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COMPARATIVE INSIGHTS FROM POLLUTION AND METAL INDICES IN ASSESSING TOXIC METAL CONTAMINATION IN COASTAL RECREATION ZONES

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ABSTRACT

Kuwait Bay is a popular recreational destination, and its significance as a semi-closed water body stretching from the Arabian Gulf makes it vulnerable to pollution. Various industrial, medical, and residential facilities along its shores raise the risk of pollutant contamination, notably from heavy metals. Heavy metals at five effluent outlets along Kuwait Bay's recreational beaches were investigated to gauge the degree of pollution. 70 samples of coastal water near outfall were analyzed for the concentrations of (Cd, Hg, Fe, Cu, Pb, and As), and the Metal Index and Pollution Index (PI) were employed to determine the level of pollution in Kuwait Bay's coastal waters. The findings showed that the average concentrations of heavy metals in coastal water were Fe > Hg > Cu > Pb > Cd > As, with Hg, Cd, and As mean values of 1.785 mg/l, 0.023 mg/l, and 0.006 mg/l respectively above the Kuwait Environmental Public Authority's (KEPA) permissible limits for discharging water into Kuwait Bay. The findings of the PI and MI indices were comparable in terms of severe Hg pollution and relevance of As and Cd contamination; however, the MI index revealed that outfall C8 had the highest amount of heavy metal contamination, whereas (PI) indicated C10 in comparison to other places. Substantial variations in the investigated heavy metals have been identified in summer over winter in all sampling locations. The research demonstrated that Kuwait Bay's recreational beaches had been contaminated by wastewater outfalls, rendering them unsafe for both people and aquatic life. Also, wastewater discharge regulations must be strictly adhered to avoid further contamination.

KEYWORDS: Heavy Metals, Pollution, Recreational Water Quality, Pollution Index PI, Metal Index MI.

1. INTRODUCTION

The growing influx of anthropogenic heavy metals into coastal and marine ecosystems has emerged as a significant environmental concern, leading to contamination that presents severe threats to human health, biodiversity, and overall ecosystem stability [1-3]. In addition, heavy metals have potentially harmful effects on humans, such as toxicity and carcinogenicity, and they may also contribute to species decline and disrupt the food chain in marine environments [2-6]. The non-biodegradable nature of these metals allows them to bioaccumulate in living things and stay in the environment, harming a wide range of species both directly and indirectly [7-9]. Additionally, even in trace amounts, certain heavy metal ions can cause serious organ damage and neurological issues in people, while also causing immune system depression, oxidative damage, and endocrine disruption in aquatic organisms [1][7-11]. Metals such as arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), and zinc (Zn) are especially detrimental when introduced into the environment through industrial and agricultural operations [12-13]. Globally, coastal waters are contaminated with heavy metals as a result of both natural and human-caused processes, including industrial operations and wastewater discharge, which have been further exacerbated by rapid population growth and industrial expansion [14-17].

Kuwait Bay, a significant Arabian Gulf extension, is under extreme environmental stress as a consequence of coastal habitat changes, untreated wastewater discharge, and the region's naturally challenging circumstances, including high salinity, temperature, and pH levels along with a shallow depth [12] [18-21]. Despite advancements in wastewater treatment, heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) are commonly found in coastal and marine zones [1] [5] [18] [22] [16]. Industrial facilities and oil spills have also been identified as important contributors to heavy metal contamination in Kuwait Bay [1][2] [23-24]. Kuwait's coastline environment has been extensively degraded as a result of occasional sewage treatment plant outages and the continuous discharge of pollutants through several outfalls along Kuwait Bay's south side [1][5]. In addition, there was a rise in pollution levels resulting from the previously 25 percent untreated wastewater thrown into the Kuwait coastal water [5]. Relevant prior studies show that excessive nutrient, heavy metal, and microbiological contamination exceeded Kuwait's EPA-permitted limits, highlighting the harmful effects of wastewater discharge on beaches [18] [22]. Considering these limitations, Kuwait Bay is the habitat of an array of marine ecosystems, including mud and sand flats, mangrove swamps, coral reefs, and seagrass beds. Several aquatic creatures depend on these habitats for feeding and reproduction [25-26]. Kuwait Bay's coastal and marine zones commonly include lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr). Although certain heavy metals, such as iron (Fe) and nickel (Ni), are essential micronutrients for both creatures and plants, others, such as Pb, Cd, and Cr, provide no physiological significance [17].

Monitoring and measuring heavy metal concentrations in coastal waterways is critical for addressing this significant concern. Heavy metal pollution indices may assist in measuring the degree of contamination and identify probable pollution sources. Balancing numerous evaluation techniques and methodologies can improve accuracy and ease the formulation of successful management plans [27-28] [6] [29-30]. This study employs two heavy metal pollution indices, the Pollution Index (PI) of Heavy Metal, the Metal Index (MI), and the Enrichment Factor (EF), to examine the contamination levels of a few specific heavy metals, including cadmium (Cd), mercury (Hg), copper (Cu), iron (Fe), lead (Pb), and Arsenic (As), in the coastal water of Kuwait Bay. The study's purpose is to offer a comprehensive understanding of the effects of these heavy metals on the marine ecology and recreational visitors to Kuwait Bay.

2. MATERIALS AND METHODS

2.1. Study Area

Kuwait Bay is a shallow, partially closed extension of the Arabian Gulf that is situated in the northwest corner of the Arabian Gulf. It has a shallow depth, a low surface area and is distinctive owing to its location within the more substantial Arabian Gulf. The length and width of Kuwait Bay at its entry are 40 and 25 kilometers, respectively, and it juts out 48 kilometers into the Arabian Gulf [20] [31-32]. Kuwait bay is a tidal bay with a shallow depth, not exceeding 8 meters at the entrance, with semi-diurnal tides, with a mean tidal height of 3.26 meters [16] [31] [33]. Kuwait Bay is a popular recreational attraction due to its sandy beaches, abundant marine life, and crystal-clear waters. Nevertheless, owing to the release of storm water and wastewater from coastal outfalls, the bay water quality could be affected and must be effectively managed to be kept safe for recreational use [1] [23] [32-34]. Five wastewater outfalls with the codes C3, C5, C8, C10, and C18 were

picked along Kuwait Bay's recreational beaches based on their proximity to various facilities to expand the spectrum of probable activities that might result in the heavy metal contamination of coastal water (Figure.1).

On the shore of Kuwait Bay, samples have been obtained at five locations close to beach outfalls. The location of Site OC3 (47.863044 E, 29.320015 N is close to residential and recreational areas. Medical facilities are nearby C5 (29.334869 N, 47.902617 E), and Industrial and recreational sites are close to C8 (29.357277 N, 47.946706 E). While, residential and entertainment areas are close to C10 (29.365538 N, 47.957159 E). Finally, C18 (29.391525 N, 47.989117 E) is close to recreational activities. Sites C3, C10, and C18 are located on common beaches with leisure activities, C5 being close to medical facilities and hospitals, and C8 being close to major commercial ports and industrial districts [22].

Figure 1: The Map of the Five Selected Locations (Modified After Bushaibah et al., 2023a).

2.2. Methodology

From January to July 2022, seventy water samples were collected from five sites along Kuwait Bay, each providing fourteen samples. In this investigation, the heavy metals (Fe), (Cu), lead (Pb), (Hg), (Cd), (As), (Cr), (Ni), (Mn), (Zn), and (Ag) were analyzed to determine the level of heavy metal contamination in Kuwait Bay's coastal waters. The seawater samples were collected within 1 meter below the surface using a Teflon bailer, stored in sterilized glass bottles at 4°C in iceboxes, and transported to the laboratory for the analysis of the heavy metals. The obtained samples were filtered to remove any biological growth or metal precipitates using Whatman No. 42 filter sheets. Inductively coupled plasma optical emission spectrometry (ICP-OES; Agilent 720 Series ICP-OES Spectrometer) was used for analyzing the filtered samples. For quality control, procedural blanks and randomly chosen duplicate samples were examined, ensuring the compatibility and stability of all elements during analysis following APHA (2017) guidelines [35]. Results were compared to worldwide guidelines established by the World Health Organization (WHO) [36] for recreational water and the United States Environmental Protection Agency (EPA) for aquatic life [37-40] and regulations issued by the Kuwait Environmental Public Authority (KEPA) [41] for water discharge to Kuwait Bay. While all heavy metals have the potential to endanger human health and the environment, not every element must be considered when analyzing unknown or low-level concentrations. Heavy metals (Cr, Ni, Mn, Zn, and Ag) were either undetectable or observed in minimal quantities in the study's samples, indicating a minor potential influence on the environment under review. As a result, the contamination of the six most significant contaminating metals (Cd, Hg, Pb, Cu, As, and Fe) guided the analyses of the coastal waters, which are classified as highly toxic and may bioaccumulate in marine animals and ecosystems, posing serious risks to human health and the environment [42-44]. Regulatory bodies are concerned with certain heavy metals including Pb, As, Cd, and Hg since they may be dangerous even in tiny amounts and can have an impact on human health if exposed for an extended period [3] [45]. Even though the concentrations of iron (Fe) are below the limits, it is critical to consider any potential interactions between iron and other heavy metals that are present at higher levels [12].

2.2.1. Metal Quality Indices

The Pollution Index (PI) of Heavy Metal and the Metal Index (MI) were employed to assess the quality of the coastal water in Kuwait Bay. The equation presented by Caeiro and Goher [46-47] provided the basis for the calculation of the PI (Eq.1), while Tamasi & Cini's method [48] was used to calculate the MI (Eq.2)

$$PI = \sqrt{[(Ci/Si)^2 max + (Ci/Si)^2\ min]/2} \text{-----(1)}$$

The PI was calculated using the equation that considers the concentration of each metal element (Ci) and its respective standard permissible value (Si). The PI was then divided into five categories, as indicated in Table 1. In contrast, the MI evaluates each metal's relative contamination independently and then adds the findings to provide an anticipated value. Water quality declines as metal concentrations

exceed their maximum acceptable concentration (MAC) threshold [49]. The Metal Index (MI) is a grading system that shows the combined effect of several elements on the overall quality of water [48]. The categorization of the MI values in Table 1, shows the perceived significance of various metal quality criteria, which has a scale of 0 to 1. As a result of an additive effect, the presence of many elements in concentrations below but near their MAC values will also lower the overall quality of water. Thus, an MI value >1 is a warning threshold, even if C -MAC is used for all components [48]. The metal index of pollution is widely used as a helpful indicator of the quality of drinking water [50-51], river water [52], surface [27-28], and seawater [30] [16] [53]. The following equation was proposed to compute the MI (Eq.2):

$$MI = \sum_{i=1}^{n} [C_i/(MAC)_i] \text{----- (2)}$$

The concentration of each metal, Ci, is measured and compared to its respective Maximum Allowable Concentration (MAC) value to determine the quality of the water The enrichment factor (EF) is a popular method for determining the extent of heavy metal contamination in aquatic settings. According to Kalpana et al. (2016), EFs (Eq.3) are determined by comparing a specific heavy metal's concentration in sediment or water to a reference value, which may include the concentration of a conservative element (which could be iron (Fe)) or a natural baseline value. Fe was utilized as a benchmark in the current investigation to discriminate between anthropogenic and natural sources [47] [54-56]. Previous studies have utilized a particular methodology to assess the extent of heavy metal contamination [47, 54-56]. The formula of (EF) (Eq.3) employed in these investigations to compute the relevant metrics is as follows

Table 1: Water Pollution Index (PI) and Metal Index (MI) Value Water Quality Classification. Categories.

Class	PI value	Effect	Class	MI value	Effect
1	< 1	No	I	<0.3	Very pure
2	1-2	Slight	II	0.3-1.0	Pure
3	2-3	Moderate	III	1.0-2.0	Slightly affected
4	3-5	Strong	IV	2.0-4.0	Moderately affected
5	> 5	Serious	V	4.0-6.0	Strongly affected
			VI	>6	Seriously affected

$$EF = \frac{(\frac{M}{Fe})\ sample}{(\frac{M}{Fe})\ background} \text{------(3)}$$

Where the (M/Fe) sample is the ratio of the heavy metal sample-to-Fe mean observed concentrations to the (M/Fe) background values. According to (Sutherland, 2000), the EF categories were divided into five contamination index classifications: EF < 2, depletion to mineral enrichment suggestive of nil or minimum pollution: EF ≥ 2 and moderate enrichment indicative of moderate pollution; EF ≥ 5 and ≤ 20, major enrichment indicative of substantial pollution; EF ≥ 20 and ≤ 40, very high enrichment indicative of highly intense pollution; and EF > 40, extremely high enrichment, indicating severe pollution [57].

3. RESULTS AND DISCUSSION

The average levels of heavy metal concentrations and the KEPA, WHO, and EPA aquatic life requirements for each metal for the obtained samples are shown in Figure 2 and Table 2. The analysis revealed that iron (Fe) had the greatest mean content, followed by Cu, Pb, Hg, and (Cd). The mean concentration of (Fe) was within standard levels set by the KEPA for seawater and EPA aquatic life, with a value of 0.48 ± 0.185 mg/l [41]. However, the mean concentration of Pb exceeded the limits established by the Kuwait EPA Standards [41] for water discharge into Kuwait Bay. At a mean value of 0.035 and Standard Deviation (STD) of ± 0.014 mg/l, Pb was still within the permitted levels established by the (WHO) guidelines for recreational water [36] and the EPA aquatic life standards [37-40][58]. The average concentration of the (Cd) in the water samples collected from Kuwait Bay coastal water was 0.023 ± 0.007 mg/l, above the seawater guidelines set by the Kuwait EPA Standards (0.01 mg/l) but remaining within the permitted limits of WHO recreational water standards and EPA aquatic life as in Table 2. The average (Cu) content was 0.048 ± 0.028 mg/l, below the limits of the EPA's aquatic life recommendations as well as WHO and KEPA regulations [41] [36]. On the other hand, the mean concentrations of (Hg) and (As) in the water samples were 0.178 ± 0.07 mg/l and 0.00612± 0.00179 mg/l respectively, greatly beyond the limits established by the EPA aquatic life and the KEPA regulations for the Hg and slightly exceeded KEPA standard whereas with the WHO and EPA aquatic life guidelines. The heavy metals were relatively small, indicating that

the concentrations were consistent among the sampling locations. The water was found hazardous to aquatic life, exceeding the permissible levels set by the Kuwait EPA Standards [41]. Analysis of the data showed that the average heavy metal concentrations in the water were below the KEPA-allowed levels except for Cd and Hg in all sampling sites. The standard deviation values for all metals were relatively small, indicating that the concentrations were consistent among the sampling locations.

Table 2: The Mean Values and Standard Deviation (STD) of the Analytical Results of Heavy Metals Concentrations (mg/L) Compared to KEPA, WHO, and EPA Aquatic Life Guidelines.

Heavy Metals Mean concentration. ±S.D.		Water Guidelines		
		[a] (mg/l)	(WHO)[b] (mg/l)	Aquatic life (EPA)[c] (mg/l)
Cd	0.02315±0.0068	0.01	0.06	0.01
Hg	0.1785±0.0698	0.001	NG	0.0005
Fe	0.48485±0.1856	2	NG	1
Cu	0.04811±0.0279	0.2	40	1.3
Pb	0.0354±0.01405	0.1	0.2	0.05
As	0.00612±0.00179	0.005	0.2	0.036

a Kuwait EPA (KEPA, 2017), b WHO (WHO, 2021), b EPA standards [(EPA, 2001; EPA, 2002; EPA, 2016; EPA, 2017; NOAA, 2021)] NG: No Guidelines.

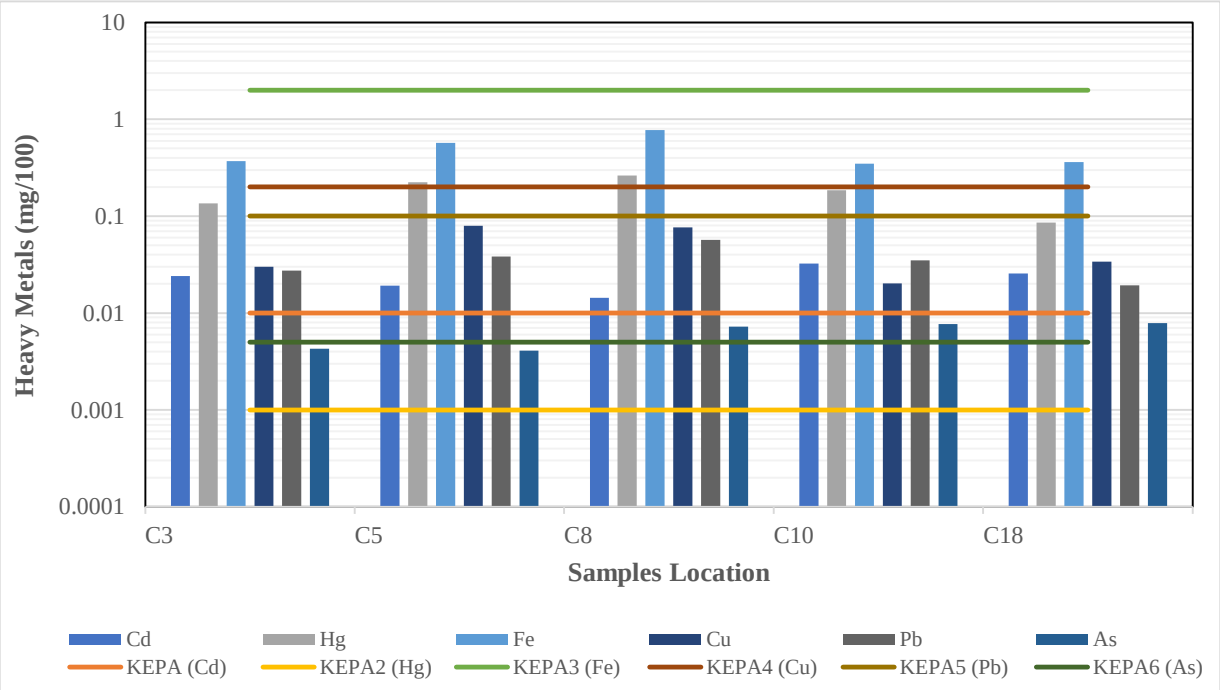

Figure 2: The Mean Concentrations of Heavy Metals Compared to KEPA Standards.

According to the findings of a research study [16], there was a very high concentration of metals in Kuwait Bay water, however, Hg and Pb were not discovered in the southwest and northeast of Kuwait Bay water. Even though the sample sites vary, the present study's findings underline the need to continue to monitor heavy metal pollution in Kuwait Bay. The average concentration order of heavy metals in the present study followed the sequence Fe > Hg > Cu > Pb > Cd > As, reflecting the relative dominance of iron and mercury in Kuwait Bay coastal waters. According to the World Health Organization (WHO) recreational water quality guidelines, no health-based guideline values are specified for iron (Fe) and mercury (Hg) in recreational waters [36]. Therefore, the evaluation of these metals was primarily based on comparisons with the Kuwait Environmental Public Authority (KEPA) discharge limits and U.S. Environmental Protection Agency (EPA) aquatic life criteria. Based on these regulatory benchmarks, mercury concentrations exceeded permissible limits at all sampling sites, indicating a high potential ecological risk, whereas iron concentrations remained within acceptable guideline limits.

The current study's mean values of the heavy metal concentrations were compared to reported concentrations in the local Kuwait Bay and regional

locations in the northern Arabian Gulf area, and the Gulf of Chabahar in the Oman Sea [23] [59] [12] as shown in Table 3. The regional locations in the northern Arabian Gulf are considered to be popular recreational beaches in Bahrain and the Kingdom of Saudi Arabia (KSA), or with locations associated with human activities such as in the Iran study, which will justify the comparison to this research's findings and improve understanding of the level of heavy metal contamination with comparable regional locations. Even though Kuwait Bay is a unique semi-closed water body and may be experiencing environmental stress due to various facilities along its southern beaches, this comparison could support the research findings as a thorough overview of heavy metal contaminations in Kuwait Bay's coasts. Local research [23] [18] was conducted a year before the current investigation in the coastal areas surrounding Kuwait Bay, which are believed to be near the current study sample locations. Although several heavy elements were investigated in this study, Cd and Hg were not, so including this comparison in the current study may improve a general understanding of how heavy metals are valued. The mean value of Fe in the Kuwait Bay local study (1.289 mg/l) is significantly higher than the maximum mean value of (0.773 mg/l) in location C8 in the current study and compared to the reported maximum mean value in Galali, Bahrain (0.61mg/l), whereas the other locations in the regional study were relatively low. However, the maximum mean Pb concentration in C8 in the current study (0.057mg/l) and the local Kuwait Bay study (0.141mg/l) had been lower than the highest value of Pb mean concentrations in the regional study, which was in Corniche Al Kahfji in the Kingdom of Saudi Arabia (KSA) with a mean value of (0.528 mg/l). Despite high Pb levels, Corniche Al Khafji showed the lowest levels of heavy metal contamination when compared to other region-wide sampling sites. In terms of As, the average measured levels across all regional sites were lower than the values reported in the local study [23]; however, this difference was not detected in the Bahrain and Saudi Arabia studies [59] and declined to be taken into account in the analysis of the Iran studies. In this investigation, the concentrations of the heavy metals followed the order of Fe > Hg > Cu > Pb > Cd > As, and they were more significant in the summer than in the winter. In general, the contamination of heavy metals in our investigation was comparable to regional analysis, with similar contamination for Cu and Pb. Methodological variability across reference studies necessitates cautious interpretation of comparative outcomes.

Table 3: Mean of Heavy Metal Concentrations (mg/l) of Regional Locations in Arabian Gulf.

Rivers &location	Cd	Hg	Fe	Cu	Pb	AS	Reference
Kuwait Bay C3	0.024	0.135	0.371	0.030	0.027	0.0043	Current study
Kuwait Bay C5	0.019	0.223	0.572	0.079	0.038	0.0041	
Kuwait Bay C8	0.014	0.263	0.773	0.0768	0.057	0.0072	
Kuwait Bay C10	0.032	0.185	0.347	0.020	0.035	0.0071	
Kuwait Bay C18	0.026	0.086	0.361	0.034	0.019	0.0078	
Kuwait Bay (local)	-	-	1.289	0.4745	0.0141	0.0021	(Nour et al., 2022)
Galali, (Bahrain)	ND	0.0008	0.61	0.003	0.011	ND	(Amin & Almahasheer, 2022)
Amwaj Island (Bahrain)	ND	0.0015	0.03	0.003	0.011	ND	
Al Khobar Corniche (KSA)	ND	0.0010	0.017	0.0010	0.013	ND	
Corniche Al Khafji (KSA)	ND	0.0010	ND	0.002	0.528	ND	
Shahid Beheshti Port (Iran)	0.0001	-	0.023	0.003	0.002		(Bazzi, 2014)
Tiss harbor (Iran)	0.0002	-	.0.018	0.0045	0.004		
ND: not detected							

3.1. Metal Pollution Indices Assessment

The Heavy Metal Pollution Index (PI) was used to assess the levels of contamination of cadmium (Cd), mercury (Hg), iron (Fe), copper (Cu), and lead (Pb) in Kuwait Bay coastal waters, with reference values from KEPA, WHO, and aquatic life guidelines used as benchmarks [36-41] [58]. The Heavy Metal Pollution Index (PI) for the heavy metals Cd, Hg, Fe, Cu, Pb, and As was measured across five observation

sites as shown in Table 4, revealing pollution index values fluctuating from no effect to serious compared to the guideline levels established by KEPA, WHO, and EPA guides for aquatic life [36-41] [58]. The highest Cd pollution index value of 3.123 according to KEPA and aquatic life guidelines was observed in Station C10, which falls in Class 4 in Table 1 and is categorized as having a substantial effect on water pollution, indicating a severe level of Cd pollution that requires urgent attention, while it is no pollution effect according to WHO recreational water guidelines and strong effect according to EPA for aquatic life. Moreover, sampling sites C3, C5, C8, and C18, had a mix of slight pollution according to KEPA and EPA for aquatic life and similar no effect concerning WHO guidelines for recreational water index values.

Table 4: Pollution Index of Heavy Metals (PI) of Cd, Hg, Fe, Cu, Pb, and As According to KEPA, WHO, and EPA Aquatic Life Guidelines.

HEAVY METALS	SITES	PI					
		KEPA	Effect	WHO	Effect	EPA (Aquatic life)	Effect
(Cd)	C3	1.94	Slight	0.324	No	1.943	Slight
	C5	1.83	Slight	0.304	No	1.825	Slight
	C8	1.36	Slight	0.227	No	1.36	Slight
	C10	3.123	Strong	0.521	No	3.123	Strong
	C18	1.775	Slight	0.296	No	1.775	Slight
(Hg)	C3	283.17	Serious	N/A	-	566.35	Serious
	C5	498.12	Serious	N/A	-	996.25	Serious
	C8	279.45	Serious	N/A	-	558.9	Serious
	C10	207.87	Serious	N/A	-	415.75	Serious
	C18	122.92	Serious	N/A	-	245.83	Serious
(Fe)	C3	0.166	No	N/A	-	0.478	No
	C5	0.239	No	N/A	-	1.14	No
	C8	0.57	No	N/A	-	0.457	No
	C10	0.228	No	N/A	-	0.67	No
	C18	0.335	No	N/A	-	0.334	No
(Cu)	C3	0.0177	No	0.0009	No	0.027	No
	C5	0.088	No	0.0044	No	0.136	No
	C8	0.083	No	0.0041	No	0.127	No
	C10	0.0115	No	0.0006	No	0.0177	No
	C18	0.0228	No	0.0011	No	0.0351	No
(Pb)	C3	0.186	No	0.037	No	0.371	No
	C5	0.376	No	0.075	No	0.752	No
	C8	0.42	No	0.084	No	0.84	No
	C10	0.514	No	0.13	No	1.028	Slight
(As)	C3	1.63	slight	0.041	No	1.35	Slight
	C5	2.390	Moderate	0.06	No	0.339	No
	C8	2.71	Moderate	0.677	No	0.376	No
	C10	4.46	Strong	0.11	No	0.62	No
	C18	3.31	Strong	0.083	No	0.46	No
NA: NOT APPLICABLE.							

PI values of Cd demonstrate a widespread issue of Cd pollution across all stations and may threaten the recreational quality and aquatic life as Cadmium is a toxic heavy metal that can accumulate in the tissues of aquatic organisms, leading to a range of harmful effects. Considerably, the pollution index values for Mercury (Hg), across the five observation sites exceeded the KEPA and EPA Aquatic life guideline levels. Considering that the WHO has no criteria for Hg in recreational water standards, the PI was not applicable (NA). However, according to KEPA and aquatic life standards, station C5 had the highest Hg pollution index value of 996.25, which falls far above the critical point category of class 5 in Table 1indicating severe Hg pollution in all sites. Likewise, the remaining sampling sites (C3, C8, C10, and C18) had substantial Hg pollution with PI Index values also far exceeding the critical point of 5 representing the serious Hg contamination in all sampling sites. Although the KEPA and EPA Pollution Index (PI) values were lowest at station C18, this does not imply reduced contamination. Instead, these findings underscore the pervasive severity of mercury pollution across all stations. The elevated PI values indicate hazardous levels of Hg, reflecting a high degree of ecological risk due to

mercury's extreme toxicity and its well-documented adverse effects on aquatic biota and human health. In the aquatic environment, Hg undergoes methylation to form methylmercury, a highly toxic compound that bioaccumulates in aquatic organisms [3][59].

The pollution index of iron (Fe) in Kuwait Bay coastal water at all five sampling sites illustrated that the highest PI value was observed at station C8 with a value of 1.14 as per EPA guidelines for aquatic life, this value indicates slight heavy metals pollution. Nevertheless, the other sites have PI values of Fe ranging from 0.166 to 0.57, which falls in class 1 demonstrating no effects of the heavy metals on seawater pollution based on KEPA standards. Alternatively, the PI values of Cu in all sample locations varied from 0.0115 to 0.083, placing it in Class 1, indicating minimal impacts on water degradation and therefore representing the least contamination across all the heavy metals regarding the 3 compared standards. Contrarily, the low values of the pollution index for Lead (Pb) across the five sites regarding the guideline levels established by KEPA, WHO, and EPA Aquatic Life indicate no contamination exists during this study. Yet, the greatest pollution PI index was detected at station C10, with a value of 1.028 according to the EPA aquatic life standard, which lies in Class 2 showing somewhat heavy metals contamination that affects seawater quality and may have negative impacts on aquatic life in the bay. For the As, the PI index values varied from strong for C10 and C18, moderate for and C8 to a slight pollution effect for C3 according to KEPA permitted levels while slight to no effect of contamination based on WHO and EPA aquatic life guidelines. The PI index results of all observation locations are generally indicating severe pollution of the Hg and As particularly based on KEPA standards while slight to no effects according to WHO-permitted levels for the recreational beaches. Nonetheless, ongoing monitoring of heavy metals levels is required, and necessary actions are taken to decrease contamination and safeguard the aquatic habitat in the bay, specifically at station C10.

3.2. Assessment of Metal Index

Metal Index (MI) is a rating system that provides an overview of the combined effects of heavy metal pollution in water and illustrates the composite influence of various parameters on overall quality [24]. In this study, the MI index was measured based on the KEPA guidelines to assess the status' overall tendency according to the guidelines of the state of Kuwait.

According to the results in Table 1, all sampling points had MI values far over class VI, indicating that the samples were gravely contaminated with heavy metals. The greatest MI value was discovered in sampling site C8 (266.86), while the lowest MI value was found in sample location C18 (90.8), indicating that sample C3 had the least heavy metal contamination of the samples but was nevertheless categorized as a highly polluted site. Furthermore, the MI findings for the sample sites C5, C10, and C3 were (226.96), (190.2), and (139.25), respectively, representing significantly heavy metals polluted locations. Based on the MI results in Table 5, the main contributing factor to the substantial MI value in all sampling locations, was (Hg), which had a mean concentration range of (0.0862 - 0.2627 mg/l), being significantly higher than the Maximum Accepted Concentration (MAC) of KEPA (0.001 mg/l). Moreover, Cd may be identified as a significant contributor that slightly enhanced the MI values since the ratio of mean concentrations to the MAC ranged from 1.923 at location C5 to 3.24 at C10, highlighting the considerable presence of hazardous metals like Hg and Cd above the MAC in all samples and endangering the health and the balance of aquatic life. The ratio of the measured values to the MAC at all locations was not exceeded, however, at 0.397 for Cu, 0.773 for Fe, and 0.0568 for Pb, all of which represented a neglected impact on the total MI at all locations, but they might still pose a threat to aquatic life and be hazardous to the environment and public health. With comparable effects, the Fe ratio of measured values to the MAC did not surpass 0.773 at all sites, nevertheless, the As ratio of mean concentration to MAC values ranged from 0.818 at location C5 to a high of 1.57 at location C18, somewhat impacting the overall MI values. Given their high toxicity, which may result in major health consequences even at low concentrations, this considerable pollution across all the evaluated locations shows a potential risk to aquatic life balance and, therefore, human health. It is essential to use effective remedial approaches to lower mercury contents in highly mercury-polluted aquatic systems since mercury is persistent in the environment [45]. On the other hand, both PI and MI showed comparable highest levels of Hg in C5 and C8, but PI suggested that Hg maximum contamination was in the order of C5>C3>C8 correspondingly, but individual MI of the Hg indicated that the highest values were in the order of C8>C5>C10, highlighting the necessity of using various criteria to provide a comprehensive picture of the heavy metal's pollution status [6][29]. The heavy metal EF obtained results showed that Hg has the highest value of 736.1>40,

indicating severe anthropogenic pollution source, Cd and as with values of 9.5 and 5.03 which laid in the class of (EF ≥ 5 and ≤ 20) which indicating significant anthropogenic pollution source with major enrichment. However, the EF of Cu and Pb was < 2, indicating depletion to mineral enrichment and therefore implying that there are no anthropogenic sources of contamination and that the concentrations of these metals were derived from natural resources. Cu and Pb with EF < 1.5 indicated that the heavy metal originated naturally, whereas Hg, Cd, and As (EF > 1.5) suggested a potential for heavy metal contamination as a result of anthropogenic activities [60].

Table 5: Heavy Metal Index (MI) of Heavy Metals of Cd, Hg, Fe, Cu, Pb, and As According to KEPA Guidelines.

SITE	HEAVY METALS	CI	MAC	CI/MAC	MI	EFFECT
C3	Cd	0.0241	0.01	2.407	139.25	Seriously Affected
	Hg	0.1354	0.001	135.38		
	Fe	0.3714	2	0.1857		
	Cu	0.0299	0.2	0.1496		
	Pb	0.02733	0.1	0.2733		
	As	0.00429	0.005	0.858		
C5	Cd	0.0192	0.01	1.923	226.9	Seriously Affected
	Hg	0.223	0.001	223.15		
	Fe	0.572	2	0.286		
	Cu	0.0795	0.2	0.397		
	Pb	0.0384	0.1	0.384		
	As	0.0041	0.005	0.818		
C8	Cd	0.01438	0.01	1.438	266.86	Seriously Affected
	Hg	0.2627	0.001	262.65		
	Fe	0.773	2	0.3865		
	Cu	0.0769	0.2	0.3843		
	Pb	0.0568	0.1	0.568		
	As	0.00722	0.005	1.445		
C10	Cd	0.03248	0.01	3.24	190.2	Seriously Affected
	Hg	0.1849	0.001	184.88		
	Fe	0.3471	2	0.1736		
	Cu	0.0202	0.2	0.1012		
	Pb	0.035	0.1	0.3502		
	As	0.00717	0.005	1.434		
C18	Cd	0.0256	0.01	2.56	90.8	Seriously Affected
	Hg	0.0862	0.001	86.18		
	Fe	0.3607	2	0.1803		
	Cu	0.034	0.2	0.1701		
	Pb	0.0194	0.1	0.1936		
	As	0.00785	0.005	1.57		

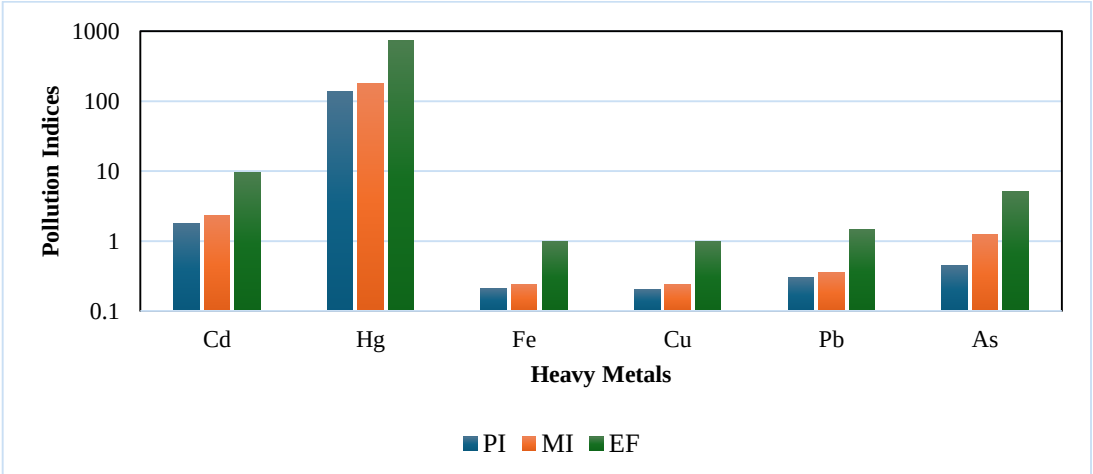

Figure 3: The Values of Heavy Metals Indices PI, MI, and EF of the Heavy Metals in the Sampling Locations.

The PI, MI, and EF exhibited equivalent findings to Hg and Cd as in Figure 3 had the most significant

contamination, whereas based on the index results Pb, Fe, and Cu were comparable in content suggesting the least contamination in the analyzed samples. Furthermore, the contamination pattern was comparable and followed the sequence of Hg > Cd > As > Pb > Fe > Cu, and MI findings marginally surpassed PI values for all heavy metals except As, where the difference was more substantial.

3.3. Seasonal Variation of Heavy Metals Concentrations

The seasonal assessment of heavy metal pollution in seawater, considering anthropogenic sources, would improve understanding of the background of this contamination's characteristics and patterns. The seasonal variation of the heavy metal concentrations in Kuwait Bay has been investigated in several studies of research. According to a study, there are higher concentrations of heavy metals during the summer compared to other times of the year at ten coastal locations around Kuwait Bay [23]. Similar findings were discovered previously that substantial changes in examined variables throughout summer vs winter indicate different seasonal dynamics [12]. There might be various causes for disparities, including different research locations, ecosystems, and environmental circumstances, which could result in distinct seasonal patterns. In this research study, the seasonal variation of heavy metals with the greatest prevalence is shown in Figure 4. The maximum concentrations of Cd, Fe, and as were higher in winter than in summer for the most sampling locations, whereas Hg and Pb were on contrasting trends illustrating the higher contamination in summer over the winter. The Cu concentrations in C5, C8, and C18 were comparable between seasons, although Cu concentrations in C3 and C10 were more substantial in summer than in winter. The seasonal analysis of the Pollution Index (PI), Metal Index (MI), and Enrichment Factor (EF) is outlined in Figure 5, which demonstrated the same findings of significant Hg contamination with summer heavy metals pollution exceeding winter at all locations. The results of the analysis of PI in the summer indicated the pattern Hg> As> Cu > Fe > Pb > Cd, with a value of PI = 232.069 > 6 for the Mercury (Hg) beyond class 5 as in Table 1, which showed substantial contamination with this metal. It is worth noting that Cd was the least polluted metal throughout the summer, with a spike in winter PI value that was the second highest value of PI; similarly, Fe, Cu, and Pb had winter PI levels that surpassed summer values. However, Hg and As continue to follow the heavy metals seasonal concentration trend, with summer PI levels exceeding winter PI values.

The seasonal fluctuations in the MI of each location revealed that the MI in the summer was significantly greater than the MI in the winter (Fig. 4). According to the MI analysis, contamination occurred in the following pattern during the summer: C5>C8> C10>C3>C18, however during the winter, the sequence of contamination was C5>C3>C10>C8>C18, suggesting that C18 was the least contaminated site in the current investigation and coincided with the prior analysis. In addition, according to the MI values in Table 1 for the winter, C18, C10, and C8 fell into class V, suggesting that they had been greatly affected by heavy metal pollution, while C3 and C5 were seriously affected (class IV) by the contamination. On the contrary, the MI findings disclosed that during the summer, all the sites suffered serious effects of heavy metals contamination, with values substantially beyond class VI, the highest contamination classification according to the MI classifications. According to the MI seasonal analysis, site C5 was the most polluted, indicating that it had suffered from substantial pollution, perhaps from the neighboring medical facility. Summer MI data indicated that C8 had considerable heavy metal contamination, whereas winter C3 had significant heavy metal pollution, confirming that contamination levels fluctuated spatially and temporally over the current experiment.

The enrichment factor (EF) seasonal results presented the trend of contamination following the pattern of Hg> As> Cd> Cu> Fe > Pb in summer while in winter Hg > As> Cd> Fe > Cu > Pb. In the summer, Hg was at the severe enrichment EF>40 and declared that the source of contamination was anthropogenic, while Cd and As were EF < 5 suggesting that the pollution was of moderate enrichment, though based on [60] could imply that the source of contamination is anthropogenic. However, winter EF data revealed that Hg and as displayed considerable enrichment, indicating a significant anthropogenic pollution source, whilst Cd showed moderate enrichment, indicating an adequate anthropogenic pollution source. Notwithstanding a finding that the Fe, Cu, and Pb EF assessments for summer were higher than those for winter, they illustrated only minimal enrichment and raised the possibility that the heavy metals contents during the research period originated from natural resources. Conversely, arsenic (As) demonstrated an increased enrichment factor of winter over summer with the opposite tendency of all the heavy metals

under investigation, which is linked to (As) summer mean levels being lower than winter. Metals under investigation, which is linked to (As) summer mean levels being lower than winter. These findings demonstrated that input sources of Hg contamination originated at all sites during the summer, but particularly at sites C5 (near medical facilities) and C8 (near one of the main ports, a route that is popular for commercial ships and one of the busiest beaches in the summer).

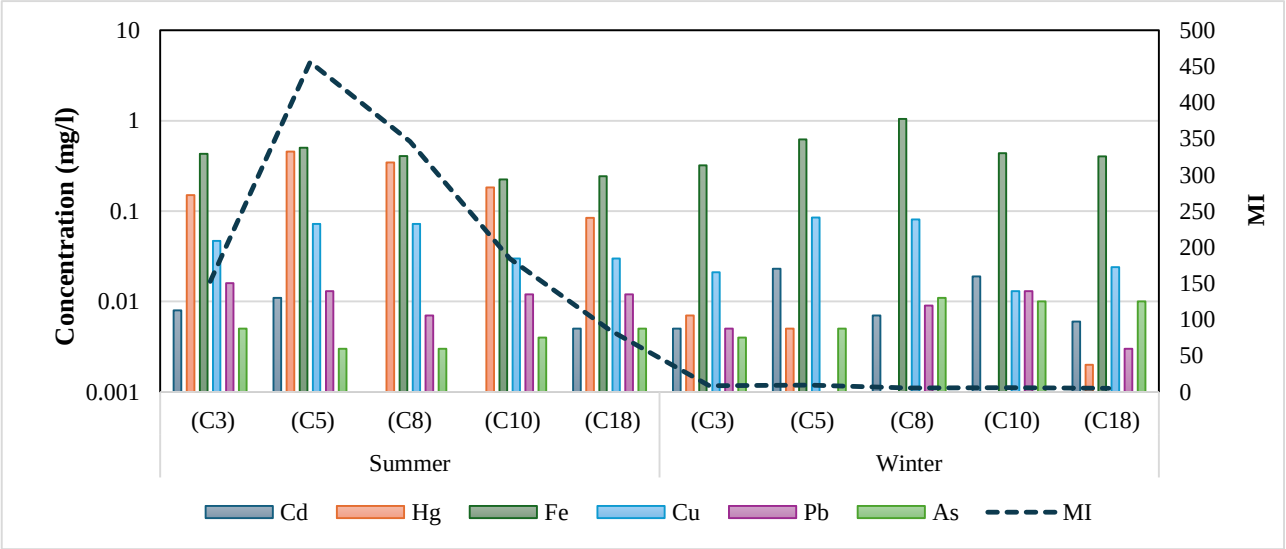

Figure 4: Seasonal Heavy Metals Mean Concentrations in the Sampling Locations.

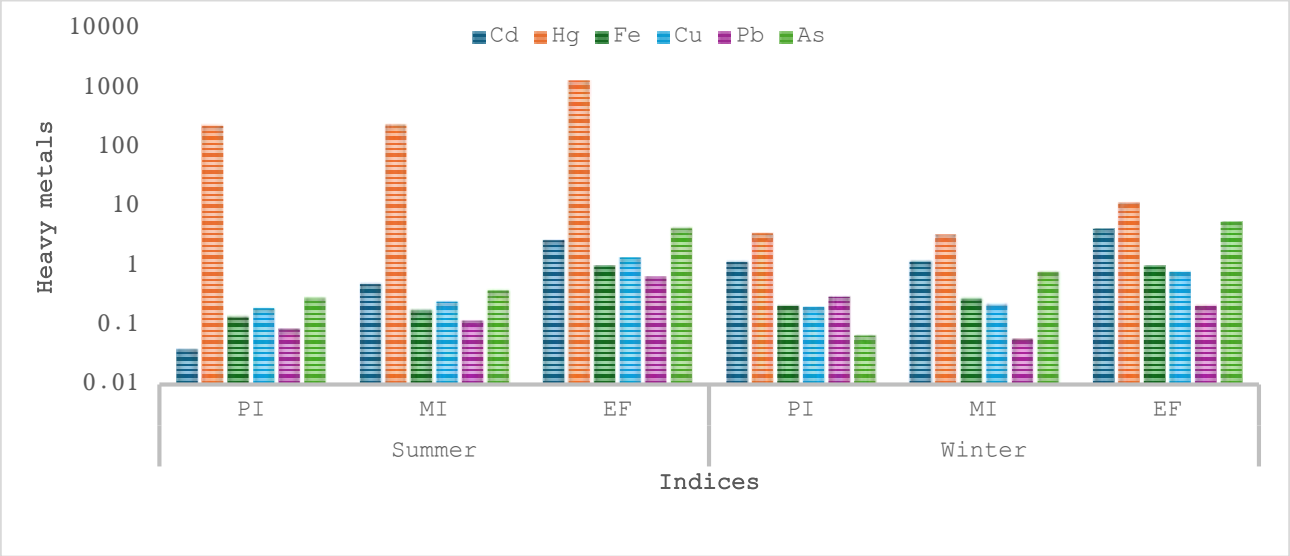

Figure 5: The Comparison of the Seasonal Analysis of the Metal Indices PI, MI, and EF.

In contrast to the Hg results, which were consistent with the outcome of increasing summer contamination more than the winter, the findings of the seasonal variation when comparing the metal indices of PI, MI, and EF results (Fig. 5) showed that Cd winter contamination was greater than summer contamination. The calculated metals indices for Cu and Fe levels were similar, indicating a possible association between these heavy metals. Considering the exception of the PI findings, the As and Pb based on the MI and EF index values were larger in the winter than in the summer. Notably, the MI outcome of the accumulation of heavy metals has different insights when assessing the individual effects of the MI of each heavy metal.

Pearson's correlation matrix was employed, and the significance of the correlations was assessed using p-values, to identify the association between heavy metals' pollution during the two seasons as illustrated in Table 6. Correlation analyses have been widely used in environmental research to give an efficient technique to expose the correlations between

numerous variables to identify the causes and sources of chemical components [23] [59-60]. There was a correspondingly strong negative significant association between Hg and As in winter (r= -0.988, p<0.01) and summer (r= -0.865, p<0.05) in this investigation, indicating inverse relationship suggests differing inputs or geochemical controls. Conversely, Fe and Cu showed a substantial link with a significant positive association (r= 0.873, p<0.05) in the summer and (r= 0.806, p<0.05) in the winter, conveying that these metals share input sources and supporting the seasonal finding that was previously discussed. It is worth noting that Hg was considerably positively linked with Cu during the summer, however, no association occurred between the two metals during the winter, indicating a difference in the origin and source input of the Hg contamination during the summer. Notably, the MI and Hg had a significant positive correlation (r = 0.999, p <0.01) in the summer and (r = 0.907, p <0.05) in the winter, indicating that Hg was primarily responsible for the metal's contamination. In contrast, As was significantly negatively associated to the MI results in summer (r = 0.864, p <0.05). At the same time, in winter the negative connection became more significant (r = 0.954, p <0.01), illustrating that Hg and As emanated from distinct sources of contamination. Cu disputed its contribution to the MI value and also suggested that it is not from the common source of contamination with Hg and As in winter, even though Cu was significantly positively related to MI in summer (r = 0.906, p<0.05). These findings support the notion that the sources of heavy metals differ seasonally in summer and winter.

Table 6: Pearson's Correlation Matrices of the Seasonal Mean Concentration of Heavy Metals.

Summer

	Cd	*Hg*	*Fe*	*Cu*	*Pb*	*As*	*MI*
Cd	1						
Hg	0.258	1					
Fe	0.604	0.744	1				
Cu	0.23	**0.905***	**0.873***	1			
Pb	0.725	-0.374	0.108	-0.385	1		
As	0.232	**-0.865***	-0.355	-0.754	0.748	1	
MI	0.257	**0.999****	0.745	**0.906***	-0.375	**-0.864***	1

Winter

	Cd	*Hg*	*Fe*	*Cu*	*Pb*	*As*	*MI*
Cd	1						
Hg	-0.032	1					
Fe	0.013	-0.421	1				
Cu	0.278	0.021	**0.806***	1			
Pb	0.003	-0.607	0.194	-0.347	1		
As	-0.121	**-0.988****	0.422	-0.044	0.571	1	
MI	0.365	**0.907***	-0.254	0.267	-0.581	**-0.954****	1

***Significant at 0.05, **Significant at 0.01**

4. CONCLUSION

Measuring heavy metals in Kuwait Bay recreational waters is crucial due to the threats they pose to human and environmental health. Various effective techniques, methodologies, recommendations, and indices were used to analyze and evaluate heavy metal pollution, providing a broad assessment of heavy metal contamination. The Metal index MI, the heavy metal pollution index PI, and the Enrichment factor imposed different estimations based on various approaches, yet both provided helpful insights into contamination patterns, thus using several indices allows for more in-depth knowledge of heavy metal contamination. The pollution indices show contamination by focusing solely on metal concentrations; however, they fail to account for risk characteristics such as bioavailability, seasonality, and speciation. According to PI data, the highest levels of arsenic (As) and cadmium (Cd) pollution were discovered in sites C10 and C18, while MI results showed that the most polluted sites were C8 and C5 The findings of the heavy metals indices confirmed that all of the tested locations had significant levels of (Hg) pollution, which posed a threat to the aquatic life and ecosystem of Kuwait Bay. According to EF findings, anthropogenic activities may be to blame for the considerable seasonal variation in heavy metal pollution, which was higher in the summer than in the winter. To address the levels of heavy metal contamination, effective mitigation strategies, such as frequent monitoring, identifying pollution sources, and lowering metal use, are required. In addition, legislation, public awareness efforts, and biological remediation for mild pollution might aid in reducing inputs from various sources. Future studies ought to investigate additional contaminants, metal bioaccumulation in marine life, and linkages to public health consequences to improve risk assessments by factoring temporal and geographical variation into consideration. Additionally, a comprehensive management strategy is required to reduce metal pollution at Kuwait Bay beaches and

ensure the security of aquatic activities, highlighting the need for long-term water quality monitoring and management in safeguarding water resources.

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