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RESEARCH ARTICLE

Assessment of trace element contamination in the historical nesting grounds of green sea turtle (*Chelonia mydas*) in Hainan Island, China

Ting Zhang[1] · **Liu Lin**[1] · **Deqin Li**[1] · **Li Jian**[1] · **Rui Li**[1] · **Jichao Wang**[1] · **Haitao Shi**[1]

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Abstract

Trace element pollution is a potential threat to the reproduction of sea turtles. Hainan Island was previously the most important nesting ground of green sea turtles in China before they disappeared approximately 36 years ago. The Chinese government has encouraged restoration work on historical nesting grounds, and it is necessary to evaluate the status of these sites before conducting habitat restoration. This study analyzed the concentrations of seven trace elements in the surface sediments of 13 historical nesting grounds in Hainan. The average concentrations were 19.47 (Cr), 4.67 (Ni), 6.99 (Cu), 0.08 (Cd), 16.68 (Pb), 0.02 (Hg), and 5.27 (As) mg/kg, which were lower than the first-grade limit values of the GB (18668–2002) national standard in China. The concentrations were close to the background value, except for the relatively high Cd value. The potential ecological risk was ranked as Cd > Hg > As > Cu > Pb > Cr. The spatial distribution of trace element contamination in Hainan was uneven, with high potential ecological risk levels of Cd and Hg contamination in Longwan'gang, Shimeiwan, Yazhou Qu, and Fushicun. Marine mariculture, wastewater discharge, and fishing boats are the main sources of trace element contamination in Hainan. We recommend strengthening the control of Hg and Cd contamination sources, monitoring trace elements in relevant/interest areas, and the environmental protection department should curb local residents from directly discharging mariculture wastewater and domestic sewage into the sea.

Keywords Habitat restoration · Mariculture · Risk index · Surface sediment · Trace element · Wastewater discharge

Introduction

In recent years, rapid economic development in coastal areas has led to the increasingly serious impact of human activities, heavily affecting the beach and intertidal sediments (Ye et al. 2014). Typical marine environmental pollutants include trace metals, whose toxicity and non-biodegradable characteristics pose a significant threat to marine wildlife (Finlayson et al. 2016). The content of metal elements in marine sediments is relatively stable, which typically occurs in regionalization, and variations in its distribution have become an important indicator in marine environmental assessment (Chabukdhara and Nema 2012).

Sea turtles are long-living species, and most adult females return to their birthplace to lay eggs (Triessnig et al. 2012). Therefore, trace element pollution is a potential threat that affects sea turtles' life span and survival (Marco et al. 2004; Çelik et al. 2006). During incubation, sea turtle eggs absorb trace element pollutants through their shell membrane, reducing the hatching success rate (Andreani et al. 2008; Yuiko et al. 2014; Tapilatu et al. 2020a, b; Jian et al. 2021; Savoca et al. 2021). Thus, it is imperative to evaluate the status of trace element contamination in the nesting grounds of sea turtles (da Silva et al. 2016). However, little attention has been paid to monitoring trace element contamination in sea turtles' nesting grounds worldwide. To our knowledge, only Çelik et al. (2006) and Jian et al. (2021) investigated within-habitat trace element contamination in the nesting sites of sea turtles; other studies only briefly introduced the trace element contents of nesting grounds as a background value.

Historically, nesting grounds of green sea turtles are scattered at several sites on Hainan, including Haikou,

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Ting Zhang and Liu Lin are co-first authors.

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✉ Haitao Shi
haitao-shi@263.net

[1] Ministry of Education Key Laboratory for Ecology of Tropical Islands, Key Laboratory of Tropical Animal and Plant Ecology of Hainan Province, College of Life Sciences, Hainan Normal University, Haikou 571158, China

Wenchang, Qionghai, Wanning, Lingshui, Sanya, and Dongfang, among others. However, sea turtles have disappeared from those historical beaches for over 30 years, and the last nesting record was in 1985 (Frazier et al. 1988; Chan et al. 2007). Various factors such as illegal hunting, beach encroachment, and marine pollution contributed to the disappearance of sea turtles (Tan and Huang 1989; Wang 1993; Wei 2016). Fortunately, a few successful cases have shown that if the historical nesting grounds are strictly managed and protected, the sea turtles will return to these grounds to lay eggs. For example, after having strictly managed and protected historical nesting grounds at Pearl Cays, Nicaragua, and Versova beach in Mumbai, India, sea turtles finally returned to lay eggs (Wilson 2015; Caunt 2019).

The Chinese government issued the “Sea Turtle Conservation Action Plan (2019–2033)” in 2018, and the restoration of historical nesting grounds is encouraged by this plan (Chinese Ministry of Agriculture and Rural Affairs 2019). Therefore, locating and evaluating those historical nesting grounds is necessary before selecting them as potential restoration sites. In this study, we surveyed the trace element contamination at 13 historical nesting grounds of green sea turtles to determine the following: (1) the current status of trace element contamination in these nesting grounds in Hainan; (2) the potential ecological risks of the trace elements. Management suggestions are also proposed according to those survey results.

Materials and methods

Study area and sampling setting

Hainan Island (18° 10′–20° 10′ N, 108° 37′–111° 03′ E) is located in the northwestern part of the South China Sea, and it is the second largest island in China, covering an area of 33,900 km^2. This island is dominated by agriculture and tourism, with less heavy chemical industry. The total number of tourists from China and abroad is approximately 50 million each year, and most of the beaches have been developed as tourist attractions (Cai et al. 2016; Xu et al. 2016).

Through documentary records and preliminary investigations, we selected 13 historical nesting grounds of sea turtles around Hainan to conduct this study in July 2019, including Da’aowan (DAW), Fengjiawan (FJW), Longwan’gang (LWG), Shimeiwan (SMW), Li’an’gang (LAG), Qingshuiwan (QSW), Tufuwan (TFW), Dadonghai (DDH), Yazhou Qu (YZQ), Fushicun (FSC), Qiziwan (QZW), Lin’gaojiao Fishermen Village (LGY), and Rongshanliao (RSL) (Fig. 1).

Sample collection

The geographic coordinates of the nesting grounds were recorded using a global positioning system. Surface sediment samples from a depth of 0–2 cm were collected at each sampling station as a composite of three subsamples (Li et al. 2015; Beckwith and Fuentes 2018; Duncan et al. 2018; Zhang et al. 2020). After collecting samples, they were stored in airtight polyethylene bags and refrigerated for further laboratory analysis. All utensils required for sampling were soaked in dilute HNO_3 (1:3) for 24 h. The collection, storage, and transportation of samples were performed following the National Standards of Marine Monitoring Regulations established by the Chinese government (GB 17378.3-2007) (Luo et al. 2010; Li et al. 2013; Wang et al. 2017).

Trace element analysis

Before conducting the elemental analysis, approximately 20 g of sediment sample was dried at 56 °C for 24 h, then ground to < 0.125 mm, and stored in a clean ziplock bag at 15–25 °C. Containers, such as the polytetrafluoroethylene microwave digestion tank, 50-mL volumetric flask, 25-mL glass colorimetric tube, and 15-mL polyethylene tube, were cleaned, completely soaked in 10% HNO_3 for 24 h, washed with ultrapure water, dried at 56 °C, and stored in a sealed container for later use.

The sediment sample was weighed to 0.1 g (accurate to 0.0001 g) and transported to the bottom of the digestion tank with weighing paper. Mixed acid (i.e., 6 mL HNO_3 and 2 mL HF) was added, and the sample was pre-digested for 2 h. The sample was sealed and placed in a microwave digestion apparatus after stabilizing the reaction (i.e., the foam disappeared). The chemical system of the ETHOS One microwave (Milestone, Sorisole, Italy) was used to perform microwave-assisted digestion with HNO_3 (i.e., increased to 200 °C in 15 min, reacted for 20 min, then cooled) at 1500 W, and the total reaction time was 110 min. After the completion of digestion, the acid inside the solution was removed from the solution at 105 °C. After cooling, the solution was washed in a volumetric flask with 10% HNO_3 at least five times, then its volume was adjusted to 50 mL (Wang and Luo 2016). The mass concentrations of Cu, Pb, Cr, Cd, and Ni were determined by inductively coupled plasma mass spectrometry (XSERIES 2 ICP-MS; Thermo Fisher Scientific, Waltham, MA).

To determine Hg and As concentrations, the sediment sample was weighted to 0.2 g (accurate to 0.0001 g) and transported to the bottom of the colorimetric tube with weighing paper. Aqua regia was configured as the

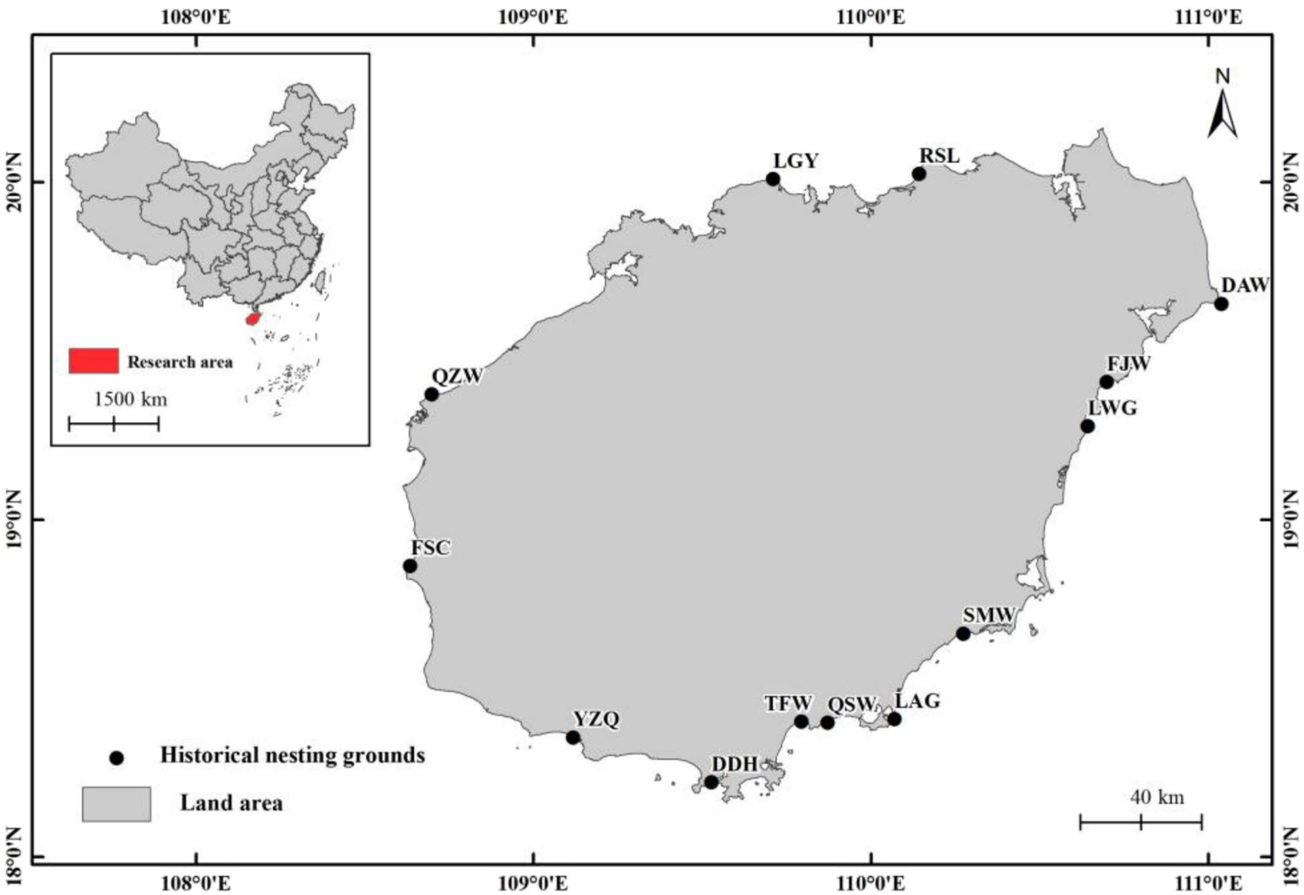


Fig. 1 Map of Hainan Island and 13 historical nesting grounds of sea turtles. DAW: Da'aowan; FJW: Fengjiawan; LWG: Longwan'gang; SMW: Shimeiwan; LAG: Li'an'gang; QSW: Qingshuiwan; TFW: Tufuwan; DDH: Dadonghai; YZQ: Yazhou Qu; FSC: Fushicun; QZW: Qiziwan; LGY: Lin'gaojiao Fishermen Village; RSL: Rongshanliao

digestion solution, as follows: concentrated HCl and concentrated HNO_3 were mixed (3:1) in a beaker, and the mixture was diluted (1:1) with ultrapure water, stirred evenly with a glass rod, and left at approximately 15–25 °C for 30 min until the solution turned blood red (Sun 2018). Consequently, 10 mL of the digestion solution was added to the sample's calorimetric tube. Next, water bath digestion was conducted for an hour, and the solution was finally diluted to 25 mL with ultrapure water after cooling. Atomic fluorescence spectrometry (AFS-3000, Beijing Haiguang Instrument Co., Ltd., Beijing, China) was used to determine the mass concentration of Hg and As.

The efficiency of the digestion process is an important step (Sun 2018). To ensure the accuracy and credibility of the experimental data, repeated samples, blank samples, and standard samples were analyzed in all test processes. For the chemical analysis, the standard sediment reference materials (i.e., GBW 07314, GBW 07316) provided by the Second Institute of Oceanography of the Chinese State Oceanic Administration were used to evaluate the measurement accuracy. The recovery rates of the trace element concentrations were in the range of 90.5–113.35% (Table S1), which was within 20% of the certified values (Ma et al. 2022). The detection limits of the trace element for sediment were 0.005, 0.002, 0.01, 0.001, 0.002, 0.02, and 0.001 mg/kg for Cr, Ni, Cu, Cd, Pb, As, and Hg, respectively (Table S2). Therefore, the experimental data had high credibility and reliability and could further analyze the trace element contamination in beach sediments.

Statistical analysis

SPSS 19.0 software was used for statistical analysis. Pearson's cluster analysis was performed to determine the associations between trace element concentrations in the historical nesting grounds, and significance was set at $p = 0.05$. The relevant data in the article are expressed as the mean ± standard deviation (mean ± SD).

Potential ecological risk assessment of trace elements

The potential ecological risk index method proposed by Hakanson (1980) was used to assess the ecological risks of six trace elements in the historical nesting grounds from Hainan. Notably, since Ni has no background reference value, it was not evaluated (Hakanson 1980). The calculation formula of the synthesized potential ecological risk index (*RI*) was as follows:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i * c_f^i$$

$$c_f^i = c_s^i / c_n^i$$

where E_r^i is the individual potential ecological risk factor for the trace element *i*; the toxicity coefficient of the trace elementT_r^i is Cr (2), Cu (5), Cd (30), Pb (5), Hg (40), and As (10) (Hakanson 1980); C_f^i is the enrichment coefficient of the trace element *i*; c_s^f is the determined average concentration of the trace element *i*; and c_n^i is the local background value of the trace element *i* (Xia et al. 2011). According to the ecological risk classification standard, the E_r^i value can be classified as follows: (1)$E_r^i < 40$: slight pollution; (2) $40 \leq E_r^i \leq 80$: moderate pollution; (3) $80 \leq E_r^i \leq 160$: high pollution; (4) $E_r^i > 160$: extremely high pollution. The *RI* value can be classified as follows: (1) $RI < 105$: slight pollution; (2) $105 \leq RI \leq 210$: moderate pollution; (3) $210 \leq RI \leq 420$: high pollution; (4) $RI > 420$: extremely high pollution (Li and Xu 2014).

Results

Trace element average concentrations in historical nesting grounds

The median concentrations (mg/kg) of seven trace elements in the sediments were in the order Cr (19.47) > Pb (16.68) > Cu (6.99) > As (5.27) > Ni (4.67) > Cd (0.08) > Hg (0.02) (Table 1). The maximum concentrations (mg/kg) of the seven trace elements Cr (46.98), Pb(30.01), Cu (31.29), As (9.25), Ni (10.01), Cd (0.23), and Hg (0.06) in each nesting ground were lower than the first-grade limit values of the GB (18668–2002) national standard in China (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 2002) and less than the threshold effect levels developed by Long et al. (1995), which represents a minimal-adverse biological effect range. Accordingly, the average concentration of the elements from 13 nesting grounds was taken for the overall evaluation of the historical nesting grounds in Hainan. The concentrations of the trace elements analyzed were all close to the background values, except for a high Cd value. Meanwhile, the variation coefficients of five trace elements (Cr, Ni, Cu, Cd, Hg) were greater than 0.5, indicating that these elements' distribution varied greatly in Hainan (Table 1). Compared with other nesting grounds of sea turtles worldwide, elements' concentrations Hainan were at low levels, except for Cd (Table 2).

Spatial distribution pattern of trace element contamination

The spatial distribution of Cr, Cu, and Cd showed similar patterns, and the highest values were predominantly registered in LWG and SMW. The areas with high values for Ni were mainly distributed in FJW, DDH, and LGY. The As concentration from SMW to TFW ranged from 4.70 to 5.70 mg/kg, indicating that As is evenly distributed in the southeast of Hainan. The distribution patterns As and Hg were similar, with high values principally distributed in YZQ and FSC, and a high As value was also registered in FJW (Fig. 2).

Trace element statistical analysis

There was a significant positive correlation between Cr, Cu, and Cd, highlighting that these three elements are homologous, and their sources and migration pathways were similar. Furthermore, the element As was characterized as not correlating with Cr, Cu, Cd, and Pb. In contrast, it was significantly and positively correlated with Hg, which indicates that As and Hg are homologous (Table 3).

The heatmap shows that the trace elements were divided into two clusters. Cluster 1 consisted of Cr, Cu, Cd, and Pb, whereas cluster 2 consisted of Hg, As, and Ni, consistent with the correlation analysis results. Furthermore, the 13 historical nesting grounds were also divided into two clusters, cluster 1: FSC, QZW, QSW, RSL, LAG, and YZQ; cluster 2: FJW, LGY, DDH, DAW, TFW, LWG, and SMW. There was a significant correlation between LWG and SMW, with high Cr, Cd, Cu, and Pb values. Whereas FSC and YZQ had high concentrations of Hg and As, FJW, LGY and DDH had a higher concentration of Ni than did other nesting grounds (Fig. 3).

Potential ecological risk of trace elements

Since Ni has no sediment background value, its potential ecological risk assessment was not conducted in this study. However, the overall potential ecological risk of the other six elements in Hainan was ranked as Cd > Hg > As > Cu > Pb > Cr. Both Cd and Hg had moderate ecological risks, with extremely high contamination at some points (Table 4). Therefore, among the trace elements measured in this study, Cd and Hg are the biggest polluting agents in the historical nesting grounds in Hainan.

Table 1 Average concentration of seven trace elements (mg/kg) in the surface sediments of the historical nesting grounds in Hainan[a]

Term	Cr	Ni	Cu	Cd	Pb	Hg	As
Range	4.64–46.98	1.35–10.01	1.34–31.29	0.02–0.23	6.07–30.01	0.01–0.06	1.18–9.25
Mean ± SD	19.47 ± 12.61	4.67 ± 2.64	6.99 ± 7.94	0.08 ± 0.06	16.68 ± 7.50	0.02 ± 0.02	5.27 ± 2.23
CV	0.65	0.57	1.14	0.72	0.45	0.69	0.42
BV[b]	16.05	-	4.48	0.03	16.09	0.012	5.5
Threshold values[c]	≤80.0	≤40.0	≤35.0	≤0.5	≤60.0	≤0.20	≤20.0
ERL[d]	81	20.9	34	1.2	46.7	1.0	8.2
ERM[d]	370	51.6	270	9.6	218	3.7	70

SD standard deviation, *CV* coefficient of variation, *ERL* threshold effects range low, *ERM* threshold effect range median

[a]“-” indicates no data

[b]Background value of marine sediments offshore of Hainan (Xia et al. 2011)

[c]Environmental quality standards for marine sediment of China (grade I, GB18668-2002)

[d]Sediment quality guidelines for coastal and marine waters developed by Long et al. (1995)

The synthesized potential ecological *RI* indicated that among the 13 historical nesting grounds in Hainan, only three, namely, LAG, QSW, and QZW, were at a slight potential ecological risk level. Four nesting grounds, LWG, SMW, YZQ, and FSC, were at a high potential ecological risk level of Cd and Hg contamination. Three nesting grounds, DAW, TFW, and DDH, were at a moderate potential ecological risk of Cd contamination. In contrast, the other three nesting grounds, FJW, LGY, and RSL, were at a moderate potential ecological risk of Hg contamination (Table 4).

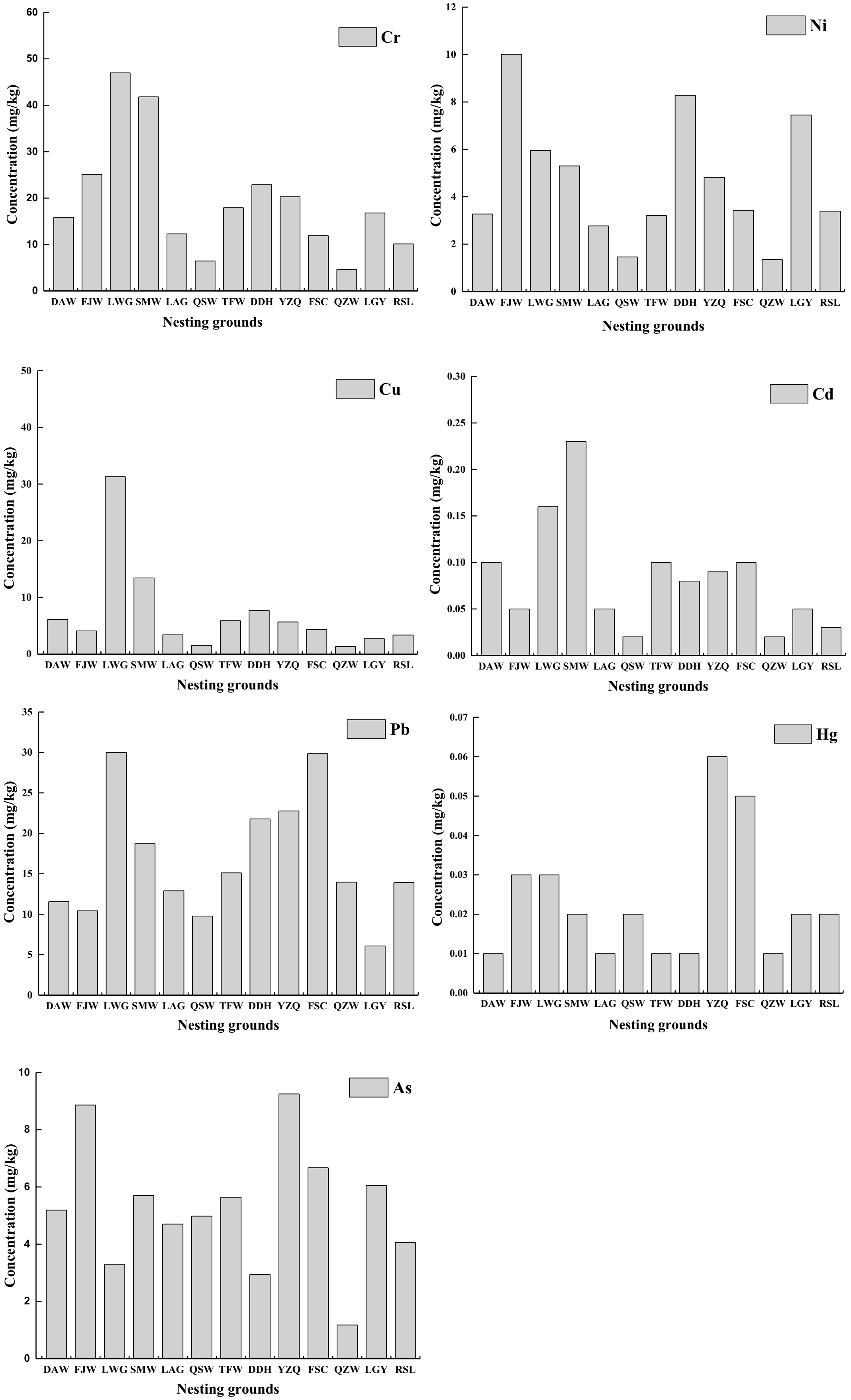
Discussion

With the rapid growth of the human population, acceleration of urbanization, and continuous expansion of industrial activities, the pristine marine environments of many countries and regions are polluted by trace elements (Beldowska et al. 2012; Castillo et al. 2016). Due to the development of industries, mariculture, and tourism in recent years, the coastal areas of Hainan have significantly been affected by various anthropogenic factors, which have led to the accretion of trace elements into the marine environment (He et al. 2017). The mariculture and wastewater discharges are considered the critical contamination sources in Hainan (Cai et al. 2016).

The spatial distribution of trace elements in the beach sediments of Hainan was found to be uneven, especially for Cu, Cd, Hg, and Cr. This is because the distribution of trace elements is closely related to human activities (Xia et al. 2011). The elements Cr, Cu, and Cd had similar spatial distribution, and all were predominantly distributed in LWG and SMW. Moreover, these three elements had the same source and migration path. Based on our field investigation, there are several shrimp ponds and fish farms near LWG and SMW, and there is a sizeable air-open refuse landfill within 1 km of SMW (Anonymity 2014; Liu et al. 2019). Several studies have shown that coastal shrimp ponds and fish farms contribute substantially to trace element contamination in the local offshore marine environment. The contamination stems from metal elements that may be present in fish and shrimp feeds, which may be carried into the environment by effluents released from farms (Chen et al. 2018a; Xing et al. 2018). In addition, Deng et al. (2007) indicated that the

Table 2 The concentration of trace elements (mg/kg) in the nesting grounds of sea turtles worldwide

Nesting grounds	Cr	Ni	Cu	Cd	Pb	Hg	As	Reference
Hainan, China	19.47	4.67	6.99	0.08	16.68	0.02	5.27	In this study
Kazanlı, Mersin-Turkey	80.92~89.05	35.82~45.02	31.66~41.08	5.34~9.03	8.50~12.23	-	3.26~5.35	Çelik et al. (2006)
Santa Rosalía Harbor, Baja California Peninsula, Mexico	-	-	3390	3.76	226	-	-	Shumilin et al. (2013)
Western Moreton Bay, Queensland, Australia	15.00	13.00	-	0.02	15.00	0.10	3.70	Cox and Preda (2005)
Fisherman Island, Queensland, Australia	331.00	13.00	-	0.09	16.00	0.73	-	


Cr
Ni
Cu
Cd
Pb
Hg
As
Concentration (mg/kg)
Nesting grounds
DAW FJW LWG SMW LAG QSW TFW DDH YZQ FSC QZW LGY RSL
0 10 20 30 40 50 60
0 2 4 6 8 10 12
0 10 20 30 40 50
0.00 0.05 0.10 0.15 0.20 0.25 0.30
0 5 10 15 20 25 30 35
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07
0 2 4 6 8 10

◀**Fig. 2** Distribution pattern of seven trace elements in the historical nesting grounds. Notes: Cr: chromium; Ni: nickel; Cu: copper; Cd: cadmium; Pb: lead; Hg: mercury; As: arsenic; DAW: Da'aowan; FJW: Fengjiawan; LWG: Longwan'gang; SMW: Shimeiwan; LAG: Li'an'gang; QSW: Qingshuiwan; TFW: Tufuwan; DDH: Dadonghai; YZQ: Yazhou Qu; FSC: Fushicun; QZW: Qiziwan; LGY: Lin'gaojiao Fishermen Village; RSL: Rongshanliao

refuse landfill could cause serious trace element contamination (e.g., Cu and Cr) to the surrounding environment. Therefore, we believe that the high concentration of Cr, Cu, and Cd in LWG and SMW is likely caused by the nearby mariculture operations and air-open refuse landfills. The concentration of Hg was elevated on some beaches, such as YZQ and FSC, consistent with the results of previous studies (Xia et al. 2011; He et al. 2017). Hg concentration is usually associated with human activities, and its concentration is significantly correlated with the number of mariculture farms and fishing boats in coastal areas (Guo and Huang 2006; He et al. 2017). The nesting grounds surveyed in YZQ and FSC are close to fishing ports and seafood purchasing stations. There are many cage farming activities offshore, and many fishing boats are moored or operated nearby, which release wastewater, leading to severe Hg contamination (Li and Hu 1997; Chen et al. 2018b).

The elements Cd and Hg are the main polluting agents in the historical nesting grounds in Hainan, and both have moderate ecological risks of point source contamination. Cd and Hg contamination are considered to originate from industrial pollution (Cai et al. 2016). Notably, these two elements are potentially highly toxic for organisms (Fraga et al. 2018), and their enrichment in marine environments might threaten marine animals, including sea turtles. This is an ecological warning against excessive urban and industrial development and the destruction of marine resources that damages these coastal areas. Therefore, to restore the historical nesting grounds for sea turtles to return in the future, we should pay more attention to the nesting grounds with medium and high potential ecological risks. For example, Cd and Hg contamination in the nesting grounds of LWG, SMW, YZQ, and FSC should be monitored, and targeted recovery work based on the contamination characteristics of each nesting ground should be conducted. Moreover, the environmental awareness of the local government and residents should be enhanced, and the investigation and management of trace element contamination sources should be strengthened.

Conclusion

This study describes the concentrations of seven trace elements in the surface sediments of 13 historical nesting grounds in Hainan. The potential ecological risk was ranked as Cd > Hg > As > Cu > Pb > Cr. Furthermore, the spatial distribution of trace element contamination was uneven in Hainan. High potential ecological risk levels of Cd and Hg contamination occurred in four historical nesting grounds, LWG, SMW, YZQ, and FSC. The high concentration of Cr, Cu, and Cd in LWG and SMW was likely caused by the nearby mariculture and air-open refuse landfills. On the other hand, FSC and YZQ showed high concentrations of Hg and As, possibly due to cage farming practices and fishing boats offshore. Therefore, the number of highly polluting mariculture and industrial wastes should be limited, and the management of the processing and discharge of sewage in these areas should be improved. To reestablish suitable habitats for sea turtles, we recommended strengthening the control of Hg and Cd contamination sources, and monitoring trace elements in relevant/interest areas. In addition, the environmental protection department should curb local residents from directly discharging mariculture wastewater and domestic sewage into the sea.

Table 3 Pearson correlation coefficient matrix of trace elements

Element	Cr	Ni	Cu	Cd	Pb	Hg	As
Cr	1						
Ni	0.545	1					
Cu	0.872**	0.254	1				
Cd	0.841**	0.205	0.701**	1			
Pb	0.469	0.041	0.621*	0.541	1		
Hg	0.155	0.157	0.122	0.164	0.548	1	
As	0.112	0.372	−0.182	0.119	−0.035	0.664*	1

**Indicates a significant correlation at the 0.01 level (two-sided)

*Indicates a significant correlation at the 0.05 level (two-sided)

Fig. 3 Heatmap analysis of the trace element contents of sediments from 13 historical nesting grounds. DAW: Da'aowan; FJW: Fengjiawan; LWG: Longwan'gang; SMW: Shimeiwan; LAG: Li'an'gang; QSW: Qingshuiwan; TFW: Tufuwan; DDH: Dadonghai; YZQ: Yazhou Qu; FSC: Fushicun; QZW: Qiziwan; LGY: Lin'gaojiao Fishermen Village; RSL: Rongshanliao

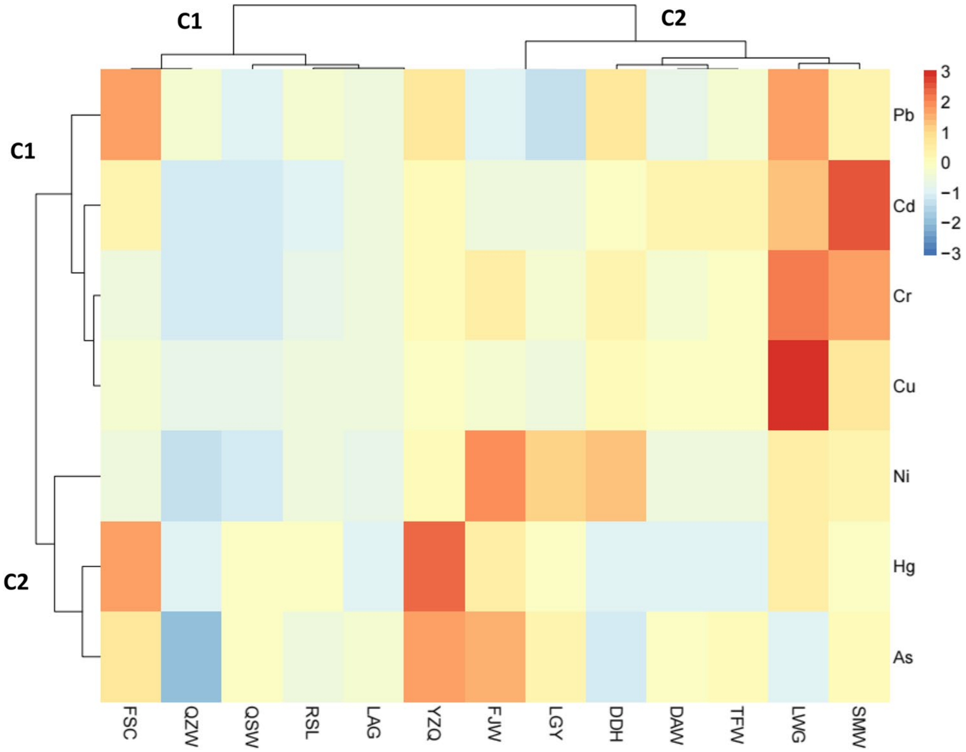


Table 4 Values of individual potential ecological risk index (E_r^i) and synthesized potential ecological risk index (*RI*) in the historical nesting grounds[a]

Nesting grounds	E_r^i						*RI*
	Cr	Cu	Cd	Pb	Hg	As	
DAW	1.97	6.83	99.75	3.59	27.88	9.43	149.45
FJW	3.13	4.56	46.00	3.24	115.98	16.11	189.01
LWG	5.85	34.92	162.25	9.32	87.98	6.01	306.33
SMW	5.21	14.99	232.50	5.82	83.02	10.37	351.91
LAG	1.53	3.79	47.75	4.01	26.04	8.55	91.67
QSW	0.80	1.73	22.00	3.04	57.52	9.06	94.15
TFW	2.24	6.58	95.00	4.70	28.00	10.25	146.77
DDH	2.85	8.61	79.75	6.77	47.73	5.35	151.05
YZQ	2.53	6.33	86.75	7.07	203.65	16.81	323.14
FSC	1.49	4.86	95.25	9.28	165.63	12.13	288.62
QZW	0.58	1.49	24.00	4.34	40.77	2.14	73.33
LGY	2.09	3.03	50.50	1.89	62.33	11.01	130.85
RSL	1.26	3.75	33.50	4.32	71.40	7.38	121.61
Range	0.58–5.85	1.50–34.92	20.00–230	1.89–9.33	33.33–200	2.15–16.82	73.33–351.91
Mean	2.43	7.80	80.00	5.18	66.67	9.58	189.54
Degree of risks	Slight	Slight	Moderate, extremely high pollution in some points	Slight	Moderate, extremely high pollution in some points	Slight	-

[a] E_r^i values were classified as follows: (1) $E_r^i < 40$: slight pollution; (2) $40 \le E_r^i \le 80$: moderate pollution; (3) $80 \le E_r^i \le 160$: high pollution; (4) $E_r^i > 160$: extremely high pollution. The *RI*value can be classified as follows: (1) $RI < 105$: slight pollution; (2) $105 \le RI \le 210$: moderate pollution; (3) $210 \le RI \le 420$: high pollution; (4) $RI > 420$: extremely high pollution

DAW Da'aowan, *FJW* Fengjiawan, *LWG* Longwan'gang, *SMW* Shimeiwan, *LAG* Li'an'gang, *QSW* Qingshuiwan, *TFW* Tufuwan, *DDH* Dadonghai, *YZQ* Yazhou Qu, *FSC* Fushicun, *QZW* Qiziwan, *LGY* Lin'gaojiao Fishermen Village, *RSL* Rongshanliao

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Availability of data and materials All authors consent when it is published.

Author contribution Ting Zhang: conceptualization; formal analysis; investigation; methodology; writing-original draft; writing-review and editing. Liu Lin: conceptualization; funding acquisition; formal analysis; investigation; methodology; writing-original draft; writing-review and editing. Deqin Li: investigation, methodology, writing-review and editing. Li Jian: writing-review and editing, methodology. Rui Li: investigation, methodology. Jichao Wang: validation; visualization; writing-review and editing. Haitao Shi: conceptualization; funding acquisition; writing-review and editing.

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Declarations

Ethics approval Not applicable.

Consent to participate All authors consent.

Consent for publication All authors consent when it is published.

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References

Andreani G, Santoro M, Cottignoli S, Fabbri M, Carpenè E, Isani G (2008) Metal distribution and metallothionein in loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles. Sci Total Environ 39:287–294. https://doi.org/10.1016/j.scitotenv.2007.09.014

Anonymity (2014) A high-grade residential area is close to a air-open refuse landfill in Shimei Bay, Hainan, and local residents have long suffered from the stink. Sohu. https://www.sohu.com/a/521195_100539. Accessed 26 November 2014

Beckwith VK, Fuentes MMPB (2018) Microplastic at nesting grounds used by the northern Gulf of Mexico loggerhead recovery unit. Mar Pollut Bull 131:32–37. https://doi.org/10.1016/j.marpolbul.2018.04.001

Beldowska M, Saniewska D, Falkowska L, Lewandowska A (2012) Mercury in particulate matter over Polish zone of the southern Baltic Sea. Atmos Environ 46:397–404. https://doi.org/10.1016/j.atmosenv.2011.09.046

Cai TI, Ni JY, Jia JJ, Liu YF, Xia XM, Fan YT (2016) The characteristics of chemical parameters and the pollution evaluation of heavy metals in surficial sediments of four typical bays, Hainan province. Quaternary Sci 36:93–102

Castillo AB, Al-Maslamani I, Obbard JP (2016) Prevalence of microplastics in the marine waters of Qatar. Mar Pollut Bull 4:947–951. https://doi.org/10.1016/j.marpolbul.2016.06.108

Caunt J (2019) Turtles come back to Indian beach for the first time in 20 years after world's biggest clean up, prove we can make a difference. (https://www.boredpanda.com/sea-turtles-conservation-comeback/?utm_source=baidu&utm_medium=organic&utm_campaign=organic)

Çelik A, Kaska Y, Bag H, Aureggi M, Semiz G, Kartal AA (2006) Heavy metal monitoring around the nesting environment of green sea turtles in Turkey. Water Air Soil Pollut 169(1/4):67–79. https://doi.org/10.1007/s11270-006-1562-0

Chabukdhara M, Nema AK (2012) Assessment of heavy metal contamination in Hindon river sediments: a chemometric and geochemical approach. Chemosphere 87(8):945–953

Chan SKF, Cheng IJ, Zhou T, Wang HJ, Gu HX, Son XJ (2007) A comprehensive overview of the population and conservation status of sea turtles in China. Chelonian Conserv Bi 6:185–198. https://doi.org/10.2744/1071-8443(2007)6[185:ACOOTP]2.0.CO;2

Chen SQ, Cai ZF, Wu ZJ, Lin GY, Ma K, Xing KM, Wang DR (2018a) Distribution characteristics of heavy metals and its evaluation in the surface sediment of Huachang Bay, Hainan Province. J Appl Oceanography 37:84–93

Chen SQ, Wu ZJ, Cai ZF, Xiang YY, Xing KM, Wang DR, Lin GY, Tong YH (2018b) Distribution characteristics and pollution evaluation of heavy metals in the surface sediments of Li'an lagoon, Hainan province. Mar Sci 42(2):124–133

Chinese Ministry of Agriculture and Rural Affairs (2019) Notice of the Ministry of Agriculture and Rural Affairs on Printing and Distributing the Action Plan for the Protection of Sea Turtles (2019-2033) Nongyufa[2018] No. 31. Bull Ministry of Agric Rural Affairs People's Republic China 1:56–56

Cox ME, Preda M (2005) Trace metal distribution within marine and estuarine sediments of Western Moreton Bay, Queensland, Australia: relation to land use and setting. Geogr Res 43(2):173–193. https://doi.org/10.1111/j.1745-5871.2005.00312.x

da Silva CC, Klein RD, Barcarolli IF, Bianchini A (2016) Metal contamination as a possible etiology of fibropapillomatosis in juvenile female green sea turtles *Chelonia mydas* from the southern Atlantic Ocean. Aquat Toxicol 170:42–51. https://doi.org/10.1016/j.aquatox.2015.11.007

Deng HG, Zhang J, Chen ZL, Wang DQ (2007) Pollution and assessment of heavy metals in the tidal flat sediment near Laogang Garbage Landfill of Shanghai. Chin J Soil Sci 38:347–351

Duncan EM, Arrowsmith J, Bain C, Broderick AC, Lee J, Metcalfe K, Pikesley SK, Snape RTE, van Sebille E, Godley BJ (2018) The true depth of the Mediterranean plastic problem: extreme microplastic pollution on marine turtle nesting beaches in Cyprus. Mar Pollut Bull 136:334–340. https://doi.org/10.1016/j.marpolbul.2018.09.019

Finlayson KA, Leusch FDL, van de Merwe JP (2016) The current state and future directions of sea turtle toxicology research. Environ Int 94:113–123

Fraga NS, Martins AS, Faust DR, Sakai H, Bianchini A, da Silva CC, Aguirre AA (2018) Cadmium in tissues of green turtles (*Chelonia mydas*): a global perspective for marine biota. Sci Total Environ 637-638:389–397. https://doi.org/10.1016/j.scitotenv.2018.04.317

Frazier SS, Frezier JG, Ding HB, Huang ZJ, Zheng J, Lu L (1988) Sea turtles in Fujian and Guangdong Provinces. Acta Herpetologica Sinica 7:16–46

General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (2002) Standards Press of China. Standards Press of China, Beijing, 2

Guo XY, Huang CJ (2006) Distribution and source of heavy metal elements in sediments of Zhanjiang Harbor. J Trop Oceanography 25:91–97

Hakanson L (1980) An ecological risk index for aquatic pollution control: a sediment to logical approach. Water Res 14:975–1001

He HJ, Gan HY, He JX, Xia Z, Ruan M, Yang YP (2017) Distribution pattern of heavy metals in the coastal sediment of southern Hainan island and ecological risk assessment. Marine Geol Front 33:47–55

Jian L, Guo R, Zheng XB, Shi HT, Wang JC (2021) Trace elements in green turtle eggshells and coral sand sediments from the Xisha Islands, South China Sea. Mar Pollut Bull 164:112036. https://doi.org/10.1016/j.marpolbul.2021.112036

Li YQ, Hu ZM (1997) Hg pollution in the sea. Marine Scientific Tech Doc 5:5–19

Li F, Xu M (2014) Source characteristics and contamination evaluation of heavy metals in the surface sediments of Haizhou Bay. Environ Sci 35(3):1035–1040. https://doi.org/10.13227/j.hjkx.2014.03.031

Li JX, Li JF, Zheng L, Wang ZG, Chen FR, Wang XR (2013) Distribution of heavy metals in the mid-south part of South China Sea water. Environ Monitor China 29:65–71

Li JC, Deng YG, Sun JJ, Zheng HS, Han J, Fan K, Li C, Wei LM (2015) Re-study on particle size variation of surface sediments on Guantouling beach in the North Sea. Geological Review 61:77–78

Liu CL, Wang JF, Chen KZ (2019) Trash trapped islands, hidden safety hazards in many garbage dumps in Hainan. Economic Information Daily. http://www.jjckb.cn/2019-07/22/c_138246295.htm. Accessed 22 July 2019

Long ER, Macdonald DD, Smith SL, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ Manag 19(1):81–97

Luo XX, Zhang R, Yang JQ, Liu RH, Tang W, Yan Q (2010) Distribution and pollution assessment of heavy metals in surface sediment in Laizhou Bay. Ecol Environ 19:262–269

Ma ZH, Qu XN, He ZR, Zhao XN, Liu YQ, Zhang YX, Yang L (2022) Spatial distribution characteristics and source analysis of heavy metals in the sediments of Yuehai Lake, Ningxia. J Hydroecol 43:116–124

Marco A, Lopez-Vicente M, Perez-Mellado V (2004) Arsenic uptake by reptile flexible-shelled eggs from contaminated nest substrates and toxic effect on embryos. Bull Environ Contam Toxicol 72:983–990. https://doi.org/10.1007/s00128-004-0340-1

Savoca D, Arculeo M, Vecchioni L, Cambera I, Visconti G, Melfi R, Arizza V, Piccionello AP, Buscemi S, Pace A (2021) Can phthalates move into the eggs of the loggerhead sea turtle Caretta caretta? The case of the nests on the Linosa Island in the Mediterranean Sea. Mar Pollut Bull 168:112395

Shumilin E, Jimenez-Illescas RA, Lopez-Lopez S (2013) Anthropogenic contamination of metals in sediments of the Santa Rosalıa Harbor, Baja California Peninsula. Bull Environ Contam Toxicol 90:333–337

Sun CH (2018) Microplastics and heavy metal pollution in the intertidal zone of Bohai Bay and its ecological risks. Master's Dissertation. Tianjin Normal University in China.

Tan YX, Huang ZJ (1989) Resource restoration and artificial breeding of sea turtles. Mar Sci Bull 8:114–117

Tapilatu RF, Wona H, Siburian RHS (2020a) Data on environmental contaminants in sea turtle eggs at Venu Island, Kaimana – West Papua, Indonesia. Data in Brief 31(6):105778

Tapilatu RF, Wona H, Siburian RHS, Saleda ST (2020b) Heavy metals contaminants in the eggs and temperatures of nesting beaches of sea turtles in Kaimana, West Papua, Indonesia. Biodiversitas J Biol Divers 21(10):4582–4590

Triessnig P, Roetzer A, Stachowitsch M (2012) Beach condition and marine debris: new hurdles for sea turtle hatchling survival. Chelonian Conserv and Bi 11:68–77. https://doi.org/10.2744/CCB-0899.1

Wang YM (1993) Achievement and perspective of the researches on South China Sea turtle resources and protection in China. Chin J Ecol 12:60–61

Wang CD, Luo SX (2016) Determination of metal elements in marine sediments by nitric acid-hydrofluoric acid digestion and ICP-MS. J Guilin Univ Technol 36:337–340

Wang L, Yu KF, Wang YH, Wang SP, Huang XY, Zhang RJ, Wang LW (2017) Distribution characteristic of heavy metals in coral reefs located in the Zhongsha Islands and Xisha Islands of South China Sea. Trop Geogr 37:718–727

Wei WZ (2016) The study on conservation biology of green sea turtle (*Chelonia mydas*) from South China Sea, China. Master's Dissertation. East China Normal University.

Wilson S (2015) With local help, hawksbill sea turtles make a comeback in Nicaragua, (https://news.mongabay.com/2015/01/with-local-help-hawksbill-sea-turtles-make-a-comeback-in-nicaragua/)

Xia N, Xue GC, Fu YR, Yang Y, Liu CZ, Ma RL (2011) Analysis of ecological risk and the content situation of heavy metals in surface sediments of Hainan Island's Inshore. Resour Environ Eng 25(3):244–247

Xing KM, Chen SQ, Cai ZF, Xiang YY, Chen XH, Wang HX, Wang DR (2018) Distribution characteristics and pollution evaluation of heavy metals in surface sediment of Dongzhai Haibor, Hainan Province. Advances Marine Sci 36(3):478–488

Xu FJ, Yan HM, Tian X, Qiu LW, Liu ZQ, Li AF, Zhao YF, Yin XB (2016) Evaluation of heavy metal pollution in surface sediments in the continental shelf to the east of Hainan Island. China Environ Sci 36:252–261

Ye XY, Wang P, Li X, Wang JG, Zhao ZZ (2014) A study on enrichment of heavy metals in the surface sediments of mangrove wetland from Northeast Hainan Island. Ecol Econ 5:318–321

Yuiko M, Brette H, David C (2014) Embryonic PCB exposure alters phenotypic, genetic, and epigenetic profiles in turtle sex determination, a biomarker of environmental contamination. Endocrinology 155:4168–4177

Zhang XY, Pang CB, Wang AT, Yuan GL, Sang XZ, Li YZ, Yang Y (2020) Distribution characteristics and source identification of heavy metals in topsoils and subsoils of Hainan Island. Geoscience 34(5):970–978