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Bacteriological Quality of the Northern Khors of Lake Nasser, Egypt Along Two Successive Drought and Flooding Seasons

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ABSTRACT

Lake Nasser is the main water resource in Egypt, thus continuous evaluation of Lake Nasser is very important to avoid any problems at an appropriate time. In this study, bacterial loads of water, sediments, and plants were estimated in the northern Lake Nasser Khors (El-Ramla, Rahma, Kalabsha, and Wadi Abyad) to evaluate the quality of the lake. Results showed that the bacterial loads increased the inlet khor, especially in El-Ramla and Rahma Khors, hence the inlet khors are considered more suitable for living fish. Wadi abyad Khor recorded higher numbers of all bacterial indicators of pollution; this may be due to the increasing tourism ships south of the Lake to visit Abu Simbel Temple, observe migratory birds, and transport ships to Sudan. The Egyptian government is concerned with implementing an effective fisheries policy and an effective pollution control policy. This is evidenced by the comparison between this study (2022) and our previous study (2015). The comparison revealed a percentage increase of less than 25% for the various bacterial groups, with a decrease of more than 100% for bacterial indicators of pollution; this indicates some improvement. But it is still exposed to pollution, hence the laws and rules must be followed strictly for tourism ships and fishermen during their work in the lake and residence around the lake, as well as rationing the coastal agriculture around Lake Nasser.

INTRODUCTION

Lake Nasser is Africa's second largest artificial lake, after Lake Volta in Ghana. Lake Nasser was named after President Abdel Nasser. The lake was created after the construction of the Aswan High Dam in the 1960s (the dam store floodwater to release during the drought season) **(Habib *et al*., 2014)**. Lake Nasser has many side extensions (flooded side valleys) known as Khors. It represents about 79% of the total lake surface and about 55% of the total lake volume **(Entz, 1973)**. The lake water affects water levels and currents in the Khors. These Khors are essential for spawning and feeding fish habitat **(Habib *et al*., 2014)**. Thus, Lake Nasser and its Khors represent the main source of fresh water and freshwater fish. About 13,450 fishers and 3,046 boats work in the lake

(GAFRD, 2015). In addition, more than 150 carrier boats and refrigerated trucks are used to collect fish from Lake Nasser **(Halls *et al*., 2015)**. Thus, a more rational and sustainable use of Lake Nasser must be achieved. Two government organizations are concerned about the quality of Lake Nasser and its fish, those are The Ministry of Water Resources and Irrigation, and the General Authority for Fishery Resources Development (GAFRD).

The quality of Lake Nasser is affected by water levels, inflows and circulation, as well as by loading and sedimentation, and thermal stratification **(Heikal, 2010; El-Shabrawy, 2014)**. In this context, **Abd Ellah (2020)** illustrated that, the morphometric information for Lake Nasser varies depending on the water level of Lake Nasser (160-180m above mean sea level). Additionally, the characteristics of Lake Nasser, such as loading, sedimentation, thermal layers, etc., vary according to the flood and drought seasons and the amount of water and its flow rate during the flood season, which extends from the end of July to November. Therefore, the quality of Lake Nasser must be assessed by analyzing its water, sediments, and fish periodically, either via the determination of heavy metal concentrations **(Goher *et al*., 2014)**, or microbiological analyses **(Ali *et al*., 2016; Iskaros *et al*., 2021; Ali, 2022, 2023)**, as well as through evaluating the physicochemical parameters **(Korium, 2021)**.

Microorganisms are present in the ecosystem, so their load and species are affected by any change in the aquatic environment. **Uttah *et al*. (2008)** used a bio-survey of plankton as indicators of water quality; also **Iskaros *et al*. (2021)** determined the abundant species of macrobenthic invertebrates. In addition, **Ali (2022, 2023)** assessed the microbial density of water, sediments and fish as bio-indicators of pollution.

This study aimed to estimate the bacterial loads in water, sediments, and plants in the northern Lake Nasser Khors (El-Ramla, Rahma, Kalabsha, and Wadi Abyad) to evaluate their quality.

MATERIALS AND METHODS

1. The study area

Four khors in the northern part of Lake Nasser were selected, El-Ramla and Kalabsha located on the western side of the lake (at 12 and 44km, respectively, from the High Dam), and Rahma and Wadi Abyad located on the eastern side (at 55 and 70km, respectively, from the High Dam) as illustrated in Fig. (1). For each Khor, three sites were selected, namely the main channel of the lake (front of Khor), the beginning of Khor (inlet) and the middle area of Khor. Some characteristics of the studied Khors are shown in Table (1).

2. Collection of samples

Samples were collected before and after flooding seasons in March and August 2022, respectively, for microbial analysis. About 24 samples of water, sediment and plant samples were collected at the same time and from the same site.

2.1. Water sampling

Water samples were manually and aseptically collected from the surface water (ca. <1 m) in sterilized 500ml glass bottles.

2.2. Sediment sampling

Sediment samples were collected using Ekman grab.

2.3. Plant sampling

Myriophyllum spicatum (the most abundant plant) samples were collected manually.

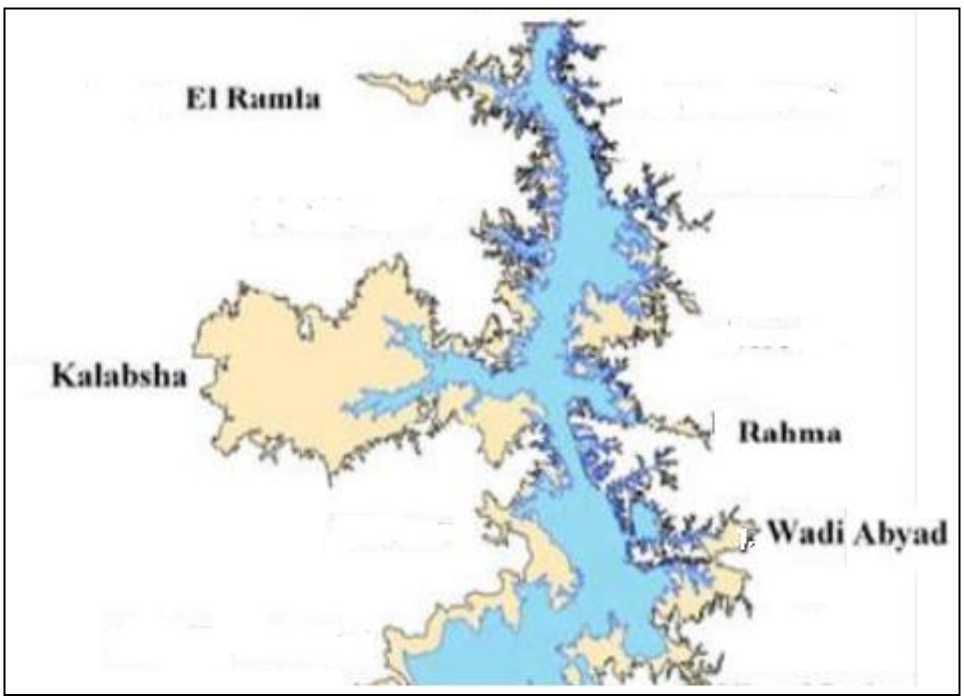

Fig. 1. Location map of the northern Khors of Lake Nasser **(Abd Ellah & El-Geziry, 2016)**.

Table 1. GPS data and characteristics for the studied northern Khors of Lake Nasser at 180m above sea level **(Latif, 1974** as cited in **Iskaros *et al*., 2021)**

Khor name	**Length (km)**	**Surface area (km^2)**	**Perimeter (km)**	**Volume (km3)**	**Latitude**	**Longitude**
El Ramla	25.3	101.2	284	0.96	23º 52\ N	32º 50\ E
Kalabsha	47.2	620.0	517	7.16	23º 32\ N	32º 50\ E
Rahma	23.6	95.2	232	2.15	23º 31\ N	32º 54\ E
Wadi-Abyad	18.3	48.7	184	1.11	23º 21\ N	32º 57\ E

3. Bacteriological analyses

3.1. Bacteriological analyses of water samples

Water samples were serially diluted in sterile physiological saline (0.85% wt.vol.$^{-1}$ NaCl) and subjected to**:**

a) Enumeration of total viable bacterial counts at 22 and at 37°C using the pour plate technique on nutrient agar plates **(APHA, 1999)**;

b) Enumeration of total spore-forming bacteria: successive dilutions were pasteurized for 15min at 80°C prior to plating on nutrient agar plates, and incubation at 30°C **(APHA, 1999)**;

c) Enumeration of total thermophilic bacteria: nutrient agar plates of total thermophilic bacteria were incubated at 55°C **(APHA, 1999)**;

d) Enumeration of total coliforms using MPN technique and MacConkey broth medium, and incubation at 37°C for 24- 48h **(APHA, 1999)**. The tubes were observed for acid and gas production;

e) Enumeration of faecal coliforms using MPN technique and MacConkey broth medium, and incubation at 44.5°C for 24h **(APHA, 1999)**. The tubes were observed for acid and gas production;

f) Enumeration of faecal streptococci using MPN technique and Azide dextrose broth medium, and incubation at 37°C for 24- 48h **(APHA, 1999)**. The tubes were observed for turbidity.

3.2. Bacteriological analyses of sediment samples

Ten grams of sediment was aseptically transferred into 90ml of sterilized 0.85% normal saline solution, shaken for an hour, then allowed to stand for about five minutes. Serially diluted in sterile physiological saline (0.85% wt.vol.$^{-1}$NaCl) were followed by**:**

a) Counting the total viable bacteria at 32°C using the pour plate technique on nutrient plate count agar **(APHA, 1999)**;

b) Counting the total spore-forming bacteria, successive dilutions were pasteurized for 15min at 80°C prior for plating on nutrient agar plates, and incubation at 30°C **(APHA, 1999)**;

c) Counting the total thermophilic bacteria, nutrient agar plates of total thermophilic bacteria were incubated at 55°C **(APHA, 1999)**.

3.3. Bacteriological analyses of plant samples

To determine the bacterial load on the plant surface (epiphytic bacteria), ten grams of the plant (*Myriophyllum spicatum*) was aseptically transferred to 90ml of sterilized 0.85% normal saline, shaken for an hour, then allowed to stand for about five minutes. It was serially diluted in sterile physiological saline solution (0.85% wt.vol.$^{-1}$ NaCl). The same method for sediment was applied to enumerate a) total viable bacteria counts, b) total spore-forming bacteria, and c) total thermophilic bacteria.

4. Statistical analysis

Data obtained were statistically analyzed using STATISTICA 10 (StatSoft, Inc., Tulsa, USA). Analysis of variance (ANOVA) was used to examine the independent effects.

RESULTS

1. Bacterial load of water

The total bacterial loads of the northern Khors of Lake Nasser water before and after the flood of the year 2022 are illustrated in Fig. (2). It is affected by seasons (drought and flooding seasons), where flooding season extends from the end of July to November **(Abd Ellah and El-Geziry, 2016)** and the sites (front, inlet and middle of the Khor). Total bacterial counts growing at 22ºC (autochthonous) ranged from 1.5 to 6.5 Log No. ml^{-1}. Total bacterial counts growing at 37ºC (allochthonous) ranged from 2.1 to 6.5 Log No. ml^{-1}. It is noticeable that the ratio of total bacteria counts at 22 and 37^{o}C ranged from 0.5 to 1.3. Counts after flooding were higher than before flooding. Before flooding, El-Ramla Khor recorded the highest bacterial populations for either autochthonous or allochthonous (means of 4.2 and 4.3 Log No. ml^{-1} respectively); Wadi Abyad Khor recorded the lowest populations (means of 2.9 and 3.1 Log No. ml^{-1}), respectively. While, El-Ramla Khor after flooding recorded the lowest populations of autochthonous (means of 5.1 Log No. ml^{-1}), and the highest populations for allochthonous (means of 6.0 Log No. ml^{-1}). In most of the studied Khors, the main channel of Lake Nasser (front of the Khor) recorded the highest bacterial populations than the inlet or middle of the Khor (Fig. 2). In Rahma Khor before flooding, the lowest populations were recorded in the front of the Khor (main channel of Lake Nasser) and gradually increased in the inlet and the middle of Khor, either for autochthonous or allochthonous bacteria.

Numbers of spore-forming bacteria before flooding follows the order: Kalabsha> Wadi Abyad > Rahma> El-Ramla (means of 0.4, 0.3, 0.2 and 0.1 Log No. ml^{-1}, respectively). While after flooding, the order was Wadi Abyad > Kalabsha> Rahma> El-Ramla (means of 1.9, 1.7, 1.5 and 1.4 Log No. ml^{-1} respectively). In general, after flooding, higher numbers of spore-forming and thermophilic bacteria were recorded than before flooding. After flooding, El-Ramla Khor recorded the lowest numbers of spore-forming bacteria and the highest numbers of thermophilic bacteria. The lowest populations were recorded in the front of Khor (the main channel of Lake Nasser) and gradually increased in the inlet and the middle of the Khor (Fig. 2).

Bacterial indicators of pollution population are presented in Table (2). Total coliforms showed higher population than faecal coliforms and faecal streptococci. Total coliforms were detected in all water samples before flooding and 25% of water samples after flooding. While, faecal coliforms were detected in 16 and 25% of water samples before and after flooding, respectively, as well as faecal streptococci were detected in 25 and 8% of the water samples before and after flooding, respectively. Before flooding, higher population of total coliforms were found than after flooding, and it followed the order of Kalabsha> Wadi Abyad >El-Ramla> Rahma (means of 128, 86, 12 and 8 MPN/ 100ml, respectively). Wadi Abyad Khor after flooding recorded higher pollution for all bacterial indicators in the inlet Khor compared to the front and middle Khor.

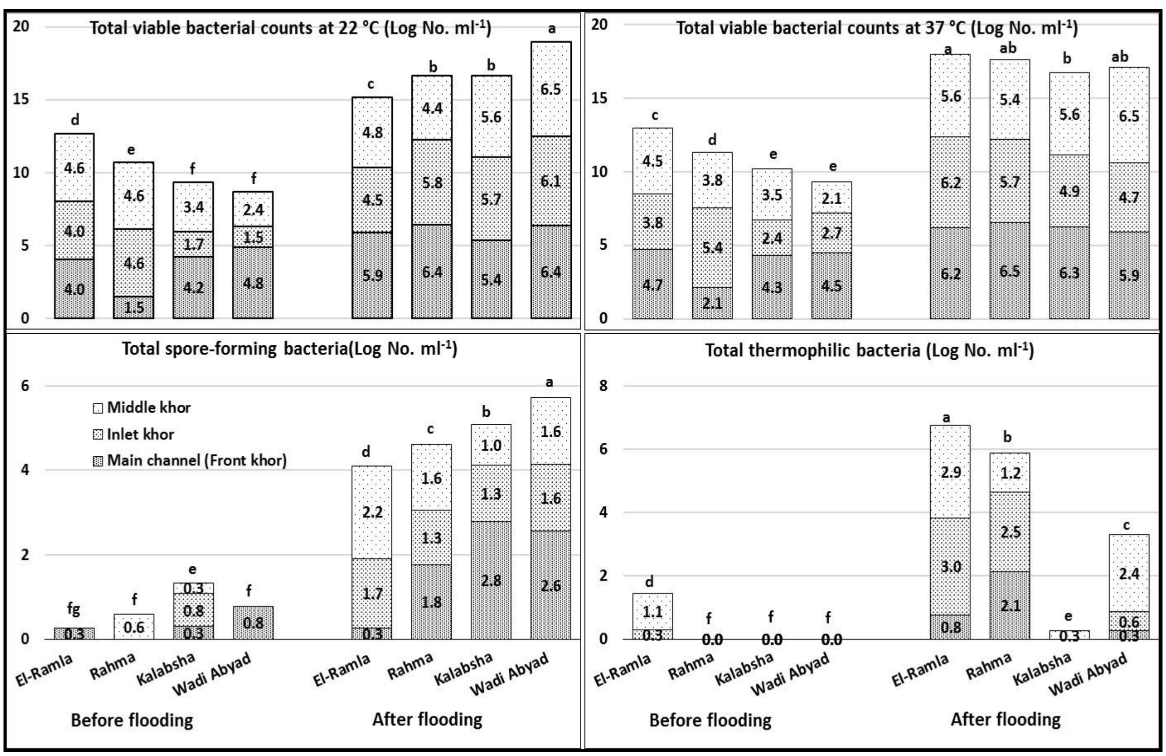

Fig. 2. Total bacterial loads for water samples obtained from different sites of the northern Lake Nasser Khors (main channel, front of the khor; inlet, in the beginning of the khor, and in the middle of the khor) before and after flooding 2022. The differ letter are significantly different ($P \leq 0.05$)

Table 2. Numbers of bacterial indicators of pollution (MPN. 100 ml^{-1}) for water samples obtained from different sites of northern Lake Nasser Khors (main channel, front of the khor; inlet, in the beginning of the khor, and in the middle of the khor) during before and after flooding season 2022

Khor	Front khor	Inlet khor	Middle khor	Front khor	Inlet khor	Middle khor
	Before flooding			**After flooding**		
	Total coliforms					
El-Ramla	7.0 e	25.0 d	5.0 e	0.0 e	0.0 e	0.0 e
Rahma	8.0 e	8.0 e	8.0 e	0.0 e	7.0 e	0.0 e
Kalabsha	350.0 b	25.0 d	8.0 e	0.0 e	0.0 e	0.0 e
Wadi Abyad	246.7 c	2.0 e	8.0 e	0.0 e	1800.0 a	20.0 d
	F(6,48)=10249.95; p<0.000 The different letters are significantly different ($P \leq 0.05$)					
	Faecal coliforms					
El-Ramla	0.0 f	8.0 c	0.0 f	0.0 f	0.0 f	0.0 f
Rahma	0.0 f	0.0 f	0.0 f	0.0 f	7.0 d	0.0 f
Kalabsha	0.0 f	2.0 e	0.0 f	0.0 f	0.0 f	0.0 f
Wadi Abyad	0.0 f	0.0 f	0.0 f	0.0 f	1800.0 a	20.0 b
	F(6,48)=1604067.; p<0.000 The different letters are significantly different ($P \leq 0.05$)					
	Faecal *streptococci*					
El-Ramla	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
Rahma	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
Kalabsha	2.0 a	0.0 b	2.0 a	0.0 b	0.0 b	0.0 b
Wadi Abyad	0.0 b	0.0 b	2.0 a	0.0 b	2.0 a	0.0 b
	F(6,48)=1604067; P<0.000 The different letters are significantly different ($P \leq 0.05$)					

2. Bacterial load of sediment

Bacterial loads of sediment samples are illustrated in Fig. (3). The bacterial load ranged from 5.1 to 7.9 Log No. g^{-1} sediment. Flooding season recorded higher bacterial loads than the drought season. After flooding, El-Ramla Khor recorded the highest bacteria numbers compared to other khors (mean 7.6 Log No. g^{-1}), followed by Wadi Abyad Khor (mean 7.0 Log No. g^{-1}). In the flooding season, the highest bacterial counts were recorded in the middle of El-Ramla Khor (7.9 Log No. g^{-1}) than in the front of Khor (7.6 Log No. g^{-1}). Additionally, inlet Kalabsha Khor recorded higher bacterial counts than the front khor (7.3 and 6.4 Log No. g^{-1}, respectively). The same observation was recorded for El-Ramla Khor in the drought season (5.8 and 5.3 Log No. g^{-1}, respectively). While the other khors recorded the highest number of populations in the front khor than the inlet or the middle of the khor.

The total numbers of spore-forming and thermophilic bacteria increased in the flooding season compared to the drought season (Fig. 3). Number of spore-forming bacteria ranged from 0 to 2.1 and 3.7 to 4.6 Log No. g^{-1} for the drought and flooding seasons respectively. Kalabsha and El-Ramla Khors recorded higher spore-forming bacterial loads in the drought and flooding seasons respectively.

Numbers of thermophilic bacteria ranged from 1.1 to 3.0 and 1.7 to 3.2 Log No. g^{-1} for the drought and flooding seasons, respectively. El-Ramla Khor recorded higher thermophilic bacterial load in the drought and flooding seasons. In the flooding season, El-Ramla and Wadi Abyad Khors showed that the lowest number of thermophilic bacteria at the front of the Khor (2.7 and 2.0 Log No. g^{-1} respectively) and gradually increased at the inlet and middle Khor (from 2.8 to 3.2 Log No. g^{-1} for El-Ramla Khor, and from 2.1 to 2.7 Log No. g^{-1} for Wadi Abyad Khor.

3. Bacterial load of plant

The bacterial loads for plant samples are illustrated in Fig. (4). The bacterial load ranged from 8.7 to 10.1 Log No. g^{-1} plant in the drought season, and ranged from 7.5 to 9.0 Log No. g^{-1} plant in the flooding season. In the drought season, the main channel of Lake Nasser front Wadi Abyad Khor recorded higher bacterial load (10.1 Log No. g^{-1} plant). While, in the flooding season, the main channel of Lake Nasser front of El-Ramla Khor recorded a higher bacterial load (9.0 Log No. g^{-1} plant). In general, drought season recorded higher bacterial load than the flooding season, and it followed the order: El-Ramla > Wadi abyad > Kalabsha > Rahma as shown in Table (3).

The total numbers of spore-forming bacteria ranged from 3.8 to 5.9 Log No. g^{-1} plant Fig. (4). El-Ramla Khor recorded higher number of spore-forming bacteria either in the drought or flooding season. Table (3) shows no statistically significant differences between the drought and flooding seasons in the same Khor (except for Rahma Khor).

Numbers of thermophilic bacteria ranged from 2.8 to 5.3 Log No. g^{-1}plant. The lowest numbers (2.8 Log No. g^{-1} plant) were recorded in the inlet of Wadi Abyad Khor, while the highest numbers (5.3 Log No. g^{-1} plant) were recorded in the front of Rahma Khor (Fig.4). Significantly, flooding season recorded a higher thermophilic bacterial load than the drought season in the same Khor as shown in Table (3).

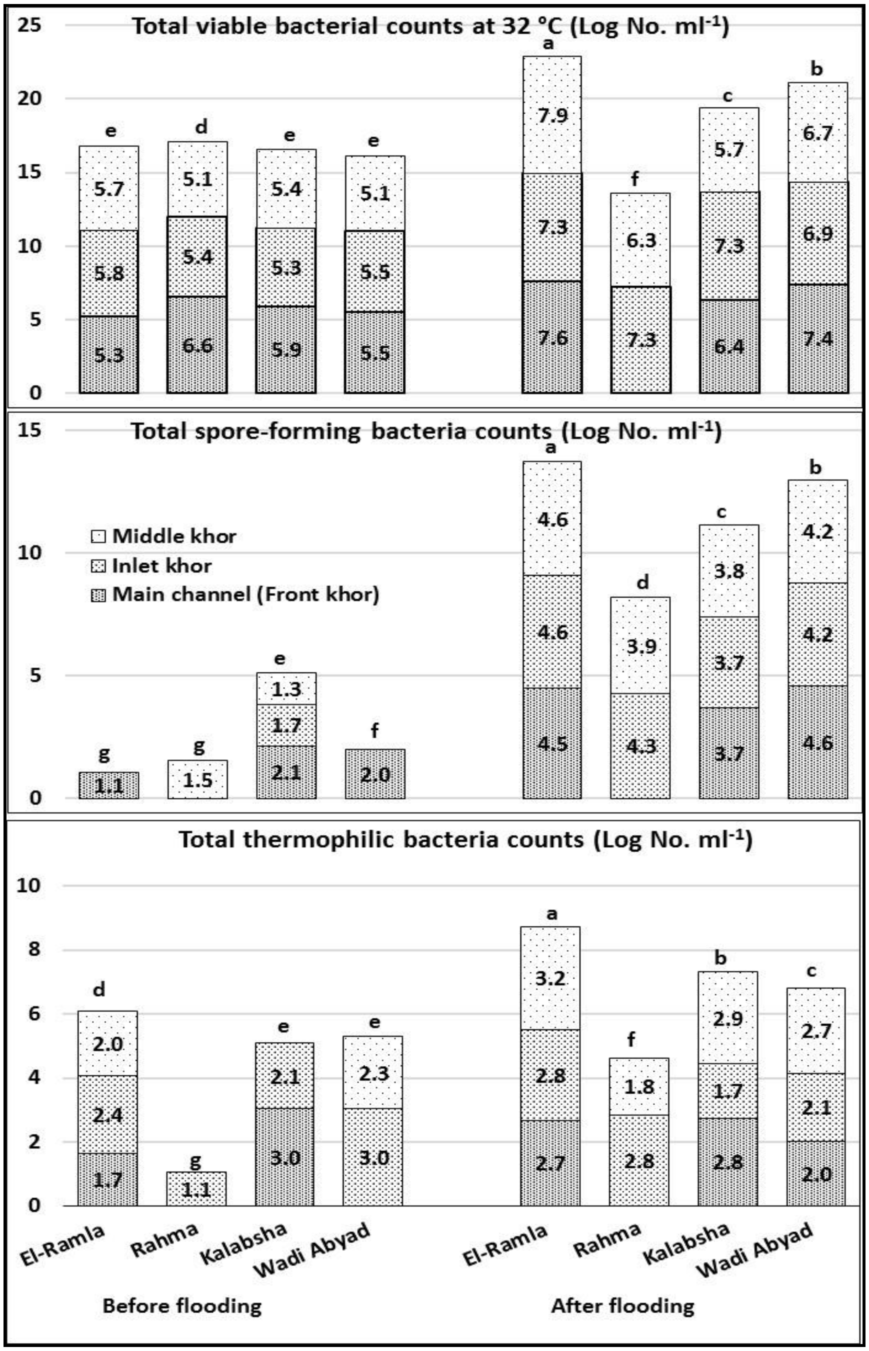

Fig. 3. Total bacterial loads for sediment samples obtained from different sites of the northern Lake Nasser Khors (main channel, front of the khor; inlet, in the beginning of the khor, and in the middle of the khor) before and after flooding 2022. The differ letter are significantly different (P ≤ 0.05).

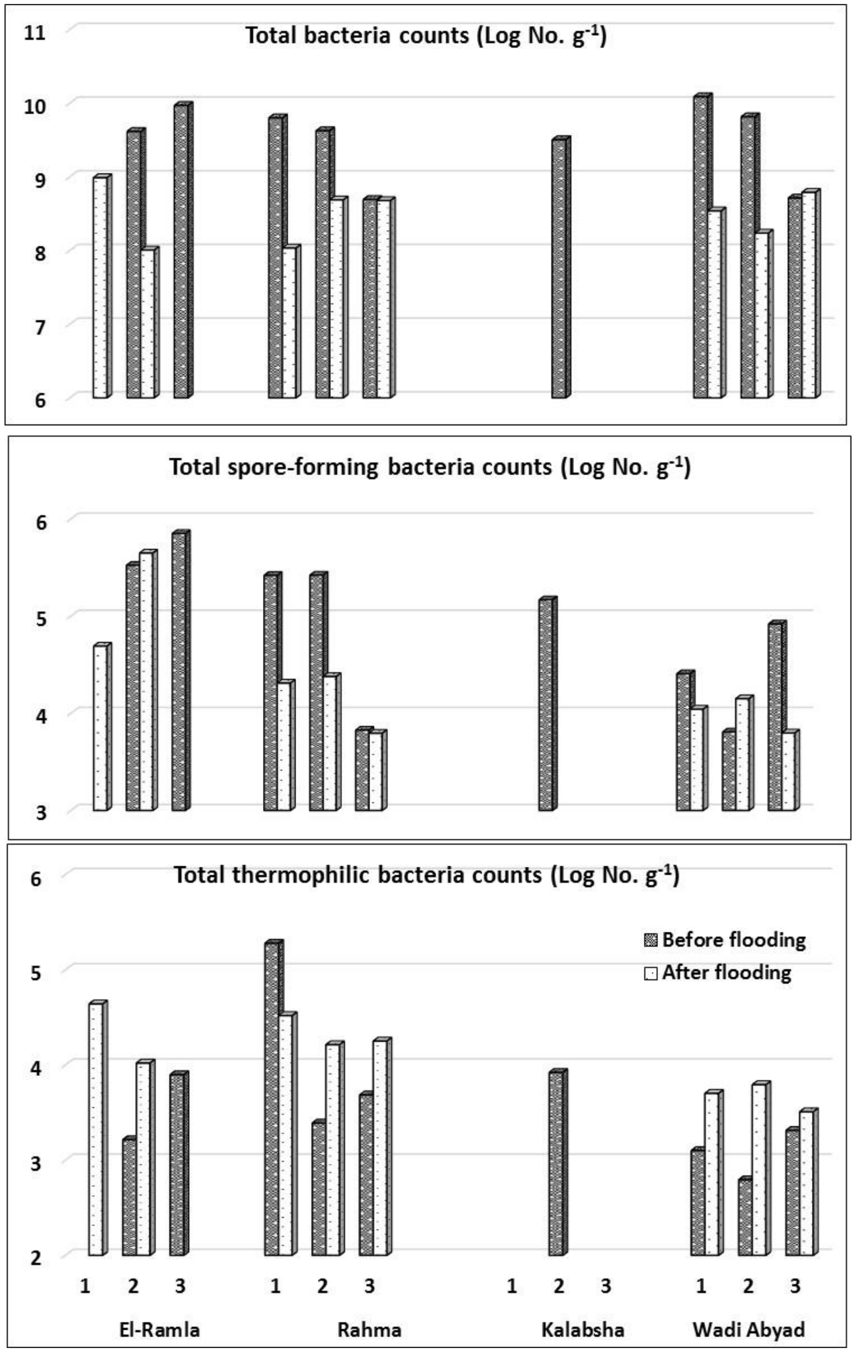

Fig. 4. Total bacterial loads for plant (*Myriophyllum spicatum*) samples obtained from different sites of the northern Lake Nasser Khors (main channel, front of the khor; inlet, in the beginning of the khor, and in the middle of the khor) before and after flooding seasons 2022.

1, main channel, front of the khor; 2, inlet, in the beginning of the khor; 3, in the middle of the khor, and missing values, not collected

Table 3. Statistical analysis (ANOVA analysis) of bacteria population (Log No. g^{-1}) of khor plant samples as affected by seasons (before and after flooding) and sites (main channel, front of the khor; inlet, in the beginning of the khor, and in the middle of the khor)

Khors	TBC	TSFB	THERMO
	Before flooding		
El-Ramla	9.79 a	5.69 a	3.56 e
Rahma	9.37 a	4.89 b	4.12 b
Kalabsha	9.50 a	5.17 b	3.92 c
Wadi abyad	9.54 a	4.38 c	3.07 f
	After flooding		
El-Ramla	8.50 b	5.18 ab	4.33 a
Rahma	8.47 b	4.16 c	4.33 a
Kalabsha	NC	NC	NC
Wadi abyad	8.52 b	4.00 c	3.67 d

TBC, total bacteria count; TSFB, total spore-forming bacteria; THERMO, total thermophilic bacteria, and NC not collected

In the same column, means followed by the differ letter are significantly different ($P \leq 0.05$).

DISCUSSION

Lake Nasser is one of the most important sources of fresh water in Egypt, so it receives great attention and continuous evaluation to maintain its quality. The results of this study indicated that the northern Khors are exposed to pollution, where, the differential temperature ratio (total bacteria counts at 22 °C: total bacteria counts at 37 °C) ranged from 0.5 to 1.3, which is less than the Egyptian Ministry of Health's permitted limits (10:1) **(Ministry of Health, 1939)**. The bacterial load on plants was higher than that of water and sediment due to the ability of plants to attract bacteria because bacteria have the ability to sense and respond to plant hormones. The results showed that flooding seasons recorded higher bacterial loads for water and sediment samples than the drought seasons because the flood carries a lot of nutrients **(Korium, 2021)**, which rises the number of bacteria. While the drought season recorded a higher bacterial load for plant samples than the flooding season, this may be due to the rising water current and water level with the flood **(El-Shabrawy and Dumont, 2003)**.

In the drought season, the bacterial load increased in the inlet khor, especially in El-Ramla and Rahma Khors because the inlet khor is considered a suitable place for the living of fish, and consequently increased fisheries and fisherman's nest (the house has one room built with thatch) near the beaches in the inlet of the khor. In addition, fishers increased in El-Ramla Khor since it is considered the smallest and the nearest khor to the

High Dam; the same observation was recorded in the study of **Ali *et al*. (2016)**. Wadi Abyad Khor recorded higher numbers of all bacterial indicators of pollution; this may be due to the increase of tourism ships south of the lake to visit Abu Simbel Temple and observation of migratory birds, as well as transportation ships to Sudan. In general, the drought season recorded the highest counts of total coliforms due to the increasing human activity, such as fishing and tourism in the drought season; the same observation was recorded by **Rabeh (2001, 2003)** and **Ali *et al.* (2016)**.

The Egyptian government is concerned with implementing an effective fisheries policy and pollution control policy. This is evidenced by the comparison between the current study (2022) and our previous study (2015). The comparison of bacterial loads of drought and flooding seasons between both years (2015 and 2022) is illustrated in Table (4). The number of total bacteria developed at 22 and 37°C increased in 2022 from 1 to 25% over the year 2015. Among the khors, El-Ramla Khor recorded higher percentage increase for total bacteria developed at 22 and 37°C (12 and 25%, respectively); this may be due to the increase in fishing activity inside El-Ramla Khor **(Ali, 2022)**. Although Wadi Abyad Khor recorded the lowest percentage increase of total bacteria developed at 22 and 37°C (1.9 and 0.9% respectively), it recorded the highest percentage increase for total and faecal coliforms (621 and 2658%, respectively), owing to the increase in coastal agriculture around the lake in addition to fishing activity **(Ali, 2023)**. On the contrary, decreases in numbers of spore-forming and thermophilic bacteria were observed in 2022 compared to 2015, by 32 to 50% for spore-forming bacteria, and 35 to 98% for thermophilic bacteria; such decreases were elevated to 100% for faecal *streptococci* in El-Ramla and Rahma Khor (Table 4). In general, a minimal percentage increase (less than 25%) in various bacterial groups, with a maximal percentage decrease (more than 100%) were scored in various bacterial indicators of pollution; this indicates some improvement which may be traced back to the increased awareness of workers in Lake Nasser about the importance of following a pollution control policy.

Table 4. Percentage increases (+) or decreases (-) in bacterial loads of water samples obtained during before and after flooding season 2022 (the current study) compared to 2015 (the previous study, **Ali *et al*., 2016**)

Khor	**TBC at 22**°C	**TBC at 37**°C	**TSFB**	**TThB**	**TC**	**FC**	**FS**
El-Ramla	+11.5	+25.0	-50.3	-34.6	-98.0	-97.0	-100.0
Rahma	+9.6	+16.8	-41.3	-53.2	-98.0	-96.6	-100.0
Kalabsha	+3.8	+10.9	-32.2	-97.9	-70.6	-97.9	-83.3
Wadi abyad	+1.9	+0. 9	-47.0	-76.5	+621.1	+2657.6	-83.3

TBC, Total bacteria count; TSFB, Total spore-forming bacteria; TThB, Total thermophilic bacteria; TC, Total coliform; FC, Faecal coliform; and FS, Faecal *streptococci*.

CONCLUSION

In conclusion, a decrease was detected in the bacterial load in 2022 compared to 2015, which indicates an improvement in the natural resources of Lake Nasser. This may be due to government monitoring of boats, ships and fishermen, but it is still exposed to pollution. Thus, searching for the causes of pollution is a must, as well as the implementation of an effective fisheries policy and an effective pollution control policy through the safe disposal of ship fuel and ship waste to improve the quality of Lake Nasser.

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