. Temperature change depends mainly on the climatic conditions, sampling times and the number of sunshine hours. Air and water temperatures were positively correlated during studied seasons. This indicated that the water temperature is affected only by the ambient air temperature, pointing to the absence of any source for thermal water pollution. Correlation coefficient matrix presented in Table 4 revealed that temperature and pH are positively correlated (r = 0.63). This is due to the increase in temperature is usually accompanied by hydrolysis of HCO_3^- and CO_3^{2-} ions, leading to the appearance of hydroxyl (OH^-) ions that increase pH value. Similar relationship was reported by Toufeek and Korium [7].

pH: The pH value represents the instantaneous hydrogen ion activity and affects biological and chemical reactions in a water body. pH values for all collected water samples are within the permissible limits (Tables 2 and 3). These values are always higher than 6.5 which are normally expected in raw water due to the presence of carbonates or bicarbonates as reported by Friedl *et al*. [8].

Table 2: Mean values of physico-chemical parameters of water samples collected from drains outlets in summer and winter seasons

Parameters	Unit	R	S	G	Z	T[a]	LAW 48/1982[b]
Temp.	°C	25.5	26.2	27	27.5	27.7	5 degrees above normal
pH		7	7.5	7.65	7.65	7.65	7-8.5
EC	µmohs/cm	1101	1368.5	803.5	864	1623	-[c]
TDS	mg/l	705	876	514	553	1038	not exceed than 500
Tur.	NTU	29	75	21	17.5	62.5	-
NH_3	mg/l	22.3	7.9	1	0.95	5.15	not exceed than 0.5
DO	mg/l	0.3	3.2	5.2	4.15	4.4	not less than 5
BOD	mg/l	120	18	5.5	8	7	not exceed than 10
Cl^-	mg/l	187.4	174.15	53.75	71.88	212.4	-
NO_2^-	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	-
NO_3^-	mg/l	106.8	52.15	40.6	41.125	55.65	not exceed than 45
PO_4^{3-}	mg/l	4.76	<0.2	<0.2	<0.2	<0.2	not exceed than 1
SO_4^{2-}	mg/l	108.1	215.45	106.75	143.4	320.2	not exceed than 200
CO_3^{2-}	mg/l	0	0	0	0	0	-
HCO_3^-	mg/l	319	424.5	282.5	289	426.5	-
Total alka.	mg/l	319	424.5	282.5	289	426.5	50-200
Ca^{2+}	mg/l	50.88	72.38	67.815	49.475	72.12	-
K^+	mg/l	19.55	29.45	19	16.15	29.95	-
Mg^{+2}	mg/l	19.58	27.8	17.26	20.8	26.57	-
Na^+	mg/l	130	108	61	90	185	-

[a] R, S, G, Z& T are location sites recorded in Fig. (1) and Table (1); [b] LAW 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution; [c] -: No guideline available

Table 3: Mean values of physico-chemical parameters of water samples collected from Rosetta branch in summer and winter seasons

Parameters	Unit	R_1	R_2	S_1	S_2	G_1	G_2	Z_1	Z_2	T_1	T_2[a]	LAW 48/1982[b]
Temp.	°C	25	25.5	25.9	25.8	26.55	27.05	27.55	27.65	27.9	28.3	5 degrees above normal
pH		7.65	7.5	7.5	7.75	7.45	7.6	7.9	7.8	7.9	7.85	7-8.5
EC	µmohs/cm	375.5	626	516	803.5	520.5	632	553.5	537	555	560	-[c]
TDS	mg/l	240	401	330	532	333	404.5	354.5	373	353.5	408	not exceed than 500
Tur.	NTU	8	14.5	11	26.5	11	15.5	11	13.5	15	22	-
NH_3	mg/l	3.6	8.35	4.6	5.5	3.15	2.25	1.25	1.9	4.35	4.75	not exceed than 0.5
DO	mg/l	6.55	1.7	3.75	3.55	4.25	4.75	4.65	4.35	6.6	6.8	not less than 5
BOD	mg/l	5	52.5	11	13	8.5	6.5	5.5	6.5	5.5	5	not exceed than 6
Cl^-	mg/l	21.8	76.15	50.35	81.2	47.15	48.95	55.65	51.7	48.16	54.2	-
NO_2^-	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-
NO_3^-	mg/l	5.71	37.15	19.1	26.2	20.1	27.1	20.15	21.8	13.35	17.8	not exceed than 45
PO_4^{3-}	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-
SO_4^{2-}	mg/l	30.4	56.7	41.1	83.8	44.95	75.3	45.3	49.4	47.65	49.45	not exceed than 200
CO_3^{2-}	mg/l	0	0	0	0	0	0	0	0	0	0	-
HCO_3^-	mg/l	151	192.5	187.5	236	177.5	219.5	204.5	180	192	197	-
Total alka.	mg/l	151	192.5	187.5	236	177.5	219.5	204.5	180	192	197	20-150
Ca^{2+}	mg/l	32.1	37.7	36.2	51.8	38.8	52.6	37.4	40.4	42.7	39	-
K^+	mg/l	6.5	9	8	9.5	8	9.5	8.5	11	8	8	-
Mg^{2+}	mg/l	16.25	18.85	18.2	21.3	16.1	21.5	17.75	15.95	16.05	19.05	-
Na^+	mg/l	30	62	45.5	79.5	46.5	50	48.5	44.5	47.5	53	-

[a] R_1, R_2, S_1, S_2, G_1, G_2, Z_1, Z_2, T_1& T_2 are location sites and recorded in Fig. (1) and Table (1); [b]LAW 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution; [c] -: No guideline available.

Table 4: Correlation coefficient matrix between water quality parameters

Variable	Temp.	pH	EC	TDS	Tur.	NH_3	DO	BOD	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	Ca^{2+}	K^+	Mg^{2+}	Na^+	SPC	TC	FC	FS
Temp.	1																			
pH	0.63	1																		
EC	0.05	-0.34	1																	
TDS	0.08	-0.31	0.99	1																
Tur.	0.04	-0.19	0.92	0.92	1															
NH_3	-0.49	-0.79	0.38	0.38	0.29	1														
DO	0.53	0.78	-0.40	-0.39	-0.24	-0.72	1													
BOD	-0.49	-0.81	0.26	0.26	0.10	0.95	-0.81	1												
Cl^-	-0.08	-0.50	0.94	0.94	0.85	0.63	-0.56	0.51	1											
NO_3^-	-0.22	-0.76	0.71	0.71	0.51	0.80	-0.76	0.82	0.82	1										
SO_4^{2-}	0.16	-0.17	0.96	0.96	0.88	0.15	-0.21	0.04	0.84	0.54	1									
HCO_3^-	0.07	-0.32	0.98	0.98	0.92	0.32	-0.36	0.22	0.90	0.70	0.90	1								
Ca^{2+}	0.14	-0.17	0.87	0.86	0.83	0.11	-0.18	0.02	0.70	0.54	0.85	0.90	1							
K^+	0.07	-0.33	0.96	0.95	0.90	0.29	-0.33	0.20	0.87	0.68	0.93	0.98	0.90	1						
Mg^{2+}	0.01	-0.19	0.87	0.87	0.90	0.47	-0.29	0.06	0.78	0.46	0.86	0.87	0.77	0.80	1					
Na^+	0.04	0.04	0.96	0.95	0.79	0.93	-0.45	0.38	0.95	0.76	0.91	0.89	0.73	0.86	0.77	1				
SPC	-0.4	-0.8	0.27	0.26	0.09	0.93	-0.7	0.97	0.51	0.83	0.04	0.23	0.04	0.21	0.03	0.39	1			
TC	-0.36	-0.78	0.27	0.26	0.08	0.92	-0.67	0.94	0.50	0.83	0.04	0.23	0.05	0.22	0.01	0.39	0.99	1		
FC	-0.36	-0.78	0.27	0.26	0.08	0.92	-0.66	0.94	0.50	0.83	0.04	0.23	0.05	0.22	0.01	0.39	0.99	0.99	1	
FS	-0.43	-0.79	0.25	0.24	0.06	0.94	-0.74	0.99	0.49	0.82	0.04	0.20	0.01	0.19	0.01	0.37	0.99	0.97	0.97	1

Value 1: complete correlation; Positive value: correlated; Negative value: no correlation

Table 5: Mean values of trace metals concentrations of water samples collected from drains in summer and winter seasons (values in mg/l)

Parameters	R	S	G	Z	T	LAW 48/1982
Al	0.026	<0.005	0.006	0.005	<0.005	-
As	<0.001	<0.001	<0.001	<0.001	<0.001	not to exceed 0.01
Ba	0.032	0.048	0.056	0.069	0.027	-
Cd	0.004	0.006	0.004	0.003	0.001	not to exceed 0.01
Co	0.023	0.008	0.017	0.037	0.031	-
Cr	<0.001	<0.001	<0.001	<0.001	<0.001	not to exceed 0.01
Cu	0.024	0.1275	0.101	0.1745	0.21	not to exceed 1.0
Fe	<0.02	<0.02	<0.02	<0.02	0.27	not to exceed 1.0
Mn	<0.006	<0.006	<0.006	<0.006	0.071	not to exceed 1.5
Mo	<0.001	<0.001	<0.001	<0.001	<0.001	-
Ni	0.0255	0.003	0.0155	0.0255	0.003	-
Pb	0.024	0.015	0.007	0.007	0.024	not to exceed 0.05
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.001	<0.001	<0.001	<0.001	<0.001	-
Sn	<0.005	<0.005	<0.005	<0.005	<0.005	-
V	0.006	0.007	0.005	<0.005	0.01	-
Zn	0.026	0.042	0.019	0.075	0.074	not to exceed 1.0

Table 6: Mean values of trace metals concentrations of water samples collected from Rosetta branch in summer and winter seasons (values in mg/l)

Parameters	R_1	R_2	S_1	S_2	G_1	G_2	Z_1	Z_2	T_1	T_2	LAW 48/1982
Al	0.029	0.014	0.009	0.007	0.006	0.009	0.007	0.007	0.005	0.006	-
As	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	not to exceed 0.05
Ba	0.042	0.05	0.042	0.048	0.065	0.0655	0.069	0.0915	0.015	0.0535	-
Cd	0.002	0.003	0.009	0.008	0.004	0.007	0.006	0.008	0.008	0.008	not to exceed 0.01
Co	0.011	0.03	0.04	0.024	0.03	0.009	0.02	0.026	0.032	0.033	-
Cr	0.035	<0.001	<0.001	<0.001	0.048	<0.001	<0.001	0.029	<0.001	<0.001	not to exceed 0.05
Cu	0.1415	0.017	0.08	0.0885	0.068	0.1445	0.2235	0.127	0.1285	0.1465	not to exceed 1.0
Fe	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	not to exceed 1.0
Mn	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.094	<0.006	<0.006	<0.006	not to exceed 0.5
Mo	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Ni	0.0135	0.002	0.002	0.002	0.0095	0.0285	0.002	0.0275	0.015	0.005	-
Pb	0.006	0.009	0.021	0.021	0.004	0.021	0.022	<0.001	0.039	0.036	not to exceed 0.05
Sb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	not to exceed 0.01
Sn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-
Zn	0.029	0.0295	0.018	0.035	0.0145	0.041	0.02	0.03	0.0195	0.038	not to exceed 1.0

Table 7: Mean values of bacteriological parameters of water samples collected from drains in summer and winter seasons

Parameters	Unit	R	S	G	Z	T	LAW 48/1982
SPC at 22°C	CFU/ml	$861x10^4$	$335x10^3$	$2x10^3$	$49\ x10^2$	3450	-
SPC at 37°C	CFU/ml	$49x10^5$	$227x10^3$	1550	$42\ x10^2$	2950	-
TC	CFU/100ml	$389x10^5$	$55x10^4$	$46\ x10^2$	$636x10^2$	$444x10^2$	-
FC	CFU/100ml	$217x10^5$	$255x10^3$	$8\ x10^2$	$245x10^2$	16650	-
FS	CFU/100ml	$262x10^3$	$75x10^2$	37	1380	1015	-

Table 8: Mean values of bacteriological parameters of water samples collected from Rosetta branch in summer and winter seasons

Parameters	Unit	R_1	R_2	S_1	S_2	G_1	G_2	Z_1	Z_2	T_1	T_2	LAW 48/1982
SPC at 22°C	CFU/ml	$26\ x10^2$	$87\ x10^4$	$26\ x10^4$	$21\ x10^4$	4150	2400	1850	2950	2500	2800	-
SPC at 37°C	CFU/ml	1450	$71\ x10^4$	$20\ x10^4$	$18\ x10^4$	3650	2000	1350	2400	2050	$22\ x10^2$	-
TC	CFU/100ml	$15\ x10^3$	$27\ x10^5$	$37\ x10^4$	$26\ x10^4$	$25\ x10^3$	$11\ x10^3$	$51\ x10^2$	$88\ x10^2$	$11\ x10^3$	$73\ x10^2$	-
FC	CFU/100ml	9150	$14\ x10^5$	$14\ x10^4$	$10\ x10^4$	$3\ x10^3$	$17\ x10^3$	650	6600	5500	1800	-
FS	CFU/100ml	11	$8\ x10^4$	365	60	80	45	16	35	78	58	-

The increase in pH in the rivers could be related to photosynthesis and growth of aquatic plants, where photosynthesis consumes CO_2 leading to arise in the pH values [9].

Electric Conductivity: EC is a measure of the ability of water to carry electric current and it is sensitive to variations in dissolved solids, mostly mineral salts. Throughout this study, EC values at drains outlets ranged between 803.5-1623 µmhos/cm. The maximum values were recorded at Tala, Sabal and El-Rahawy drains and decreased in Zawiet El-bahr and El-Tahreer drains outfalls (Table 2). These high values might indicate that these drains are receiving large quantities of land run off and/or industrial pollution and suggest potential irrigation problems in case of illegal and unofficial drainage use due to salinity hazards (EC should be <700 µmhos/cm) as adopted from Ayres and Westcott [10]. On the other hand, EC levels recorded in Rosetta branch ranged between 375.5-803.5 µmhos/cm. The maximum EC values are always recognized downstream the drains compared to the drains upstreams (Table 3). EC exhibited negative correlation with DO (r = -0.4) and high positive correlations with different studied parameters (Table 4). Our results are in accordance with Abdo *et al*. [11].

Total Dissolved Solids: TDS may be organic or inorganic in nature and many are undesirable in water and produce displeasing color, tastes and odors and may also exert osmotic pressure that affect aquatic life or become carcinogenic especially halogenated compounds. TDS concentrations for water samples collected from Rosetta branch are almost within the permissible limits (Table 3). On contrast, TDS values in drains outfalls exceeded the permissible limits where they ranged from 514-1038 mg/l (Table 2). This reflects possible irrigation problems in case of illegal and unofficial drainage uses (TDS should be <450 mg/l) as adopted from Ayres and Westcott [10]. In parallel to these findings, TDS, EC and turbidity values revealed positively strong correlation to each other (r = +0.99) as illustrated in Table 4. Toufeek and Korium [7] reported the same correlations.

Turbidity: Turbidity is the measure of fine suspended matter in water, mostly caused by colloidal particles such as clay, silt, non-living organic particulates, plankton and other microscopic organisms, in addition to suspended organic and inorganic matter. The turbidity degree of stream water is an approximate measure of pollution intensity [12]. As given in Tables 2 and 3, turbidity values ranged between 21-62.5 and 8-26.5 NTU in drains and Rosetta branch, respectively. Increasing values from up-stream to down-stream along the branch may be attributed to drains discharge. Positive correlations were found between turbidity values and all studied parameters (Table 4). Turbidity values are negatively correlated with DO and pH (r = -0.24 & -0.19, respectively).

Ammonia: Ammonia is a form of the nitrogenous compounds present in nature and is essential for the growth and reproduction of plants and animals. The ammonia ion is either released from proteinaceous organic matter and urea or is synthesized by industrial processes. Throughout this study, NH_3 concentrations showed variations both regionally and seasonally. The recorded mean values violate the permissible limits of law 48/1982 (not to exceed 0.5 mg/l). Generally, NH_3 concentrations ranged from 1.25-8.35 mg/l in Rosetta branch (Table 3) and 1-22.3 mg/l in drains outfalls (Table 2). Increasing in ammonia concentrations could be attributed to organic pollution resulting from domestic sewage and fertilizers runoff [13].It is well known that, the toxicity of ammonia is pH dependent. The mean values of pH recorded in present study ranged from 7 to 7.9 and NH_3 concentrations from 1 to 22.3 mg/l. Our results exceeded the normal limits guidelines (1.27-3.88 mg/l) at pH (8.0-8.1) cited by USEPA [14]. Statistical analysis showed high positive correlations of NH_3 with NO^-_3, BOD and bacteriological parameters (r = +0.9), while negative correlation was observed with DO (Table 4). This confirms the impact of sewage discharge and agricultural runoff in this area.

Dissolved Oxygen: DO is required for the metabolism of aerobic organisms and it influences organic decomposition. DO is often used as an indicator of water quality, such that high concentrations indicate good water quality. Inadequate DO may contribute to unfavourable environmental conditions in which aerobic bacteria are replaced by anaerobic ones leading to water deterioration and disagreeable odors due to production of gases (H_2S, NH_3 and CH_4) as reported by El-Sherbini *et al.* [15]. DO concentrations showed variable results according to site nature and extent of pollution. Almost all water samples collected from drains outlets exceeded the permissible limits of law 48/1982 (DO should not be less than 5 mg/l) where they ranged from 0.3-5.2 mg/l (Table 2). Depletion in DO might indicate high organic matter and nutrients load as reported by El-Gamel and Shafik [16]. On the other hand, DO values for water samples collected from Rosetta branch were variable and fluctuated between 1.7-6.8 mg/l as indicated in Table 3. The amount of DO depends highly on temperature and salinity, such that oxygen is low in highly saline waters and vice versa and its budget usually increases with decrease in temperature. The depletion of DO could be anticipated to microbial decomposition of the excessive organic matter discharged directly from the drains.

Biological Oxygen Demand: BOD is a measure of the amount of dissolved oxygen removed from water by aerobic bacteria for their metabolic requirements during the breakdown of organic matter [17]. Measurement of BOD is used to determine the level of organic pollution of water. Data in Tables 2&3 recorded elevated BOD values in most investigated drains outfalls and sites in Rosetta branch. The mean BOD values at drains outfalls range from 5.5-120 mg/l, while in Rosetta branch, they range between 5-52.5 mg/l. Drains violating permissible limits exceed BOD values of 10 mg/l, while along Rosetta branch the impacted sites are above 6 mg/l. Our results reflect high level of organic matter load from sewage, industrial or urban discharges as reported by Chapman [13]. On the other hand, BOD revealed high positive correlations with all bacteriological parameters (r = +0.9) and a significant negative correlation to temperature (r = -0.49), pH and DO (r = -0.81) mainly due to removal of free oxygen by bacteria during decomposition of organic matter which is usually accompanied by increase in BOD levels particularly in winter season.

Major Anions: Data presented in Tables 2 and 3 indicated that normal concentrations of chloride and sulphate ions at most studied sites. In drains outfalls, Cl^- concentrations range from 53.75-212.4 mg/l and SO_4^{2-} range from 106.75-320.2 mg/l. On the other hand in Rosetta branch, Cl^- ions range from 21.8-81.2 mg/l and SO_4^{2-} ions range from 30.4-83.8 mg/l. Some sites recorded high levels of chloride indicating that these points are receiving sewage water and industrial effluent that rich in chloride (Cl^- should be <50 mg/l) as adopted by Ravindra *et al.* [18]. Concerning phosphate concentrations, all studied sites are <0.2 mg/l except in El-Rahawy drain outlet phosphate is 4.76 mg/l. These results are in agreement with limits of law 48/1982 (1 mg/l). On the contrary, nitrate recorded high levels that are above the permissible limits (45 mg/l) in drains outfalls except in El-Tahreer and Zawiet El-Bahr outlet. Those higher values of nitrates are attributed to the oxidation of ammonia (NH_4^+) to nitrate (NO_3^-) and nitrite (NO_2^-) by aerobic bacteria in a process called nitrification. On the other hand, NO_3^- recorded normal values within the permissible limits in all studied sites along Rosetta branch. Carbonate ions could not be detected in all collected samples. Meanwhile, bicarbonate values range from 282.5-426.5 mg/l at drains outfalls and the range fluctuated in Rosetta branch between 151-236 mg/l. Bicarbonate values revealed positive correlation with TC (r = +0.21). All values of total alkalinity in drains outfalls and Rosetta branch are above the permissible limits of law 48/1982 (200 mg/l for drains& 150 mg/l for Rosetta branch) except in El-Rahawy upstream site (151 mg/l in two studied seasons). This clearly reflects the impact of drains discharge on Rosetta branch.

Major Cations: All concentrations of major cations (calcium Ca^{2+}, potassium K^+, magnesium Mg^{2+} and sodium Na^+) in water samples collected either form drains outfalls or selected sites along Rosetta branch, were found within the permissible limits. The mean values of the cations at different sites revealed that Na^+ is the most abundant element seasonally and regionally in all points followed by Ca^{2+}, K^+ and Mg^{2+} (Tables 2 and 3).

Trace Metals: Metals occur naturally in fresh water in low concentrations. They come from the weathering of rocks and soils in addition to industrial wastewater discharges, sewage as well as from atmospheric deposition. The mean values of trace metals concentrations in the water samples collected during our study are presented in Tables 5& 6. Generally, results revealed that all concentrations of studied seventeen trace metals in drains outlets and Rosetta branch were found within the permissible limits mentioned in the Egyptian law 48/1982. This reflects that the nature of pollution in our area of study is mainly due to agricultural and sewage discharge.

Bacteriological Characteristics of Water Samples: Bacteriological characteristics are still the primary water quality issue in any water resources especially those used in drinking purposes. Bacteriological analyses for water samples collected from Rosetta branch and five main drains located on its sides (15 sites) in summer and winter seasons are presented in Tables 7 and 8.

Standard Plate Counts (SPC) Bacteria: SPC at 22°C and 35°C in all collected water samples recorded high values and varied regionally and seasonally, being the highest at El-Rahawy drain outlet. SPC at drains outfalls range between 2×10^3-861×10^4 CFU/ml (at 22°C) and between 1550-49×10^5CFU/ml (at 37°C). In Rosetta branch, they fluctuated between 1850-87×10^4 CFU/ml (at 22°C) and from 1350-71×10^4 CFU/ml (at 37°C).

Total Coliforms: TC densities varied between 4600-389×10^5 CFU/100 ml (at drains outfalls) and 51×10^2-27×10^5 CFU/100 ml (at Rosetta branch). The highest count at drains outfalls and Rosetta branch was recorded at El-Rahawy and its downstream. It is worth to mention that, all monitored points in drains (except El-Tahreer drain in summer season) and more than 90% of all sites along Rosetta branch are out of the international standard limits recommended by Tebbutt [19] (TC should not exceed 5000 CFU/100 ml). Much more restricted limits have been reported by Cabelli [20] who recommended a maximum total coliforms count of 1000 CFU/100ml, particularly in surface water that are going to be used as drinking water supply.

Fecal Coliforms: FC counts at the drains outfalls fluctuated around a maximum of $217x10^5$ CFU/100 ml at El- Rahawy drain and a minimum of $8x10^2$ CFU/100 ml at El-Tahreer drain. On the other hand, FC counts in Rosetta branch range between 650 and $14x10^5$CFU/100 ml. It seems that El-Tahreer is the only drain complying with the international standard limits of Tebbutt [19], in which FC count didn't exceed 2000 CFU/100 ml in both seasons, unlike the case with the rest of studied drains. Meanwhile, about 70% of the sites along Rosetta branch throughout this study didn't comply with the standard levels. Restricted limits for surface water intended for use as drinking water supply (200 CFU/100ml) indicate unsafe water from bacteriological point of view [20].

Fecal Streptococci: FS fluctuated between a maximum of $262x10^3$ CFU/100 ml at El- Rahawy drain and a minimum of 37 CFU/100 ml at El-Tahreer drain. On the other hand, FS counts in Rosetta branch ranged between 11 and $8x10^4$ CFU/100ml. Generally, sites in drains and Rosetta branch exceeding 1000 CFU/100 ml were reported out of international standard limits [19]. The data revealed that there is a gradual increase in bacterial indicators counts (TC, FC& FS) from upstream to downstream, which might be attributed to the drains discharge into the branch, this agrees with the results of Abdo [21] and Ezzat [22]. Statistical analysis indicated highly positive significant correlation ($r = +0.99$) between different bacteriological parameters (SPC, TC, FC and FS). The same results were concluded by Heikal [23] who investigated the bacteriological quality of Lake Nasser, main River Nile, Rosetta and Damietta as reported by branches as well as River Nile waters at Damietta branch Sabae and Rabeh [24]. Regarding the correlation between bacteriological and physico-chemical parameters, positive strong correlation ($r > 0.8$) was observed with ammonia, BOD and nitrate, while intermediate positive correlation ($r > 0.6$) was recorded with EC, TDS, turbidity, cations and anions. It is worth to mention that, there is a strong negative significant relationship between different bacterial indicators and DO ($r = -0.78$). This indicates that depletion in DO is a strong evidence for bacterial water deterioration [25].

Water Quality Index (WQI): Results of WQI indicate that water quality is seasonally very bad in El-Rahawy drain outlet and bad for most sites taken in this study (Table 9). WQI is highly correlated with the previously mentioned physico-chemical and bacteriological results. It is worth to mention that, the index calculations confirmed that the fecal coliform is a major contributor parameter in the indices calculations. The same observation was previously reported by El-Sherbini [26].

Table 9: Mean values of water quality index for collected water samples.

Site No.	WQI	Quality
R1	50.8	Medium
R	24.5	Very bad
R2	34.5	Bad
S1	40.3	Bad
S	33.3	Bad
S2	38.6	Bad
G1	43.1	Bad
G	46.0	Bad
G2	42.5	Bad
Z1	46.8	Bad
Z	41.0	Bad
Z2	44.0	Bad
T1	50.3	Medium
T	42.5	Bad
T2	50.2	Medium

According to the previously mentioned data from both physico-chemical and bacteriological analyses, it is clear that all drains selected in this study are seasonally suffering from chemical and bacteriological pollution with varying levels and varying nature, being maximum at El-Rahawy, Sabal and Tala drains in which the levels of pollution fluctuated between them from one measured parameter to another. Fluctuation observed here is probably due to combination of several factors including industrial, agricultural and domestic waste discharge as reported by Salah El-Din [27]. El-Rahawy drain has serious impacts on the water quality of Rosetta branch due to its high organic loads, which affect suitability of the branch as a source of drinking water supply. This could be attributed to high load of bacterial pollution and high concentrations of NH_3, TDS, EC, turbidity, BOD, total alkalinity and recognized depletion in DO as reported by El Gammal and El Shazely [2]. The present findings are in harmony with those reported by several authors who reported that the highest levels of pollution detected in Rosetta branch are always found at downstream El-Rahawy and Sabal sites [3, 22, 23, 28, 29]. The gradual decrease in pollution levels along the branch (from downstream El-Rahawy to downstream Tala drain) could be interpreted in terms of ‘‘self-purification’’ phenomenon of streams as reported by Tebbutt [19] and dilution effect concept concluded by Ezzat and El Korashey [30].

It is worth to mention that, higher levels of physico-chemical and bacteriological pollution indicators were almost recorded in winter months compared to summer months. This phenomenon may be attributed to accumulation of wastes in drains which is usually accompanied by winter closure that lowers water levels in River Nile leading to an increase in pollutants load and a decrease in dilution effects. Moreover, the relative decrease in both temperature and pH values in winter favours the increased mobilization of metals and pollutants from sediment to water [31]. Meanwhile, during summer season the increasing discharge at high flood usually releases excess water through the main River body and its two branches. The impact of releasing excess water in most cases improves the quality in Rosetta branch in summer months [9]. Here the water management politics play a major role that affect the quality of water resources in Egypt.

CONCLUSIONS

From the results of the present study it could be concluded that the water quality along the studied area in Rosetta branch (120 km) is remarkably influenced by wastewater discharge from drains located on its sides regarding both physico-chemical and bacteriological characteristics. Agricultural and sewage wastes are the key factors in this environmental problem. However, self-purification and dilution concepts contributed to the gradual improvement recognized at the end of the branch particularly in summer season.

Recommendations: The results of this study recommended enforcement of all articles of law 48/1982 regarding the protection of River Nile and waterways from pollution as well as treating wastewater before discharge or reuse. Monitoring of River Nile water regularly and constantly should be followed up in order to record any alteration in quality and mitigate outbreak of health disorders and the detrimental impacts on the aquatic ecosystem.

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