pollutants

MDPI

Review

Ecological–Health Risk Assessments of Copper in the Sediments: A Review and Synthesis

Chee Kong Yap [1,*], Muhammad Saleem [2,*], Wen Siang Tan [3,4], Wan Mohd Syazwan [1], Noor Azrizal-Wahid [1], Rosimah Nulit [1], Mohd. Hafiz Ibrahim [1], Muskhazli Mustafa [1], Mohd Amiruddin Abd Rahman [5], Franklin Berandah Edward [6], Takaomi Arai [7], Wan Hee Cheng [8], Hideo Okamura [9], Mohamad Saupi Ismail [10], Krishnan Kumar [8], Ram Avtar [11], Khalid Awadh Al-Mutair [12], Salman Abdo Al-Shami [13], Geetha Subramaniam [8] and Ling Shing Wong [8]

1 Department of Biology, Faculty of Science, University Putra Malaysia, Serdang 43400, Selangor, Malaysia; mhdsyazwan@upm.edu.my (W.M.S.); azrizal_wahid@yahoo.com (N.A.-W.); rosimahn@upm.edu.my (R.N.); mhafiz_ibrahim@upm.edu.my (M.H.I.); muskhazli@upm.edu.my (M.M.)
2 Department of Pathology, School of Medicine and Health Sciences, University of North Dakota, Grand Forks, ND 58202, USA
3 Department of Microbiology, Faculty of Biotechnology and Biomolecular Sciences, University Putra Malaysia, Serdang 43400, Selangor, Malaysia; wstan@upm.edu.my
4 Laboratory of Vaccines and Biomolecules, Institute of Bioscience, University Putra Malaysia, Serdang 43400, Selangor, Malaysia
5 Department of Physics, Faculty of Science, University Putra Malaysia, Serdang 43400, Selangor, Malaysia; mohdamir@upm.edu.my
6 Natural Resources and Environment Board, Petra Jaya, Kuching 93050, Sarawak, Malaysia; franklin_dwrd@yahoo.com
7 Environmental and Life Sciences Programme, Faculty of Science, University Brunei Darussalam, Jalan Tungku Link, Gadong BE1410, Brunei; takaomi.arai@ubd.edu.bn
8 Faculty of Health and Life Sciences, Inti International University, Persiaran Perdana BBN, Nilai 71800, Negeri Sembilan, Malaysia; wanhee.cheng@newinti.edu.my (W.H.C.); kumar.krishnan@newinti.edu.my (K.K.); geetha.subramaniam@newinti.edu.my (G.S.); lingshing.wong@newinti.edu.my (L.S.W.)
9 Faculty of Maritime Sciences, Graduate School of Maritime Sciences, Kobe University, Kobe 658-0022, Japan; okamurah@maritime.kobe-u.ac.jp
10 Fisheries Research Institute, Batu Maung, Pulau Pinang 11960, Malaysia; saupi@rocketmail.com
11 Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0808, Japan; ram@ees.hokudai.ac.jp
12 Department of Biology, Faculty of Science, University of Tabuk, Tabuk P.O. Box 741, Saudi Arabia; kmutairi@ut.edu.sa
13 Indian River Research and Education Center, IFAS, University of Florida, Fort Pierce, FL 34945, USA; alshami200@gmail.com
* Correspondence: yapckong@hotmail.com or yapchee@upm.edu.my (C.K.Y.); msaleemqau@yahoo.com or muhammad.saleem.1@und.edu (M.S.)

Citation: Yap, C.K.; Saleem, M.; Tan, W.S.; Syazwan, W.M.; Azrizal-Wahid, N.; Nulit, R.; Ibrahim, M.H.; Mustafa, M.; Rahman, M.A.A.; Edward, F.B.; et al. Ecological–Health Risk Assessments of Copper in the Sediments: A Review and Synthesis. *Pollutants* **2022**, *2*, 269–288. https://doi.org/10.3390/pollutants2030018

Academic Editor: Mauro Marini

Received: 11 May 2022
Accepted: 15 June 2022
Published: 28 June 2022

Abstract: The ecological and children's Health Risk Assessments (HRA) of Copper (Cu) in aquatic bodies ranging from rivers, mangrove, estuaries, and offshore areas were studied using the Cited Cu Data in The Sediments (CCDITS) from 125 randomly selected papers published from 1980 to 2022. The ecological and children's HRA were assessed in all CCDITS. Generally, local point Cu sources (8%) and lithogenic sources were the main controlling factors of Cu concentrations. The present review revealed three interesting points. First, there were 11 papers (8%) documenting Cu levels of more than 500 mg/kg dw while China was the country with the highest number (26%) of papers published between 1980 and 2022, out of 37 countries. Second, with the Cu data cited from the literature not normally distributed, the maximum Cu level was higher than all the established guidelines. However, the median Cu concentration was lower than most of the established guidelines. The median values of the geoaccumulation index (I_{geo}) indicated a status of 'unpolluted' and 'moderate contamination' for the contamination factor (CF), and 'low potential ecological risk' for the ecological risk (ER) of Cu. However, the Cu ER could be based at present on the above mentioned 8% of the literature in the present study. Third, the calculated hazard index (HI) values were found to be below 1, indicating no potential chance of Cu non–carcinogenic effects in both adults and children, except for children's HI values from Lake Pamvotis of Greece, and Victoria Harbor in Hong Kong. Thus, regular monitoring (every 2 years), depending upon the available resources, is recommended to assess the ecological–health risk of Cu pollution in aquatic bodies to abate the risk of Cu exposure to children's health and avoid injurious impacts on the biota. It can be concluded that there is always a need for the mitigation and management of a Cu exposure risk assessment that can be used successfully for screening purposes to detect important human health exposure routes. Consequently, any sediments contaminated with Cu require rapid sediment remediation techniques.

Keywords: copper; sediments; geochemical indexes; health risk assessment

1. Introduction

There are five main reasons why copper (Cu) in sediments is focused on in this review. Firstly, based on global resources data in [1,2], Chile remains the dominant country with 658.2 Mt Cu and world copper resources were at least 1860 Mt Cu (including China). This is mainly caused by human mining for Cu due to the high demand for Cu used in manufacturing industries [1]. Currently, Cu and its compounds have been widely applied in various industries, including textiles, antifouling paints, electrical conductors, plumbing fixtures and pipes, cooking utensils, wood preservatives, pesticides fungicides, fertilizers, etc. [3].

Secondly, due to social-economic activities such as smelting, electroplating, leather production, electronics, agriculture (fertilisers and pesticides), and aquaculture sectors, Cu in sediments can be a secondary source of pollution in aquatic ecosystems. All of the aforementioned activities add to the stress on water and the environment by creating enormous amounts of municipal [4,5] and industrial wastewater [6,7] including potentially harmful compounds such as Cu.

Thirdly, Cu enters the marine environment mostly through rivers and estuaries, it is typically linked to particulate debris which settles and is absorbed into the sediment [8]. As a result, surface sediments constitute the major store and sink for metals and pollutants in aquatic ecosystems [8,9].

Fourthly, human expansion has prompted an increasing release to the environment due to rapid urbanization and industrialization which have led to significant increases in the levels, causing substantial pollution to the aquatic ecosystem. Therefore, it is important to address the role of anthropogenic activities on Cu pollution [8] in relation to many environmental media including sediments which end up as human health risks through different exposure pathways [10–13].

Fifthly, this topic has generated a lot of articles in the literature. According to the Scopus database, there were 674 publications published in scholarly journals between 1930 and May 2022 that featured the words 'copper' and 'sediments,' according to the Scopus database. If the names of the papers included words such as 'metals' and 'elements,' the number would be substantially higher. If non-Scopus indexed journals were taken into consideration, the number would likely be substantially greater. These figures demonstrate the need to keep an eye on Cu levels in aquatic sediments. It is realistic to expect that monitoring studies will become more common in the future.

Sediment refers to a layer of solid particles on the bed of a water body, which consists of any insoluble particulate matter [14]. These particulate matters could be transported from one area to others by various means, for instance, wind, and flowing rivers. Throughout the fate of a sediment particle, there might be a temporary settlement in between its origin and its final resting place. These sediments may also become settled in a delta at the river mouth or become beach deposits by the action of tides, currents, and waves. Coastal sediments are a major sink for metals of both anthropogenic and natural origin [15]. Under certain conditions, these accumulated metals in sediment may be remobilized, changing the surrounding aquatic ecosystem [16].

Both direct and indirect pathways are likely to play a role in the entry of sediment-bound metals into the human body [17]. Therefore, heavy metal pollution in coastal ecosystem is a serious concern. Despite these concerns, there are few studies that have focused on or have investigated the impact of sediment-bound metals on human health directly. The Cu bound to beach sand particles could enter the human body via inhalation of the sand or sedimentary particles, and direct ingestion via hand-to-mouth action especially by children [18]. Therefore, this implies that humans, especially children playing on beaches, may be exposed to these metal contaminants settled in the sand.

The Hazard Index (HI), Hazard Quotient (HQ), or Target Hazard Quotient (THQ) are used to measure the health risk posed by toxic metals. The HI value reported in urban park soils [18] and kindergartens soils [19] was noted to be comparatively higher in children than adults. Therefore, the risks posed by the ingestion route of sedimentary particles by both children and adults were the highest, followed by dermal contact/inhalation. Therefore, the health risk assessments (HRA) for children should be given a higher priority.

The objectives of this paper are to (a) review Cu concentrations in the sediments from 125 publications from 1980 to 2022 based on Scopus and Google Scholar databases and, (b) make commentary based on the reassessment of ecological–health risks of Cu from 125 articles on adults and children's HRA based on the reported Cu concentrations in the sediments.

2. Materials and Methods

2.1. Data Collection

Cu data reported in Scopus and Google Scholar databases ranging from 1980 to April 2022 were used. A total of 125 publications were randomly selected, with a special focus on different regions and countries. The keywords for the search were 'copper' and 'sediment' which were mostly found in the titles of the articles. However, only those papers that reported the Cu ranges (minimum and maximum concentrations) were selected in the present study for easy and direct comparative purposes, and the standardization of the calculation of the ecological–health risks of Cu.

The current review used Moher et al. [20]'s Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) systematic literature review approach to contribute to the existing body of information on 'copper' and 'sediment.' PRISMA is an evidence-based reporting standard that can be used for critical evaluation. Figure 1 shows the metrics of the formal method that were updated for this review work.

2.2. Data Treatment

2.2.1. Geoaccumulation Index

The geoaccumulation index (I_{geo}) has been shown to be a useful tool for assessing sedimentary heavy metal pollution [21]. The degree of Cu contamination in the area was determined using the geoaccumulation index (I_{geo}). The calculation of I_{geo} was based on Equation (1) [21].

$$I_{geo} = \log_2 \left(\frac{\text{Sample}}{1.5 \times \text{Bg}} \right) \tag{1}$$

where sample is the total Cu concentrations in the sediments and Bg is the geochemical background value for Cu. The present study used the background concentrations in the earth's upper continental crust (UCC) which were Cu (14.3 mg/kg) based on Wedepohl [22].

The value (1.5) was the correction factor to mitigate the lithogenic effluents. There are six established classifications of pollution: 'practically unpolluted' (<0), 'unpolluted' (0–1), 'moderately polluted' (1–2), 'moderately polluted to strongly polluted' (2–3), 'strongly polluted' (3–4), 'strongly to very strongly polluted' (4–5), and 'very strongly polluted' (>5) [21].

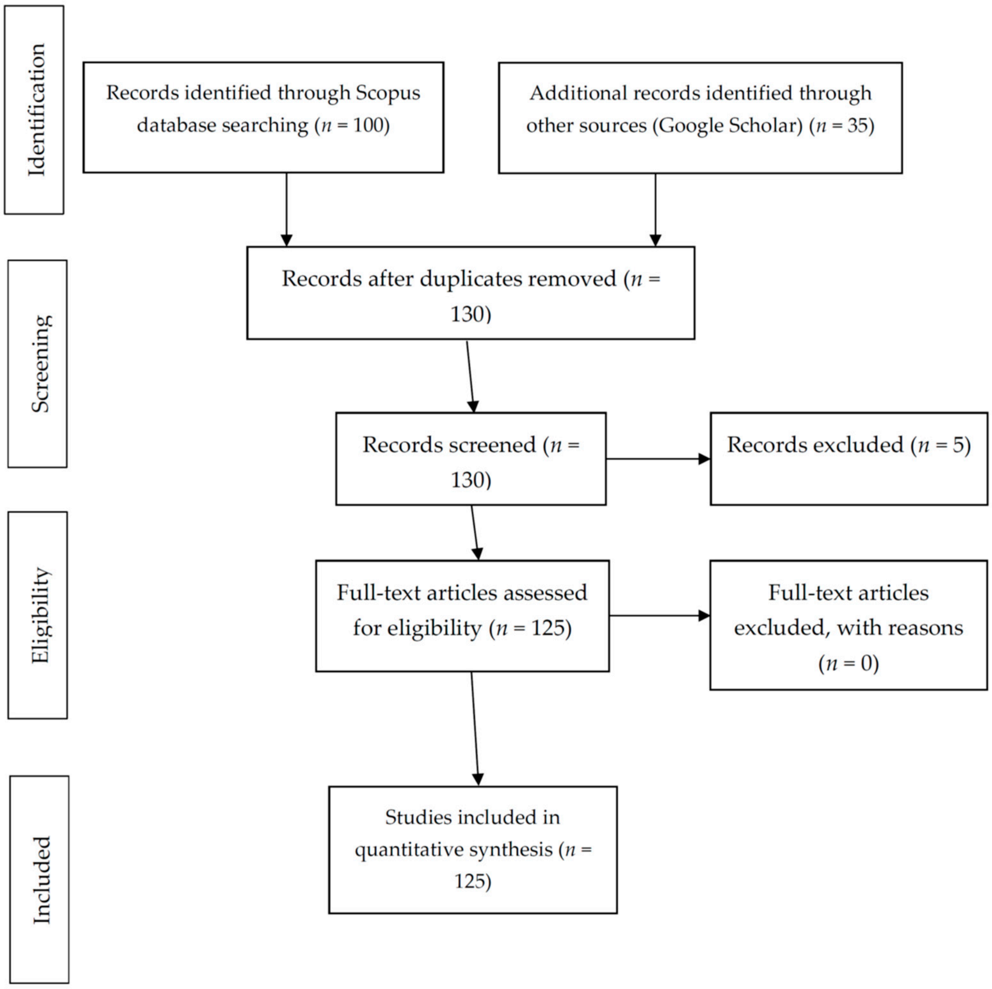

Figure 1. Flowchart of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (adapted from Moher et al. [20]), used in the present study.

2.2.2. Ecological Risk Index

Firstly, the calculation of the contamination factor (CF) was based on the pollution of a single Cu factor in Equation (2).

$$CF = \frac{C_s}{C_B} \tag{2}$$

where CF is the contamination factor; C_s is the mean Cu concentration in the sediment; and C_B is the Cu background level by based on Wedepohl [22], as mentioned previously. According to Hakanson [23], 4 classifications for CF values are 'low contamination' (CF< 1), 'moderate contamination' ($1 \leq CF < 3$), 'considerable contamination' ($3 \leq CF < 6$), and 'very high contamination' ($CF \geq 6$).

Later, the calculation of the ecological risk (ER), which is the potential ecological risk of a single element, was calculated based on Equation (3).

$$ER = T_R \times CF \tag{3}$$

The Cu toxic response factor (T_R) value used in the present study was 5.00 [22]. According to Hakanson [23], 5 classifications for the ER are 'low potential ecological risk' ($ER < 40$), 'moderate potential ecological risk' ($40 \leq ER < 80$), 'considerable potential ecological risk' ($80 \leq ER < 160$), 'high potential ecological risk' ($160 \leq ER < 320$), and 'very high ecological risk' ($ER \geq 320$).

2.2.3. Human Health Risk Assessment

Human health risk assessment (HHRA) of sediments is commonly used to assess both carcinogenic and non-carcinogenic risks to people through three exposure pathways: ingestion, inhalation, and skin contact. The HHRA technique was based on the US Environmental Protection Agency's guidelines and Exposure Factors Handbook [24–27]. The average daily doses (ADDs) (mg/kg day) of Cu through ingestion (ADD_{ing}), inhalation (ADD_{inh}), and dermal contact (ADD_{der}) for both children and adults were calculated by using Equations (4)–(6) as follows:

$$ADD_{ing} = C_{sediment}\left(\frac{IngR \times EF \times ED}{BW \times AT}\right) \times 10^{-6} \quad (4)$$

$$ADD_{inh} = C_{sediment}\left(\frac{IngR \times EF \times ED}{PEF \times BW \times AT}\right) \quad (5)$$

$$ADD_{der} = C_{sediment}\left(\frac{SA \times AF \times ABS \times EF \times ED}{BW \times AT}\right) \times 10^{-6} \quad (6)$$

where all the abbreviations are given and explained in Table 1. The daily levels of exposure to metals (mg/kg day) by ingestion, inhalation, and dermal contact are represented by ADD_{ing}, ADD_{inh}, and ADD_{der}, respectively. The hazard quotient (HQ) and hazard index (HI) were used to calculate the non-carcinogenic risk (NCR) of Cu in this investigation [24,25]. Table 1 shows the definition, exposure parameters, and reference values used in the literature to determine the intake values and health hazards of Cu in sediments.

Table 1. Definition, exposure factors, and reference values used to estimate the intake values and health risks of potentially toxic metals in sediment for the present study.

Factor	Definition	Unit	Values		References
			Children	Adults	
IngR	Ingestion rate of sediment	mg/day	200	100	[24]
ED	Exposure duration	Years	6.0	24	[24]
PEF	Particle emission factor	m^3/kg	1.36×10^9	1.36×10^9	[24]
AT	Average time	Days	365 × ED	365 × ED	[25]
BW	Bodyweight of the exposed individual	kg	15	55.9	[28]
EF	Exposure frequency	days/year	365	365	-
SA	Exposed skin surface area	cm^2	1600	4350	[28]
AF	Skin adherence factor	mg/cm day	0.20	0.70	[29]
Cu RfD_{ing}	Reference dose for ingestion	mg/kg day	4.00×10^{-2}	4.00×10^{-2}	[30]
Cu RfD_{inh}	Reference dose for inhalation	mg/kg day	4.02×10^{-2}	4.02×10^{-2}	[30]
Cu RfD_{der}	Reference dose for dermal contact	mg/kg day	1.20×10^{-2}	1.20×10^{-2}	[30]
InhR	Inhalation rate of sediment	m^3/day	7.63	12.8	[31]
ABF	Dermal absorption factor	Unitless	1.00×10^{-3}	1.00×10^{-3}	[32]

The HQ is the ratio of a metal's ADD to its reference dose (RfD) for exposure pathways that are similar [26]. The RfD (mg/kg day) is the maximum daily dosage of metal from a certain exposure pathway that is considered not to pose a significant risk of detrimental consequences to sensitive individuals over their lifetime, including both children and adults. Table 1 shows the RfD (mg/kg day) values of Cu used in this study for ingestion, inhalation, and dermal contact. If the ADD is less than the RfD value (HQ < 1), no adverse health effects are expected, but if the ADD exceeds the RfD value (HQ > 1), there are likely to be detrimental health effects [24,26].

HI, which is the total of the HQs in the three exposure paths, is used to calculate the NCR [33–35]. A HI value less than 1.0 indicates that there was no considerable risk of non-carcinogenic consequences. A HI of greater than 1.0 indicates the possibility of non-carcinogenic effects. Non-carcinogenic effects are likely to have a favorable relationship with the increase in the HI value [31]. The HI was calculated according to Equation (7).

$$HI = \sum HQ_i = \sum \left(\frac{ADD_i}{RfD_i} \right) \quad (7)$$

Data Analysis

All graphical bar charts were plotted using the KaleidaGraph (Version 3.08, Sygnergy Software, Eden Prairie, MN, USA). The overall statistics were also obtained from KaleidaGraph.

3. Results and Discussion

3.1. Ecological Risk Assessments

Figure 2 shows the world map of Cu levels in the sediments cited in the 125 publications [36–160]. The detailed Cu concentrations (mg/kg, dw) in the sediments reported in the 125 papers are provided in Tables S1 and S2.

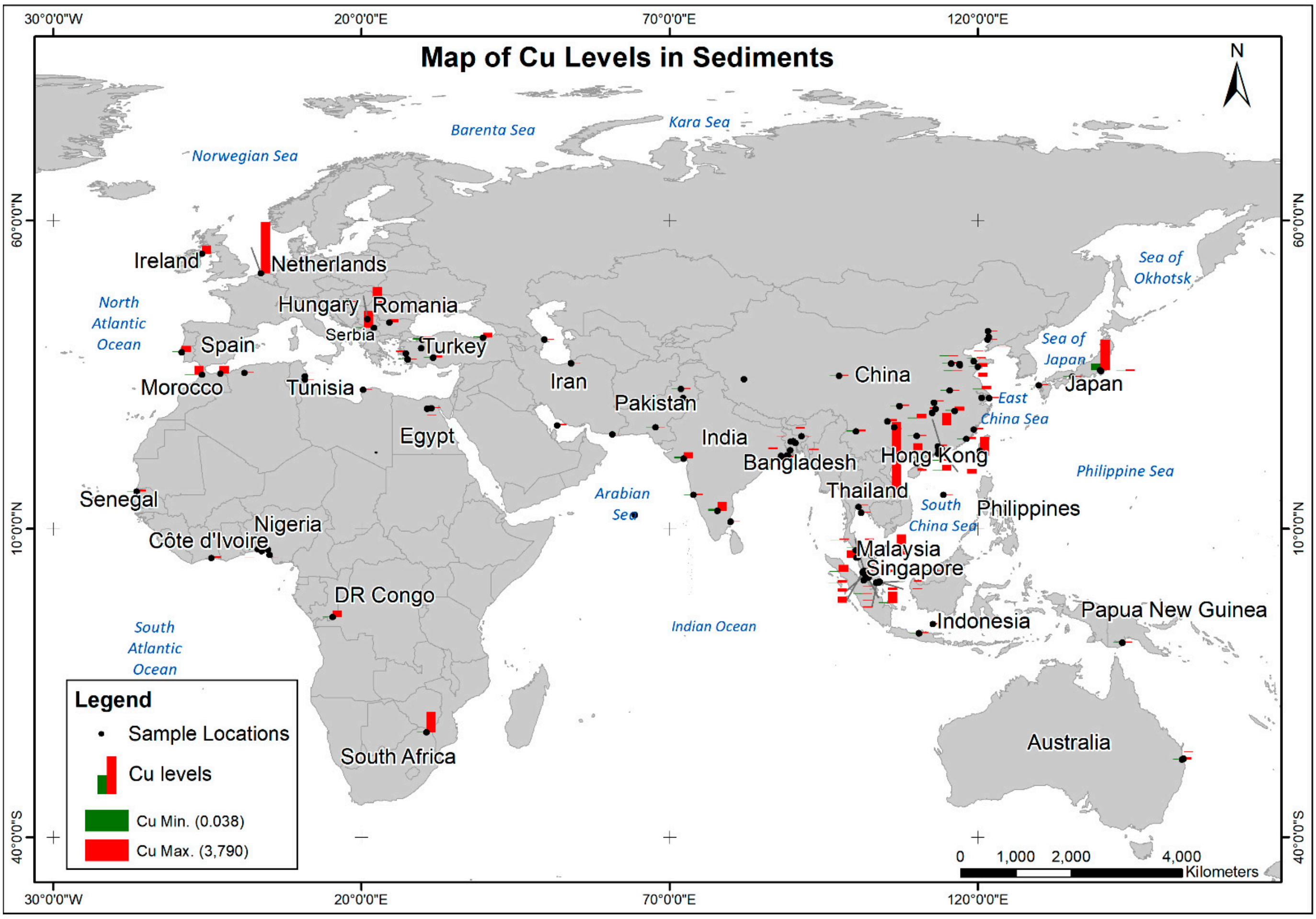

Figure 2. A world map covering the continents of Africa and Europe and the Asia–Pacific areas for the Cu levels in the sediments cited in the 125 publications. Source: https://www.efrainmaps.es/english-version/free-downloads/world/ (assessed on 1 June 2022).

A total of 37 countries (Table 2; Table S1) were coincidentally documented with their respective Cu concentrations in the sediments, mostly reporting the Cu concentrations in combination with other heavy or trace metals in the sediments from the coastal areas, mangrove, rivers, lakes, or estuaries. Clearly, many studies of Cu levels were reported in Asian countries, and there were scattered studies in Europe and African countries. Among the Asian countries, China topped the list with 33 papers, followed by Malaysia (19), India and Tunisia (7), Bangladesh (6), Japan (4), Hong Kong (3), Singapore (3), Indonesia (3), Iran (3), Pakistan (3), 8 other countries with two papers, and 18 other countries with one paper [36–160].

Table 2. Overall number of papers (NP) reported in different countries out of the 125 papers cited in the present study.

No.	Country	NP	No.	Country	NP
1	China	33	20	Netherlands	1
2	Malaysia	19	21	Ghana	1
3	India	7	22	Greece	1
4	Tunisia	7	23	Hungary	1
5	Bangladesh	6	24	Ivory Coast	1
6	Japan	4	25	Libya	1
7	Hong Kong	3	26	Morocco	1
8	Indonesia	3	27	Netherlands	1
9	Singapore	3	28	Nigeria	1
10	Iran	3	29	Oman	1
11	Pakistan	3	30	Papua New Guinea	1
12	Algeria	2	31	Philippines	1
13	Australia	2	32	Senegal	1
14	Taiwan	2	33	USA	1
15	Thailand	2	34	South Africa	1
16	Nigeria	2	35	Oman	1
17	Turkey	2	36	Spain	1
18	Egypt	2	37	Romania	1
19	Serbia	2			

Based on the 125 reviewed papers, there were 11 papers (8%) documenting the total Cu concentrations of more than 500 mg/kg dw (Tables S1 and S2; Figure 3). These papers included Lake Pamvotis of Greece (24985 mg/kg; [92])> Victoria Harbor of Hong Kong (3790 mg/kg; [46]) > Scheldt Estuarine of the Netherlands (2600 mg/kg; [47]), Old Nakagawa River of Tokyo, Japan (1565 mg/kg; [76]) > Mvudi River of South Africa (1027 mg/kg; [66]) > polluted drainage sediments from Peninsular Malaysia (1019 mg/kg; [72]) > Kaohsiung Harbor in Taiwan (946 mg/kg; [68]) > Serbia (870 mg/kg [98], 859.9 mg/kg; [143]) > Kaohsiung Harbor in Taiwan (760 mg/kg; [108]) > Shima River of China (630 mg/kg; [110]). From these top eleven citations with elevated Cu levels in the sediments, the levels in the Kaohsiung Harbor of Taiwan were reported to be twice as high, between 760–946 mg/kg, by Chen et al. [68] and Chen et al. [108]. However, based on HQ, only Lake Pamvotis of Greece (24,985 mg/kg; [92]) was found to have a HQ value over 1, indicating a potential chance of Cu NCR at this site.

Table 3 shows the comparisons of the concentrations of Cu sediment quality guidelines in the available literature, with the overall statistics of the 125 reviewed papers containing Cu data in the present study. There are three patterns that can be observed.

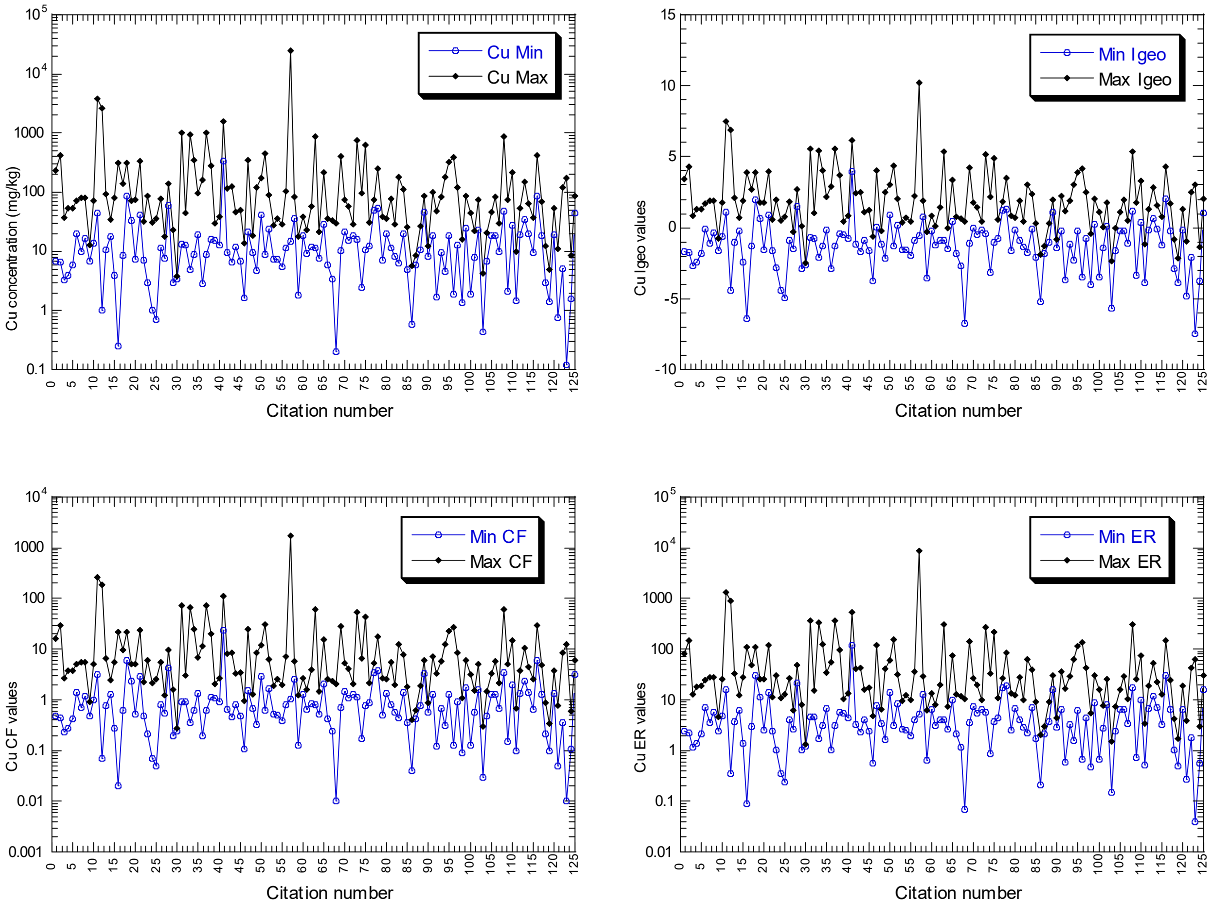

Figure 3. The calculated values of the geoaccumulation index (I_{geo}), contamination factor (CF), and ecological risk (ER), based on the Cu concentration ranges (mg/kg dry weight) (minimum and maximum) in the sediments cited from 125 papers in the literature published between 1980 and 2022. The citation numbers follow the detailed reference numbers presented in Tables S1 and S2.

Firstly, the average values of skewness and kurtosis were 14.8 and 224, respectively. This indicates that the Cu data cited from the literature were not normally distributed in which the Cu data were not within the normality ranges for skewness (−2 to +2) [161–163] and kurtosis (−7 to +7) [161,162]. Therefore, we used medians, rather than means, for a more meaningful interpretation with the understanding of outliers which were represented by the extremely elevated Cu data in 8% (11 papers as mentioned previously) of the data cited. Secondly, based on the 125 papers, the Cu concentrations (mg/kg dry weight) ranged from 0.12 to 24,985. The maximum Cu level was higher than all the established guidelines in Table 3. However, the median Cu concentration (22.95) was lower than all the established guidelines [22,23,164–168], except for the threshold effect level (TEL) [168] and upper continental crust (UCC) [22].

Thirdly, the I_{geo} values ranged from −7.48 to 10.19. This indicates that they ranged from 'practically unpolluted' to 'very strongly polluted' with a median (0.09) status of 'unpolluted' based on Muller [21]'s classifications. The CF values ranged from 0.01 to 1747. This indicates that they ranged from 'low contamination' to 'very high contamination' with a median (1.61) status of 'moderate contamination' according to Hakanson [23]. The ER values ranged from 0.04 to 8736. This means that they ranged from a 'low potential ecological risk' to a 'very high ecological risk' with a median (8.02) status of 'low potential ecological risk' according to Hakanson [23].

Table 3. Comparison of the overall statistics of the Cu calculated values of the geoaccumulation index (I_{geo}), contamination factor (CF), and ecological risk (ER), hazard quotient ingestion (HQ_{ing}), hazard quotient inhalation (HQ_{inh}), hazard quotient dermal contact (HQ_{der}), hazard index (HI) for adults (A) and children (C) based on the Cu concentrations ranges (mg/kg dry weight) (minimum and maximum) in the sediments cited from 125 papers in the literature published between 1980 and 2022 with the different established guidelines values.

	Cu	**I_{geo}**	**CF**	**ER**	**A HQ_{ing}**	**A HQ_{inh}**	**A HQ_{der}**	**A HI**	**C HQ_{ing}**	**C HQ_{inh}**	**C HQ_{der}**	**C HI**	**Reference**
Minimum	0.12	−7.48	0.01	0.04	5.50×10^{-6}	5.03×10^{-10}	5.58×10^{-7}	6.06×10^{-6}	4.10×10^{-5}	1.12×10^{-9}	2.19×10^{-7}	4.12×10^{-5}	This study
Maximum	24,985	10.19	1747	8736	1.15	1.05×10^{-4}	1.16×10^{-1}	1.26	8.54	2.32×10^{-4}	4.55×10^{-2}	8.58	
Mean	209	0.25	14.65	73.23	9.62×10^{-3}	8.79×10^{-7}	9.73×10^{-4}	1.06×10^{-2}	7.16×10^{-2}	1.95×10^{-6}	3.82×10^{-4}	7.19×10^{-2}	
Median	22.95	0.09	1.61	8.02	1.05×10^{-3}	9.62×10^{-8}	1.07×10^{-4}	1.16×10^{-3}	7.85×10^{-3}	2.14×10^{-7}	4.18×10^{-5}	$7.88E \times 10^{-3}$	
SD	1609	2.52	113	563	7.41×10^{-2}	6.76×10^{-6}	7.47×10^{-3}	8.12×10^{-2}	5.50×10^{-1}	1.49×10^{-5}	2.93×10^{-3}	5.53×10^{-1}	
SE	102	0.16	7.12	35.6	4.68×10^{-3}	4.28×10^{-7}	4.73×10^{-4}	5.13×10^{-3}	3.48×10^{-2}	9.45×10^{-7}	1.85×10^{-4}	3.50×10^{-2}	
Skewness	14.8	0.21	14.8	14.8	1.48×10	1.47×10	1.47×10	1.47×10	1.47×10	1.47×10	1.47×10	1.47×10	
Kurtosis	224	1.06	224	224	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	2.24×10^{2}	
Guidelines	Cu	I_{geo}	CF	ER	A HQ_{ing}	A HQ_{inh}	A HQ_{der}	A HI	C HQ_{ing}	C HQ_{inh}	C HQ_{der}	C HI	Reference
ERL	34.0	0.66	2.38	11.89	1.56×10^{-3}	1.42×10^{-7}	1.58×10^{-4}	1.72×10^{-3}	1.16×10^{-2}	3.16×10^{-7}	6.20×10^{-5}	1.17×10^{-2}	[166]
ERM	270	3.65	18.88	94.41	1.24×10^{-2}	1.13×10^{-6}	1.26×10^{-3}	1.36×10^{-2}	9.23×10^{-2}	2.51×10^{-6}	4.92×10^{-4}	9.28×10^{-2}	[166]
ISQV-low	65.0	1.60	4.55	22.73	2.98×10^{-3}	2.72×10^{-7}	3.03×10^{-4}	3.28×10^{-3}	2.22×10^{-2}	6.05×10^{-7}	1.18×10^{-4}	2.23×10^{-2}	[167]
ISQV-high	270	3.65	18.88	94.41	1.24×10^{-2}	1.13×10^{-6}	1.26×10^{-3}	1.36×10^{-2}	9.23×10^{-2}	2.51×10^{-6}	4.92×10^{-4}	9.28×10^{-2}	[167]
TEL	18.7	−0.20	1.31	6.54	8.57×10^{-4}	7.83×10^{-8}	8.70×10^{-5}	9.45×10^{-4}	6.39×10^{-3}	1.74×10^{-7}	3.41×10^{-5}	6.43×10^{-3}	[168]
PEL	108.2	2.33	7.57	37.83	4.96×10^{-3}	4.53×10^{-7}	5.04×10^{-4}	5.47×10^{-3}	3.70×10^{-2}	1.01×10^{-6}	1.97×10^{-4}	3.72×10^{-2}	[168]
PRL	50.0	1.22	3.50	17.48	2.29×10^{-3}	2.09×10^{-7}	2.33×10^{-4}	2.53×10^{-3}	1.71×10^{-2}	4.65×10^{-7}	9.11×10^{-5}	1.72×10^{-2}	[23]
UCC	25.0	0.22	1.75	8.74	1.15×10^{-3}	1.05×10^{-7}	1.16×10^{-4}	1.26×10^{-3}	8.54×10^{-3}	2.33×10^{-7}	4.56×10^{-5}	8.59×10^{-3}	[164]
UCC	14.3	−0.58	1.00	5.00	6.56×10^{-4}	5.99×10^{-8}	6.66×10^{-5}	7.22×10^{-4}	4.89×10^{-3}	1.33×10^{-7}	2.61×10^{-5}	4.91×10^{-3}	[22]
UCC	28.0	0.38	1.96	9.79	1.28×10^{-3}	1.17×10^{-7}	1.30×10^{-4}	1.41×10^{-3}	9.57×10^{-3}	2.61×10^{-7}	5.10×10^{-5}	9.62×10^{-3}	[165]

Note: UCC = Upper continental crust; ERL = Effects range low; ERM = Effects range median; ISQV-low = Interim sediment quality value-low; ISQV-high = Interim sediment quality value-high; TEL = Threshold effect level; PEL = Probable effect level; PRL = Pre-industrial reference level. SD = standard deviation; SE = standard error.

3.2. Health Risk Assessments

Figure 4 shows the values of HQ_{ing}, HQ_{inh}, HQ_{der}, and HI for adults and children based on the Cu data ranges (minimum, Table S1 and maximum, Table S2) in the sediments cited from 125 papers in the literature published between 1980 and 2022. The overall statistics of the above values are provided in Table 3.

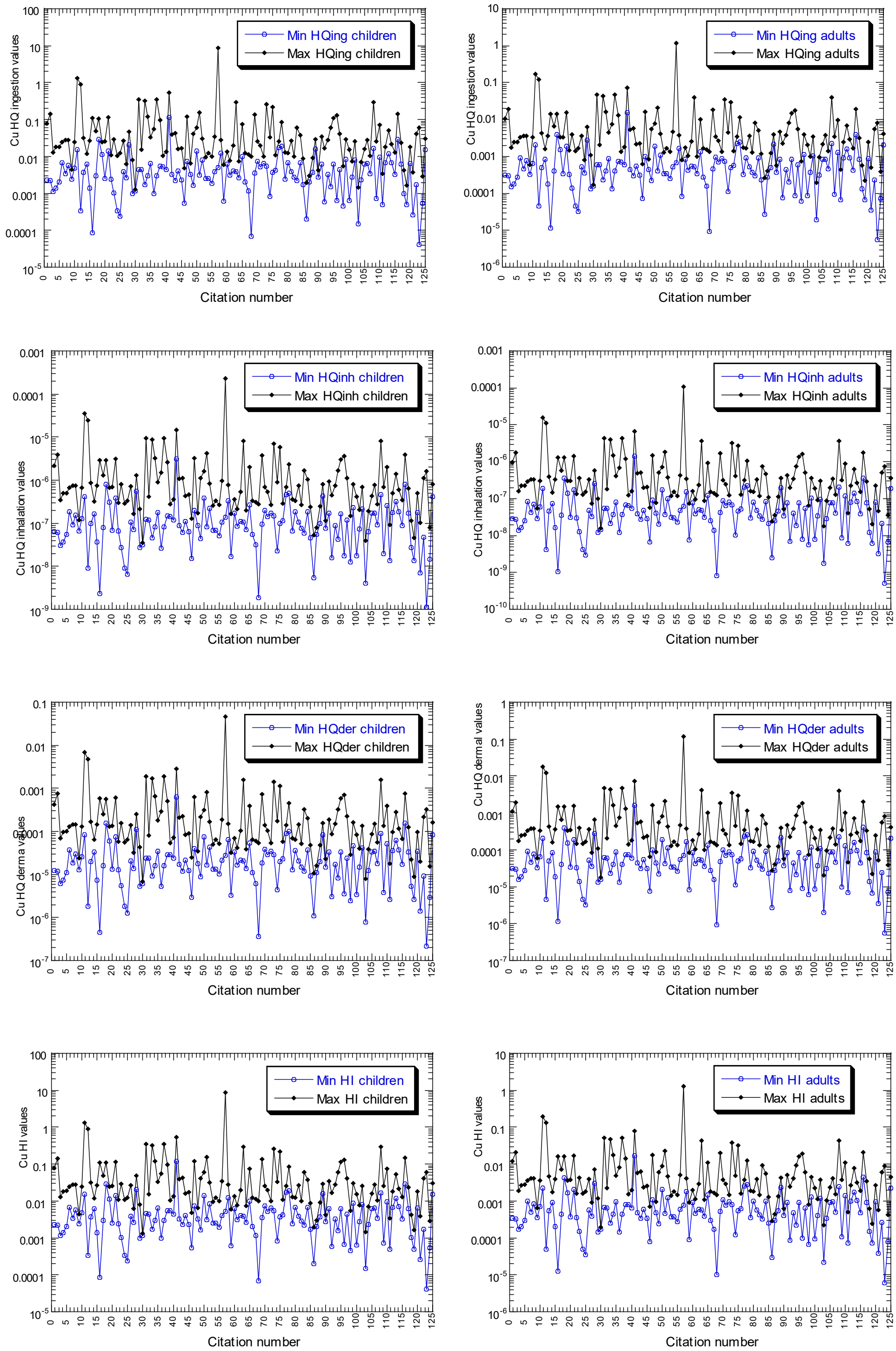

Figure 4. The values of hazard quotient ingestion (HQ_{ing}), hazard quotient inhalation (HQ_{inh}), hazard quotient dermal contact (HQ_{der}), and hazard index (HI) for adults and children based on the Cu data ranges (minimum and maximum) in the sediments cited from 125 papers in the literature published between 1980 and 2022. The citation numbers follow the detailed reference numbers presented in Tables S1 and S2.

For children, the values of HQ_{ing}, HQ_{inh}, HQ_{der}, and HI ranged from 4.10×10^{-5} to 8.54 (mean: 7.16×10^{-2}), 1.12×10^{-9} to 2.32×10^{-4} (mean: 1.95×10^{-6}), 2.19×10^{-7} to 4.55×10^{-2} (mean: 3.82×10^{-4}), and 4.12×10^{-5} to 8.58 (mean: 7.19×10^{-2}), respectively.

For adults, the values of HQ_{ing}, HQ_{inh}, HQ_{der}, and HI ranged from 5.50×10^{-6} to 1.15 (mean: 9.62×10^{-3}), 5.03×10^{-10} to 1.05×10^{-4} (mean: 8.79×10^{-7}), 5.58×10^{-7} to 1.16×10^{-1} (mean: 9.73×10^{-4}), and 6.06×10^{-6} to 1.26 (mean: 1.06×10^{-2}), respectively.

Based on Figure 4, the HI values for children from Lake Pamvotis of Greece (24,985 mg/kg; [92]), and Victoria Harbor in Hong Kong (3790 mg/kg; [36] exceeded 1.00. For adult HI values, only the HI value from Lake Pamvotis of Greece exceeded 1.00. This indicates a non-carcinogenic risk of Cu. These HI values were mainly due to the HQ_{ing} value (> 90%) when compared to HQ_{inh} and HQ_{der}.

4. Comments on the Hazard Quotients of Children

From the present estimation of the children's HRA based on Cu levels in the sediments, it is rather far from reality. The ingestion pathway was included in this study with two assumptions that (1) children spend more time on the beach (or muddy sediment areas in the coastal areas), and (2) the sediment-bound metal pollutants could be introduced into children's bodies via the direct ingestion of small particles by hand-to-mouth action. The first assumption is arguable as the definition for children should be well defined. Most of the papers reviewed in this study did not clearly specify the age groups for their children's HRA. Children aged 1–2 years old are different from those who are 10–12 years old. The resistance and sensitivity of the children's bodies are very different between these two groups of ages. Therefore, if those aged 2 to 12 years old are all considered as children, erroneous assumptions could be reached, and as a result, the conclusions would be invalid. Perhaps specifying the body weight of children could reduce the error. However, a similar body resistance and maturity of children between 5 and 12 year old, with a similar body weight of 40 kg, can be assumed. Since obesity among children has become an issue nowadays, the estimation of HQ through the ingestion pathway in a child is somewhat questionable.

The present ecological risk of Cu indicated the median concentration of Cu is generally low and not considered a polluted or a low ecological risk. The localized Cu contamination of the 11 papers exceeding 500 mg/kg dry weight is focused on in this commentary section, as shown in Table 4.

Table 4. Comments on the 11 papers with Cu concentrations over 500 mg/kg dry weight from 125 papers in the literature.

No.	Locations	Cu > 1000	Sources	Comment	Reference
1	Lake Pamvotis, Greece	24,985	Industrial activities; urban stormwater runoff; agriculture, livestock, and domestic sewage.	The report offered baseline data for future research on the anthropogenic influences on the protection and management of Lake Pamvotis, which have been a concern of city officials for decades. Cu must be continuously monitored for ecological and health risks.	[92]
2	Victoria Harbor, Hong Kong	3790	Traffic due to its vicinity to the airport runway and the industrialized area.	Evidently, the increasing levels of toxic Cu in Hong Kong were attributable to the escalating population density, rapid industrialization, and land reclamation. This study can therefore offer a significant source of information about Cu mitigation and pollution management in Victoria Harbor.	[46]

Table 4. *Cont.*

No.	Locations	Cu > 1000	Sources	Comment	Reference
3	Scheldt Estuarine, Netherlands	2600	Industrial discharges.	According to the study, the Cu load in the Scheldt estuary has decreased dramatically for three decades (1960–1990). The extent to which these alterations represent a shift in manufacturing strategies, or a purification of industrial waste is unknown. Cu must be regularly evaluated for environmental and health hazards.	[47]
4	Old Nakagawa River, Japan	1565	Industrialization, urbanization, deposition of industrial wastes and others.	The paper stated that, in order to monitor the trend of Cu contamination, industrial establishments, the municipal council, and/or the government of Japan should reevaluate the current waste treatment and disposal methods for urban sediments or introduce more effective ones.	[76]
5	Mvudi River, South Africa	1027	Release of partially treated wastewater effluents from the Thohoyandou wastewater treatment plant, runoffs from agricultural soil, landfill sites very close to the river and other non-point sources, such as atmospheric deposition	The paper emphasized that higher Cu concentrations in river sediments could potentially have deleterious impacts on aquatic life. Cu must be continuously monitored for ecological and health risks.	[66]
6	Polluted drainage sediments from Peninsular Malaysia	1019	Untreated urban wastes; industrial effluents.	The paper highlighted the importance of treating effluents in this drainage basin. In order to limit unlawful discharges and dumping into drainages, it is necessary to increase public awareness. Cu must be continuously monitored for ecological and health risks.	[72]
7	Kaoshiung Harbor, Taiwan	946	Industrial and municipal wastewaters were discharged from the neighboring industrial parks and river basins. The Cu area was severely affected by untreated or partially treated industrial effluents and municipal sewages.	The paper shed light on the properties and mechanisms of metal distributions in Kaohsiung Harbor sediments. The data would aid in the creation of more effective watershed and harbor management methods to minimize metal discharges into the harbor, as well as a strategy for the cleanup of polluted sediments.	[68]
8	Serbia	870	Not specifically mentioned.	The study indicated that the river sediments examined were highly polluted with Cu. Cu must be continuously monitored for ecological and health risks.	[98]
9	Korbevačka River, Serbia	859.9	Mining and processing of metal ore/ smelting.	The paper stressed the need for a human exposure risk assessment of Cu for screening purposes in order to identify significant exposure pathways and establish the urgency of sediment cleanup measures.	[143]
10	Kaohsiung Harbor, Taiwan.	760	Derived from the polluted Canon River and the Love River, Salt River, and Jen-Gen River.	The paper provided harbor management departments with a great deal of important information, particularly on the Cu derived from the four major contamination sources, allowing for the future control of Cu according to the severity of contamination in sediments.	[108]
11	Shima River, China.	630	Industrial effluents; receiving discharges from Huizhou City.	The paper showed that the Cu bound to sedimentary particles may be resuspended and migrate from the upper and medium reaches to the lower reaches, endangering the safety of the local water supply. Therefore, improving sediment quality necessitates the control of pesticide application, the reduction in industrial wastewater discharge, and the implementation of a river channel dredging project.	[110]

It can be synthesized that, based on Table 4, there is always a need for mitigation, and the management of an exposure risk assessment of Cu that may be utilized effectively for screening purposes in order to identify significant human health exposure routes. Consequently, all Cu-polluted sediments necessitate immediate sediment cleanup measures. Lastly, there is a need for the ongoing monitoring of Cu's ecological and health risks in the future.

5. Conclusions

The present review on Cu concentrations in the sediments based on 125 publications revealed three interesting points. First, there were 11 papers (8%) documenting Cu levels of more than 500 mg/kg dw while China was the country with the highest number (26%) of papers published between 1980 and 2022, out of 37 countries. Second, given that the Cu data cited from the literature were not normally distributed, the maximum Cu level was higher than all the established guidelines in Table 3. However, the median Cu concentration (22.95) was lower than most of all the established guidelines. The I_{geo} median value indicated a status of 'unpolluted', while the CF median value indicated a status of 'moderate contamination', and the ER median value indicated a status of 'low potential ecological risk'. However, ecological risks for Cu could be based at present on the above mentioned 8% of the literature in the present study. Third, all calculated HI values were found to be below 1, indicating no potential chance of Cu non–carcinogenic effects in both adults and children, except for children's HI values from Lake Pamvotis of Greece, and Victoria Harbor in Hong Kong.

It can be synthesized that, based on Table 4, there is always a need for mitigation, and the management of an exposure risk assessment of Cu that may be utilized effectively for screening purposes in order to identify significant human health exposure routes. Consequently, all Cu-polluted sediments necessitate immediate sediment cleanup measures. Lastly, it is recommended that regular monitoring of the ecological–health risks of Cu in sediments should be carried out in view of the expansion of domestic wastes related to urbanization, and the mismanagement of effluents related to industrialization. All these issues are complicated since they are a blend of socio-economic and environmental factors. It is difficult to decide which one is responsible in the first place, and which one will be the priority from the governing body's point of view.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pollutants2030018/s1, Table S1. The minimum range of Cu concentrations (mg/kg dry weight) in the sediments cited from 125 papers the literature published between 1980 and 2022, and their calculated values of geoaccumulation index (Igeo), contamination factor (CF), ecological risk (ER), hazard quotient ingestion (HQ_{ing}), hazard quotient inhalation (HQ_{inh}), hazard quotient derma contact (HQ_{der}), hazard index (HI) for adults and children based on the cited Cu data; Table S2. The maximum range of Cu concentrations (mg/kg dry weight) in the sediments cited from 125 papers the literature published between 1980 and 2022, and their calculated values of geoaccumulation index (Igeo), contamination factor (CF), ecological risk (ER), hazard quotient ingestion (HQ_{ing}), hazard quotient inhalation (HQ_{inh}), hazard quotient derma contact (HQ_{der}), hazard index (HI) for adults and children based on the cited Cu data.

Author Contributions: Conceptualization, C.K.Y.; Formal analysis, W.H.C.; Funding acquisition, C.K.Y.; Investigation, M.S. and C.K.Y.; Methodology, M.S., W.S.T., R.N. and W.M.S.; Project administration, C.K.Y. and W.S.T.; Resources, W.S.T., W.M.S., N.A.-W., M.H.I. and M.M.; Supervision, C.K.Y.; Validation, W.S.T.; Writing—original draft, C.K.Y.; Writing—review and editing, M.S., W.S.T., M.H.I., M.M., M.A.A.R., F.B.E., T.A., W.H.C., H.O., M.S.I., K.K., R.A., K.A.A.-M., S.A.A.-S., G.S. and L.S.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mudd, G.M.; Weng, Z.; Memary, R.; Northey, S.A.; Giurco, D.; Mohr, S.; Mason, L. Future Greenhouse Gas Emissions from Copper Mining: Assessing Clean Energy Scenarios. Prepared for CSIRO Minerals down under Flagship by Monash University and Institute for Sustainable Futures, UTS. 2012. Available online: https://opus.lib.uts.edu.au/bitstream/10453/32524/1/muddetal2012copperemissionscleanenergy.pdf (accessed on 1 June 2022).
2. Memary, R.; Giurco, D.; Mudd, G.M.; Mason, L. Life Cycle Assessment: A Time-Series Analysis of Copper. *J. Clean. Prod.* **2012**, *33*, 97–108. [CrossRef]
3. CCME (Canadian Council of Ministers of the Environment). Copper. In *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health*; Canadian Council of Ministers of the Environment: Winnipeg, MA, Canada, 1999.
4. Costa-Böddeker, S.; Hoelzmann, P.; Thuyên, L.X.; Huy, H.D.; Nguyen, H.A.; Richter, O.; Schwalb, A. Ecological Risk Assessment of a Coastal Zone in Southern Vietnam: Spatial Distribution and Content of Heavy Metals in Water and Surface Sediments of the Thi Vai Estuary and Can Gio Mangrove Forest. *Mar. Pollut. Bull.* **2017**, *114*, 1141–1151. [CrossRef] [PubMed]
5. Dung, T.T.T.; Linh, T.M.; Chau, T.B.; Hoang, T.M.; Swennen, R.; Cappuyns, V. Contamination Status and Potential Release of Trace Metals in a Mangrove Forest Sediment in Ho Chi Minh City, Vietnam. *Environ. Sci. Pollut. Res.* **2019**, *26*, 9536–9551. [CrossRef] [PubMed]
6. Huong, N.T.L.; Masami, O.; Li, L.; Higashi, T.; Kanayama, M. Heavy Metal Contamination of River Sediments in Vietnam. *Proc. Inst. Civ. Eng. Water Manag.* **2010**, *163*, 111–121. [CrossRef]
7. Phuong, N.M.; Kang, Y.; Sakurai, K.; Iwasaki, K.; Kien, C.N.; Van Noi, N.; Son, L.T. Levels and Chemical Forms of Heavy Metals in Soils from Red River Delta, Vietnam. *Water. Air. Soil Pollut.* **2010**, *207*, 319–332. [CrossRef]
8. Yap, C.K. *Sediment Watch: Monitoring, Ecological Risk Assessment and Environmental Management*; Nova Science Publishers: New York, NY, USA, 2018.
9. Sany, S.B.T.; Salleh, A.; Sulaiman, A.H.; Sasekumar, A.; Rezayi, M.; Monazami Tehrani, G. Heavy Metal Contamination in Water and Sediment of the Port Klang Coastal Area, Selangor, Malaysia. *Environ. Earth Sci.* **2012**, *69*, 2013–2025. [CrossRef]
10. Yap, C.K.; Chew, W.; Al-Mutairi, K.A.; Nulit, R.; Ibrahim, M.H.; Wong, K.W.; Bakhtiari, A.R.; Sharifinia, M.; Ismail, M.S.; Leong, W.J.; et al. Assessments of the Ecological and Health Risks of Potentially Toxic Metals in the Topsoils of Different Land Uses: A Case Study in Peninsular Malaysia. *Biology* **2022**, *11*, 2. [CrossRef]
11. Yap, C.K.; Al-Mutairi, K.A. Ecological-Health Risk Assessments of Heavy Metals (Cu, Pb, and Zn) in Aquatic Sediments from the ASEAN-5 Emerging Developing Countries: A Review and Synthesis. *Biology* **2022**, *11*, 7. [CrossRef]
12. Luo, X.-S.; Ding, J.; Xu, B.; Wang, Y.-J.; Li, H.-B.; Yu, S. Incorporating Bioaccessibility into Human Health Risk Assessments of Heavy Metals in Urban Park Soils. *Sci. Total Environ.* **2012**, *424*, 88–96. [CrossRef]
13. Xu, D.-M.; Fu, R.-B.; Liu, H.-Q.; Guo, X.-P. Current Knowledge from Heavy Metal Pollution in Chinese Smelter Contaminated Soils, Health Risk Implications and Associated Remediation Progress in Recent Decades: A Critical Review. *J. Clean. Prod.* **2020**, *286*, 124989. [CrossRef]
14. Allen, J.R.L. *Sedimentary Structures: Their Character and Physical Basis, Volume 1. Developments in Sedimentology*; Elsevier: Amsterdam, The Netherlands, 1982; p. 593.
15. Zhang, A.; Wang, L.; Zhao, S.; Yang, X.; Zhao, Q.; Zhang, X.; Yuan, X. Heavy metals in seawater and sediments from the northern Liaodong Bay of China: Levels, distribution and potential risks. *Reg. Stud. Mar. Sci.* **2017**, *11*, 32–42. [CrossRef]
16. Zhu, Z.; Xue, J.; Deng, Y.; Chen, L.; Liu, J. Trace metal contamination in surface sediments of intertidal zone from Qinhuangdao, China, revealed by geochemical and magnetic approaches: Distribution, sources, and health risk assessment. *Mar. Pollut. Bull.* **2016**, *105*, 422–429. [CrossRef] [PubMed]
17. Perrodin, Y.; Donguy, G.; Emmanuel, E.; Winiarski, T. Health risk assessment linked to filling coastal quarries with treated dredged seaport sediments. *Sci. Total Environ.* **2014**, *485-486*, 387–395. [CrossRef]
18. Du, Y.; Gao, B.; Zhou, H.; Ju, X.; Hao, H.; Yin, S. Health risk assessment of heavy metals in road dusts in urban parks of Beijing, China. *Procedia Environ. Sci.* **2013**, *18*, 299–309. [CrossRef]
19. Tepanosyan, G.; Maghakyan, N.; Sahakyan, L.; Saghatelyan, A. Heavy metals pollution levels and children health risk assessment of Yerevan kindergartens soils. *Ecotoxicol. Environ. Saf.* **2017**, *142*, 257–265. [CrossRef] [PubMed]
20. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. PRISMA Group Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
21. Muller, G. Index of geoaccumulation in sediments of the Rhine River. *Geojournal* **1969**, *2*, 108–118.
22. Wedepohl, K.H. The composition of the continental crust. *Geochim. Cosmochim. Acta* **1995**, *59*, 1217–1232. [CrossRef]
23. Hakanson, L. An ecological risk index for aquatic pollution control. A sedimentary approach. *Water Res.* **1980**, *14*, 975–1001. [CrossRef]
24. US EPA. *Baseline Human Health Risk Assessment Vasquez Boulevard and I-70 Superfund Site Demver, Co*; U.S. Environmental Protection Agency: Washington, DC, USA, 2001.

25. US EPA. *Exposure Factors Handbook (1997)*; EPA/600/P-95/002F; National Center for Environmental Assessment, US EPA Office of Research and Development: Washington, DC, USA, 1997.
26. US EPA. Human Health Evaluation Manual. In *Risk Assessment Guidance for Superfund*; EPA/540/1-89/002; Office of Emergency and Remedial Response, U.S. Environmental Protection Agency: Washington, DC, USA, 1989; Volume 1.
27. US EPA. *Superfund Public Health Evaluation Manual*; U.S. Environmental Protection Agency: Washington, DC, USA, 1986; pp. 1–86.
28. Beijing Quality and Technology Supervision Bureau. *Environmental Site Assessment Guideline*; DB11/T 656-2009; Beijing Quality and Technology Supervision Bureau: Beijing, China, 2009.
29. Barnes, D.G.; Dourson, M.; Dourson, M.; Preuss, P.; Barnes, D.G.; Bellin, J.; Derosa, C.; Engler, R.; Erdreich, L.; Farber, T.; et al. Reference Dose (RfD): Description and Use in Health Risk Assessments. *Regul. Toxicol. Pharmacol.* **1988**, *8*, 471–486. [CrossRef]
30. Qing, X.; Yutong, Z.; Shenggao, L. Assessment of Heavy Metal Pollution and Human Health Risk in Urban Soils of Steel Industrial City (Anshan), Liaoning, Northeast China. *Ecotoxicol. Environ. Saf.* **2015**, *120*, 377–385. [CrossRef] [PubMed]
31. Li, Z.; Ma, Z.; van der Kuijp, T.J.; Yuan, Z.; Huang, L. A Review of Soil Heavy Metal Pollution from Mines in China: Pollution and Health Risk Assessment. *Sci. Total Environ.* **2014**, *468*, 843–853. [CrossRef] [PubMed]
32. Chabukdhara, M.; Nema, A.K. Heavy Metals Assessment in Urban Soil around Industrial Clusters in Ghaziabad, India: Probabilistic Health Risk Approach. *Ecotoxicol. Environ. Saf.* **2013**, *87*, 57–64. [CrossRef] [PubMed]
33. Ferreira-Baptista, L.; De Miguel, E. Geochemistry and Risk Assessment of Street Dust in Luanda, Angola: A Tropical Urban Environment. *Atmos. Environ.* **2005**, *39*, 4501–4512. [CrossRef]
34. Hu, X.; Zhang, Y.; Luo, J.; Wang, T.; Lian, H.; Ding, Z. Bioaccessibility and Health Risk of Arsenic, Mercury and Other Metals in Urban Street Dusts from a Mega-City, Nanjing, China. *Environ. Pollut.* **2011**, *159*, 1215–1221. [CrossRef]
35. Kelepertzis, E. Investigating the Sources and Potential Health Risks of Environmental Contaminants in the Soils and Drinking Waters from the Rural Clusters in Thiva Area (Greece). *Ecotoxicol. Environ. Saf.* **2014**, *100*, 258–265. [CrossRef]
36. Wong, M.H.; Ho, K.C.; Kwok, T.K. Degree of pollution of several major streams entering Tolo Harbour, Hong Kong. *Mar. Pollut. Bull.* **1980**, *11*, 36–40. [CrossRef]
37. Manga, N.; Hanvey, W.; Byers, W.; Brown, J. Trace metal analysis of surficial sediments from Belfast Lough. *Ir. Nat. J.* **1982**, *20*, 425–429.
38. Polprasert, C. Heavy metal pollution in the Chao Phraya River Estuary, Thailand. *Water Res.* **1982**, *16*, 775–784. [CrossRef]
39. Subramanian, V.; Jha, P.K.; Van Grielen, R. Heavy metals in the Ganges Estuary. *Mar. Pollut. Bull.* **1988**, *19*, 290–293. [CrossRef]
40. Everaarts, J.M. Heavy metals (Cu, Zn, Cd, Pb) in sediment of the Java Sea, estuarine and coastal areas of the East Java and some deep–sea areas. *Neth. J Sea Res.* **1989**, *23*, 403–413. [CrossRef]
41. Baker, E.; Harris, P.T. Copper, lead and zinc distribution in the sediments of the Fly River Delta and Torres Straits. *Mar. Pollut. Bull.* **1991**, *22*, 614–618. [CrossRef]
42. Sin, Y.M.; Wong, M.K.; Chou, L.M.; Normala, A. A study on heavy metal contents of the Singapore River. *Environ. Monit. Assess.* **1991**, *19*, 481–494. [CrossRef] [PubMed]
43. Fukushima, K.; Saino, T.; Kodama, Y. Trace metal contamination in Tokyo Bay, Japan. *Sci. Total Environ.* **1992**, *125*, 373–389. [CrossRef]
44. Ismail, A. Heavy metal concentration in sediment of Bintulu, Malaysia. *Mar. Pollut. Bull.* **1993**, *26*, 706–707. [CrossRef]
45. Lim, P.E.; Kiu, M.Y. Determination and speciation of heavy metals in sediments of the Juru River, Penang, Malaysia. *Environ. Monit. Assess.* **1995**, *35*, 85–95. [CrossRef]
46. Wong, Y.S.; Tam, N.F.Y.; Lau, P.S.; Xue, X.Z. The toxicity of marine sediment in Victoria Harbour, Hong Kong. *Mar. Pollut. Bull.* **1995**, *31*, 464–470. [CrossRef]
47. Zwolsman, J.J.G.; Vaneck, G.T.M.; Burger, G. Spatial and temporal distribution of trace metals in sediments from the Scheldt estuarine, south–west Netherlands. *Estuar. Coast. Shelf Sci.* **1996**, *43*, 55–79. [CrossRef]
48. Wood, A.K.; Ahmad, Z.; Shazili, N.A.; Yaakob, R.; Carpenter, R. Geochemistry of sediments in Johore Strait between Malaysia and Singapore. *Continent. Shelf Res.* **1997**, *10*, 1207–1228. [CrossRef]
49. Fukue, M.; Nakamura, T.; Kato, Y.; Yamasaki, S. Degree of pollution for marine sediment. *Eng. Geol.* **1999**, *53*, 131–137. [CrossRef]
50. Kucuksezgin, F. Distribution of trace metals in the surficial sediments of Izmir Bay (Turkey). *Toxicol. Environ. Chem.* **2001**, *80*, 203–207. [CrossRef]
51. Yap, C.K.; Ismail, A.; Tan, S.G. Concentrations of Cu and Pb in the offshore and intertidal sediments of the west coast of Peninsular Malaysia. *Environ. Int.* **2002**, *28*, 467–479. [CrossRef]
52. Cheung, K.C.; Poon, B.H.T.; Lan, C.Y.; Wong, M.H. Assessment of metal and nutrient concentrations in river water and sediment collected from the cities in the Pearl River Delta. South China. *Chemosphere* **2003**, *52*, 1431–1440. [CrossRef]
53. Reddy, M.S.; Basha, S.; Kumar, V.G.S.; Joshi, H.V.; Ramachandraiah, G. Distribution, enrichment and accumulation of heavy metals in coastal sediments of Alang–Sosiya ship scrapping yard, India. *Mar. Pollut. Bull.* **2004**, *48*, 1055–1059. [CrossRef] [PubMed]
54. Takarina, N.D.; David, R.B.; Micheal, J.R. Speciation of heavy metal in coastal sediments of Semarang, Indonesia. *Mar. Pollut. Bull.* **2004**, *49*, 854–874. [CrossRef]
55. Ismail, A.; Yap, C.K.; Chan, F.F. Concentrations of Cd, Cu and Zn in sediments collected from urban lakes at Kelana Jaya, Peninsular Malaysia. *Wetl. Sci.* **2004**, *2*, 248–258.

56. Morillo, J.; Usero, J.; Gracia, I. Heavy metal distribution in marine sediments from the southwest coast of Spain. *Chemosphere* **2004**, *55*, 431–442. [CrossRef]
57. Cuong, D.T.; Bayen, S.; Wurl, O.; Subramanian, K.; Wong, K.K.S.; Sivasothi, N.; Obbard, J.P. Heavy metal contamination in mangrove habitats of Singapore. *Mar. Pollut. Bull.* **2005**, *50*, 1713–1744. [CrossRef]
58. Kouadio, I.; Trefry, J.H. Sediment trace metal contamination in the Ivory Coast, West Africa. *Water Air Soil Pollut.* **1987**, *32*, 145–154. [CrossRef]
59. Cox, M.E.; Preda, M. Trace metal distribution within marine and estuarine sediments of Western Moreton bay, Queensland, Australia: Relation to land use and setting. *Geogr. Res.* **2005**, *43*, 173–193. [CrossRef]
60. Nguyen, H.L.; Leermakers, M.; Osán, J.; Török, S.; Baeyens, W. Heavy metals in Lake Balaton: Water column, suspended matter, sediment and biota. *Sci. Total Environ.* **2005**, *340*, 213–230. [CrossRef] [PubMed]
61. Alagarsamy, R. Distribution and seasonal variation of trace metals in surface sediments of the Mandovi estuary west coast of India. *Estuar. Coast. Shelf Sci.* **2006**, *67*, 333–339. [CrossRef]
62. Cuong, D.T.; Obbard, N. Metal speciation in coastal marine sediments from Singapore using a modified BCR sequential extraction procedure. *Appl. Geochem.* **2006**, *21*, 1335–1346. [CrossRef]
63. Pekey, H. Heavy metal pollution assessment in sediments of Izmit Bay, Turkey. *Environ. Monit. Assess.* **2006**, *123*, 219–231. [CrossRef] [PubMed]
64. Olubunnmi, F.E.; Olorunsola, O.E. Evaluation of the status of heavy metal pollution of sediment of Agbabu Bitumen Deposit Area, Nigeria. *Eur. J. Sci. Res.* **2010**, *41*, 373–382.
65. Yap, C.K.; Choh, M.S.; Edward, F.B.; Ismail, A.; Tan, S.G. Comparison of heavy metal concentrations in surface sediment of Tanjung Piai wetland with other sites receiving anthropogenic inputs along the southwestern coast of Peninsular Malaysia. *Wetl. Sci.* **2006**, *4*, 48–57.
66. Edokpayi, J.N.; Odiyo, J.O.; Popoola, O.E.; Msagati, T.A.M. Assessment of trace metals contamination of surface water and sediment: A case study of Mvudi River, South Africa. *Sustanability* **2016**, *8*, 135. [CrossRef]
67. Bibi, M.H.; Ahmed, F.; Ishiga, H. Assessment of metal concentrations in lake sediments of southwest Japan based on sediment quality guidelines. *Environ. Geol.* **2007**, *52*, 625–639. [CrossRef]
68. Chen, C.W.; Kao, C.M.; Chen, C.F.; Dong, C.D. Distribution and accumulation of heavy metals in sediments of Kaoshiung Harbor, Taiwan. *Chemosphere* **2007**, *66*, 1431–1440. [CrossRef]
69. Li, Q.S.; Wu, Z.F.; Chu, B.; Zhang, N.; Czi, S.S.; Fang, J.H. Heavy metals in the coastal wetland sediments of the Pearl River Estuary, China. *Environ. Pollut.* **2007**, *149*, 158–164. [CrossRef]
70. Zhang, L.; Ye, X.; Feng, H.; Jing, Y.; Ouyang, T.; Yu, X.; Liang, R.; Gao, C.; Chen, W. Heavy metal contamination in western Xiamen Bay sediments and its vicinity, China. *Mar. Pollut. Bull.* **2007**, *54*, 974–982. [CrossRef] [PubMed]
71. Yap, C.K.; Ismail, A.; Low, C.H.; Tan, S.G. Interpretation of Cu and Zn contamination in the aquatic environment of Peninsular Malaysia with special reference to a polluted river, Sepang River. *Wetl. Sci.* **2007**, *5*, 311–321.
72. Yap, C.K.; Pang, B.H.; Fairuz, M.S.; Hoo, Y.I.; Tan, S.G. Heavy metal (Cd, Cu, Ni, Pb and Zn) pollution in surface sediments collected from drainages receiving different anthropogenic sources from Peninsular Malaysia. *Wetl. Sci.* **2007**, *5*, 97–104.
73. Chloe, W.Y.T.; Carman, C.I.; Zhang, G.; Paul, K.S.S.; Qian, P.; Xiang-dong, L. The spatial and temporal distribution of heavy metals in sediments of Victoria Harbour, Hong Kong. *Mar. Pollut. Bull.* **2008**, *57*, 816–825.
74. Arain, M.B.; Kazi, T.G.; Jamali, M.K.; Jalbani, N.; Afridi, H.I.; Baig, J.A. Speciation of heavy metals in sediment by conventional, ultrasound and microwave assisted single extraction methods: A comparison with modified sequential extraction procedure. *J. Hazard. Mater.* **2008**, *154*, 998–1006. [CrossRef] [PubMed]
75. Yap, C.K.; Cheng, W.H.; Tan, S.G. Comparative studies of concentrations of Cu and Zn in the surface intertidal sediments collected from east, south and west coasts of Peninsular Malaysia. *Asian J. Water Environ. Pollut.* **2008**, *5*, 23–29.
76. Zakir, H.M.; Shikazono, N.; Otomo, K. Geochemical distribution of trace metals and assessment of anthropogenic pollution in sediments of Old Nakagawa River, Tokyo, Japan. *Am. J. Environ. Sci.* **2008**, *4*, 654–665. [CrossRef]
77. Yap, C.K.; Wong, C.H. Assessment Cu, Ni and Zn pollution in the surface sediments in the southern Peninsular Malaysia using cluster analysis, ratios of geochemical nonresistant to resistant fractions, and geochemical indices. *Environ. Asia* **2011**, *4*, 53–61.
78. Yap, C.K.; Fairuz, M.S.; Cheng, W.H. How elevated of Cd, Cu and Pb levels in the surface sediments collected from drainage receiving metal industrial effluents? Comparison with metal industrial drainage and intertidal sediments in Selangor, Malaysia. *Asian J. Microbiol. Biotechnol. Environ. Sci.* **2008**, *10*, 385–391.
79. An, Q.; Wu, Y.; Wang, J.; Li, Z. Heavy metals and polychlorinated biphenyls in sediments of the Yangtze river estuary, China. *Environ. Earth Sci.* **2009**, *59*, 363–370. [CrossRef]
80. Zhang, W.; Feng, H.; Chang, J.; Qu, J.; Xie, H.; Yu, X. Heavy metal contamination in surface sediments of Yangtze River intertidal zone: An assessment from different indexes. *Environ. Pollut.* **2009**, *157*, 1533–1543. [CrossRef] [PubMed]
81. Amin, B.; Ismail, A.; Arshad, A.; Yap, C.K.; Kamarudin, M.S. Anthropogenic impacts on heavy metal concentrations in the coastal sediments of Dumai, Indonesia. *Environ. Monit. Assess.* **2009**, *148*, 291–305. [CrossRef] [PubMed]
82. Yap, C.K.; Yazdani, M.; Tan, S.G. The importance of the identification of point sources in a river receiving industrial metal effluents at the Serdang Industrial Area, Selangor. *J. Sustain. Sci. Manag.* **2009**, *4*, 18–26.
83. Pradit, S.; Wattayakorn, G.; Angsupanich, S.; Leemaker, M.; Baeyens, W. Distribution of trace elements in sediments and biota of Songkhla Lake, southern Thailand. *Water Air Soil Pollut.* **2010**, *206*, 155–174. [CrossRef]

84. Yap, C.K.; Pang, B.H. Assessment of Cu, Pb and Zn contamination in sediment of north western Peninsular Malaysia by using sediment quality values and different geochemical indices. *Environ. Monit. Assess.* **2011**, *183*, 23–39. [CrossRef]
85. Mei, J.; Li, Z.; Sun, L.; Gui, H.; Wang, X. Assessment of heavy metals in the urban river sediments in Suzhou city, northern Anhui Province, China. *Procedia Environ. Sci.* **2011**, *10*, 547–2553. [CrossRef]
86. Sahli, L.; Afri–Mehennaoui, F.Z.; El Okki, M.E.H.; Blaise, C.; Mehennaoui, S. Spatial and seasonal variations and ecotoxicological significance of sediment trace metal concentrations in Kebir–Rhumel basin (Northeast of Algeria). *Water Sci. Technol.* **2011**, *64*, 1759–1766. [CrossRef]
87. Aktumsek, A.; Gezgin, S. Seasonal variations of metal concentrations in muscle tissue of tench (*Tinca tinca*), water and sediment in Beysehir Lake (Turkey). *Environ. Tech.* **2011**, *32*, 1479–1485. [CrossRef]
88. Sany, B.T.; Sulaiman, A.; Monazami, G.; Salleh, A. Assessment of sediment quality according to heavy metal status in the West Port of Malaysia. *World Acad. Sci. Eng. Technol.* **2011**, *74*, 639–643.
89. Jamil, T.; Lias, K.; Hanif, H.; Norsila, D.; Aeisyah, A.; Kamaruzzaman, B. The spatial variability of heavy metals concentrations and sedimentary organicmatter in estuary sediment of Sungai Perlis, Perlis, Malaysia. *Sci. Postprint* **2014**, *1*, e00016.
90. Cheng, W.H.; Yap, C.K. Potential human health risks from toxic metals via mangrove snail consumption and their ecological risk assessments in the habitat sediment from Peninsular Malaysia. *Chemosphere* **2015**, *135*, 156–165. [CrossRef] [PubMed]
91. Antizar–Ladislao, B.; Mondal, P.; Mitra, S.; Sarkar, S.K. Assessment of trace metal contamination level and toxicity in sediments from coastal regions of West Bengal, eastern part of India. *Mar. Pollut. Bull.* **2015**, *101*, 886–894. [CrossRef] [PubMed]
92. Ioannides, K.; Stamoulis, K.; Papachristodoulou, C.; Tziamou, E.; Markantonaki, C.; Tsodoulos, I. Distribution of heavy metals in sediment cores of Lake Pamvotis (Greece): A pollution and potential risk assessment. *Environ. Monit. Assess.* **2015**, *187*, 4209. [CrossRef] [PubMed]
93. Kumar, A.; Ramanathan, A.L. Speciation of selected trace metals (Fe, Mn, Cu and Zn) with depth in the sediments of Sundarban mangroves: India and Bangladesh. *J. Soils Sed.* **2015**, *15*, 2476–2486. [CrossRef]
94. Li, C.; Song, C.; Yin, Y.; Sun, M.; Tao, P.; Shao, M. Spatial distribution and risk assessment of heavy metals in sediments of Shuangtaizi estuary, China. *Mar. Pollut. Bull.* **2015**, *98*, 358–364. [CrossRef]
95. Liu, H.; Liu, G.; Da, C.; Yuan, Z.; Wang, J. Concentration and fractionation of heavy metals in the old Yellow River Estuary, China. *J. Environ. Qual.* **2015**, *44*, 174–182. [CrossRef]
96. Nasr, S.M.; Okbah, M.A.; El Haddad, H.S.; Soliman, N.F. Fractionation profile and mobility pattern of metals in sediments from the Mediterranean Coast, Libya. *Environ. Monit. Assess.* **2015**, *187*, 8. [CrossRef]
97. Ren, J.; Shang, Z.; Tao, L.; Wang, X. Multivariate analysis and heavy metals pollution evaluation in Yellow river surface sediments. *Polish J. Environ. Stud.* **2015**, *24*, 1041–1048.
98. Sakan, S.M.; Sakan, N.M.; Dordevic, D.S. Pollution characteristics and potential ecological risk assessment of heavy metals in river sediments based on calculation of pollution indices. *Adv. Environ. Res.* **2015**, *41*, 63–84.
99. Zhang, J.; Gao, X. Heavy metals in surface sediments of the intertidal Laizhou Bay, Bohai Sea, China: Distributions, sources and contamination assessment. *Mar. Pollut. Bull.* **2015**, *98*, 320–327. [CrossRef]
100. Zhang, G.; Xie, Y.; Mo, Y. Spatial distribution characteristics and potential ecological risk assessment of heavy metals in typical water surface sediments of Dongting Lake. *Res. Environ. Sci.* **2015**, *28*, 1545–1552.
101. Qiao, S.; Shi, X.; Fang, X.; Liu, S.; Kornkanitnan, N.; Gao, J.; Zhu, A.; Hu, L.; Yu, Y. Heavy metal and clay mineral analyses in the sediments of Upper Gulf of Thailand and their implications on sedimentary provenance and dispersion pattern. *J. Asian Earth Sci.* **2015**, *114*, 488–496. [CrossRef]
102. Liu, J.; Ma, K.; Qu, L. Ecological risk assessments and context–dependence analysis of heavy metal contamination in the sediments of mangrove swamp in Leizhou Peninsula, China. *Mar. Pollut. Bull.* **2015**, *100*, 224–230. [CrossRef] [PubMed]
103. Mahu, E.; Nyarko, E.; Hulme, S.; Coale, K.H. Distribution and enrichment of trace metals in marine sediments from the Eastern equatorial Atlantic, off the coast of Ghana in the Gulf of Guinea. *Mar. Pollut. Bull.* **2015**, *98*, 301–307. [CrossRef]
104. Maanan, M.; Saddik, M.; Maanan, M.; Chaibi, M.; Assobhei, O.; Zourarah, B. Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. *Ecol. Ind.* **2015**, *48*, 616–626. [CrossRef]
105. Liang, A.; Wang, Y.; Guo, H.; Bo, L.; Zhang, S.; Bai, Y. Assessment of pollution and identification of sources of heavy metals in the sediments of Changshou Lake in a branch of the Three Gorges Reservoir. *Environ. Sci. Pollut. Res.* **2015**, *22*, 16067–16076. [CrossRef]
106. Shang, Z.; Ren, J.; Tao, L.; Wang, X. Assessment of heavy metals in surface sediments from Gansu section of Yellow River, China. *Environ. Monit. Assess.* **2015**, *187*, 79. [CrossRef]
107. Shang, Z.; Ren, J.; Zhao, Y.; Hao, J.; Guo, Y. Distribution, fraction and pollution assessment of metals in surface sediments from Yinchuan section of Yellow River, China. *Fresenius Environ. Bull.* **2015**, *24*, 4485–4491.
108. Chen, C.F.; Ju, Y.R.; Chen, C.W.; Dong, C.D. Vertical profile, contamination assessment, and source apportionment of heavy metals in sediment cores of Kaohsiung Harbor, Taiwan. *Chemosphere* **2016**, *165*, 67–79. [CrossRef]
109. Fang, H.; Chen, X.; Zhang, X.; Li, J.; Yang, H. Heavy metal pollution in the surface sediments from Minjiang River (Fuzhou Section) and urban rivers. *Acta Sci. Circumstantiae* **2016**, *36*, 1160–1168.
110. Gao, L.; Wang, Z.; Shan, J.; Chen, J.; Tang, C.; Yi, M.; Zhao, X. Distribution characteristics and sources of trace metals in sediment cores from a trans–boundary watercourse: An example from the Shima River, Pearl River Delta. *Ecotoxicol. Environ. Saf.* **2016**, *134*, 186–195. [CrossRef] [PubMed]

111. Kouidri, M.; Dali Youcef, N.; Benabdellah, I.; Ghoubali, R.; Bernoussi, A.; Lagha, A. Enrichment and geoaccumulation of heavy metals and risk assessment of sediments from coast of Ain Temouchent (Algeria). *Arab. J. Geosci.* **2016**, *9*, 354. [CrossRef]
112. Li, R.; Xu, H.; Chai, M.; Qiu, G.Y. Distribution and accumulation of mercury and copper in mangrove sediments in Shenzhen, the world's most rapid urbanized city. *Environ. Monit. Assess.* **2016**, *188*, 87. [CrossRef] [PubMed]
113. Ozseker, K.; Seyhan, K.; Eruz, C. Ecological risk assessment and spatial distribution of heavy metals in sediment and pore water around Trabzon harbor, Turkey. *Fresenius Environ. Bull.* **2016**, *25*, 3125–3133.
114. Xu, F.; Tian, X.; Yin, F.; Zhao, Y.; Yin, X. Heavy metals in the surface sediments of the northern portion of the South China Sea shelf: Distribution, contamination, and sources. *Environ. Sci. Pollut. Res.* **2016**, *23*, 8940–8950. [CrossRef]
115. Yuan, H.; An, S.; Zhu, Z.; Pan, W. Speciation and bioavailability of heavy metals in sediments taken from wetland in the Huaihe River Basin. *J. Environ. Eng.* **2016**, *142*, C5015001. [CrossRef]
116. Zhao, G.; Lu, Q.; Ye, S.; Yuan, H.; Ding, X.; Wang, J. Assessment of heavy metal contamination in surface sediments of the west Guangdong coastal region, China. *Mar. Pollut. Bull.* **2016**, *108*, 268–274. [CrossRef]
117. Zohra, B.S.; Habib, A. Assessment of heavy metal contamination levels and toxicity in sediments and fishes from the Mediterranean Sea (southern coast of Sfax, Tunisia). *Environ. Sci. Pollut. Res.* **2016**, *23*, 13954–13963. [CrossRef]
118. Liu, J.; Yang, T.; Chen, Q.; Liu, F.; Wang, B. Distribution and potential ecological risk of heavy metals in the typical eco-units of Haihe River Basin. *Front. Environ. Sci. Eng.* **2016**, *10*, 103–113. [CrossRef]
119. Duodu, G.O.; Goonetilleke, A.; Ayoko, G.A. Comparison of pollution indices for the assessment of heavy metal in Brisbane River sediment. *Environ. Pollut.* **2016**, *219*, 1077–1091. [CrossRef]
120. Agah, H.; Saleh, A.; Bastami, K.D.; Fumani, N.S. Ecological risk, source and preliminary assessment of metals in the surface sediments of Chabahar Bay, Oman Sea. *Mar. Pollut. Bull.* **2016**, *107*, 383–388. [CrossRef] [PubMed]
121. El Zrelli, R.; Courjault–Radé, P.; Rabaoui, L.; Castet, S.; Michel, S.; Bejaoui, N. Heavy metal contamination and ecological risk assessment in the surface sediments of the coastal area surrounding the industrial complex of Gabes city, Gulf of Gabes, SE Tunisia. *Mar. Pollut. Bull.* **2016**, *101*, 922–929. [CrossRef] [PubMed]
122. Hanif, N.; Shah Eqani, S.A.M.A.; Ali, S.M.; Cincinelli, A.; Ali, N.; Katsoyiannis, I.A.; Tanveer, Z.A.; Bokhari, H. Geo–accumulation and enrichment of trace metals in sediments and their associated risks in the Chenab River, Pakistan. *J. Geochem. Explor.* **2016**, *165*, 62–70. [CrossRef]
123. Wang, J.; Du, H.; Xu, Y.; Chen, K.; Liang, J.; Ke, H.; Cheng, S.Y.; Liu, M.; Deng, H.; He, T.; et al. Environmental and ecological risk assessment of trace metal contamination in mangrove ecosystems: A case from Zhangjiangkou Mangrove National Nature Reserve, China. *BioMed Res. Int.* **2016**, *2016*, 2167053. [CrossRef] [PubMed]
124. Zhuo, H.H.; Sun, Z.W.; Tan, L.Z.; Wu, Y.L.; Lan, J. Temporal and spatial variation characteristics of the heavy metals content in the surface sediment and the potential ecological risk trends in the Three Gorges Reservoir area. *Environ. Sci.* **2016**, *37*, 4633–4643.
125. Ghorbanzadeh, Z.S.; Machinchian, M.A.; Mousavi, N.R.; Sari, A.R.; Fatemi, S.M.R. Distribution pattern of heavy metals in the surficial sediment of Gorgan Bay (South Caspian Sea, Iran). *Iran. J. Fish. Sci.* **2016**, *15*, 1144–1166.
126. Hossen, M.Z.; Islam, M.M.; Hossain, M.S. Heavy Metal Contents in Sediments of an Urban Industrialized Area—A Case Study of Tongi Canal, Bangladesh. *Asian J. Water Environ. Pollut.* **2017**, *14*, 59–68. [CrossRef]
127. Li, H.; Ye, S.; Ye, J.; Fan, J.; Gao, M.; Guo, H. Baseline survey of sediments and marine organisms in Liaohe Estuary: Heavy metals, polychlorinated biphenyls and organochlorine pesticides. *Mar. Pollut. Bull.* **2017**, *114*, 555–563. [CrossRef]
128. Liu, J.; Xu, Y.; Cheng, Y.; Zhao, Y.; Pan, Y.; Fu, G.; Dai, Y. Occurrence and risk assessment of heavy metals in sediments of the Xiangjiang River, China. *Environ. Sci. Pollut. Res.* **2017**, *24*, 2711–2723. [CrossRef]
129. Xu, F.; Liu, Z.; Cao, Y.; Qiu, L.; Feng, J.; Xu, F.; Tian, X. Assessment of heavy metal contamination in urban river sediments in the Jiaozhou Bay catchment, Qingdao, China. *Catena* **2017**, *150*, 9–16. [CrossRef]
130. Kilunga, P.I.; Sivalingam, P.; Laffite, A.; Grandjean, D.; Mulaji, C.K.; de Alencastro, L.F.; Mpiana, P.T.; Pot, J. Accumulation of toxic metals and organic micro–pollutants in sediments from tropical urban rivers, Kinshasa, Democratic Republic of the Congo. *Chemosphere* **2017**, *179*, 37–48. [CrossRef] [PubMed]
131. Khodami, S.; Surif, M.; Wan Maznah, W.O.; Daryanabard, R. Assessment of heavy metal pollution in surface sediments of the Bayan Lepas area, Penang, Malaysia. *Mar. Pollut. Bull.* **2017**, *114*, 615–622. [CrossRef] [PubMed]
132. Diop, C.; Dewaele, D.; Cazier, F.; Diouf, A.; Ouddane, B. Assessment of trace metals contamination level, bioavailability and toxicity in sediments from Dakar coast and Saint Louis estuary in Senegal, West Africa. *Chemosphere* **2015**, *138*, 980–987. [CrossRef] [PubMed]
133. Kumar, S.B.; Padhi, R.K.; Mohanty, A.K.; Satpathy, K.K. Elemental distribution and trace metal contamination in the surface sediment of south east coast of India. *Mar. Pollut. Bull.* **2017**, *114*, 1164–1170. [CrossRef]
134. Pourkerman, M.; Amjadi, S.; Beni, A.N.; Lahijani, H.; Mehdinia, A. Evaluation of metal contamination in the Mand River delta, Persian Gulf. *Mar. Pollut. Bull.* **2017**, *119*, 261–267. [CrossRef]
135. Kusin, F.M.; Azani, N.N.M.; Hasan, S.N.M.S.; Sulong, N.A. Distribution of heavy metals and metalloid in surface sediments of heavily-mined area for bauxite ore in Pengerang, Malaysia and associated risk assessment. *Catena* **2018**, *165*, 454–464. [CrossRef]
136. Gholizadeh, M.; Patimar, R. Ecological risk assessment of heavy metals in surface sediments from the Gorgan Bay, Caspian Sea. *Mar. Pollut. Bull.* **2018**, *137*, 662–667. [CrossRef]
137. Wang, G.; Hu, X.; Zhu, Y.; Jiang, H.; Wang, H. Historical accumulation and ecological risk assessment of heavy metals in sediments of a drinking water lake. *Environ. Sci. Pollut. Res.* **2018**, *25*, 24882–24894. [CrossRef]

138. Proshad, R.; Islam, M.S.; Kormoker, T.; Masud, M.E.M.; Ali, M.M. Assessment of toxic metals contamination with ecological risk of surface water and sediment of Korotoa River in Bangladesh. *Int. J. Adv. Geosci.* **2018**, *6*, 214–221. [CrossRef]
139. Enuneku, A.; Omoruyi, O.; Tongo, I.; Ogbomida, E.; Ogbeide, O.; Ezemonye, L. Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. *Appl. Water Sci.* **2018**, *8*, 224. [CrossRef]
140. Javed, T.; Ahmad, N.; Mashiatullah, A. Heavy Metals Contamination and Ecological Risk Assessment in Surface Sediments of Namal Lake, Pakistan. *Pol. J. Environ. Stud.* **2018**, *27*, 675–688. [CrossRef]
141. Proshad, R.; Kormoker, T.; Islam, S. Distribution, source identification, ecological and health risks of heavy metals in surface sediments of the Rupsa River, Bangladesh. *Toxin Rev.* **2019**, *40*, 1135–1154. [CrossRef]
142. Kormoker, T.; Proshad, R.; Islam, M.S. Ecological risk assessment of heavy metals in sediment of the Louhajang River, Bangladesh. *SF J. Environ. Earth Sci.* **2019**, *2*, 1030.
143. Živković, N.; Takić, L.; Djordjević, L.; Djordjević, A.; Mladenović-Ranisavljević, I.; Golubović, T.; Božilov, A. Concentrations of heavy metal cations and a health risk assessment of sediments and river surface water: A case study from a Serbian mine. *Pol. J. Environ. Stud.* **2019**, *28*, 2009–2020. [CrossRef]
144. Siddiqui, E.; Pandey, J. Assessment of heavy metal pollution in water and surface sediment and evaluation of ecological risks associated with sediment contamination in the Ganga River: A basin-scale study. *Environ. Sci. Pollut. Res.* **2019**, *26*, 10926–10940. [CrossRef] [PubMed]
145. Wang, M.; Liu, J.; Lai, J. Metals pollution and ecological risk assessment of sediments in the Poyang Lake, China. *Bull. Environ. Contam. Toxicol.* **2019**, *102*, 511–518. [CrossRef] [PubMed]
146. El-Kady, A.A.; Wade, T.L.; Sweet, S.T.; Klein, A.G. Spatial distribution and ecological risk assessment of trace metals in surface sediments of Lake Qaroun, Egypt. *Environ. Monit. Assess.* **2019**, *191*, 413. [CrossRef]
147. Xiao, H.; Shahab, A.; Li, J.; Xi, B.; Sun, X.; He, H.; Yu, G. Distribution, ecological risk assessment and source identification of heavy metals in surface sediments of Huixian karst wetland, China. *Ecotoxicol. Environ. Saf.* **2019**, *185*, 109700. [CrossRef]
148. Emenike, P.C.; Tenebe, I.T.; Neris, J.B.; Omole, D.O.; Afolayan, O.; Okeke, C.U.; Emenike, I.K. An integrated assessment of land-use change impact, seasonal variation of pollution indices and human health risk of selected toxic elements in sediments of River Atuwara, Nigeria. *Environ. Pollut.* **2020**, *265*, 114795. [CrossRef]
149. Zerizghi, T.; Yang, Y.; Wang, W.; Zhou, Y.; Zhang, J.; Yi, Y. Ecological risk assessment of heavy metal concentrations in sediment and fish of a shallow lake: A case study of Baiyangdian Lake, North China. *Environ. Monit. Assess.* **2020**, *192*, 154. [CrossRef]
150. Algül, F.; Beyhan, M. Concentrations and sources of heavy metals in shallow sediments in Lake Bafa, Turkey. *Sci. Rep.* **2020**, *10*, 11782. [CrossRef] [PubMed]
151. Sudarshan, P.; Mahesh, M.K.; Ramachandra, T.V. Dynamics of metal pollution in sediment and macrophytes of Varthur Lake, Bangalore. *Bull. Environ. Contam. Toxicol.* **2020**, *104*, 411–417. [CrossRef] [PubMed]
152. Ahamad, M.I.; Song, J.; Sun, H.; Wang, X.; Mehmood, M.S.; Sajid, M.; Su, P.; Khan, A.J. Contamination level, ecological risk, and source identification of heavy metals in the hyporheic zone of the Weihe River, China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1070. [CrossRef]
153. Ustaoğlu, F. Ecotoxicological risk assessment and source identification of heavy metals in the surface sediments of Çömlekci stream, Giresun, Turkey. *Environ. Forensics* **2021**, *22*, 130–142. [CrossRef]
154. Sadeghi, P.; Loghmani, M.; Yousuf, D.J.; Abadi, Z.T.R. Ecological and human health risk assessment of trace element pollution in sediments and five important commercial fishes of the Oman Sea. *Mar. Pollut. Bull.* **2021**, *173*, 112962. [CrossRef]
155. Goher, M.E.; Mangood, A.H.; Mousa, I.E.; Salem, S.G.; Hussein, M.M. Ecological risk assessment of heavy metal pollution in sediments of Nile River, Egypt. *Environ. Monit. Assess.* **2021**, *193*, 703. [CrossRef]
156. Talukder, R.; Rabbi, M.H.; Baharim, N.B.; Carnicelli, S. Source identification and ecological risk assessment of heavy metal pollution in sediments of Setiu Wetland, Malaysia. *Environ. Forensics* **2022**, *23*, 241–254. [CrossRef]
157. Li, F.; Yu, X.; Lv, J.; Wu, Q.; An, Y. Assessment of heavy metal pollution in surface sediments of the Chishui River Basin, China. *PLoS ONE* **2022**, *17*, e0260901. [CrossRef]
158. Iordache, A.M.; Nechita, C.; Zgavarogea, R.; Voica, C.; Varlam, M.; Ionete, R.E. Accumulation and ecotoxicological risk assessment of heavy metals in surface sediments of the Olt River, Romania. *Sci. Rep.* **2022**, *12*, 880. [CrossRef]
159. Acharjee, A.; Ahmed, Z.; Kumar, P.; Alam, R.; Rahman, M.S.; Simal-Gandara, J. Assessment of the Ecological Risk from Heavy Metals in the Surface Sediment of River Surma, Bangladesh: Coupled Approach of Monte Carlo Simulation and Multi-Component Statistical Analysis. *Water* **2022**, *14*, 180. [CrossRef]
160. Liu, H.; Liu, E.; Yu, Z.; Lin, Q.; Zhang, E.; Shen, J. Spatio-temporal accumulation patterns of trace metals in sediments of a large plateau lake (Erhai) in Southwest China and their relationship with human activities over the past century. *J. Geochem. Explor.* **2022**, *234*, 106943. [CrossRef]
161. Hair, J.F.; Black, W.C.; Babin, B.J. *Multivariate Data Analysis: A Global Perspective*; Pearson Education: London, UK, 2010.
162. Byrne, B.M. *Structural Equation Modeling with AMOS: Basic Concepts, Applications, and Programming*, 2nd ed.; Routledge: New York, NY, USA, 2010.
163. Garson, G.D. *Partial Least Squares: Regression and Structural Equation Models*; Statistical Associates Publishers: Asheboro, NC, USA, 2016; ISBN 13 978-1-62638-039-4.
164. Taylor, S.R.; McLennan, S.M. The geochemical evolution of the continental crust. *Rev. Geophys.* **1995**, *33*, 241–265. [CrossRef]

165. Rudnick, R.L.; Gao, S. Composition of the continental crust. In *The Crust*; Rudnick, R.L., Ed.; Elsevier: Amsterdam, The Netherlands, 2003; Volume 3, pp. 1–64.
166. Long, E.R.; MacDonald, D.D.; Smith, S.L.; Calder, F.D. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environ. Manag.* **1995**, *19*, 81–97. [CrossRef]
167. Chapman, P.M.; Patrick, J.A.; Vigers, G.A. Development of sediment quality values for Hong Kong special administrative region: A possible model for other jurisdictions. *Mar. Pollut. Bull.* **1999**, *38*, 161–169. [CrossRef]
168. MacDonald, D.D.; Carr, R.S.; Calder, F.D.; Long, E.R.; Ingersoll, C.G. Development and evaluation of sediment quality guidelines for Florida coastal waters. *Ecotoxicology* **1996**, *5*, 253–278. [CrossRef]