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Monitoring some chemical properties and human health risk assessments of Cd and Pb of Bardawil lagoon water, north of Sinai, Egypt

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ABSTRACT

This study aims to monitor the pollution and health risk of Bardawil lagoon water for 10 y from 2011 to 2021. Here the levels of salinity, dissolved oxygen, total nitrogen, total phosphorus, and lead (Pb) were briefly studied. The averages of the studied parameters were calculated and some equations were used to estimate the health risk assessment. The heavy metal index (HMI), hazard quotient for ingestion (HQ_{ing}), hazard quotient for dermal (HQ_{dr}), probability of cancer risk for ingestion (PCR_{ing}), probability of cancer risk for dermal (PCR_{dr}), and hazard index for any site (HI_s) were estimated. The HMI of Cd and Pb were within the acceptable limit (HMI is <2) except for the HMI of Pb in 2011, 2012, 2013, and 2014. The PCR equation led to cancer risk more on the adults working in Bardawil lagoon, who need some intervention and remediation.

Keywords: Pollution; Health risk; Cancer; Heavy metals; Bardawil lagoon

1. Introduction

Bardawil lagoon is a shallow wetland water body in north Sinai separated by a narrow sand barrier, its width range from 80 to 1,000 m. Bardawil lagoon has three openings connected with the Mediterranean Sea for the inflow of water. Two of these openings are artificial called Boughaze I at the western side and Boughaze II at the nearly middle side. These two Boughazes need periodic dredging to permit the login of Mediterranean Sea water. The third opening is natural and located on the eastern side of the El-Zaranik Protectorate. After the war of 1967, these openings were closed by Israel's occupation, thus the salinity of the Bardawil lagoon increased (salinity reached 120%) [1,2]. But these openings opened after October Victory and the salinity decreased. Bardawil lagoon is famous for various fish species such as Sparus auratus and Mugil, and fishing is limited from January to May each year [3,4]. More than 3,000 fishermen are required to produce saltwater fish from this lagoon. Bardawil lagoon is the famous hypersaline lagoon in the north of Egypt. Some authors believe that two Boughaze are the origins of all water in the lagoon from the Mediterranean Sea and that excessive salinity occurs along the lagoon's southern shoreline [5]. Most of the coastal lagoons of Egypt are sensitive to some activities such as reclamation, pollution phenomenon, hydrological modification, and erosion [6]. Furthermore, climate change has a negative impact on water supplies and sea level rise in coastal lagoons such as the Bardawil lagoon [7].

According to Elshinnawy and Almaliki [8], the sources of Bardawil lagoon (inflow) from three resources, that is the Mediterranean Sea, rainfall, and groundwater. The

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most rainfall [9] of rainfall is about 61.95 million m^3 to Bardawil lagoon's hydrologic balance. Groundwater comes from the sand dune aquifer system, where this system supplies the Bardawil lagoon with about 8.64 million m^3/y [8]. Annual outflow from Bardawil lagoon (by evaporation and salt production) is about 1,405.05 million m^3 greater than the annual inflow by rainfall and groundwater (70.59 million m^3), then the difference between outflow and inflow is about 1,334.46 million m^3. This difference comes from the three openings in the Bardawil lagoon, where this difference in the volume of water replenished from the continuous movement of Mediterranean Sea water to the Bardawil lagoon.

The water from lagoons is used in many activities such as cooking, farming, laundry, and industrial processes. Many economic activities take place in the lagoon such as fishing, salt, and sand extraction [10], as well as relaxation, agriculture, tourism, and urban development [9]. Usually, the lagoon water is polluted by discharging untreated wastewater from agricultural and industrial activities as well as municipal wastewater [10]. The heavy metals in wastewater may cause the loss of some organisms and negatively affect people depending on the lagoons [9].

According to Çelo et al. [11], Singh et al. [12], and Fabbri et al. [13], heavy metals carry on the sediments, thus the sediment is considered a source of pollution. Where the heavy metals are not permanently fixed and can be released into the water easily. The occurrence of heavy metals in the bottom sediment of Bardawil lagoon indicates that the Cd, Pb, and Cu have occurred on the western side of the lagoon which was affected by the water entry through Boughaz I, while the Fe, Zn, and Mn occurred in the eastern part of lagoon affected by the water come from the Mediterranean Sea through Boughaz II. Many authors such as Yacoub and Abdel-Satar, [14] studied the effect of heavy metals in the sediment and water of a lagoon on many fish species.

Heavy metals are the main pollutants in sediment, water, and organisms because of their characteristics such as being persistent, stable, and non-biodegradable. Some heavy metals are toxic at certain levels of concentrations, these heavy metals result from anthropogenic activities (domestic and industrial wastewater, agricultural and urban activities) and from natural resources [15–17]. The natural sources of heavy metals are discussed by many authors such as Bryan [18] and Connell & Miller [19]. They suggested that the heavy metals of natural sources come to the marine environment from erosion and rivers. The heavy metals can transfer from the water to sediment by adsorption and sedimentation process according to the pH, organic matter, and redox potential [20–22]. The pH and temperature of water affect the transfer the metals from water to the bottom sediments. Where the heavy metals are strongly difficult to dissolve thus they may be settled in the bottom sediment, also the temperature of water in various seasons affecting on the heavy concentration and the toxicity, especially Cd and Pb [23].

From the middle of the twentieth century after 1940 due to the acceleration of industrial and urban activities heavy metals are observed in the water, soil, and sediment, some of them play a useful role as coenzymes (Fe and Cu) and some are toxic at certain levels (Pb and Cd) [24,25]. The toxic heavy metals are recognized by International Agency for Research on Cancer (IARC) and are mainly documented.

According to Mansourri and Madani [26], heavy metals toxicity is different from one metal to another and the toxicity of each metal is different due to its level of concentration some selected toxic heavy metals harmful to humans are in the following order of toxicity Co < Al < Cr < Pb < Ni < Zn < Cu < Cd < Hg. Cd, Pb, and Hg have more attention due to their great affecting on humans [27].

Heavy metals were accumulated in the tissues and become more toxic because the metals are not metabolized by the body. The condition surrounding the organism causes the heavy metal to become more toxic by increasing its levels with time [28,29]. Cd and Pb are considered hazardous metals, which are listed in the European Union (EU, 2001). The toxicity of Cd in children leads to damage to the renal skeletal, respiratory system, and cardiovascular system as well as increases the cancers of the prostate, stomach, kidneys, and lungs [30,31]. The people may be subjected to the toxicity of Cd due to contaminated food, working in places contaminated by Cd, and smoking [32]. Pb may be subjected the humans by inhalation of dust and aerosols or by eating and drinking contaminated food and water [33]. The toxicity of Pb causes damage to the liver, brain, kidneys, nervous and skeleton systems. The toxicity of Pb may cause a decreasing the intelligence ability of the children [30,31].

In this study, pH, Cd and Pb, electrical conductivity (EC), salinity (TDS), dissolved oxygen (DO), total nitrogen (TN), and total phosphorus (TP) were determined during the period from 2011 to 2021. The work was extended to study the average daily dose by ingestion (ADD_{ing}) and average daily dose by skin absorption or contact (ADD_{dr}) of Cd and Pb in Bardawil lagoon water.

2. Materials and methods

2.1. Study area and sampling

Bardawil lagoon is the study area located in the north Sinai Peninsula with three openings acting as inlets of the lagoon. Bardawil lagoon is located between long. 32°40′ and 33°30′E and between lat. 31°19′ and 31°03′N (Fig. 1). About ten samples were collected from Bardawil lagoon, covering most portions of the lagoon (Fig. 1 and Table 1) [34]. The data of Cd and Pb, pH, EC, salinity, DO, TN, and TP were obtained from the Egyptian Environmental Affairs Agency (EEAA) annual reports. EEAA collects the samples from about 12 sites in Bardawil lagoon in different seasons. The samples in this study were collected in the summer season (August month).

2.2. Methods and calculations

Traditional chemical analysis is used to determine the values of pH, EC, TN, TP, DO, and salinity (Table 2). Concentration of heavy metals (Cd and Pb) (Table 3) was measured by atomic absorption spectrophotometer (AAS) according to the APHA, [35].

All parameters were measured and compared to the USEPA and WHO regulatory limits for heavy metals in drinking water. The data was analyzed to determine the

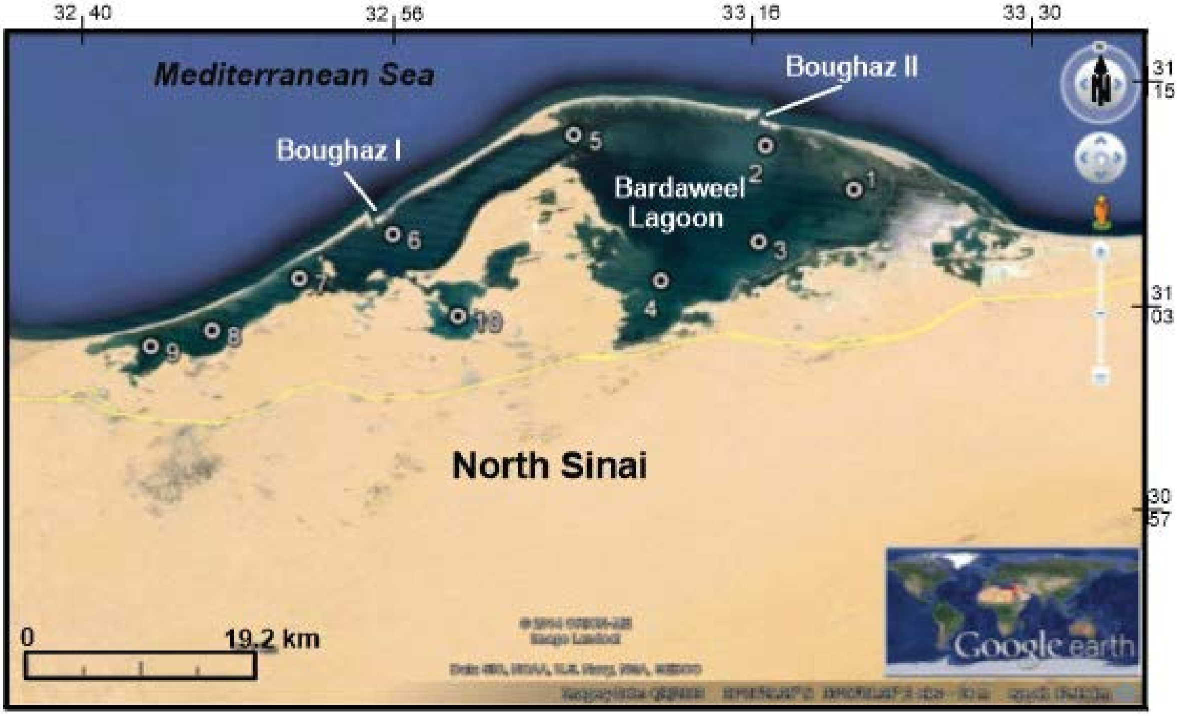

Fig. 1. Location map and the sites of sampling (modified by El-Bady and Samy [34]).

Table 1
Locations of samples of the bottom sediments of Bardawil lagoon [34]

Samples	Sites	Latitude	Longitude
1	Alroak North	31°9′21.18″N	33°21′11.16″E
2	Boughaz I	31°11′27.05″N	33°16′34.03″E
3	Zaranik	31°7′6.52″N	33°16′3.92″E
4	ELtelol	31°5′27.88″N	33°10′49.68″E
5	Masct eblis	31°12′10.42″N	33°6′25.47″E
6	Boughaz II	31°7′52.54″N	32°56′43.55″E
7	Messefek	31°5′59.12″N	32°51′42.91″E
8	EL-Nasr	31°3′43.38″N	32°47′1.47″E
9	Elrabaa	31°3′4.10″N	32°43′45.57″E
10	EL-Roak	31°4′5.93″N	33°0′3.91″E

mean, standard deviation, maximum and minimum values. All tables were plotted using Microsoft (Word and Excel) programs.

Heavy metals are absorbed through the skin of humans who come in touch with lagoon water. In general, humans were exposed to heavy metals via three routes: direct ingestion, inhalation, and skin absorption [36–38]. According to the equations of Yahaya et al. [40,41], the health risk assessment of Cd and Pb in Bardawil lagoon was calculated for adults only. Equations used in calculations are as follows and explained in Table 4.

$$\text{ADD}_{\text{ing}}\left(\text{mg/kg/day}\right)=\frac{C\times\text{EF}\times\text{ED}\times\text{IR}}{\text{BWT}\times\text{AT}} \tag{1}$$

$$\text{ADD}_{\text{dr}}\left(\text{mg/kg/day}\right)=\frac{C\times\text{Sa}\times\text{Pc}\times\text{EF}\times\text{ED}\times\text{Et}}{\text{BWT}\times\text{AT}} \tag{2}$$

$$\text{HQ}=\frac{\text{ADD}_{\text{ing}}}{\text{RFD}} \tag{3}$$

$$\text{HMI}=\frac{C}{\text{MPC}} \tag{4}$$

$$\text{PCR}=\text{ADD}_{\text{ing}}\times\text{CSF} \tag{5}$$

$$H_{\text{is}}=\text{HQ}_{\text{ing}}+\text{HQ}_{\text{dr}} \tag{6}$$

$$H_{\text{im}}=\text{HQ}_{\text{Cd}}+\text{HQ}_{\text{Pb}} \tag{7}$$

3. Results and discussion

3.1. Chemical properties

The pH of the Bardawil lagoon water ranges from 7.88 to 8.59, where the order of pH in the period of study (2011–2021) as the following 2017 < 2019 < 2011 < 2021 < 2 015 < 2016 < 2014 < 2012 < 2013. The pH values during the period from 2011 to 2021 have minor variations through 10 y (Table 2).

EC is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. The averages of EC in Bardawil lagoon through 10 y from 2011 to 2021 ranged from 48.65 mS/cm in 2021 to 75.01 mS/cm in 2015. Many sites of Bardawil lagoon water have high EC due to the high content of minerals and total dissolved

Table 2
Chemical analysis of Bardawil lagoon water in August month

Year		pH	EC (mS/cm)	Salinity (‰)	DO (mg/L)	TN (mg/L)	TP (μg/L)	TP (mg/L)
2021		8.04–8.6	43.6–53.7	0.49–38.96	4.39–8.29	0.54–0.89	45.37–131.06	Divided by 1,000
	Average	8.3	48.65	19.72	6.34	0.74	86.52	0.086
2019		7.85–8.55	58.79–79.89	40.27–69.32	4.88–10.08	0.99–1.28	56.52–115.79	
	Average	8.16	69.40	48.31	6.86	1.09	76.29	0.076
2017		7.18–8.32	48.54–65.98	38.04–54.45	5.77–7.39	0.31–0.57	21.51–38.36	
	Average	7.88	55.26	44.04	6.59	0.37	30.18	0.030
2016		7.94–8.62	57.98–107.5	37.11–68.80	2.76–5.28	0.59–1.52	17.06–33.57	
	Average	8.38	75.01	48.01%	4.35	1.00	24.03	0.024
2015		8.2–8.46	61.97–81.24	40.49–56.10	4.31–7.33	0.99–2.62	38.58–212.19	
	Average	8.30	71.06	47.49	5.68	1.55	108.97	0.108
2014		8.24–8.70	59.13–99.13	39.16–71.10	3.82–6.18	0.51–1.27	26.8–52.19	
	Average	8.47	73.39	50.31	5.05	0.78	34.79	0.034
2013		8.39–8.9	58.79–79.89	62.3–39.3	5.7–7.6	0.25–0.99	11.18–45.59	
	Average	8.6	69.40	48.12	6.78	0.6	20.50	0.020
2012		8.38–9.01	57.98–89.17	38.5–63.23	3.25–6.18	0.31–0.80	17.26–37.56	
	Average	8.59	69.84	47.6	5.22	0.55	28.09	0.028
2011		8.03–8.45	58.44–92.4	38.79–65.59	3.84–6.13	0.78–1.87	17.21–201.3	
	Average	8.23	70.37	48.09	5.20	1.36	42.37	0.042

Table 3
Concentration of Cd and Pb in Bardawil lagoon water from 2011 to 2021

Year	Cd (μg/L)			Pb (μg/L)			HMI Cd	HMI Pb
	Min.	Max.	Average	Min.	Max.	Average		
2021	0.45	0.77	0.58	0.23	0.58	0.422	0.193	0.042
2019	0.76	1.29	1.01	1.15	2.1	1.65	0.336	0.165
2017	0.025	0.85	0.54	2	7.46	3.72	0.18	0.372
2016	0	0.37	0.14	2.31	9.32	5.46	0.046	0.546
2015	1.83	2.95	2.27	2.8	3.73	3.25	0.756	0.325
2014	0.29	1.17	0.47	13.15	24.06	20.69	0.156	2.069
2013	0.32	2.4	0.67	14.13	29	20	0.223	2
2012	0.15	2.4	0.45	16.5	26.98	21.2	0.15	2.12
2011	0.21	0.79	0.38	17.75	37.02	25.84	0.126	2.584
WHO, [53]	0.003 mg/L		3 μg/L	0.01 mg/L		10 μg/L		
EOSQ [54]	0.003 mg/L		3 μg/L	0.01 mg/L		10 μg/L		
CCME, [55]	0.001 mg/L		1 μg/L	0.007 mg/L		7 μg/L		
USEPA, [56]	0.005 mg/L		5 μg/L	0.015 mg/L		15 μg/L		

solids (Table 2). Generally, the EC is directly proportional to the minerals and solid contents of water.

Salinity is estimated by measuring the total dissolved salts in water, its units are part per thousand (ppt) or percentage (%). Salinity is a significant ecological parameter that influences the types of organisms that inhabit bodies of water. Water salinity is divided into four categories: freshwater (0.5 g/L), brackish water (0.5–30 g/L), saline water (30–50 g/L), and brine water (>50 g/L). The lagoons are classified according to salinity into brackish, marine, or hypersaline. The hypersaline lagoons such as Sivash in the Black Sea [42] and Bardawil in the south of the Mediterranean Sea in Egypt may have salinity exceeding 100 mg/L. The hypersaline lagoon showed evaporation more than precipitation. Thus, the salinity of surface water increases. The surface waters may sink down to the bottom and may flow seaward, to be replaced by incoming surface water from the sea. Consequently, the salinity increased with depth and with distance from lagoon openings such as Boughaz [42]. The salinity of lagoon water affects aquatic organism distribution, where many organisms try to adapt to prevailing salinity and other environmental conditions. The average salinity

Table 4
Abbreviations used in health risk assessment calculations

Abbreviation	Meaning	Abbreviation	Meaning
ADD_{ing}	average daily dose by ingestion, μg/kg·d	ADD_{dr}	average daily dose by skin absorption, μg/kg·d
HQ_{ing}	hazard quotient for ingestion	HMI	heavy metal index
PCR_{ing}	probability of cancer risk for ingestion	HQ_{dr}	hazard quotient for dermal
PCR_{dr}	probability of cancer risk for dermal	HI_s	hazard index for any site
C	concentration of metal	HI_m	hazard index for each metal
ED	exposure duration, in this study 68 y; (the average lifespan of Egyptian peoples)	EF	exposure frequency = 365 d/y
BWT	BWT (average body weight) = 65 kg (average body weight of Egyptian peoples	IR	ingestion rate = 2 L/d
RFD	reference dose for different metals, for Fe: 45, Mn: 0.8, Zn: 60, Cu: 12, Pb: 0.42, Hg: 0.0003 and Cd: 0.005 μg/kg·d, according to U.S. risk-based assessments (USEPA, 2006)	AT	AT = ED × 365 average time = 24,820 d
MPC	maximum permissible concentration of each heavy metal	CSF	standard CSF for carcinogenic heavy metals are Pb (0.0085), Cr (0.05), Cd (0.38), and Ni (0.91)
SA	exposed skin area, in this study, 5700 cm^2; Kp	ET	exposure time during bathing and shower, in this study 0.6 h/d
PC	Pc (dermal permeability coefficient) = 0.004 for Pb, 0.001 for both Cd and Cu, 0.0002 for Ni, and 0.002 for Cr	CF	CF is the unit conversion factor, 1 × l/1.000 cm^3
RDI	recommended daily intake		

of Bardawil lagoon through 10 y from 2011 to 2021 ranged from 19.72 mg/L (2021) to 50.31 mg/L (2014) as shown in Table 2.

The averages of DO of Bardawil lagoon water through 10 y from 2011 to 2021 ranged from 4.35 mg/L in 2016 to 6.86 mg/L in 2017. The averages of dissolved oxygen in the Bardawil lagoon water in the following order: 2016 < 2014 < 2011 < 2012 < 2015 < 2021 < 2017 < 2013 < 2019 (Table 2). The low DO values are due to the high temperatures that cause a decrease of oxygen solubility [43,44]. All the studied samples were collected in the summer (August). The DO may increase due to the decrease in temperature which increases the oxygen solubility.

Dissolved oxygen greater than 5 mg/L is suitable for the growth and activity of most aquatic organisms especially fishes, while dissolved oxygen less than 2 mg/L cause the damage the fishes and other organisms, but dissolved oxygen between 2–4 mg/L cause aquatic organism difficulty living [41]. When the lagoon receives a huge quantity of agricultural and domestic wastewater, the dissolved oxygen is lower and when the quantity of wastewater is low, the dissolved oxygen is more. Some site in the lagoon influenced by wave action comes from seawater, thus these sites have more dissolved oxygen [45]. The dissolved oxygen in Bardawil lagoon is suitable for the growth and production of many species' fishes [46].

The average TN of water samples ranged from 0.37 in 2017 to 1.55 in 2015. The concentration of the TN of 10 y of the Bardawil lagoon water in the following order 201 7 < 2012 < 2013 < 2021 < 2014 < 2016 < 2019 < 2011 < 2015 (Table 2).

Nitrogen in polluted water occurred in the forms of organic nitrogen matter and ammonia. By some surrounding conditions, the organic matter is slowly converted to ammonia, where the ammonia is used as a nutrient. Nitrogen is occurred in water due to some industrial activities, excretions of animals and humans, and fertilizers. Large amounts of nitrogen in the air or in water cause the decrease of oxygen, thus asphyxiation and death of fish appear in air and water, respectively. Excess nitrogen is not toxic to aquatic organisms, but when the nitrogen increased growth of algae increased, thereby the DO content of the water decreased [47]. Also, TP as nitrogen causes the growth of algae, thus the DO is decreased. Phosphate appears as a result of sewage, industrial, and agricultural drainage in water.

The TP related to the lake trophic state, where the orthophosphate (soluble reactive phosphate) is not used to measure phosphate in the lake because it changes quickly in a short time but the total phosphate (orthophosphate and phosphate in all remains suspended in lake water) is the accurate way to measure the phosphate in the lake because it more stable and not change in a short time [48].

According to Carlson and Simpson [48] the TP concentrations in the lake or water body classify into four types as following oligotrophic or hypertrophic (TP, 0–12 μg/L), mesotrophic (TP, 12–24 μg/L), eutrophic (TP, 24–96 μg/L), and hypertrophic (TP, 96–384 μg/L).

In Bardawil lagoon the TP largely varies through 10 y from 2011 to 2021, where the total phosphate ranges from 20.50 to 108.97 μg/L. The type of Bardawil lagoon is not stable through the previous 10 y (2011–2021), most of the years (2011, 2012, 2014, 2016, 2017, 2019, and 2021) the lagoon was the eutrophic type, in 2013 was oligotrophic and in 2015 the Bardawil lagoon was the hypertrophic type (Table 2). According to the above types of Bardawil lagoon, the Bardawil lagoon has high nutrient levels (phosphate and nitrogen) in most previous periods. The changes in Bardawil lagoon type or the change of nutrient levels from low to very high quantities of nutrients indicate that the lagoon is suffering from contentious and fluctuating changes (pollution), thus it needs a continuous cleansing process to remove the aquatic plants and algae. The TP of Bardawil lagoon during the 10 y have the following ascending order 2013 < 2016 < 2012 < 2017 < 2014 < 2011 < 2019 < 2021 < 2015 (Table 2).

3.2. Concentrations of heavy metal

The average concentrations of Cd in Bardawil lagoon water range from 0.14 to 2.27 μg/L. Cadmium concentration during the studied period is shown in the following order 2016 < 2011 < 2012 < 2014 < 2017 < 2021 < 2013 < 2019 < 2015 (Table 3).

According to Goering et al. [49], Cd is a serious metal causing carcinogenic effects in humans, where it occurred in the aquatic environment. Some countries determined the permissible limits of Pb and Cd in foods, especially commercial handling foods.

According to Lewinsky [50] the sources of Pb in the lagoon water environment are industrial waste, pesticides, water pipes, diesel of fishery vehicles and tourism boats, and pigment. Pb is not essential heavy metal and it has damage effects on human organs, especially children [50]. According to Patrick [51] Pb accumulation in the human body may cause headaches, colic, anaemia, and distortion of the nervous system. Averages concentrations of Pb in Bardawil lagoon water range from 0.422 to 25.84 μg/L. Lead concentration during the studied period is shown in the following order 2021 < 2019 < 2015 < 2017 < 2016 < 2013 < 2014 < 2012 < 2011 (Table 3). Heavy metal index (HMI) of Cd and Pb in the acceptable limit (HMI is <2) except in HMI of Pb in 2011, 2012, 2013 and 2014 (Table 3) [52].

3.3. Human health risk assessment

Most of the average daily dose by ingestion (ADD_{ing}) and average daily dose by skin absorption or contact (ADD_{dr}) of Cd in Bardawil lagoon water is in recommended daily

Table 5
HQ, HI, and PCR of Cd in Bardawil lagoon water for adults

Years	Cd						
	ADD_{ing}	ADD_{dr}	HQ_{ing}	HQ_{dr}	PCR_{ing}	PCR_{dr}	HI_m
2021	0.0178	0.030517	3.569	6.103385	0.0067	0.011596	9.67261538
2019	0.0310	0.053142	6.215	10.62831	0.0118	0.020194	16.8436923
2017	0.0166	0.028412	3.323	5.682462	0.0063	0.010797	9.00553846
2016	0.0043	0.007366	0.861	1.473231	0.0016	0.002799	2.33476923
2015	0.0698	0.119437	13.964	23.88738	0.0265	0.045386	37.8566154
2014	0.0144	0.024729	2.892	4.945846	0.0054	0.009397	7.83815385
2013	0.0206	0.035252	4.123	7.050462	0.0078	0.013396	11.1735385
2012	0.0138	0.023677	2.769	4.735385	0.0052	0.008997	7.50461538
2011	0.0116	0.019994	2.338	3.998769	0.0044	0.007598	6.33723077
RDI	0.06						

Table 6
HQ, HI and PCR of Pb in Bardawil lagoon water for adults

Years	Pb							HI_s
	ADD_{ing}	ADD_{dr}	HQ_{ing}	HQ_{dr}	PCR_{ing}	PCR_{dr}	HI_m	
2021	0.0129	0.0888147	0.030	0.21146	0.0001	0.000755	0.2423	9.914995
2019	0.0507	0.3472615	0.120	0.82681	0.00043	0.002952	0.9476	17.79138
2017	0.1144	0.7829169	0.272	1.86408	0.00097	0.006655	2.1366	11.14215
2016	0.168	1.14912	0.4	2.736	0.00142	0.009768	3.136	5.470769
2015	0.1	0.684	0.238	1.62857	0.0008	0.005814	1.8666	39.72328
2014	0.6366	4.3544492	1.515	10.3677	0.00541	0.037013	11.883	19.72164
2013	0.6153	4.2092307	1.465	10.0219	0.00523	0.035778	11.487	22.66072
2012	0.6523	4.4617846	1.553	10.6233	0.00554	0.037925	12.176	19.68103
2011	0.7950	5.4383261	1.892	12.9484	0.00675	0.046226	14.841	21.17867
RDI	0.21							

intake limits, except ADD_{dr} of Cd of 2015 (Table 5). Most of ADD_{ing} and ADD_{dr} of Pb more than the recommended daily intake, except ADD_{ing} of Pb of years 2015, 2016, 2017, 2019, and 2021 and ADD_{ing} 2021 less than the recommended daily intake (Table 6).

In this study, the human health risk assessment is carried out for adults only. The hazard quotient (HQ) and hazard index (HI) of Cd of two pathways (Table 5) (ingestion and dermal absorption) in Bardawil lagoon is more than one in all studied years, thus may be noncarcinogenic effects occurred. While, HQ and HI of Pb (Table 6) were more than one in most years (noncarcinogenic effects occurred) and less than one in a few years such as HI (2019 and 2021), HQ_{ing} (2015, 2016, 2017, 2019, 2021) and HQ_{dr} (2019 and 2021) (no health risk occurred) (Tables 5 and 6). HQ and HI standards of USEPA, [53,54] suggested that when HQ or HI > 1 noncarcinogenic effects occurred, and when HQ or HI ≤ 1 no effect on human health. These standards are used to explain the human health risk assessment of Bardawil lagoon water for adults only. According to APHA, [35] when the hazard index for each metal (HI_m) or HI < 1 indicates an acceptable level of risk as in HI_m of Pb of years 2019 and 2021, while when HI_m or HI > 1 as in most of HI_m of Cd and Pb (Tables 5 & 6 and Figs. 2 & 3), unacceptable risk of non-carcinogenic effects occurred. As well as hazard index for each site (HI_s) is more than 1, thus the unacceptable level of risk of non-carcinogenic occurred (Table 6).

Carcinogenic or cancer risks from heavy metals are studied by three pathways ingestion, dermal absorption, and inhalation. USEPA, [30,55] suggested that the level risk of cancer is 1×10^{-6} (1/1,000,000), where this value is the point

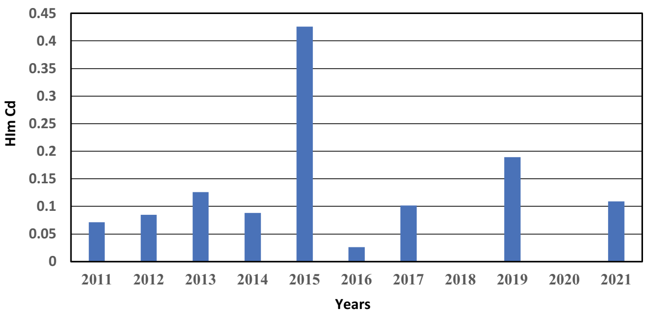

Fig. 2. Hazard index of Cd in Bardawil lagoon water from 2011 to 2021.

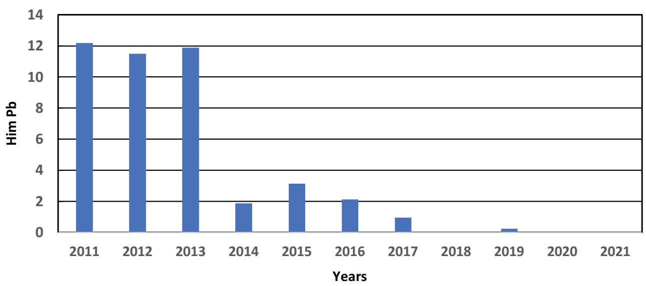

Fig. 3. Hazard index of Pb in Bardawil lagoon water from 2011 to 2021.

of excess of the cancer probability. 1/1,000,000 meaning that 1 per million is calculated by Ug/l of heavy metals consumption by oral and dermal contact during 70 y. The safe level of cancer risk must be lower than 1×10^{-6} (1/1,000,000) and the borderline range from 1×10^{-6} (1/1,000,000) to 1×10^{-4} (1/10,000), but when the level passes 1×10^{-4} the health hazards occurred.

Probably cancer risk of ingestion (PCR_{ing}) and Probably cancer risk of dermal absorption (PCR_{dr}) of Cd and Pb of Bardawil lagoon water (Tables 5 & 6 and Figs. 4–7) were more than the safe level and out the borderline 1×10^{-6} (1/1,000,000) to 1×10^{-4} (1/10,000). Thus, the exposure of adults to ingestion or dermal contact by Bardawil lagoon water according to the previous factors applied in the PCR

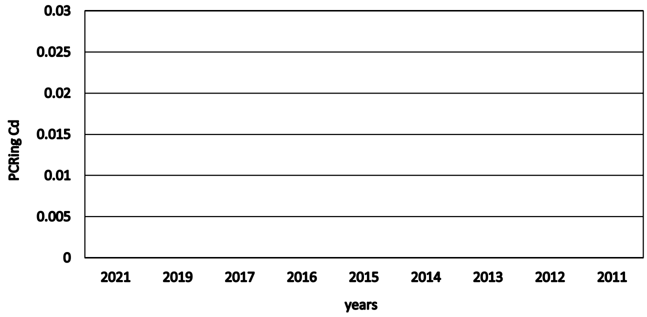

Fig. 4. Probably cancer risk for ingestion (PCR_{ing}) of Cd of Bardawil lagoon water.

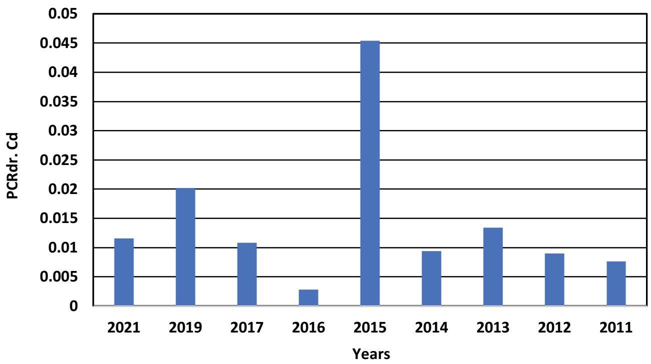

Fig. 5. Probably cancer risk for dermal absorption (PCR_{ing}) of Cd of Bardawil lagoon water.

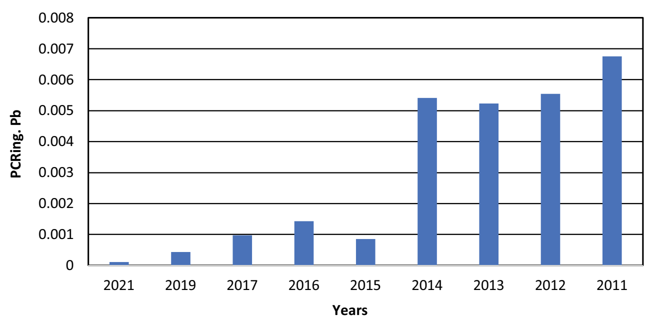

Fig. 6. Probably cancer risk for ingestion (PCR_{ing}) of Pb of Bardawil lagoon water.

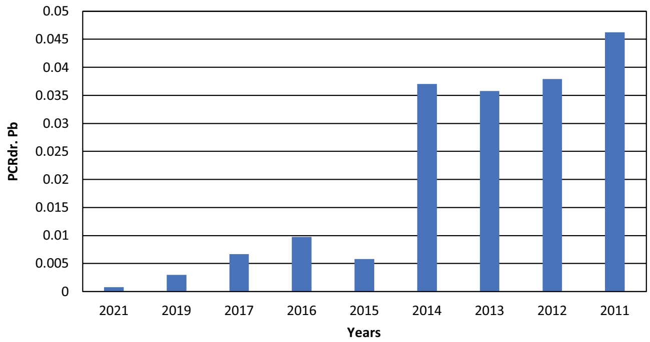

Fig. 7. Probably cancer risk for dermal absorption (PCR_{ing}) of Pb of Bardawil lagoon water.

equation led to the cancer risk is more occurred on the adults who worked in Bardawil lagoon, and they need some intervention and remediation.

4. Conclusion

The pH values during the period from 2011 to 2021 have minor variations through 10 y. Many sites of Bardawil lagoon water have high EC due to the high content of minerals and total dissolved solids. The type of Bardawil lagoon is not stable through the previous 10 y (2011–2021), most of the years (2011, 2012, 2014, 2016, 2017, 2019, and 2021) the lagoon was the eutrophic type, in 2013 was oligotrophic and in 2015 the Bardawil lagoon was a hypertrophic type. Also, total phosphate as nitrogen causes the growth of algae, thus the dissolved oxygen is decreased. Phosphate appears as a result of sewage, industrial, and agricultural drainage in water. The low DO values are due to the high temperatures, which cause a decrease in oxygen solubility. Where the all studied samples were collected in the summer (August). The study of Bardawil lagoon water led to the estimate of the heavy metals risk and another chemical risk over 10 y. HMI of Cd and Pb in the acceptable limit (HMI is <2) except in HMI of Pb in 2011, 2012, 2013, and 2014. PCR equation led to the cancer risk is more occurred on the adults working in Bardawil lagoon, and they need some intervention and remediation.

Based on the study's findings, it is recommended that enterprises that discharge wastewater into the lagoon be required to treat it before discharging it. Trash management, environmental sanitation, and public awareness of the threats posed by contaminated water are also advocated in the locations.

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