Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 469 – 491 (2025)
www.ejabf.journals.ekb.eg

New Aspects of Water Quality Assessment in the Nile River's Rosetta Branch, Egypt

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ARTICLE INFO

Article History:
Received: April 24, 2025
Accepted: Aug. 23, 2025
Online: Sep. 12, 2025

Keywords:
Coliform bacteria,
Delta region,
River Nile,
Rosetta branch,
Water quality

ABSTRACT

This study provides a thorough evaluation of water quality along the Rosetta branch, from the upstream area of the El-Rahawy drain to the branch's endpoint. The analysis used a correlation matrix to explore the relationships between various water quality parameters. Results from the water quality index (WQI) calculations highlight a significant concern regarding coliform bacterial contamination, which is particularly prevalent during the winter months and is identified as a major factor in the deterioration of water quality in the area. To further investigate the sources of pollution and their impact on mass loading, a two-way ANOVA was applied. This statistical method revealed notable differences in how various pollution sources affect water quality, with some parameters having a more significant impact on mass loading than others. The study identifies the El-Rahawy, Tala, and Sabal drains as the main contributors to pollution, while the Ganob El-Tahreer and Zawiet El-Bahr drains were found to have minimal effect. A notable improvement in water quality was observed toward the end of the branch, attributed to natural self-purification processes and dilution effects. Based on these findings, the study underscores the importance of implementing effective wastewater treatment before discharge or reuse and stresses the need for ongoing monitoring efforts to reduce health risks and protect the delicate aquatic ecosystem within the Rosetta branch.

INTRODUCTION

The Nile River, known as the longest globally, extends an impressive distance of 6,700 kilometers (approximately 4,163.2 miles) from its source at Lake Victoria in east-central Africa to its majestic endpoint at the Mediterranean Sea in northeastern Egypt **(Azzam, 2010; Woodward *et al.*, 2022)**. Encompassing a vast drainage basin of 2,900,000 square kilometers (equivalent to 1,119,696.2 square miles), the Nile traverses multiple nations **(Merem *et al.*, 2020)**. Egypt, with its arid climate, extreme temperatures, and limited rainfall, relies on the Nile for over 95% of its freshwater supply. Within Egypt's borders, the Nile River courses a significant 950 kilometers, commencing at

Aswan in the south and flowing northward to Cairo, where it branches into the Rosetta and Damietta distributaries, ultimately forming the sprawling Nile Delta **(Azzam, 2015; Haars *et al.*, 2016)**.

The Nile's vital importance to Egypt's water supply cannot be overstated, with the river's flow sustaining agriculture, industry, and the livelihoods of millions of Egyptians. The distribution of water resources from the Nile has historically been a significant geopolitical issue, leading to disputes among the countries sharing the river's waters. The Nile's role as a lifeline for Egypt underscores the critical need for countries in the Nile Basin to collaborate effectively in managing this invaluable resource to ensure sustainable development and equitable access to water for all stakeholders. The Rosetta branch, one of the primary distributaries, boasts an average flow rate of approximately 21,500,000 cubic meters per day (equivalent to 5,679,698,000 gallons/day) **(Day *et al.*, 2021)**.

The Rosetta branch, a pivotal waterway in Egypt, faces a staggering influx of millions of cubic meters of agricultural drainage water every day, compounded by discharge of domestic, industrial, and toxic waste dumping, as elucidated by **Elhaddad and Al-Zyoud (2017)** and corroborated by **Azzam and Faiesal (2019)**. This environmental conundrum is exacerbated by the contribution of five major agricultural drains, namely El-Rahawy, Sabal, Ganob El-Tahreer, Zawiet El-Bahr, and Tala, each playing a main source in the pollution of the branch, as reported by **Azzam *et al.* (2017)**, **Ezzat and Azzam (2020)** and **Elbahnasawy *et al.* (2021)**. Of these drains, the El-Rahawy drain emerges as the primary culprit, exerting a substantial adverse impact on water quality due to two significant factors. Firstly, the presence of small drains along its trajectory, discharging untreated agricultural and domestic wastewater, contributes significantly to the pollution load. Secondly, the El-Mansoria Canal worsens the issue by transporting both partially treated sewage water from the Zenen and Abu-Rawash treatment plants as highlighted by **Aya *et al.* (2019)**, **El Gohary (2021)** and **Soliman *et al.* (2023)**. This intricate interplay of various pollution sources underscores the urgent need for comprehensive remedial measures to safeguard the ecological integrity and public health implications of the Rosetta branch and its surrounding ecosystems.

Numerous research endeavors have delved into the evaluating the quality of Rosetta branch. **Elbahnasawy *et al.* (2021)** highlighted the concerning issue of low dissolved oxygen (DO) levels near the El-Rahawy drain outlet, signaling a potential threat to aquatic ecosystems. Furthermore, **Azzam and Ibrahim (2021)** pinpointed the El-Rahawy and Sabal drains as significant contributors to pollution in the region, attributed to the substantial discharge of mixed waste into the water bodies. This substantiates the assertion made by **Elhaddad and Al-Zyoud (2017)** that El-Rahawy drainage water stands out as the primary source of pollution in the Nile River. Additionally, **Azzam *et al.* (2024)** uncovered heightened levels of inorganic, organic, and microbial contaminants at the El-Rahawy drain outlet, thereby exacerbating the overall deterioration of water quality in the area. Our study aimed to identify the primary of pollution sources affecting the quality of the Rosetta branch, using WQI and statistical analysis. Through detailed data analysis, the research seeked to offer valuable insights that can inform targeted mitigation strategies to reduce the environmental impact on the branch's aquatic ecosystem. By employing a comprehensive analytical approach, the study would provide a thorough understanding of the health of this crucial waterway.

MATERIALS AND METHODS

1. Study area and sampling procedure

The investigation conducted along the Rosetta branch entailed the meticulous collection of water samples during the winter of 2024. A comprehensive total of 17 strategic locations were carefully chosen to encompass critical pollution hotspots: 10 points situated both upstream and downstream of the pollution point sources, 5 positioned at the discharge outlets, 1 situated at a midpoint between the final pollution source and the termination point of the branch, and the ultimate sampling site located at the branch's terminus (Table 1). The primary pollution sources under scrutiny included El-Rahawy, Sabal, Ganob El-Tahreer, Zawiet El-Bahr, and Tala drain outlets. Water samples were meticulously extracted from the subsurface layer at a depth of 50cm in the central section of the branch using sterilized 1-liter polyethylene containers sealed with stoppers. The samples were immediately stored in refrigerated containers and quickly transported to the Central Laboratory for Environmental Quality Monitoring at the National Water Research Center (CLEQM-NWRC), where they were thoroughly analyzed within a stringent timeframe of six hours post-collection by the Standard Methods for the Examination of Water and Wastewater **(APHA, 2017)**.

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

Code	Description	Latitude (N)	Longitude (E)
L1	Rosetta branch, upstream El-Rahawy drain	30°12'30.23"N	31° 2'02.21"E
L2	El-Rahawy drain outlet (left bank)	30°12'26.21"N	31° 1'58.90"E
L3	Rosetta branch, downstream El-Rahawy drain	30°12'25.41"N	31° 1'48.35"E
L4	Rosetta branch, upstream Sabal drain	30°31'57.94"N	30°50'53.20"E
L5	Sabal drain outlet (right bank)	30°32'13.47"N	30°51'07.09"E
L6	Rosetta branch, downstream Sabal drain	30°32'29.05"N	30°51'01.27"E
L7	Rosetta branch, upstream El-Tahreer drain	30°36'23.50"N	30°47'51.89"E
L8	Ganob El-Tahreer drain outlet (left bank)	30°36'24.68"N	30°47'48.92"E
L9	Rosetta branch, downstream El-Tahreer drain	30°36'28.90"N	30°47'47.49"E
L10	Rosetta branch, upstream Zawiet El-Bahr drain	30°42'51.10"N	30°45'55.23"E

L11	Zawiet El-Bahr drain outlet (left bank)	30°42'52.57"N	30°45'19.01"E
L12	Rosetta branch, downstream Zawiet El-Bahr drain	30°43'09.26"N	30°45'39.53"E
L13	Rosetta branch, upstream Tala drain	30°48'58.19"N	30°48'37.60"E
L14	Tala drain outlet (right bank)	30°49'01.74"N	30°48'47.77"E
L15	Rosetta branch, downstream Tala drain	30°49'10.36"N	30°48'42.11"E
L16	Downstream of the El-Kwa Water Treatment Plant	30°49'17.55"N	30°49'30.07"E
L17	At end of the Rosetta branch	30°50'03.21"N	30°49'10.35"E

2. Water samples analyses

2.1. Physicochemical analyses

Among the critical parameters scrutinized during this assessment are temperature, pH levels, dissolved oxygen (DO) concentrations, electrical conductivity (EC), total suspended solids (TSS), and total dissolved solids (TDS). These parameters are meticulously determined in water samples through the utilization of an advanced auto-calibrated multi-probe system, namely the HydroLab Surveyor from Germany.Upon the transportation of the water samples to the laboratory, a series of rigorous analyses are conducted to delve deeper into the composition and quality of the water under examination. The samples undergo manual agitation to ensure homogeneity before undergoing specific analytical procedures tailored to each parameter of interest. For instance, the concentration of ammonia (NH_3) is quantified utilizing the precision of an ORION Model 95–12 bench-top ion analyzer, while turbidity is measured with the aid of a Nephelometric turbidity meter (HACH Model 2100). The determination of total organic carbon (TOC) concentration is accomplished through a dedicated TOC analyzer (Shimadzu Model 4200). Furthermore, the assessment extends to the evaluation of biochemical oxygen demand (BOD) using a specialized BOD fast respiratory system (Model 890), and the measurement of chemical oxygen demand (COD) employing the potassium permanganate method. To delve into the intricacies of water hardness, the total hardness, calcium hardness, and magnesium hardness are scrutinized via the titrimetric method. Ion chromatography (Model DX-500) emerges as an indispensable tool for the precise measurement of key anions such as chloride (Cl^-), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), and sulfate (SO_4^{2-}), along with the determination of total alkalinity through titration. In addition to the aforementioned parameters, the concentrations of major cations including calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), and potassium (K^+), as well as trace metal elements such as aluminum (Al), arsenic (As), barium (Br), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn) are meticulously quantified using the advanced technology of ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry), specifically the Varian Lab Liberty Series II.

2.2. Bacteriological analyses

The pour plate method (Method No. 9215 B) was carefully used at two different temperatures, 22 and 37°C, to obtain the standard plate count (SPC) of bacteria, an essential indicator in microbiological water quality assessment. Furthermore, the quantification of total coliforms (TC), *fecal coliforms* (FC), and *fecal streptococci* (FS) was carefully carried out in accordance with the prescribed methodologies denoted as standard methods No. 9222B, 9222D, and 9230C, respectively. This involved the utilization of specialized dehydrated media, including M-Endo agar LES, M-FC agar, and M-Enterococcus agar sourced from Difco-USA. Sterile, surface-gridded *Sartorius* membrane filters with a precise pore size of 0.45µm and a diameter of 47mm were used in an advanced filtration process for the thorough bacteriological analysis of the water samples. The integration of an oil-free Millipore vacuum/pressure pump and an advanced stainless-steel autoclavable manifold further improved this process and guaranteed the precision and integrity of the analytical techniques. The results obtained from these rigorous analyses were meticulously recorded in terms of colony-forming units ($CFU100mL^{-1}$) of the sample, utilizing a standardized equation to precisely quantify the bacterial load present in the water samples as follows:

$$\mathbf{CFU100\ mL^{-1} = CFU \times 100/ml\ of\ filterd\ sample}$$

2.3. Water quality index (WQI)

WQI serves as a fundamental and robust metric employed in diverse locations within the study area to act as a straightforward yet highly efficacious gauge of water quality standards. This comprehensive index stands as a dependable instrument for the evaluation and continual observation of variations in water quality standards. The computation of the WQI encompasses the integration of several pivotal parameters, which include TS, DO, BOD, FC, pH level, Turbidity, NO_3^-, PO_4^{3-}, and temperature. The calculation of the WQI follows the methodology outlined by **Azzam *et al.* (2022)** and the **National Sanitation Foundation (NSF) (2022)**. The mathematical expression for determining the NSF WQI is articulated as:

$$NSF\ WQI = \Sigma W_X Q_X = W_{pH} \times Q_{pH} + W_{Phosphate} \times Q_{Phosphate} + W_{Nitrate} \times Q_{Nitrate} + W_{DO\ sat\%} \times Q_{DO\ sat\%} + W_{TSS} \times Q_{TSS} + W_{FC} \times Q_{FC} + W_{BOD} \times Q_{BOD} + W_{Turbidity} \times Q_{Turbidity} + W_{Temperature} \times Q_{Temperature}$$

Where, W_x represents the weight factors assigned to each water quality parameter, Q_x denotes the Q-value of the respective parameter, and X refers to the water quality parameters. The weight factors for DO, FC, pH, BOD, temperature, PO_4^{3-}, NO_3^-, turbidity, and TSS are 0.17, 0.16, 0.11, 0.11, 0.10, 0.10, 0.10, 0.08, and 0.07, respectively.

Once the WQI values were calculated, they were categorized to five classifications:

- 0–24: Poor water
- 25–49: Bad water
- 50–69: Medium water

- 70–89: Good water
- 90–100: Excellent water

4. Statistical analysis

A correlation matrix was created using Microsoft Office Excel (2019) to examine the complex relationships among various water quality parameters. Additionally, a detailed two-way ANOVA (analysis of variance) was conducted to assess the significant impact of individual point sources on water quality in the Nile Delta region, known as the primary source of water pollution in the area under investigation. This thorough analysis focused on evaluating the specific influence of each parameter on mass loading, while also exploring the intricate interactions between the different parameters being studied. The parameters analyzed included important indicators such as pH levels, COD, BOD, TOC, TSS, TDS, chlorides, and DO. Ten distinct groups were identified for analysis, with two groups categorized based on the mass loading theory, a concept that combines flow and concentration, and the remaining groups structured according to the loading factor concept, which considers flow, solids concentration, and organics concentration (Table 2). The first two groups in this classification were specifically related to DO and pH (expressed as -log[H^+]), both of which were multiplied by the flow rate for a more comprehensive analysis. The subsequent categories in this framework focused on the presence of solids bonded to organic matter in the water matrix, with their values calculated meticulously by taking into account the interactions among solids, organics, and flow rate.

Table 2. ANOVA terms showing the interaction between organic and solid factors

Pollution source	**Parameters**				
	COD, TSS	**COD, TDS**	**BOD, TSS**	**BOD, TDS**	**DO**
R	$Q_{n1} \times C_{COD1} \times C_{TSS1}$	$Q_{n1} \times C_{COD1} \times C_{TDS1}$	$Q_{n1} \times C_{BOD1} \times C_{TSS1}$	$Q_{n1} \times C_{BOD1} \times C_{TDS1}$	$Q_{n1} \times C_{DO1}$
S	$Q_{n2} \times C_{COD2} \times C_{TSS2}$	$Q_{n2} \times C_{COD2} \times C_{TDS2}$	$Q_{n2} \times C_{BOD2} \times C_{TSS2}$	$Q_{n2} \times C_{BOD2} \times C_{TDS2}$	$Q_{n2} \times C_{DO2}$
G	$Q_{n3} \times C_{COD3} \times C_{TSS3}$	$Q_{n3} \times C_{COD3} \times C_{TDS3}$	$Q_{n3} \times C_{BOD3} \times C_{TSS3}$	$Q_{n3} \times C_{BOD3} \times C_{TDS3}$	$Q_{n3} \times C_{DO3}$
Z	$Q_{n4} \times C_{COD4} \times C_{TSS4}$	$Q_{n4} \times C_{COD4} \times C_{TDS4}$	$Q_{n4} \times C_{BOD4} \times C_{TSS4}$	$Q_{n4} \times C_{BOD4} \times C_{TDS4}$	$Q_{n4} \times C_{DO4}$
T	$Q_{n5} \times C_{COD5} \times C_{TSS5}$	$Q_{n5} \times C_{COD5} \times C_{TDS5}$	$Q_{n5} \times C_{BOD5} \times C_{TSS5}$	$Q_{n5} \times C_{BOD5} \times C_{TDS5}$	$Q_{n5} \times C_{DO5}$
	TOC, TSS	**TOC, TDS**	**Cl^-, TSS**	**Cl^-, TDS**	**pH**
R	$Q_{n1} \times C_{TOC1} \times C_{TSS1}$	$Q_{n1} \times C_{TOC1} \times C_{TDS1}$	$Q_{n1} \times C_{Cl-1} \times C_{TSS1}$	$Q_{n1} \times C_{Cl-1} \times C_{TDS1}$	$Q_{n1} \times pH_1$
S	$Q_{n2} \times C_{TOC2} \times C_{TSS2}$	$Q_{n2} \times C_{TOC2} \times C_{TDS2}$	$Q_{n2} \times C_{Cl-2} \times C_{TSS2}$	$Q_{n2} \times C_{Cl-2} \times C_{TDS2}$	$Q_{n2} \times pH_2$
G	$Q_{n3} \times C_{TOC3} \times C_{TSS3}$	$Q_{n3} \times C_{TOC3} \times C_{TDS3}$	$Q_{n3} \times C_{Cl-3} \times C_{TSS3}$	$Q_{n3} \times C_{Cl-3} \times C_{TDS3}$	$Q_{n3} \times pH_3$
Z	$Q_{n4} \times C_{TOC4} \times C_{TSS4}$	$Q_{n4} \times C_{TOC4} \times C_{TDS4}$	$Q_{n4} \times C_{Cl-4} \times C_{TSS4}$	$Q_{n4} \times C_{Cl-4} \times C_{TDS4}$	$Q_{n4} \times pH_4$
T	$Q_{n5} \times C_{TOC5} \times C_{TSS5}$	$Q_{n5} \times C_{TOC5} \times C_{TDS5}$	$Q_{n5} \times C_{Cl-5} \times C_{TSS5}$	$Q_{n5} \times C_{Cl-5} \times C_{TDS5}$	$Q_{n5} \times pH_5$

Notation: Q, flow rate from pollution source; PS, pollution source; R, El-Rahawy drain; S, Sabal drain; G, Ganob El-Tahreer drain; Zawiet El-Bahr drain; T, Tala drain.

RESULTS AND DISCUSSION

1. Physico-chemical analyses of water samples

1.1. Water temperature

Temperature influences the dynamics of chemical reactions, metabolic processes in organisms, and the intricate interplay between pollutants, parasites, and other pathogens within aquatic ecosystems. The temperature variations observed in the study, as delineated in Table (3), spanned from 15.2 to 21.8°C at designated drain outlets (L2, L5, L8, L11, and L14), while exhibiting a broader range of 15.7°C to 24.0°C along the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17). These fluctuations were predominantly influenced by a confluence of climatic factors, sampling temporalities, and the duration of solar insolation. During the observational period, a discernible positive correlation emerged between atmospheric and aquatic temperatures, indicating that water temperature was predominantly modulated by ambient air temperature, without discernible inputs from thermal pollution sources. A comprehensive examination of the correlation coefficient matrix unveiled a strong positive correlation between temperature and pH (r = 0.71) (Fig. 1). This relationship can be elucidated by the fact that elevated temperatures often trigger the hydrolysis of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions, leading to the generation of hydroxyl (OH^-) ions, consequently elevating the pH levels of the aquatic environment. **Azzam *et al.* (2025)** also observed a similar correlation between temperature and pH values, highlighting the same phenomenon. Essentially, the complex relationship between temperature and various physicochemical parameters in aquatic systems highlights the significant influence of temperature fluctuations on the ecological dynamics and biogeochemical processes of these environments.

1.2. pH values

pH value, a crucial parameter reflecting the hydrogen ion activity in a water body, holds significant sway over a myriad of biological and chemical processes within aquatic ecosystems. The data obtained from Table (3), reveal that pH levels of all collected samples fall well within the acceptable range, consistently registering above 6.5. This elevation in pH, commonly encountered in raw water samples, can be attributed to the presence of carbonates or bicarbonates, a phenomenon remarked upon by **Soliman *et al.* (2022)**. Of particular interest is the notable rise in pH levels observed in the rivers and rayah branches under study, a phenomenon that may find its roots in the intricate dynamics of photosynthesis and the proliferation of aquatic flora. It is well-reported, as elucidated by **Azzam *et al.* (2015)** and **Omran *et al.* (2024)**, that during the process of photosynthesis, the absorption of carbon dioxide (CO_2) by aquatic plants results in a discernible increase in pH levels. This relationship underscores the profound impact that biological activities, such as photosynthesis, can exert on the chemical composition and pH balance of aquatic environments.

1.3. Electric conductivity (EC)

EC serves as a pivotal metric, elucidating the water's capacity to conduct electric currents, thereby reflecting alterations in dissolved solids, predominantly mineral salts. The investigation under scrutiny unveiled a spectrum of EC values at various drain outlets, denoted as L2, L5, L8, L11, and L14, oscillating between 450 to 1209 µmhoscm^{-1}. Eminent peaks in EC readings were documented at the El-Rahawy, Ganob El-Tahreer, and Zawiet El-Bahr drains, while relatively lower values were discerned at the Sabal and Tala drain outfalls (Table 3). Noteworthy is the inference drawn from these escalated EC levels, which alludes to the likelihood of substantial land runoff influx and/or industrial contamination seeping into these drainage systems, which could suggest potential irrigation issues if the drains are being used for illegal or unofficial drainage, due to the risks associated with salinity, as postulated by **Ayres and Westcott (1985)** in their reference to EC standards. In stark contrast, the EC measurements documented within the precincts of the Rosetta branch, encompassing L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, 16, and 17, spanned a range from 346 to 1021 µmhoscm^{-1}. Notably, the zenith of EC values consistently manifested downstream of the drains in comparison to their upstream counterparts (Table 3). An intriguing facet of the analysis pertains to the negative correlation between EC and dissolved oxygen (DO) ($r = -0.14$), alongside robust positive correlations observed with other parameters under scrutiny (Fig. 1). Of paramount significance is the alignment of our empirical discoveries with the seminal work of **Azzam *et al.* (2023)**.

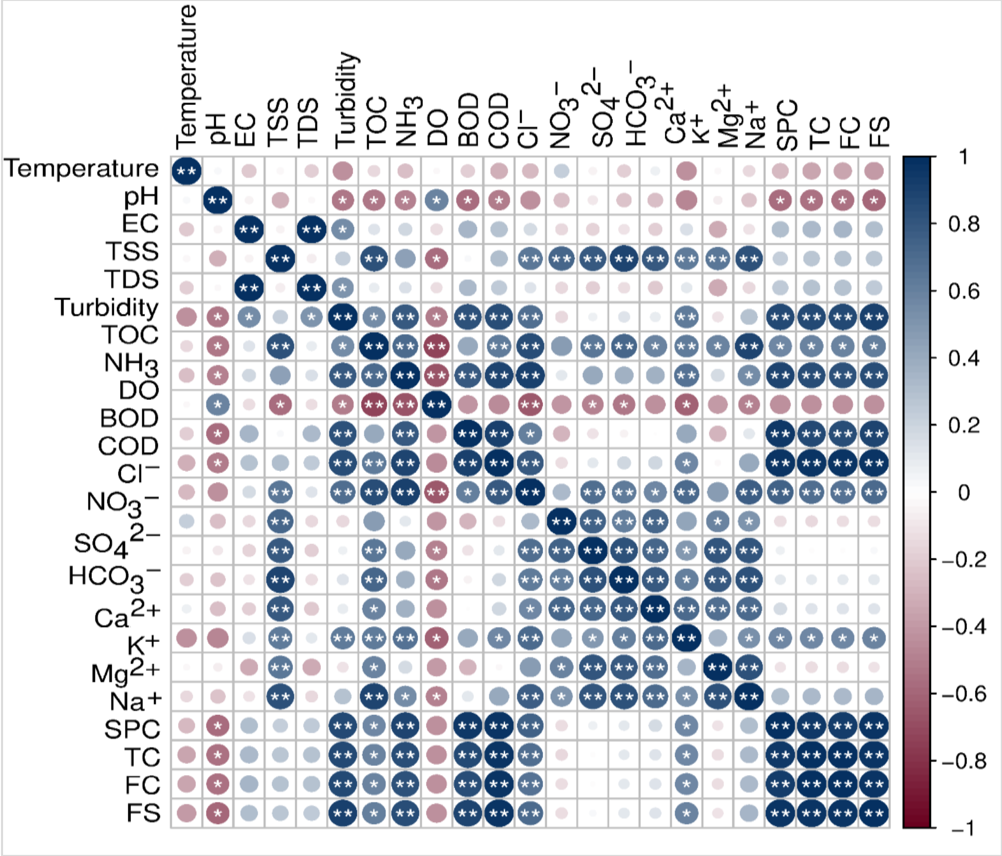


Fig. 1. Correlation matrix of physicochemical and bacteriological parameters of seventeen sites along Rosetta branch. EC: electrical conductivity, TSS: total suspended solids, TDS: total dissolved solids, TOC: total organic carbon, NH_3: ammonia, DO: dissolved oxygen, BOD: biological oxygen demand, COD: chemical oxygen demand, Cl^-: chloride, NO_3^-: nitrate, SO_4^{2-}: sulfate, Ca^{2+}: calcium, K^+: potassium, Mg^{2+}: magnesium, Na^+: sodium, and SPC: standard plate count, TC: total coliform, FC: *fecal coliform*, FS: *fecal streptococci*

1.4. Total suspended solids (TSS)

TSS are microscopic particles suspended in water that fail to pass through a 2µm filter paper during the filtration of a water sample. This assemblage of suspended solids predominantly comprises decaying plant material, silt, clay, industrial effluents, organic material, and domestic wastewater **(Azzam, 2010)**. The presence of TSS in aquatic systems is a critical indicator of water quality due to its adverse effects on environmental health and ecosystem functioning. Upon scrutinizing the data presented in Table (3), it is evident that the concentrations of TSS along the Rosetta branch during the winter season surpassed the acceptable thresholds stipulated by both Egyptian Law 48/1982 and the Environmental Protection Agency (EPA) standards, which typically prescribe limits not exceeding 20 mgL^{-1}. The sites situated along the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) exhibited notably elevated TSS levels, primarily attributable to the inflow of effluents from the drain outlets (L2, L5, L8, L11, and L14). Consequently, these particular sites registered the highest concentrations of TSS, indicating a pronounced degradation of water quality in these areas. The escalation of TSS levels in the Rosetta branch can have deleterious repercussions on the aquatic ecosystem and overall water quality. The presence of suspended particles in the water column can lead to light absorption, subsequently elevating water temperatures and impeding oxygen production **(Soliman *et al.*, 2022)**. This phenomenon can disrupt the ecological balance, adversely affecting aquatic life, biodiversity, and the overall health of the aquatic environment.

1.5. Total dissolved solids (TDS)

TDS can be either organic or inorganic, and many of these substances are undesirable in water. It can lead to changes in certain natural properties, such as unpleasant odors, which reflect osmotic pressure that impacts aquatic organisms or may even contribute to cancer, particularly in the case of halogenated compounds **(Omer, 2019)**. TDS values for Rosetta branch samples (L1, L3, L7, L12, L13, L15, L16, and L17) were mostly within the permissible limits (Table 3), except for sites L4, L6, L9, and L10, where TDS values exceeded the permissible limits (966, 539, 535, and 960 mgL^{-1}, respectively). In contrast, TDS values at the El-Rahawy drain outfall (L2) exceeded the permissible limit, recording 723 mgL^{-1} **(**Table 3), while other drains (L5, L8, L11, and L14) were within the allowable limits. These findings suggest potential irrigation issues if the drains are being used for illegal or unofficial drainage, as TDS should be >450 mgL^{-1}, according to **Ayres and Westcott (1985)**. Additionally, TDS, EC, and turbidity values

Table 3. Mean values of physico-chemical parameters of water samples collected along the Rosetta branch.

Parameters	**L1[a]**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**	**L11**	**L12**	**L13**	**L14**	**L15**	**L16**	**L17**	**Law48/1982[b]**
Temperature (°C)	16.9	15.2	17.1	18.6	16.1	15.7	15.9	21.4	23.1	16.2	21.8	19.5	15.9	21.3	21.0	24.0	23.0	5 degrees above normal
pH (Unit)	8.2	7.1	7.5	7.9	8.1	7.6	8.0	6.9	8.0	8.3	7.5	8.1	8.2	8.0	8.5	8.1	7.9	7-8.5
EC (µmohs/cm)	346	1209	601	1021	450	837	463	645	822	934	571	498	458	461	492	730	412	-[c]
TSS (mgL^{-1})	50.2	87.9	56.72	51.2	95.35	66.10	61.48	90.20	81.05	55.6	59.9	56.13	52.9	103.75	70.28	45.43	41.6	-
TDS (mgL^{-1})	215	723	380	966	284	539	276	410	535	960	371	319	304	289	311	450	292	not exceed than 500
Turbidity (NTU)	8.01	96.01	42.05	47.92	30.92	14.60	17.85	19.61	20.04	17.17	10.12	9.63	8.25	16.34	7.09	12.15	9.21	-
TOC (mgL^{-1})	0.75	3.8	2.13	1.78	2.95	1.93	1.47	2.35	1.61	1.37	2.14	1.52	1.38	3.53	1.78	1.32	1.16	-
NH_3 (mgL^{-1})	0.405	25.401	6.912	2.081	15.070	2.945	1.077	4.039	2.011	1.523	2.106	1.940	1.342	4.580	2.730	7.121	5.913	not exceed than 0.5
DO (mgL^{-1})	8.1	0.19	3.95	2.70	0.24	2.99	4.07	1.85	3.21	5.90	2.11	4.76	3.98	3.54	3.61	4.23	3.15	not less than 5
BOD (mgL^{-1})	3	112	60	23	11	34	12	9	18	10	8	7	12	5	12	50	31	not exceed than 10
COD (mgL^{-1})	21	216	75	24	51	32	30	24	29	30	26	22	35	47	32	64	25	-
Cl- (mgL^{-1})	14.00	263.51	92.01	41.70	224.82	63.11	29.14	70.22	35.81	46.01	34.95	21.72	19.30	143.12	25.80	97.50	23.16	-
NO_2^- (mgL^{-1})	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-
NO_3^- (mgL^{-1})	<0.2	1.38	<0.2	0.729	21.42	0.751	<0.2	47.20	9.11	3.27	4.82	0.649	0.815	20.13	1.98	1.07	<0.2	not exceed than 45
PO_4^{3-} (mgL^{-1})	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	not exceed than 1
SO_4^{2-} (mgL^{-1})	19.42	60.51	45.73	31.40	255.93	44.75	24.31	121.44	50.01	34.73	50.21	23.58	36.41	182.39	24.15	49.27	18.13	not exceed than 200
CO_3^{2-} (mgL^{-1})	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
HCO_3^- (mgL^{-1})	172	324	218	184	510	360	332	326	328	214	250	198	192	480	220	185	130	-
TA (mgL^{-1})	172	324	218	184	510	360	332	326	328	214	250	198	192	480	220	185	130	150-200
Ca^{2+} (mgL^{-1})	46.91	72.53	51.32	40.36	92.01	46.22	88.46	94.62	69.48	49.17	46.82	42.71	36.29	94.33	52.23	64.07	45.33	-
K^+ (mgL^{-1})	8	19	12	10	17	10	16	16	11	10	8	9	9	10	9	9	7	-
Mg^{2+} (mgL^{-1})	8.02	11.65	11.43	10.05	38.92	10.61	22.75	18.96	10.44	10.67	24.85	10.43	16.92	40.66	8.54	12.03	8.42	-
Na^+ (mgL^{-1})	27	150	68	36	180	40	74	74	42	42	65	40	42	240	50	30	26	-

[a] L1 to L17 are location sites; [b] Law 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution; [c]-: No guideline available.

showed a strong positive correlation with each other (r = +0.97) (Fig. 1), a result that aligns with the findings of **Azzam *et al.* (2024)**.

1.6. Turbidity

Turbidity measures the concentration of suspended particles in water, primarily caused by colloidal substances such as clay, silt, non-living organic matter, plankton, and other microscopic organisms, as well as suspended organic and inorganic materials. The degree of turbidity in stream water serves as an approximate indicator of pollution intensity. Turbidity values ranged from 10.12 to 96.01 NTU in drains (L2, L5, L8, L11, and L14) and from 7.09 to 47.92 NTU in Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) (Table 3). The increase in turbidity from upstream to downstream may be attributed to the discharge from the drains. Positive correlations were observed between turbidity and all other studied parameters. Additionally, turbidity values illustrated a negative correlation with dissolved oxygen (DO) and pH (r = -0.31 and r = -0.17, respectively).

1.7. Total organic carbon (TOC)

TOC measures the amount of organic compounds within water bodies **(Lee *et al.*, 2016)**. Organic compounds found in water can stem from both synthetic sources, such as solvents, detergents, oils, herbicides, fertilizers, and pesticides, as well as naturally occurring sources like tannins, humic acids, and fulvic acids **(Sharma & Bhattacharya, 2017)**. The Rosetta branch exhibited TOC values ranging from 0.75 to 2.13 mgL^{-1} during the winter season, as detailed in Table (3). Notably, the El-Rahawy (L2) and Tala (L14) drainage outlets along this branch displayed the highest TOC concentrations, owing to the substantial influx of agricultural, domestic, and industrial wastewaters laden with organic matter. Such heightened organic content in surface water can precipitate a reduction in DO levels, thus posing a detrimental threat to aquatic ecosystems **(Moiseenko, 2022)**. The distinction between synthetic and naturally occurring organic compounds highlights the diverse sources of organic pollution in aquatic environments. Variations in TOC values along the Rosetta branch reflect the localized impact of human activities, with certain drainage outlets being major pollution hotspots. The correlation between high TOC levels and low dissolved oxygen emphasizes the ecological consequences of organic pollution, which can harm aquatic biodiversity and disrupt ecosystems. Monitoring and managing TOC levels are crucial for maintaining water quality and protecting aquatic habitats.

1.8. Ammonia (NH_3)

NH_3 is a nitrogenous compound detected in nature for the growth and reproduction of plants and animals **(Chamoli *et al.*, 2024)**. NH_3 can be released from proteinaceous organic matter and urea or synthesized through industrial processes **(Berman *et al.*,**

1999). In this study, the recorded mean NH_3 values exceeded the permissible limits set by Law 48/1982 (which specifies a maximum of 0.5 mgL^{-1}). NH_3 concentrations generally ranged from 0.405 to 7.121 mgL^{-1} in the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) and from 2.106 to 25.401 mgL^{-1} in drain outfalls (L2, L5, L8, L11, and L14) (Table 3). The increase in NH_3 values can be attributed to organic pollution from domestic sewage and fertilizer runoff **(Rashmi *et al.*, 2020)**. It is well-established that ammonia toxicity is pH-dependent. The mean pH flocculated from 6.9 to 8.5, while NH_3 concentrations ranged from 0.405 to 25.401 mgL^{-1}. These results exceed the normal limits (1.27–3.88 mgL^{-1}) at a pH of 8.0–8.1, as outlined by the **USEPA (1999)**. Statistical analysis revealed a strong positive correlation between NH_3 and NO_3^-, BOD, and bacteriological parameters (r = +0.93), while a negative correlation was found with dissolved oxygen (DO) (Fig. 1). This further confirms the impact of sewage discharge and agricultural runoff in the area.

1.9. Dissolved oxygen (DO)

DO supports the metabolism of aerobic organisms and plays a crucial role in organic degradation, with higher concentrations indicating good water quality. Inadequate DO can lead to unfavorable environmental conditions, where aerobic bacteria are replaced by anaerobic ones, resulting in water deterioration and the production of unpleasant odors due to gases such as H_2S, NH_3, and CH_4 **(Azzam, 2010)**. DO concentrations varied depending on the site and the level of pollution. Most water samples collected from drain outlets (L2, L5, L8, L11, and L14) violated the standard limits, which states that DO should not be ≥ 5 mgL^{-1}, with concentrations ranging from 0.19 to 3.61 mgL^{-1} (Table 3). A reduction in DO is likely due to a high load of organic matter and nutrients, as noted by **Azzam *et al.* (2025)**. In contrast, DO values for water samples from the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) were more variable, fluctuating between 2.70 and 8.10 mgL^{-1}, as shown in Table (3). DO levels are strongly influenced by temperature and salinity, with oxygen concentrations being lower in highly saline waters and higher in freshwater, and DO generally increases as temperature decreases. The depletion of DO in this study is likely linked to bacterial degradation of high organic matter that release from drains outfalls.

1.10. Biological oxygen demand (BOD)

BOD measures the amount of DO consume by aerobic bacteria for their metabolic processes during the breakdown of organic matter **(Bezsenyi *et al.*, 2021)**. The data in Table (3) show elevated BOD values at most of the investigated drain outfalls and sites along the Rosetta branch. The mean BOD values at the drain outfalls ranged from 5 to 112 mgL^{-1}, while at the Rosetta branch sites (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17), they ranged from 3 to 60 mgL^{-1}. Drain outlets (L2, L5, L8, L11, and L14) exceeded the permissible limit of 10 mgL^{-1}, while sites along the Rosetta branch had BOD values above 6 mgL^{-1}. These elevated values suggest a high organic matter load from sewage, industrial, or urban discharges, as noted by **Azzam *et al.* (2023)**.

Additionally, BOD showed a strong positive correlation with all bacteriological parameters ($r = +0.91$) and a significant negative correlation with temperature ($r = -0.54$), pH, and DO ($r = -0.77$) (Fig. 1). This negative correlation is primarily because the consumption of free oxygen by bacterial cells during the degradation of organic compounds, which typically results in higher BOD levels, particularly during the winter season.

1.11. Chemical oxygen demand (COD)

COD serves as a key indicator of organic pollution in various aquatic environments **(Ngwenya, 2006)**. Just as BOD test, the COD test is instrumental in detecting potentially harmful effects and the presence of biologically recalcitrant organic compounds **(Abdo, 2005; Azzam *et al.*, 2022)**. The mean COD values, as presented in Table (3), exhibit a range from 21 to 75 mgL^{-1} for sampling points along the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17), while the drain outlets (L2, L5, L8, L11, and L14) displayed a wider range of 24 to 216 mgL^{-1}. Notably, all measured COD values in samples from both surface and drainage water surpassed the established permissible limit of 10 mgL^{-1}, as mandated by Law 48/1982. The elevated BOD and COD levels observed in our sites along Rosetta water signal a concerning level of organic pollution, potentially stemming from various anthropogenic activities in the area.

1.12. Major anions

The data presented in Table (3) indicate that chloride and sulfate ion concentrations are within normal ranges at most of the studied sites. At the drain outfalls (L2, L5, L8, L11, and L14), chloride (Cl^-) concentrations ranged from 34.95 to 263.51 mgL^{-1}, and sulfate (SO_4^{2-}) concentrations ranged from 50.21 to 255.93 mgL^{-1}. In contrast, at the Rosetta branch sites (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17), chloride ions ranged from 14.00 to 97.50 mgL^{-1}, and sulfate ions ranged from 18.13 to 50.12 mgL^{-1}. Certain sites showed elevated chloride levels, indicating that these areas may be receiving sewage and industrial effluents high in chloride (with Cl^- levels typically expected to be below 50 mgL^{-1}, as noted by **Azzam *et al.* (2022)**. Regarding phosphate concentrations, all studied sites had levels below 0.2 mgL^{-1}, in line with the limits set by Law 48/1982 (1 mgL^{-1}). Conversely, nitrite (NO_2^-) and nitrate (NO_3^-) levels were within the permissible limits (45 mgL^{-1}) at all Rosetta branch and drain sites, except at the Ganob El-Tahreer drain (L8), where nitrate levels reached 47.20 mgL^{-1}. These higher nitrate levels are likely due to the oxidation of ammonia (NH_3) to nitrate (NO_3^-) and nitrite (NO_2^-) by aerobic bacteria in the nitrification process. Carbonate ions were not detected in any of the samples. Bicarbonate ranged from 250 to 510 mgL^{-1} at drain outfalls, and between 172 and 360 mgL^{-1} along Rosetta branch. Bicarbonate concentrations showed a positive correlation with total coliforms ($r = +0.17$). All total alkalinity values in drain outfalls and Rosetta branch exceeded the standard limits (200 mgL^{-1} for drains and 150 mgL^{-1} for Rosetta branch), except at the end of Rosetta branch

(L17), where the value was 130 mgL^{-1}. This indicates the significant impact of drain discharge on Rosetta branch.

1.13. Major cations

Calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), and sodium (Na^+) values in drain outfalls (L2, L5, L8, L11, and L14) and selected sites along the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) were within the standard limits. The mean cation values in the different locations showed that sodium (Na^+) was the most abundant element across all points, followed by calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}) (Table 3).

1.14. Trace metals

Metals naturally occur in freshwater at low concentrations, primarily due to the weathering of rocks and soils, as well as industrial wastewater discharges, sewage, and atmospheric deposition. The mean concentrations of trace metals in the water samples collected during this study are presented in Table (4). Overall, the findings illustrated that the values of all seventeen elements in drain outlets (L2, L5, L8, L11, and L14) and Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) were below the standard limits set by Egyptian law. The pollution in the area is primarily attributed to agricultural runoff and sewage discharge. This adherence to legal standards highlights the effectiveness of existing regulations in monitoring and controlling the release of potentially hazardous substances into the environment.

Table 4. Mean values of trace metals concentrations of water samples collected along the Rosetta branch (values in mgL^{-1}).

Parameters	L1[a]	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	Law48/1982[b]
Aluminum	0.241	0.302	0.165	0.073	0.216	0.154	0.226	0.345	0.281	0.195	0.210	0.127	0.215	0.442	0.290	0.267	0.221	5 degrees above normal
Arsenic	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	7-8.5
Barium	0.042	0.077	0.036	0.071	0.108	0.093	0.054	0.078	0.043	0.076	0.129	0.081	0.034	0.102	0.069	0.048	0.061	-[c]
Cadmium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Cobalt	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	not exceed than 500
Chromium	0.026	0.053	0.020	0.012	0.049	0.022	0.034	0.062	0.009	0.023	0.040	0.028	0.012	0.033	0.007	0.035	0.009	-
Copper	0.047	0.168	0.113	0.031	0.710	0.249	0.087	0.101	0.009	0.072	0.105	0.034	0.006	0.409	0.211	0.124	0.009	-
Iron	0.093	0.780	0.452	0.159	1.064	0.731	0.086	0.112	0.094	0.056	0.109	0.077	0.102	0.414	0.0237	0.346	0.105	not exceed than 0.5
Manganese	0.113	0.215	0.201	0.030	0.046	0.009	0.011	0.039	0..010	0.024	0.275	0.091	0.010	0.039	0.016	0.204	0.087	not less than 5
Molybdenum	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	not exceed than 10
Nickel	0.009	0.031	0.017	0.011	0.019	0.007	0.010	0.027	0.015	0.015	0.034	0.007	0.008	0.045	0.021	0.024	0.007	-
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Antimony	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Selenium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	not exceed than 45
Strontium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	not exceed than 1
Vanadium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	not exceed than 200
Zinc	0.016	0.031	0.007	0.002	0.029	0.010	0.002	0.011	0.002	0.001	0.005	0.005	0.005	0.049	0.027	0.005	0.002	-

[a] L1 to L17 are location sites; [b] Law 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution; [c]-: No guideline available.

2. Bacteriological characteristics of water samples

Bacteriological characteristics remain a critical water quality concern, particularly in water resources used for drinking purposes. The results of the bacteriological analyses along Rosetta branch (17 sites) during the winter season are presented in Table (5).

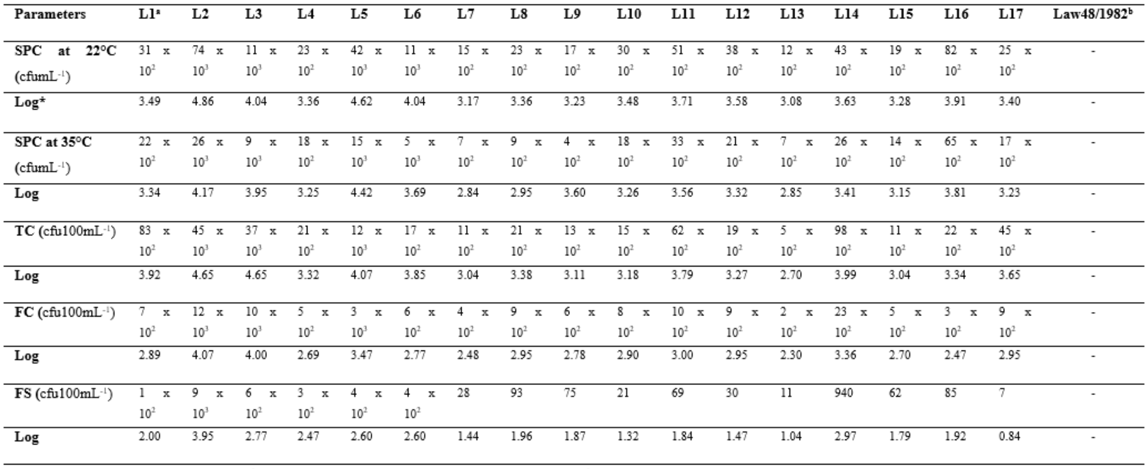
2.1. Standard plate counts (SPC) bacteria

The standard plate count (SPC) at 22°C and 35°C in all collected water samples exhibited high values that varied regionally, with the highest concentrations observed at the El-Rahawy drain outlet (L2). At the drain outfalls (L2, L5, L8, L11, and L14), SPC ranged from 23×10^{2} to 74×10^{3} CFUmL^{-1} at 22°C and from 9×10^{2} to 26×10^{3} CFUmL^{-1} at 37°C. In the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17), SPC fluctuated between 11×10^{2} and 82×10^{2} CFUmL^{-1} at 22°C and from 400 to 65×10^{2} CFUmL^{-1} at 37°C.

2.2. Total coliforms

Total coliform (TC) densities ranged from 21×10^{2} to 45×10^{3} CFU100mL^{-1} at the drain outfalls (L2, L5, L8, L11, and L14) and from 500 to 83×10^{2} CFU100mL^{-1} at the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17). The highest counts at both the drain outfalls and the Rosetta branch were recorded at El-Rahawy and its downstream locations. It is important to note that all monitored points in the drains (except for Zawiet El-Bahr and Tala drains) and over 62.5% of the sites along the Rosetta branch are above the standard limits recommended by **Tebbutt (1998)**, who stated that TC should not exceed 5,000 CFU100mL^{-1}. More stringent limits, as suggested by **Cabelli (1978)**, recommend a maximum total coliform count of 1000 CFU100mL^{-1}, especially for surface water intended for drinking water supply.

Table 5. Mean values of bacteriological parameters of water samples collected along the Rosetta branch.



Parameters	L1[a]	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	Law48/1982[b]
SPC at 22°C (cfumL^{-1})	31 x 10^2	74 x 10^3	11 x 10^3	23 x 10^2	42 x 10^3	11 x 10^3	15 x 10^2	23 x 10^2	17 x 10^2	30 x 10^2	51 x 10^2	38 x 10^2	12 x 10^2	43 x 10^2	19 x 10^2	82 x 10^2	25 x 10^2	-
Log*	3.49	4.86	4.04	3.36	4.62	4.04	3.17	3.36	3.23	3.48	3.71	3.58	3.08	3.63	3.28	3.91	3.40	-
SPC at 35°C (cfumL^{-1})	22 x 10^2	26 x 10^3	9 x 10^3	18 x 10^2	15 x 10^3	5 x 10^3	7 x 10^2	9 x 10^2	4 x 10^2	18 x 10^2	33 x 10^2	21 x 10^2	7 x 10^2	26 x 10^2	14 x 10^2	65 x 10^2	17 x 10^2	-
Log	3.34	4.17	3.95	3.25	4.42	3.69	2.84	2.95	3.60	3.26	3.56	3.32	2.85	3.41	3.15	3.81	3.23	-
TC (cfu100mL^{-1})	83 x 10^2	45 x 10^3	37 x 10^3	21 x 10^2	12 x 10^3	17 x 10^2	11 x 10^2	21 x 10^2	13 x 10^2	15 x 10^2	62 x 10^2	19 x 10^2	5 x 10^2	98 x 10^2	11 x 10^2	22 x 10^2	45 x 10^2	-
Log	3.92	4.65	4.65	3.32	4.07	3.85	3.04	3.38	3.11	3.18	3.79	3.27	2.70	3.99	3.04	3.34	3.65	-
FC (cfu100mL^{-1})	7 x 10^2	12 x 10^3	10 x 10^3	5 x 10^2	3 x 10^3	6 x 10^2	4 x 10^2	9 x 10^2	6 x 10^2	8 x 10^2	10 x 10^2	9 x 10^2	2 x 10^2	23 x 10^2	5 x 10^2	3 x 10^2	9 x 10^2	-
Log	2.89	4.07	4.00	2.69	3.47	2.77	2.48	2.95	2.78	2.90	3.00	2.95	2.30	3.36	2.70	2.47	2.95	-
FS (cfu100mL^{-1})	1 x 10^2	9 x 10^3	6 x 10^2	3 x 10^2	4 x 10^2	4 x 10^2	28	93	75	21	69	30	11	940	62	85	7	-
Log	2.00	3.95	2.77	2.47	2.60	2.60	1.44	1.96	1.87	1.32	1.84	1.47	1.04	2.97	1.79	1.92	0.84	-

* Logarithmic of counts (cfumL^{-1}) for SPC (22°C and 22°C), and (cfu100mL^{-1}) for TC, FC, FS.
[a] L1 to L17 are location sites; [b] Law 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution; [c]-: No guideline available.

2.3. Fecal coliforms

Fecal coliform (FC) counts at the drain outfalls (L2, L5, L8, L11, and L14) ranged from a maximum of 12 × 10^3 CFU100mL^{-1} at El-Rahawy drain (L2) to a minimum of 900 CFU100mL^{-1} at Ganob El-Tahreer drain (L8). In contrast, FC counts in the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17) varied between 200 and 10 × 10^3 CFU100mL^{-1}. El-Tahreer drain (L8) was the only location that complied with the international standard limits set by **Tebbutt (1998)**, with FC counts not exceeding 2000 CFU100mL^{-1}, while the other drains exceeded this threshold. Additionally, around 60% of the sites along the Rosetta branch failed to meet the standard limits. According to **Cabelli (1978)**, restricted limits for the Nile source intended for drinking water are 200 CFU100mL^{-1}, which suggests that water from these sites is unsafe from a bacteriological standpoint.

2.4. Fecal Streptococci

Fecal streptococci (FS) counts ranged from a maximum of 9 × 10^3 CFU100mL^{-1} at El-Rahawy drain (L2) to a minimum of 93 CFU100mL^{-1} at Ganob El-Tahreer drain (L8). In the Rosetta branch (L1, L3, L4, L6, L7, L9, L10, L12, L13, L15, L16, and L17), FS counts fluctuated between 7 and 6 × 10^2 CFU100mL^{-1}. Generally, sites in the drains and Rosetta branch exceeding 1000 CFU100mL^{-1} were above the international standard limits set by **Tebbutt (1998)**. The data also revealed a gradual increase in bacterial indicator counts (TC, FC, and FS) from upstream to downstream, likely due to the discharge from the drains into the branch, and this aligns with findings from **Azzam *et al.* (2017)**, **El-Dougdoug *et al.* (2020)**, **Elbahnasawy *et al.* (2021)** and **Azzam *et al.* (2025)**. Statistical analysis showed a highly significant positive correlation (r = +0.99) between SPC, TC, FC, and FS. Similar results were reported by **Azzam (2015)**, who studied the microbiological indicators of Rosetta water along the branch. Regarding the correlation between microbiological and physicochemical indicators, a strong positive correlation (r > 0.74) was observed with ammonia, BOD, and nitrate levels, while an intermediate positive correlation (r > 0.61) was found with EC, TDS, turbidity, cations, and anions (Fig. 1). Notably, a strong negative correlation (r = -0.85) was identified between the bacterial indicators and dissolved oxygen (DO), indicating that a depletion in DO is a strong indicator of bacterial water deterioration.

3. Water quality index (WQI)

Results of WQI indicate that quality is extremely poor at El-Rahawy (L2) and Tala (L14) drains outlets and generally bad for most of the sites sampled except for upstream El-Rahawy drain (L1) was medium. WQI shows a strong correlation with physicochemical and microbiological indicators. Notably, fecal coliforms are a major contributing indicator in the index calculations, a finding that aligns with the observations of **Azzam (2015)**. Based on the data from both physicochemical and bacteriological analyses, it is evident that all the drains studied are experiencing varying levels and types of physical, chemical and bacteriological pollution, with the highest levels observed at El-Rahawy, Sabal, and Tala drains. The fluctuating pollution levels between these sites can likely be attributed to a combination of industrial, agricultural, and domestic waste discharges, as noted by **Azzam and Ibrahim (2021)**.

El-Rahawy drain, in particular, has a negative impact on the Rosetta branch quality, mainly because its high organic load, which undermines the suitability of the branch as a potential drinking water source. This is reflected in the elevated levels of bacterial pollution, as well as high values of NH_3, TDS, EC, turbidity, BOD, total alkalinity, and a marked depletion in DO, as reported by **Azzam *et al.* (2025)**. These findings are consistent with studies by other researchers who found that the highest pollution levels in Rosetta branch are concentrated downstream of El-Rahawy and Sabal sites **(Mostafa & Peters, 2016; Elhaddad & Al-Zyoud, 2017; Al-Sisi *et al.*, 2024)**. The gradual decrease in pollution levels from downstream El-Rahawy to downstream Tala drain can be seen as part of the stream's "self-purification" process, as described by **Tebbutt (1998)**, along with the dilution effect proposed by **Azzam *et al.* (2024)**.

It is noteworthy that elevated levels of physical, chemical, and bacterial pollution markers are typically observed during the winter season. This pattern is believed to stem from the accumulation of waste in drainage systems, compounded by reduced water levels in the Nile due to winter closure. Consequently, there is an increase in pollutant concentrations and a decrease in the dilution effect. Moreover, the colder temperatures and higher pH values in winter facilitate the release of metals and other pollutants from sediments into the water, as highlighted by **Saleem *et al.* (2013)**. In this context, policies related to water management play a significant role in shaping the quality of water resources in Egypt.

4. Variance analyses

A two-way analysis of variance (ANOVA) was carried out to investigate variations in water samples obtained from five different pollution sources, focusing on eight key parameters: COD, BOD, TSS, TDS, TOC, DO, pH, and Cl−. Table (6) presents data on the flow information from various pollution point along Rosetta branch during winter season, while Table (7) offers a detailed breakdown of the mass loading results for each parameter at the different point sources. The main objective was to determine whether there were significant differences in the means of the water samples, with the null hypothesis (H0) suggesting no notable variations, while the alternative hypothesis (H1) proposing the presence of such differences. The results of two-way ANOVA analysis revealed a significant divergence in how each pollution source affected mass loading. Table (7) displays a very low *p*-value of 1.51×10^{-49} for the pollution source, well below the conventional significance level of 0.05, indicating strong evidence to reject the null hypothesis in favor of the alternative hypothesis. Similarly, a substantial difference was found in the impact of each parameter on mass loading, with a *P*-value of 3.11×10^{-43}, further supporting the rejection of the null hypothesis. A significant interaction effect was observed between pollution points and their relationship with different parameters. The calculated *F*-value of 31.02 exceeded the critical *F*-value of 1.78, and the interaction *p*-value of 1.09×10^{-45} was significantly below the alpha threshold of 0.05, resulting in the rejection of the null hypothesis in favor of the alternative hypothesis. The point sources were ranked based on their contributions to mass loading across all categories, with the following order: El-Rahawy, Tala, Sabal, Ganob El-Tahreer, and Zawiet El-Baher drains. This ranking, combined with the rejection of the null hypothesis for both point sources and parameters, highlights the importance of the study findings.

Table 6. Flow from various pollution sources along the Rosetta branch during winter season

Pollution source	**Flow (m^3 /day)**
R	1,980,000
S	430,000
G	530,000
Z	90,000
T	462,000

Notation: PS, pollution source; R, El-Rahawy drain outlet; S, Sabal drain outlet; G, Ganob El-Tahreer drain outlet; Zawiet El-Bahr drainoutlet; T, Tala drain outlet.

Table 7. Results of two-way ANOVA with replication at the Rosetta branch

Source of variation	SS	*df*	MS	*F*-statistics	*p*-value	*F*-critical	Hypothesis
PS	2.98E + 25	6	8.12E + 24	191.03	1.51E – 49	3.27	Alternate hypothesis (H1)
Parameter	3.27E + 25	11	2.95E + 24	60.77	3.11E – 43	2.25	Alternate hypothesis (H1)
Interaction	4.51E + 25	32	1.80E + 21	31.02	1.09E – 45	1.78	Alternate hypothesis (H1)
Within	7.63E + 25	182	6.01E + 23				
Total	1.48E + 25	209					

Notation: PS, pollution source; SS, sum of squares; df, degrees of freedom; MS, mean square.

CONCLUSION

This study highlights the significant challenges facing the quality of the Rosetta branch and its surrounding drainage outlets. The fluctuating temperatures and high concentrations of pollutants, such as NH_3, TSS, BOD, and COD, are key factors driving the decline in the region's ecological health. These parameters, largely influenced by agricultural runoff and domestic sewage, have led to a sharp decrease in dissolved oxygen levels, further intensifying the water quality deterioration. Although trace metal levels remain within permissible limits, bacterial contamination, particularly from fecal coliforms and total coliforms, exceeds international standards at several monitoring sites. The study stresses the urgent need for effective management strategies to reduce pollutant loads, especially in areas with heavy agricultural and domestic waste discharges, to protect aquatic ecosystems and the communities dependent on these water resources. Additionally, the research identifies El-Rahawy and Tala drains as major pollution sources, highlighting the need for targeted measures to mitigate their impact on the Rosetta branch’s water quality. In conclusion, the study emphasizes the importance of improving water management practices, particularly during low-flow periods, to prevent further deterioration and ensure the long-term sustainability of the region's water reserves. This reinforces the need for immediate and comprehensive action to safeguard this vital resource for present and future generations.

ACKNOWLEDGMENT

The authors would like to thank the Deanship of Scientific Research at Shaqra University for supporting this work. Also, the authors wish to express their gratitude to Microbiology Dept., Central Laboratory for Environmental Quality Monitoring (CLEQM) at the National Water Research Center (NWRC) and Chemistry Laboratory, Freshwater& Lakes Division at National Institute of Oceanography and Fisheries (NIOF) in Egypt for supporting this work.

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