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Microbial and Heavy Metal Contamination in Edible Bivalves from the Suez Canal: A Potential Health Risk

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ABSTRACT

This study investigated the bioaccumulation of heavy metals and bacteria in edible bivalves (*Ruditapes decussatus*) collected from the Suez Canal near Ismailia, Egypt. The focus was on seasonal variations in contamination levels and the associated health risks to the local population. Bivalve samples were analyzed across four seasons (2023–2024) to identify harmful microorganisms and trace metal concentrations. Naturally occurring bacteria were isolated and identified, revealing prevalent species such as *Streptococcus faecalis*, *Aeromonas* spp., and *Vibrio* spp. These bacterial strains were purified and evaluated for their pathogenic potential. Mortality experiments demonstrated that *S. faecalis* and *Vibrio* spp. exhibited high pathogenicity, while *Aeromonas* spp. showed moderate pathogenicity. In parallel, atomic absorption spectrophotometry was used to measure the concentrations of heavy metals—Fe, Cu, Mn, Zn, Pb, and Cd—in the bivalves' soft tissues. The results showed that the annual mean concentrations of Fe, Cd, Pb, Cu, and Zn exceeded FAO/WHO safety thresholds, particularly in winter, raising serious concerns regarding seafood safety. Overall, the findings highlight that bivalves function effectively as bioindicators of environmental contamination. They underscore the need for strengthened monitoring and regulatory measures in the region to protect public health.

INTRODUCTION

The name "mollusc" (or "mollusk") originates from the Latin word *mollus*, meaning "soft." The earliest mollusks appeared approximately 500 million years ago during the Cambrian period. To date, 3,370 marine mollusk species have been identified **(Venkataraman & Wafer, 2005)**. The hard clam, characterized by its two-valved shell, belongs to the Class Bivalvia.

As filter feeders, hard clams play a vital role in marine ecosystems. They contribute to nutrient cycling and enhance water quality by removing suspended particles and phytoplankton. A mature clam can filter between seven and eight liters of water per hour. In doing so, they also ingest bacteria, viruses, and other waterborne pathogens that can pose risks to human health **(Dame *et al.*, 2001; Newell, 2004)**.

In Egypt, hundreds of tons of edible mollusks are harvested and marketed annually. Shellfish are widely regarded as highly nutritious due to their palatability, ease of digestion, low fat content, and richness in essential vitamins, minerals, and omega-3 polyunsaturated fatty acids—compounds the human body cannot synthesize. These fatty acids are known to reduce the risk of cardiovascular diseases and atherosclerosis by lowering the likelihood of clot formation, which can lead to heart attacks **(Farag, 2006)**.

These shellfish are consumed either from wild harvests or aquaculture operations. They thrive in nutrient-rich, sheltered coastal environments, which also makes them susceptible to contamination by pathogens from sewage, as well as pollutants such as heavy metals, hydrocarbons, and pesticides from surrounding ecosystems **(EL-Shenawy, 2004; EL-Shenawy *et al.*, 2009)**.

Due to their filter-feeding nature, these mollusks are effective bioindicators of environmental contamination. They absorb oxygen and nutrients from the water along with contaminants, leading to accumulation in their tissues at concentrations significantly higher than those in the surrounding seawater **(Farag *et al.*, 2000; Hamed & Emara, 2006)**.

Seafood consumption can expose humans to heavy metals when contaminated aquatic organisms are ingested **(Sioen *et al.*, 2008)**. Heavy metals are among the most hazardous pollutants because they are persistent, highly toxic, and non-biodegradable **(Yuan *et al.*, 2004)**.

To prevent and predict outbreaks of bacterial gastroenteritis linked to seafood consumption, it is critical to understand the habitats and seasonal distribution of various bacterial species, particularly opportunistic pathogens. Although postharvest treatments—such as depuration, high-pressure processing, irradiation, and thermal pasteurization—have significantly reduced health risks, vulnerable populations, especially those with compromised immune systems, must remain aware of the dangers of consuming raw seafood **(George & Flick, 2007)**.

Accordingly, this study aimed to investigate the seasonal patterns of microbial contamination and heavy metal bioaccumulation in *Ruditapes decussatus* harvested from the Suez Canal. The objective is to evaluate their effectiveness as bioindicators of

environmental pollution and to assess the public health risks associated with their consumption.

MATERIALS AND METHODS

1. Bivalve sampling

One kilogram of fresh bivalve samples (*Ruditapes decussatus*)—approximately 200 individuals—was collected from the Suez Canal, Ismailia Governorate, during all four seasons (2023–2024). The samples were subjected to two types of tests. For microbiological analysis, one or two snails (approximately 1.0g of tissue) were aseptically removed and processed immediately in a sterilized mortar. For toxicological testing, approximately 80 snails were dried and digested in a furnace at 500°C.

2. Microbiological analysis

2-a. Enumeration and isolation of bacteria

To support the growth of marine bacteria, 2% (w/v) sodium chloride (NaCl) was added to all culture media used for shellfish **(Elston, 1989)**. The total viable bacterial count was determined using the standard plate count method, following APHA guidelines **(APHA, 1992)**, with Tryptic Soy Agar (TSA) medium **(Stewart *et al.*, 1966)**.

Streptococcus faecalis was quantified using the Most Probable Number (MPN) method with Azide Dextrose Broth (ADB) medium, following APHA procedures **(APHA, 1992)**. *Aeromonas* spp. were enumerated as CFU/g using phenol starch ampicillin agar (PSAA), prepared following autoclaving and cooling to 50°C, with ampicillin added to a final concentration of 10 µg/mL **(Palumbo *et al.*, 1985)**. *Vibrio* spp. were isolated on Thiosulfate Citrate Bile Salt Sucrose Agar (TCBS) medium **(Elston, 1989)**.

2-b. Purification and maintenance of bacterial isolates

Bacterial isolates were repeatedly streaked (10–12 times) on TSA medium to obtain pure single colonies. Colonies were examined microscopically using Gram staining. Purified isolates were maintained on TSA slants and stored in refrigeration, with subculturing performed monthly to ensure viability.

2-c. Identification of bacterial isolates

The most frequent bacterial isolates were preliminarily identified based on staining and biochemical tests according to *Bergey's Manual of Determinative Bacteriology* **(Holt *et al.*, 1986; Holt *et al.*, 1994)**.

3. Pathogenicity test (Mortality and survival analysis)

Ten bivalve specimens were used to assess the pathogenicity of *Streptococcus faecalis*, *Aeromonas* spp., and *Vibrio* spp. A 0.1mL bacterial inoculum (24-hour cultures) was injected intramuscularly into the foot (poda) of each snail under controlled conditions at 18 ± 2°C. The bacterial concentrations used were: 3×10^8 CFU/mL for *S. faecalis*, 1.2×10^8 CFU/mL for *Aeromonas* spp., and 0.9×10^8 CFU/mL for *Vibrio* spp. Mortality was observed over a two-day period **(Abraham, 1992)**.

4. Residual analysis in bivalve samples

Soft tissues from 30 bivalve individuals were collected, dried, and weighed. Heavy metal concentrations were determined in whole soft tissues following the method outlined by **Dybern (1983)**.

5. Detection of heavy metals (Fe, Cu, Mn, Zn, Pb, Cd)

Heavy metal analysis was conducted through dry ashing, following the procedure of **Elmer and Conn (1982)**. Between 5– 25g of tissue (muscle, gills, or liver) was dried at 60–80°C for 48 hours in crucibles. The samples were then ashed at 450–500°C overnight in a muffle furnace. After cooling, 1– 2mL of HNO_3 was added, and the samples were evaporated to dryness on a hot plate. The process was repeated as needed to obtain carbon-free ash.

The final ash was dissolved in 1.0 N HCl, filtered through Whatman No. 1 paper, and diluted to a volume of 5– 25mL with 1.0 N HCl, depending on the original sample weight. Heavy metals (Fe, Zn, Mn, Cd, Cu, and Pb) were measured using an atomic absorption spectrophotometer, following the method described by **Clowley (1978)**.

6. Statistical analysis

All data were statistically analyzed using analysis of variance (ANOVA) as described by **Snedecor and Cochran (1967)**. Mean separation was conducted using Duncan's multiple range test **(Duncan, 1958)**.

RESULTS

1- Microbiological studies on tested bivalve samples

a- Detection and enumeration of indicator microorganisms in bivalve samples

The results in Figs. (1, 2, 3, and 4) show the CFU/g and MPN/g tissue of different bacteria in the tested bivalve samples. Generally, summer yields the highest numbers of all tested bacteria, except *Aeromonas* spp., which peak in winter. Additionally, the results indicated that the highest count of bacteria is recorded for the *Aeromonas* spp. followed by *Vibrio* spp., and *Streptococcus faecalis*.

Total viable count

The total bacterial residents in bivalve samples during the four seasons are represented in Fig. (1), showing that seasonal variations had a significant effect on total bacterial counts ($P \leq 0.05$). A general trend in behavior of this group is observed in which the total forming units at 37°C are seldom equal. Some specialists consider this trend to be a possible indication of water pollution of human origin. The ranges of recovery are 17×10^6 (Log N 7.23^a) to 21×10^3 (Log N 4.32) CFU/g, depending upon the different seasonal factors influencing the bacterial occurrence, so the highest counts are in summer, 17×10^6 (Log N 7.23) CFU/g, and the lowest counts are in winter, 21×10^3 (Log N 4.32^b) CFU/g.

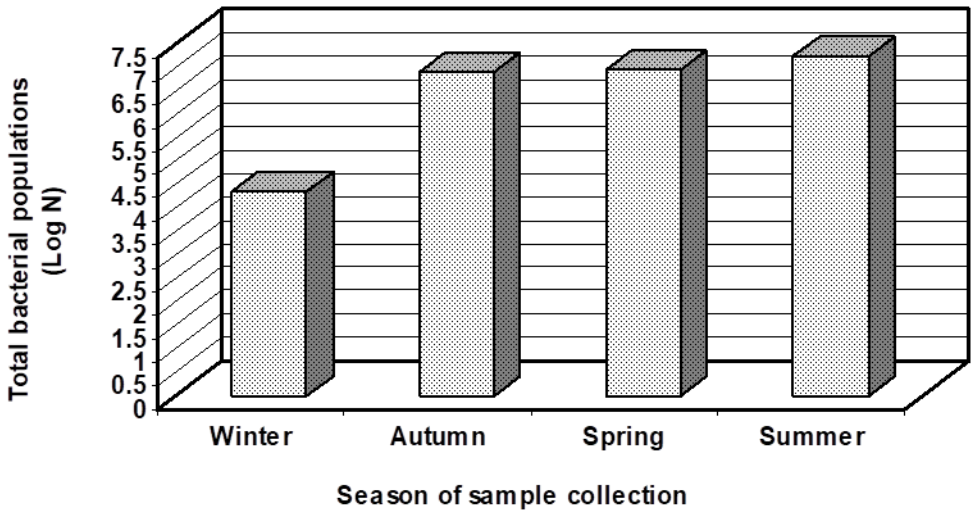

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Fig. 1. Total viable count (CFU/g) in tested bivalve samples during a four-season period (2023-2024)

Streptococcus faecalis (Fig. 2) showed relatively high loads in all bivalve samples around the year. Their seasonal variations had a significant effect on *Streptococcus faecalis* ($P \leq 0.05$), where the highest density is in summer, 2.1×10^2 (Log N 2.3^a) MPN/g, and the lowest is in winter, 2.1×10 (Log N 1.3^b) MPN/g. Pollution level proved to have a marked effect on *Streptococcus faecalis*. This trend indicated that temperature is not the only independent agent that has a bearing on the fecal streptococci, but temperature interacts with other factors, such as the level of pollution and chemical pollutants.

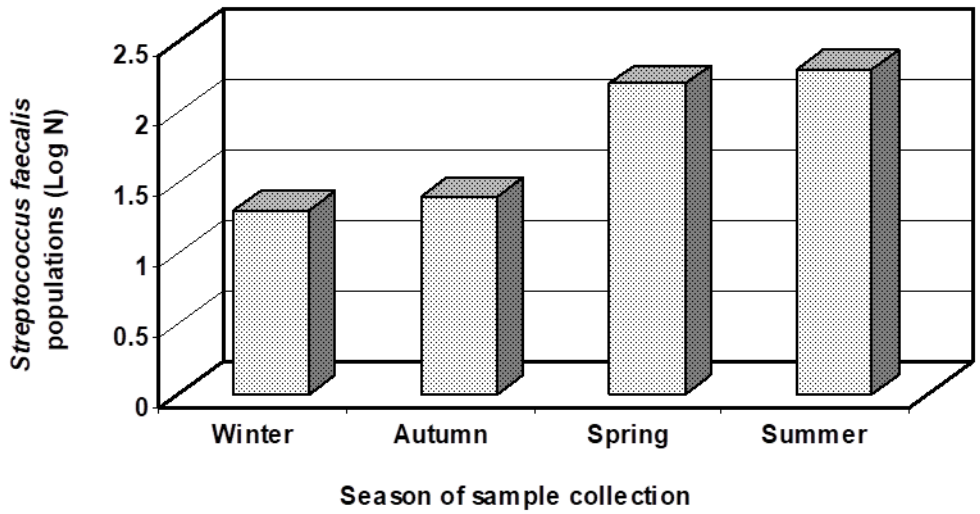

Fig. 2. *Streptococcus faecalis* populations (MPN/g) in tested bivalve samples during a four-season period (2023-2024)

***Aeromonas* spp.**

The seasonal densities of *Aeromonas* species are illustrated in Fig. (3). Seasonal variation had a statistically significant effect on the abundance of *Aeromonas* spp. ($P \leq 0.05$). The highest density recorded in bivalve samples was 2×10^4 CFU/g (Log N = 4.20^a) during winter. This value gradually declined in autumn and showed a marked decrease during the high-temperature seasons, reaching the lowest population density of 9×10 CFU/g (Log N = 1.95^c) in summer.

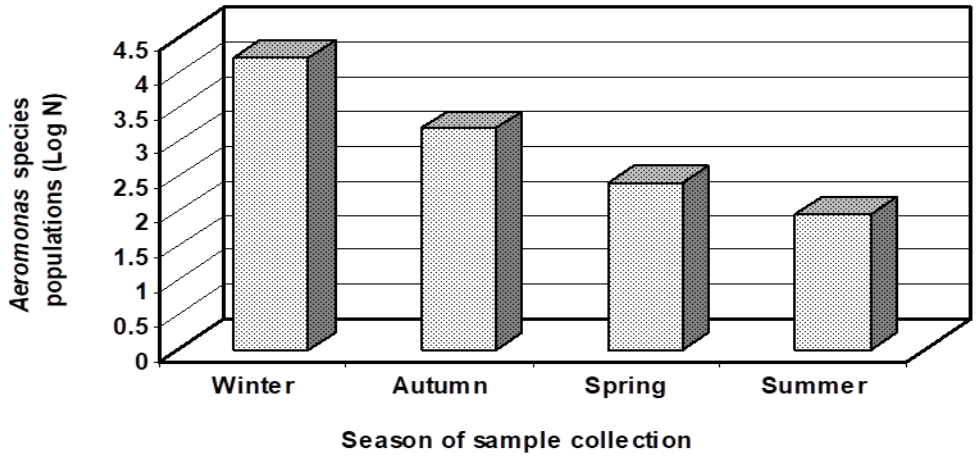

Fig. 3. *Aeromonas* spp. populations (CFU/g) in tested bivalve samples during four seasons (2023-2024)

The seasonal densities of *Vibrio* species are illustrated in Fig. (4). Seasonal variation had a significant effect on *Vibrio* spp. counts ($P \leq 0.05$). The highest density in bivalve samples was recorded during summer, reaching 85 × 10 CFU/g (Log N = 2.93^{a}). The population gradually decreased in spring and declined markedly during the colder seasons, reaching the lowest count of 2 × 10 CFU/g (Log N = 1.30^{c}) in winter.

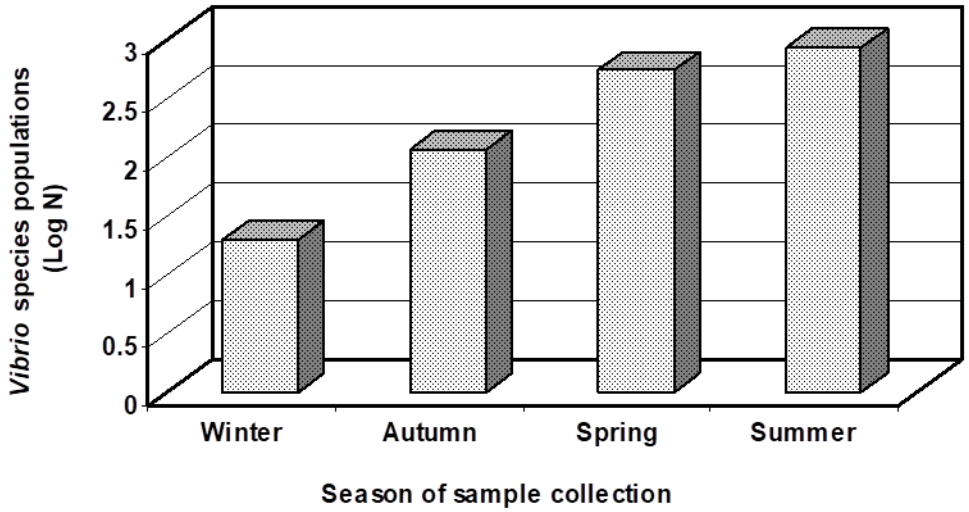

Fig. 4. *Vibrio* spp. populations (CFU/g) in tested bivalve samples during four seasons (2023-2024)

b- Identification of selected isolates:

The selected isolates ZagI, ZagII, and ZagIII are identified and named *Streptococcus faecalis*, *Aeromonas* spp., and *Vibrio* spp., respectively, according to **Bergey (1994)**.

Table 1. Morphological characteristics and physiological tests used for the identification of strains isolated from tested bivalves

Characteristics	ZagI	ZagII	ZagIII
Gram stain	+ ve	-ve	- ve
Shape and arrangement	Cocci	Rods	Rods
Oxidase test	-	+ve	+
Voges – proskauer test	-	-	+ve
Formation of Indole	-	+ve	+ve
utilization of citrate	-	+ve	+ve
Nitrate reduction test	-ve	+ve	+ve
Tween 80 test	-	+ve	-
Hydrolysis of gelatin	-ve	+ve	-
Hydrolysis of Arginine	+ ve	+ve	-ve
Hydrolysis of urea	-	-	-
production of H2S	-	+ve	-
Methyl red test	-	-	-
Acid form:-			
D- Glucose without gas	+ve	+ve	+ve
D- Arabinose without gas	-ve	+ve	-ve
D-xylose without gas	-	-ve	-ve
D-Mannitol without gas	+ve	+ve	+ve
D-Fructose without gas	+ve	-	-
D- Lactose without gas	+ve	+ve	-ve
- Sucrose without gas	+ve	+ve	-ve

c- Characterization and frequency of bacteria isolated from tested bivalves

The Gram-positive coccal isolate (Zag I) was identified as *Streptococcus faecalis*, while the Gram-negative, rod-shaped isolates (Zag II and Zag III) were identified as *Aeromonas* spp. and *Vibrio* spp., respectively.

Table (2) summarizes the number and morphological characteristics of traditional microbial indicators isolated from mollusks. A total of 80 bacterial isolates were obtained, comprising 5 Gram-positive cocci and 75 Gram-negative rods. Among them, isolates Zag I (30%), Zag II (25%), and Zag III (45%) were the most frequently encountered and were selected for further analysis.

Zag I colonies consist of ovoid cells elongated along the direction of the chain, measuring 0.5– 1.0μm in diameter. These cells are typically found in pairs or short chains, are non-motile, and are rarely pigmented. Colonies grown on solid media appear smooth, cream or white, and have entire margins. Biochemically, the isolates rarely ferment arabinose and raffinose but do ferment fructose, galactose, glucose, lactose, maltose, mannitol, and sucrose. They test negative for nitrate but positive for gelatin and casein hydrolysis. Based on these characteristics, Zag I is identified as *Streptococcus faecalis*.

Zag II colonies grown on agar plates are grayish-white, rounded, glistening, convex, and measure approximately 2mm in diameter. On R.S. media, the colonies appear yellow, while on MacConkey agar, they appear pale. These isolates test positive for oxidase, arginine dihydrolase, and also produce indole and nitrite. They ferment glucose, mannitol, sucrose, and arabinose. Based on these morphological and biochemical traits, Zag II is identified as *Aeromonas* spp.

Zag III colonies are Gram-negative, curved bacilli, and motile. On standard agar plates, the colonies are large, circular, and have entire edges. No growth is observed on R.S. media, but pale, pinhead-sized colonies are seen on MacConkey agar, and yellow colonies are produced on T.C.B.S. agar. These isolates are positive for citrate, indole, oxidase, and nitrite production, and they ferment glucose, mannitol, rhamnose, and amygdalin. Based on these features, Zag III is classified as *Vibrio* spp.

Table 2. Characterization and frequency of bacteria in tested bivalve samples

Bacterial isolates	Cultural characteristics	No: Of Isolated colonies	Freq %	Color of colony	Shape of cells	Gram stain
***Streptococcus faecalis* (ZagI)**	Oval shape in chains, colonies smooth, creamy or white and entire, (0.5 – 1.0 mm) in diameter.	24	30	Cream or white	Cocci	G+Ve
***Aeromonas* spp. (ZagII)**	Uniformly bacillary, motile colonies are rounded, convex, glistening with entire edges, and are a few millimeters (2mm) in diameter.	19	25	Grayish white or white to buff	Rods	G–Ve
***Vibrio* spp. (ZagIII)**	Curved, comma-shaped bacilli, motile; colonies are large, circular, with entire edges, (0.3-1.3 mm) in diameter.	37	45	Yellow	Rods	G–Ve
Total		**80**	**100**			

2- Pathogenicity test

Fig. (5) results show that extending the incubation period increases the mortality percentages to 24 hours. We observed 100% mortality at 48h incubation, compared to zero mortality for uninfected bivalves.

It is observed that *Streptococcus faecalis* and *Vibrio* spp. are highly pathogenic to the infected bivalves, where 70% mortality is recorded during the experiment period, followed by *Aeromonas* spp., which is moderately pathogenic, where 30% mortality is recorded within the experimental period.

The clinical signs and post-mortem findings of the experimentally infected bivalves are similar to those of naturally infected bivalves by such organisms. In addition to the most pathogenic bacteria (*Streptococcus faecalis, Aeromonas* spp., and *Vibrio* spp.), they showed loss of escape reflex, slowed and abnormal movement, and brown

lesions related to *Vibrio* spp. (Plate 1). We cultivate bacteria from all freshly dead and infected bivalves with *Streptococcus faecalis*, *Aeromonas* spp., and *Vibrio* spp.

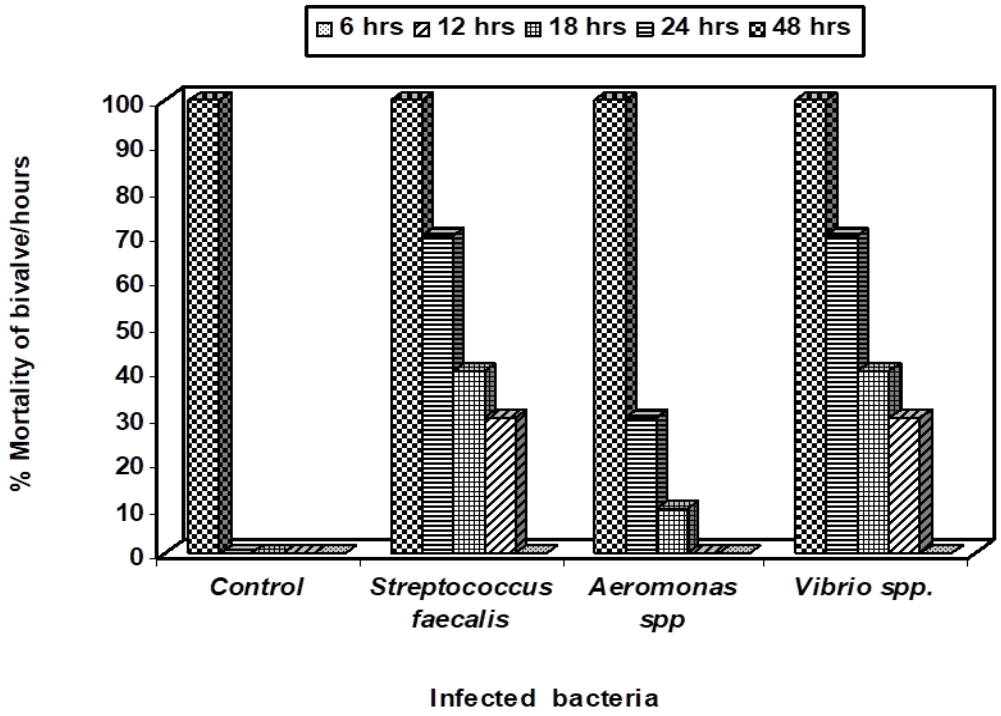

Fig. 5. Mortality rates in tested bivalve samples infected with *Streptococcus faecalis*, *Aeromonas* spp. and *Vibrio* spp.

Plate 1. Brown ring disease related to the effect of *Vibrio* spp. on a bivalve sample

3- Heavy metal residues in soft tissues of mollusc species (*Ruditapes decussatus*)

The wet and dry weights of the soft tissues, along with the concentrations of selected heavy metals (µg/g dry weight), were measured in *Ruditapes decussatus*. As summarized in Table (3), significant seasonal variations were observed in the concentrations of iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), lead (Pb), and cadmium (Cd) during the study period (2023–2024).

- Iron (Fe): The highest concentration was recorded in winter (670.4µg/ g), while the lowest was observed in spring (515.4µg/ g). The annual mean concentration was 607.5µg/ g, which exceeds the **FAO/WHO (1999)** maximum permissible limit by 14.1-fold.

- Copper (Cu): Maximum levels were recorded in winter (11.4 µg/g) and minimum levels in autumn (1.3µg/ g), with an annual mean of 7.18µg/ g. This value surpasses the FAO/WHO threshold by approximately 2.4-fold.

- Manganese (Mn): The highest Mn concentration (10.2µg/ g) occurred in summer, while the lowest (2.5µg/ g) was in spring. The annual mean was 6.7µg/ g, which remained within permissible limits except during summer, when it was slightly elevated.

- Zinc (Zn): Winter was recorded with the highest Zn concentration (168.9µg/ g), while the lowest was found in autumn (67.4µg/ g). The annual mean concentration was 117.8µg/ g, exceeding the FAO/WHO limit by 1.96-fold.

- Lead (Pb): The maximum Pb level (1.17µg/ g) occurred in winter, and the minimum (0.60µg/ g) in autumn. The annual mean of 0.8µg/ g is 3.8 times higher than the FAO/WHO recommended maximum.

- Cadmium (Cd): The highest Cd concentration (3.02µg/ g) was measured in winter, while the lowest (0.8µg/ g) was in summer. The annual mean was 1.46µg/ g, which is 14.6-fold above the FAO/WHO permissible level.

In conclusion, all studied heavy metals—except for Mn—showed their peak concentrations during winter. The most critical exceedances were noted for cadmium and iron, indicating a significant public health concern, particularly during colder months.

Table 3. Heavy metal residues in soft tissues of molluscs (*Ruditapes decussatus*) during four seasons from 2023 to 2024

Season	Dry Wt. (g)	Fresh Wt. (g)	Iron " Fe " (µg/g)	Copper ″Cu" (µg/g)	Manganese " Mn" (µg/g)	Zinc "Zn" (µg/g)	Lead. "Pb" (µg/g)	Cadmium "Cd" (µg/g)
Summer	2.1 BC	13.5 B	640.5 A	10.6 A	10.2 A	141.1 A	0.81 B	0.80 D
Autumn	8.3 A	27.5 A	603.5 B	1.3 C	5.6 C	67.4 B	0.60 C	0.81 C
Winter	2.5 B	10.7 C	670.4 A	11.4 A	8.3 B	168.9 A	1.17 A	3.02 A
Spring	1.7 C	8.3 D	515.4 C	5.4 B	2.5 D	93.6 B	0.6 C	1.22 B
Mean	3.65	15.0	607.5	7.18	6.7	117.8	0.80	1.46
MPL (µg/g)	-	-	43.0	3.0	2.0 - 9.0	60.0	0.21	0.10

The means within the same column that do not share the same superscript are significantly different ($P<0.05$).

DISCUSSION

The molluscan fishery along the Egyptian coastline has historically been poorly managed. Large quantities of mollusks were harvested using outdated methods and sold either alive or salted for consumption. These bivalves are rich in proteins, lipids, and minerals **(CSIR, 1962a, b; Biandolino *et al.*, 2019)**. They thrive in sheltered, nutrient-rich marine environments near the shore, which increases the likelihood of contamination from sewage, heavy metals, hydrocarbons, and pesticides **(EL-Shenawy, 2004; EL-Shenawy *et al.*, 2009)**. As filter feeders, bivalves are highly efficient bioindicators of

environmental pollution, absorbing both oxygen and nutrients—and along with them, pollutants—which accumulate in their tissues at concentrations much higher than those in surrounding seawater **(Farag *et al.*, 2000; EL-Gamal & Sharshar, 2004; Hamed & Emara, 2006)**.

Despite their ecological and nutritional importance, marine mollusks in Egypt have been the subject of limited scientific research. Edible species such as *Ruditapes decussatus* are commonly consumed throughout Egypt, particularly in markets near the Mediterranean Sea and its lakes. Specimens are easily collected from sandy substrates at considerable depths in coastal regions such as Alexandria, Damietta, Port Said, and Ismailia.

Specimens of *Ruditapes decussatus* collected from Ismailia and Suez exhibited blackened shells, a condition that may result from elevated concentrations of heavy metals and petroleum oil. These pollutants can alter shell coloration without affecting size. Additionally, some individuals exhibited incomplete valve closure—an impairment that compromises their defense mechanisms. According to **Eversole (1987)**, clams can survive harsh environmental conditions by closing their valves tightly.

Bacterial density was highest during the summer, reaching 17×10^6 CFU/g (Log N = 7.23), and lowest during winter at 21×10^3 CFU/g (Log N = 4.32). Rising temperatures accelerated bacterial growth, although densities remained within the range of suboptimal bacterial proliferation **(Arrhenius, 1915; Huang *et al.*, 2011)**.

George and Flick (2007) and **Ofori *et al.* (2025)** examined the spatial distribution of harmful bacteria in coastal environments to better understand the risks associated with seafood consumption. Mollusks residing in coastal waters can transmit disease due to their filter-feeding habits, which allow them to accumulate pathogens. In the present study, all bivalve samples consistently exhibited high levels of fecal streptococci throughout the year. Seasonal variation significantly influenced streptococcal densities, with the highest counts in summer (0.21×10^3 MPN/g; Log N = 2.3) and the lowest in winter (0.21×10^2 MPN/g; Log N = 1.3). This indicates that temperature is not the sole influencing factor; interactions with pollution levels and chemical contaminants also play significant roles.

A similar study conducted by **Chan and Ho (1993)** on *Crassostrea gigas* oysters from Deep Bay, Hong Kong, revealed a high prevalence of *Streptococcus faecalis*, particularly in the adductor muscle, gills, mantle, and visceral tissues. The highest bacterial load was detected in wet tissues, reaching 13.97×10^5 cells/g. Consumption of undercooked oysters from contaminated areas like Deep Bay poses serious health risks.

In this study, seasonal dynamics of *Aeromonas* spp. were also evaluated. These bacteria followed a distinct seasonal cycle. The highest density (2×10^4 CFU/g; Log N =

4.20) was observed during winter, decreasing in autumn, and dropping to the lowest levels in summer (9 × 10 CFU/g; Log N = 1.95). This trend, observed across all samples, suggests a strong temperature influence. Interestingly, *Aeromonas* spp. displayed an opposite seasonal pattern compared to common pollution indicators like total coliforms and fecal streptococci, which tend to peak during warmer months. **Rodriguez and Antillon (1989)** isolated *A. hydrophila*, *A. caviae*, and *A. sobria* from bivalves, sediment, and water samples from the Gulf of Nicoya, Costa Rica, and found no overlapping among these strains.

Vibrio species also showed seasonal variability. The highest density in bivalves was recorded during summer (85 × 10^2 CFU/g; Log N = 2.93), with gradual decline in spring and a significant reduction in winter (2 × 10 CFU/g; Log N = 1.30). These patterns suggest that environmental temperature is a key factor influencing *Vibrio* spp. populations. This aligns with findings by **Farag and Korashy (2007)**, who randomly collected 60 seafood samples from Port Said markets between May and August 2006. Among these were *Donax trunculus anatinus* ("Om El-Khloul") and *Ruditapes decussatus* ("baclawese"). Halophilic *Vibrio* spp. were detected in 29 (96.67%) and 22 (73.33%) of the samples, respectively. The mean counts were 8.3 × 10^3 CFU/g (Log N = 4.32) for *D. trunculus* and 3.5 × 10^3 CFU/g (Log N = 4.32) for *R. decussatus*. Detected species included *Vibrio alginolyticus*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus*. Similarly, **Nagvenkar and Ramaiah (2009)** identified *Vibrio cholerae* as the most prevalent species in their study, highlighting its association with sewage pollution.

Elevated levels of Cd, Cu, Fe, Mn, Zn, and Pb in the soft tissues of bivalves are primarily attributed to sewage discharge, urban runoff, and maritime activities in the Suez Canal, particularly near Ismailia **(Hamed, 1996)**. **Hamed and Emara (2006)** noted that high copper levels may result from the degradation of antifouling paints on ship hulls. The concentrations of most heavy metals in Ismailia were significantly higher than those recorded in Marsa Matrouh and Alexandria. Notably, zinc levels showed a seasonal trend—peaking in winter and declining in summer—likely due to phytoplankton uptake during warmer months **(EI-Samra *et al.*, 1995; Bassem *et al.*, 2024)**. **Abou El-Sherbini and Hamed (2000)** similarly proposed that rapid phytoplankton growth during spring and summer facilitates zinc removal from the water column.

The current findings indicate that metal concentrations near Ismailia have increased since earlier studies. The levels of Cd, Cu, Pb, and Zn are higher than those reported by **Hamed (2005)**, though Mn levels are similar and Fe levels slightly lower. This suggests a rising trend in environmental pollution in the region. Among these, cadmium is of particular concern due to its well-documented toxic, mutagenic, and carcinogenic effects **(Filipic *et al.*, 2006)**. Numerous aquatic organisms, including *Daphnia magna* **(Biesinger & Christensen, 1972)**, mollusks **(Tomasik *et al.*, 1995;**

Verstijnen *et al.*, 2024), and various fish species **(Hansen *et al.*, 2002)**, are highly sensitive to cadmium exposure.

CONCLUSION

The results of this study indicate that consuming bivalves from the Suez Canal region, specifically Ismailia Governorate, poses a potential health risk due to the elevated concentrations of heavy metals in the edible tissues—particularly iron and cadmium—which exceed the maximum permissible limits established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

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