ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2024, 9 (3): 117-128 doi: 10.28978/nesciences.1558330

Assessing the Ecological Impact of Heavy Metal Pollution in the Sediments of Sepang Besar River, Malaysia

Nadia Ab. Shukor [1*], M. Sughanti [2], Kumar Krishnan [3], Nur Indah Abd. Shukor [4], Wong Ling Shing [5]

[1*] Faculty of Health and Life Sciences, INTI International University, Persiaran Perdana BBN, Putra Nilai, Negeri Sembilan, Malaysia. E-mail: nadia.shukor@newinti.edu.my

[2] Department of Biotechnology, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Pallavaram, Chennai, Tamil Nadu, India. E-mail: suganthi.sls@velsuniv.ac.in

[3] Faculty of Health and Life Sciences, INTI International University, Persiaran Perdana BBN, Putra Nilai, Negeri Sembilan, Malaysia. E-mail: kumar.krishnan@newinti.edu.my

[4] Faculty of Agriculture, University Putra Malaysia, Seri Kembangan, Selangor, Malaysia. E-mail: indahshukor@yahoo.com

[5] Faculty of Health & Life Sciences, INTI International University, Persiaran Perdana BBN, Putra Nilai, Negeri Sembilan, Malaysia. E-mail: lingshing.wong@newinti.edu.my

Abstract

Mostly in aquatic systems, heavy metal contamination is a major environmental problem. This paper studies heavy metal pollution in the sediments of the Sepang Besar River in Malaysia at varied sediment levels of 10 cm, 20 cm, and 30 cm under an eye on elements like titanium (Ti), vanadium (V), manganese (Mn), arsenic (As), chromium (Cr), zinc (Zn), and cobalt (Co). Our data show that the maximum concentrations of Ti, Zn, and Mn are seen despite very significant depth changes. Most metals indicate little human impact based on evaluations utilising the enrichment factor (EF) and geo-accumulation index (I_{geo}), even if manganese (Mn) and arsenic (As) more investigation is required. Particularly for Zn and As, our results highlight the importance of ongoing observation and calculated actions to reduce environmental risks. This report suggests more thorough environmental management plans aimed at defending aquatic habitats against growing urbanization and industrialization.

Keywords:

Pollution, sediments, contamination, ecological monitoring.

**Corresponding Author: Nadia Ab. Shukor, E-mail: nadia.shukor@newinti.edu.my*

Article history:

Received: 02/08/2024, Revised: 18/09/2024, Accepted: 17/10/2024, Available online: 31/12/2024

Introduction

The toxicity, long-lasting effects, and capacity of heavy metal pollution to bioaccumulate in living organisms identify the main environmental problems related to them (Vardhan et al., 2019). Among other human activities, quick economic development, agricultural practices, and industrial operations have considerably boosted pollution levels (Ali et al., 2019). Aquatic surroundings including rivers, estuaries, mangroves, and coastal areas—are particularly vulnerable to heavy metal contamination because of their open and linked nature. The negative effects of heavy metals in mangrove sediments are drawing more and more attention given their potential to upset the ecosystem and the dependent species. Common heavy metals shown to be adversely impacting various species including fish, crabs, and plants include lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd) (Khodami et al., 2017). Rising quantities of these toxins may compromise human health by upsetting local animals and eradicating species all throughout the food chain. Moreover, the accumulation of these toxins in sediments can lead to output in mangrove ecosystems to decrease as well as biodiversity (Kulkarni et al., 2018).

Therefore, regular monitoring and reduction of certain contaminants defines preservation of the surroundings and the species living in them. Particularly on the west coast of Peninsular Malaysia, Malaysia is a fast-expanding country with considerable agricultural and industrial growth. This area has drawn a lot of multi-element research mostly due to its efficient land use, quick economic growth, and high population density. Rising pollution resulting from this expansion has deteriorated the air quality, soil, and water (Usmani et al., 2020). Among the activities seriously compromising the integrity and health of ecosystems are chemical manufacturing, coal conversion, and trash burning (Mohiuddin et al., 2022). Many times, heavy metals reduce the surrounding quality starting with human activities. Malaysia has to invest in greener technology, support sustainable practices, and implement stricter laws if it is to help to reduce pollution and preserve the environment (Yuan et al., 2020).

Historical Agricultural and Industry Activity

The Sepang Besar River is mostly important for the local environment and economy of Selangor, Malaysia. Historically, the region's biodiversity has been preserved by the river's essential transportation and irrigation channel. Still, previous industrial and agricultural activities as well as modern pollution from tourism, aquaculture, and agriculture might have caused notable metal contamination in the sediments (Krishnan et al., 2022). Previous farming operations with considerable pesticide and fertiliser use might have brought manganese (Mn) and zinc (Zn) into the river system (Shukor et al., 2023). These metals may have accumulated over time in sedimentary layers, worsening the current degree of contamination (Zhang et al., 2019).

According to a 2019 assessment, Sepang Besar River pollution is really high in accordance with human activity. In aquatic environments, surface sediments might be a final refuge for pollutants; thus, they give significant information on pollution levels and the prospective consequences of contaminants (Krishnan et al., 2022). Their influence on the mobility, impact, and destiny of heavy metals in the environment makes the physical and chemical properties of sediment both sink and source of heavy metal pollution in water therefore their evaluation is vital (Wang & Yang, 2016). Two generally used methods for assessing pollution and sediment quality are the geo-accumulation index (I_{geo}) and the enrichment factor (EF). While the I_{geo} gauges pollution by terms of current concentrations versus pre-industrial levels, the EF decides whether an element is natural or created by matching its concentration with the crust.

The purpose of this paper is to evaluate and contrast the degrees of heavy metal contamination in Sepang Besar River sediments at many layers. We want to find the degree of heavy metal contamination and its projected consequences on aquatic ecology by means of sediment samples collected at many sites along the river. By means of an investigation of the pollution levels in the sediments of the Sepang Besar River, one may design targeted treatments aimed at improving water quality and thereby protecting ecosystems, so supporting more general global environmental preservation operations (Bryan-Brown et al., 2020).

Materials and Methods

Research Area and Sampling Approach

Starting the Sepang Besar River in Selangor, Malaysia, the Titiwangsa Mountains at last find contact with the Straits of Malacca. For the local economy long ago, transportation and agriculture both mostly depended on this river. Variant in nature, the river supports several kinds of birds, fish, and flora. Table 1 describes the nearby activities at the sample locations; Figure 1 illustrates their positions along the Sepang River. Aquaculture, tourism, industry, and other human activities are main contributors of the rising river pollution. These challenges emphasize the need of using effective conservation and management strategies to protect the welfare of dependent populations and the condition of the river.

Table 1. The description of nearby activities at the sampling sites

Label	Nearby activity/location	GPS Coordinate
L1	Sepang Fish Farm	2° 36’7.41’ N 101° 42’39.4’ E
L2	Shrimp pond, Bukit Pelanduk	2° 39’35.8’’ N 101° 44’8.62’ E
L3	Pig Farm, Bukit Pelanduk	2° 39’18.6’ N 101° 44’7.85’ E

Figure 1. Map of the mangrove sampling site along the Sepang River in Selangor, Malaysia

Sediment samples were gathered at several points along the river using a stainless-steel sediment corer to assess the degree of heavy metal contamination. Samples were taken 10 to 30 cm deep at 10 to 30 cm intervals in order to identify variations in contamination across many layers of sediment. Every depth interval at each site was homogenized to ensure uniformity. The samples were subsequently sent to the lab in an icebox and covered in acid-washed polyethylene bags in order to halt degradation or contamination.

Analytical Method

The sediment samples were dried in an oven at 80°C for at least 72 hours to remove moisture and have a homogeneous dry weight when they got to the laboratory. After drying, the materials pulverized finely; next, for both short- and long- irradiation, they are classified by depth. With a thermal neutron flux of 4.0 x 10^{12} cm^{-2} s^{-1} the pneumatic conveyance system of the MINT TRIGA research reactor exposed the subsamples to radiation running at 750 kW of power. About 150–200 mg of the substance was measured for analysis after each specimen was packed in an airtight plastic container. Gamma spectroscopy was used to acquire elemental concentrations; half-lives and gamma energies permitted radionuclides to be identified (Kumar et al., 2014; Benarfa et al., 2020).

Blank samples mixed with Standard Reference Materials (SRM), including SJS SL-1 (Lake Sediment), were irradiated adjacent to the experimental samples to guarantee the accuracy and reliability of the results. The samples were frozen for twenty-twenty-24 hours then subjected to one minute of short-wave radiation followed by five and twenty-minute counting intervals. Six hours of long-wave radiation followed three to four days and twenty to thirty-eight days post-cooling, one-hour counting intervals. The irradiation samples were investigated under a high-density hyper-pure germanium (HPGe) detector after calibration for energy values between 60 keV and 2 MeV. For both short- and long-radiation, the sample to detector distances came out as 2 cm and 12 cm respectively. The components of the samples were searched using the precise energy of delayed gamma rays (Chajduk & Polkowska-Motrenko, 2017).

Heavy Metal Enrichement

- ***Enrichement Factor***

By means of a comparison between the concentration of a particular heavy metal and a reference value, the enrichment factor (EF) helps one to assess sediment pollution. The EF is obtained here using the following equation (1) (Zoller et al., 1974):

$$EF_{metal} = (M_{exp}/Fe_{exp})_{sample} / (M_{ref}/Fe_{ref})_{shale} \quad (1)$$

Where,

M_{exp} is the concentration of the element in the experimental sample.

Fe_{exp} is the concentration of iron in the sample.

M_{ref} and Fe_{ref} are the respective concentrations in the average shale.

An EF value of 1 implies no enrichment; values between 3 and 5 define moderate enrichment; values between 10 and 25 indicate severe enrichment; values between 25 and 50 indicate very severe enrichment; values above 50 indicate extreme enrichment (Sutherland, 2000).

- ***GEO-Accumulation Index***

Müller (1981) determined the degree of heavy metal contamination by means of a comparison between present concentrations and pre-industrial levels, therefore acquiring the geo-accumulation index (I_{geo}). Here we obtain the I_{geo} using the following equation (2) (Muller 1981).

$$I_{geo} = \log2 (C_n/1.5 \times B_n) \quad (2)$$

Where,

C_n is the measured concentration of the metal in the sediment.

B_n is the background concentration of the metal.

By using the equation (2), the factor 1.5 helps to reduce the possible effect of variations between the background values which may be contribute to lithologic variations in the sediments. Clearly displaying a pollution level rating, the I_{geo} values range from -1 (uncontaminated) to more than 5 (very contaminated).

Results and Discussion

- ***Quality Control and Verification***

The sediment quality was assessed using Standard Certified Reference Materials (CRM) SJS and SL-1, therefore ensuring the analytical approach reliability and correctness. Table 2 provides computed values for every element along with analytical data derived from Standard Reference Material (SRM). Recovery percentages from 66% to 112% within the allowed recovery range of 70% to 120% (Rouessac, 2022) indicate the reliability and efficacy of the used analytical procedures, therefore guaranteeing accurate and trustworthy results.

Table 2. The analysis of the standard reference material and comparison with certified values of SL-1 and SJS (mg/kg).

Element	Standard value (mg/kg)	Measured value (mg/kg)	Recovery (%)
Ti	5170.0*	3450.0	66.73
V	110.0	114.44	104.04
Mn	529.0	482.14	91.14
As	10.5	9.61	91.56
Cr	130.0	101.44	78.03
Zn	103.0	115.32	111.96
Co	12.8	12.5	97.66
Fe	336000.0	316900.4	94.32

- ***Heavy Metal Concentrations***

Table 3 shows the concentrations of many heavy metals, including Ti, V, Mn, As, Cr, Zn, and Co, at different sediment layers—10 cm, 20 cm, and 30 cm. At all depths the peak concentrations of Ti, Zn, and Mn were always reported with values ranging from 2580.677 to 4031.843 mg/kg for Ti, 155.278 to 173.78 mg/kg for Zn, and 123.693 to 175.675 mg/kg for Mn.

Table 3. Levels of heavy metal concentration in sediments at different depths of the sepang besar river (mg/kg)

Element	Depth (cm)	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)	Std. Dev (mg/kg)
Ti	10	2580.877	3438.00	3094.624	392.964
	20	2620.756	3517.03	3165.519	412.877
	30	2788.263	4031.843	3393.702	529.248
V	10	60.991	92.145	74.709	14.785
	20	65.403	81.992	72.272	7.712
	30	66.718	88.242	79.667	9.22
Mn	10	123.693	128.66	126.387	2.519
	20	150.631	164.943	155.963	6.523
	30	165.137	175.675	171.877	4.63
As	10	17.609	19.742	18.90	1.017
	20	18.872	20.805	19.685	0.837
	30	14.273	20.702	18.399	2.845
Cr	10	39.643	42.204	40.667	1.234
	20	40.41	44.965	42.927	1.88
	30	42.132,	45.396	43.627	1.342
Zn	10	155.278	167.562	159.204	5.632
	20	167.034	173.738	170.421	2.832
	30	150.567	169.724	158.385	8.125
Co	10	8.036	8.934	8.477	0.367
	2	8.266	9.142	8.734	0.388
	30	7.725	8.755	8.242	0.434

Metals Ti > Zn > Mn > V > Cr > As arrange here at the sedge surface. Since it implies that human activities including agricultural runoff and industrial effluent may produce high concentrations of several metals, especially Ti, Zn, and Mn, this distribution suggests the continuity of both natural and manmade deposition thus implying especially at higher sediment depths (Ashraf et al., 2018). These findings confirm past regional studies showing substantial metal enrichment in river sediments (Nyangon et al., 2019). Variations in as levels and a little increase in Mn lead to most likely long-term ecological risks requiring further research (Mohanty et al., 2024; Veysi & Salari-Aliabadi, 2021).

- ***Enrichment Factor***

The enrichment factor (EF) is quite useful in determining the heavy metal content in sediment. Table 4 reveals that the distribution of EF values for Ti, V, and Cr was not greatly affected by various sediment depths. The rising enrichment factor (EF) of manganese (Mn) shows deposition in deeper sediment layers from 0.13 at 10 cm to 0.17 at 30 cm. Most likely from both natural and manufactured sources, manganese accumulation over time might be the reason for this inclination.

Table 4. Enrichment factor (EF) of heavy metal at different sediment depth in sepang besar river

Element	Depth (cm)		
	10	20	30
Ti	0.49	0.48	0.52
V	0.53	0.49	0.55
Mn	0.13	0.15	0.17
As	0.89	0.91	0.82
Cr	0.38	0.39	0.40
Zn	0.75	0.77	0.73
Co	0.42	0.46	0.41

Notable recordable higher EF values were reached; they peaked at 0.91 at 20 cm then fell to 0.82 at 30 cm. Different depths of arsenic deposition from many environmental sources might influence this oscillation. The EF values of Zn revealed a somewhat stable distribution with few oscillations; their little increase at 20 cm (0.77) and slight decrease at 30 cm (0.73) were observed. The company's EF rose from 0.42 at 10 cm to 0.46 at 20 cm then declined to 0.41 at 30 cm assuming environmental factors or sedimentation processes may affect its dispersion (Costa-Böddeker et al., 2018).

Most heavy metals demonstrate stability across many sediment depths based on the EF data. The variance in the distribution of As, V, and Co corresponds to different sources or environmental variables; however, the significant increase in Mn indicates increasing accumulation at lesser levels.

- ***GEO-Accumulation Index***

Table 5 presents the Geo-accumuation Index (I_{geo}) values at different sediment depths, therefore evaluating the degree of contamination of the studied heavy metals. From all depths, consistent negative I_{geo} values for Ti and V show that their concentrations are below pre-industrial levels, therefore suggesting a mostly natural origin and no significant pollution. Mn's extremely low I_{geo} values revealed even more its natural source and pure nature (Dietrich et al., 2018; Ilić et al., 2018).

Table 5. Geo-accumulation index (Igeo) of heavy metal at different sediment depth in Sepang Besar River.

Element	**Depth (cm)**		
	10	**20**	**30**
Ti	-1.21	-1.17	-1.07
V	-1.07	-1.13	-0.98
Mn	-3.12	-2.81	-2.67
As	-0.33	-0.25	-0.41
Cr	-1.55	-1.48	-1.45
Zn	-0.58	-0.48	-0.58
Co	-1.40	-1.23	-1.40

I_{geo} of as was zero, especially about 20 cm, suggesting a little concentration increase within normal range. As is not now a major contributor of sedimentary contamination. Consistently negative I_{geo} findings for Cr, Zn, and Co revealed that their concentrations are below pre-industrial levels and hence no pollution concern is formed (Dendievel et al., 2020). The studies reveal that the concentrations of Mn, As, Cr, Zn, and Co in the sediment have not changed very substantially with growing industrial activity. These metals' homogeneity throughout various sediment depths suggests their fundamentally natural source free from human influence.

- ***Environment Consequences and Heavy Metal Distribution***

The lowest sediment layers collecting these metals throughout time are produced by depth, continuous shift in Mn and Ti distribution pattern. This might reveal either natural source deposits or ongoing human activities adding to them. Particularly at shallower depths, environmental changes or sedimentation mechanisms affecting deposition and retention can assist to explain the little oscillations in Co and V concentrations (Semcesen & Wells, 2021).

At 20 cm, the concentration of As peaked and suggested that past human action or natural processes might have briefly increased the arsenic levels in the sediment. Zn also obviously surged at 20 cm and dropped at 30 cm, suggesting that both anthropogenic and natural changes might influence its distribution (Hanebuth et al., 2018). The EF and I_{geo} readings for the Sepang Besar River indicate quite good sediment quality, most metals exhibit values in line with natural background. Unusual arsenic distribution and somewhat high manganese accumulation levels call for further research. Though these elements do not yet cause any notable pollution problems, continuous research is necessary to avoid any environmental problems (Shakir et al., 2024).

Table 6. Comparison of Enrichment factor and Geo-accumulatio index from previous study in Sepang Besar River

	Enrichment Factor				Geo-accumulation index				
Location	**As**	**Cr**	**Zn**	**Co**	**As**	**Cr**	**Zn**	**Co**	**References**
Sungai Sepang Besar	0.89	0.38	0.75	0.42	-0.33	-1.55	-0.58	-1.40	Present study (10 cm)
Sepang fish farm, Sungai Sepang	9.595	0.253	*nd*	0.253	1.829	-9.24	*nd*	-7.14	Kumar et al., 2022
Shrimp farm, Sungai Sepang Besar	4.38	0.12	*nd*	0.14	0.29	-4.84	*nd*	-4.71	Kumar et al., 2022
Pig farm, Sungai Sepang Besar	8.94	0.23	*nd*	0.23	1.325	-3.972	*nd*	-3.951	Kumar et al., 2022

**nd – not detected*

As presented in Table 6, despite past studies in the region, our study shows a typically low to moderate trend in heavy metal pollution in Malaysian river sediments (Nyangon et al., 2019; Duan et al., 2020). Moreover, our studies show no appreciable changes in heavy metal concentrations throughout various sediment depths, suggesting a homogeneous distribution of these metals over time. Constant environmental circumstances affecting sediment deposition or ongoing pollution sources serve to clarify the homogeneity (Hussain & Taimooz, 2024). The great arsenic concentration in the Sepang Besar River's sediments highlights the necessity of thorough investigation to pinpoint the exact arsenic sources and their effects on the surroundings. Important results on the distribution of heavy metals in Malaysian river sediments call for proactive management and continuous environmental monitoring to protect aquatic environments (ELTurk et al., 2019).

The study largely shows the trajectory of environmental management techniques for the Sepang Besar River. Frequent investigation of heavy metal content in sediments helps to detect increasing pollution trends. Moreover, particularly considering Zn and As, which might arise from agricultural and industrial activities, efforts should concentrate on locating and removing pollution sources (Shifaw, 2018). Understanding the distribution and accumulation of heavy metals in sediments helps one to develop targeted plans to preserve the ecological state of the river. Keeping the Sepang Besar River's natural integrity and diversity would assist to ensure its resistance against ongoing industrialization and development.

Conclusion

Some relevant recent estimates of the heavy metal contents and distribution in Sepang Besar River sediments are presented in this paper. Examined at 10 cm, 20 cm, and 30 cm, the study concentrated on key elements like titanium (Ti), vanadium (V), manganese (Mn), arsenic (As), chromium (Cr), zinc (Zn), and cobalt (Co). The research indicates that the concentrations of heavy metals remain constant with depth, thereby suggesting that present human activities have not especially altered the sediment ecosystem. Evaluations of the enrichment factor (EF) and geo-accumulation index (I_{geo}) reveal most heavy metal concentrations match natural background levels even with very modest variances pointing to pollution sources. Development of targeted strategies to reduce the consequences of heavy metal contamination, especially from agricultural and industrial sources, depends on this understanding.

At last, our research aid to increase the little body of knowledge on the distribution of heavy metals in Malaysian river sediments and underline the need of proactive environmental management and continuous monitoring. The local ecology depends on the Sepang Besar River to be free from pollution, therefore preserving overall environmental integrity considering the primary industry and urbanization in the vicinity.

Acknowledgements

The author wishes to acknowledge the financial support via the Research Grant Scheme (INTI IU Research Seeding Grant 2023: INTI-FHLS-01-15-2023) provided by INTI International University, Nilai, Malaysia.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

References

Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. *Journal of chemistry*, *2019*(1), 6730305. https://doi.org/10.1155/2019/6730305

Ashraf, A., Saion, E., Gharibshahi, E., Yap, C. K., Kamari, H. M., Elias, M. S., & Rahman, S. A. (2018). Distribution of heavy metals in core marine sediments of coastal east Malaysia by instrumental neutron activation analysis and inductively coupled plasma spectroscopy. *Applied Radiation and Isotopes*, *132*, 222-231. https://doi.org/10.1016/j.apradiso.2017.11.012

Benarfa, A., Begaa, S., Messaoudi, M., Hamlat, N., & Sawicka, B. (2020). Elemental composition analysis of Pistacia lentiscus L., leaves collected from Mitidja plain in Algeria using instrumental neutron activation analysis (INAA) technique. *Radiochimica Acta*, *108*(10), 821-828. https://doi.org/10.1515/ract-2020-0011

Bryan-Brown, D. N., Connolly, R. M., Richards, D. R., Adame, F., Friess, D. A., & Brown, C. J. (2020). Global trends in mangrove forest fragmentation. *Scientific reports*, *10*(1), 7117. https://doi.org/10.1038/s41598-020-63880-1

Chajduk, E., & Polkowska-Motrenko, H. (2017). Application of ICP-MS, INAA and RNAA to the determination of some “difficult” elements in infant formulas. *Journal of Radioanalytical and Nuclear Chemistry*, *311*, 1347-1353. https://doi.org/10.1007/s10967-016-5042-8

Costa-Böddeker, S., Hoelzmann, P., De Stigter, H. C., Van Gaever, P., Huy, H. Đ., & Schwalb, A. (2018). The hidden threat of heavy metal pollution in high sedimentation and highly dynamic environment: Assessment of metal accumulation rates in the Thi Vai Estuary, Southern Vietnam. *Environmental pollution*, *242*, 348-356. https://doi.org/10.1016/j.envpol.2018.05.096

Dendievel, A. M., Mourier, B., Dabrin, A., Delile, H., Coynel, A., Gosset, A., ... & Bedell, J. P. (2020). Metal pollution trajectories and mixture risk assessed by combining dated cores and subsurface sediments along a major European river (Rhône River, France). *Environment International*, *144*, 106032. https://doi.org/10.1016/j.envint.2020.106032

Dietrich, M., Huling, J., & Krekeler, M. P. (2018). Metal pollution investigation of Goldman Park, Middletown Ohio: Evidence for steel and coal pollution in a high child use setting. *Science of the Total Environment*, *618*, 1350-1362. https://doi.org/10.1016/j.scitotenv.2017.09.246

Duan, Z., Zhao, S., Zhao, L., Duan, X., Xie, S., Zhang, H., ... & Wang, L. (2020). Microplastics in Yellow River Delta wetland: Occurrence, characteristics, human influences, and marker. *Environmental pollution*, *258*, 113232. https://doi.org/10.1016/j.envpol.2019.113232

ELTurk, M., Abdullah, R., Zakaria, R. M., & Bakar, N. K. A. (2019). Heavy metal contamination in mangrove sediments in Klang estuary, Malaysia: Implication of risk assessment. *Estuarine, Coastal and Shelf Science*, *226*, 106266. https://doi.org/10.1016/j.ecss.2019.106266

Hanebuth, T. J., King, M. L., Mendes, I., Lebreiro, S., Lobo, F. J., Oberle, F. K., ... & Reguera, M. I. (2018). Hazard potential of widespread but hidden historic offshore heavy metal (Pb, Zn) contamination (Gulf of Cadiz, Spain). *Science of the Total Environment*, *637*, 561-576. https://doi.org/10.1016/j.scitotenv.2018.04.352

Hussain, L. I., & Taimooz, S. H. (2024). Measuring the Levels of Heavy Metal Pollution in Al - Diwaniyah River Water Using Oomycetes Fungus. *International Academic Journal of Science and Engineering, 11*(1), 312-316. https://doi.org/10.9756/IAJSE/V11I1/IAJSE1136

Ilić, P., Nešković Markić, D., & Stojanović Bjelić, L. (2018). Measuring and Mapping Noise Pollution in the City of Banja LUKA. *Archives for Technical Sciences, 1*(18), 89–96. https://doi.org/10.7251/afts.2018.1018.089I

Khodami, S., Surif, M., WO, W. M., & Daryanabard, R. (2017). Assessment of heavy metal pollution in surface sediments of the Bayan Lepas area, Penang, Malaysia. *Marine Pollution Bulletin*, *114*(1), 615-622. https://doi.org/10.1016/j.marpolbul.2016.09.038

Krishnan, K., As, N., & My, C. (2022). Ecological risk assessment of heavy metal pollution in mangrove sediments of the Sepang Besar river, West Coast Peninsular Malaysia. *Environ. Ecol. Res.*, *10*(4), 497-507. https://doi.org/10.13189/eer.2022.100408

Krishnan, K., Nadia, A. S., Chong, M. Y., & Balu, P. (2022). Assessment of trace element accumulation in surface sediment of sepang besar river, Malaysia. *Journal of Experimental Biology and Agricultural Sciences, 10*(4), 870–878. http://dx.doi.org/10.18006/2022.10(4).870.878

Kulkarni, R., Deobagkar, D., & Zinjarde, S. (2018). Metals in mangrove ecosystems and associated biota: a global perspective. *Ecotoxicology and environmental safety*, *153*, 215-228. https://doi.org/10.1016/j.ecoenv.2018.02.021

Kumar, K., Saion, E., Halimah, M. K., Ck, Y., & Hamzah, M. S. (2014). Rare earth element (REE) in surface mangrove sediment by instrumental neutron activation analysis. *Journal of Radioanalytical and Nuclear Chemistry*, *301*, 667-676. https://doi.org/10.1007/s10967-014-3221-z

Mohanty, S., Sahoo, S., Dhal, S., & Swain, S. C. (2024). Expanding LGBTQ+ Inclusivity: An Ecological Model of School Library Practice in Addition to Collection Development. *Indian Journal of Information Sources and Services*, *14*(3), 169–174. https://doi.org/10.51983/ijiss-2024.14.3.22

Mohiuddin, K. M., Saha, P., Hossain, M. T., Nahar, K., Ahmed, I., Hoque, A., ... & Rahman, M. A. (2022). Assessment of Health Risk Due to Consumption of Spinach (Spinacia oleracea) Cultivated with Heavy Metal Polluted Water of Bhabadah Water-Logged Area of Bangladesh. *Earth Systems and Environment*, *6*(2), 557-570. https://doi.org/10.1007/s41748-022-00302-4

Muller, G. (1981). Heavy metal pollution of the sediments of the Neckar and its tributaries: an inventory. *Chemiker Zeitung*, *105*, 157-164. https://sid.ir/paper/596736/en

Nyangon, L., Ahmad Nur, S. Z., Ahmad Mustapha, M. P., & Gandaseca, S. (2019). Heavy metals in mangrove sediments along the Selangor River, Malaysia. http://dx.doi.org/10.24259/fs.v3i2.6345

Rouessac, F. (2022). *Chemical Analysis: modern instrumentation methods and techniques*. S.L.: Wiley-Blackwell.

Semcesen, P. O., & Wells, M. G. (2021). Biofilm growth on buoyant microplastics leads to changes in settling rates: implications for microplastic retention in the Great Lakes. *Marine pollution bulletin*, *170*, 112573. https://doi.org/10.1016/j.marpolbul.2021.112573

Shakir, M., Kumaran, U., & Rakesh, N. (2024). An Approach towards Forecasting Time Series Air Pollution Data Using LSTM-based Auto-Encoders. *Journal of Internet Services and Information Security, 14*(2), 32-46. https://doi.org/10.58346/JISIS.2024.I2.003

Shifaw, E. (2018). Review of heavy metals pollution in China in agricultural and urban soils. *Journal of Health and Pollution*, *8*(18), 180607.

Shukor, N. A., Krishnan, K., Shing, W. L., Ariffin, N., & Yong, W. L. (2023). The Pollution Characteristics of Harmful Heavy Metal in Surface Sediment of Sepang River, Malaysia. *Environment and Ecology Research, 11*(4): 579-585. https://doi.org/10.13189/eer.2023.110406

Sutherland, R. A. (2000). Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. *Environmental geology*, *39*, 611-627. https://doi.org/10.1007/s002540050473

Usmani, R. S. A., Saeed, A., Abdullahi, A. M., Pillai, T. R., Jhanjhi, N. Z., & Hashem, I. A. T. (2020). Air pollution and its health impacts in Malaysia: a review. *Air Quality, Atmosphere & Health*, *13*, 1093-1118. https://doi.org/10.1007/s11869-020-00867-x

Vardhan, K. H., Kumar, P. S., & Panda, R. C. (2019). A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *Journal of Molecular Liquids*, *290*, 111197. https://doi.org/10.1016/j.molliq.2019.111197

Veysi, M. M., & Salari-Aliabadi, M. A. (2021). Ecological study of two sea cucumbers (Holothuria parva and Holothuria arenicola) in the Hormozgan and Bushehr provinces of Persian Gulf. *Natural and Engineering Sciences*, *6*(1), 1-18. http://doi.org/10.28978/nesciences.868048

Wang, Q., & Yang, Z. (2016). Industrial water pollution, water environment treatment, and health risks in China. *Environmental pollution*, *218*, 358-365. https://doi.org/10.1016/j.envpol.2016.07.011

Yuan, W., Zhou, Y., Chen, Y., Liu, X., & Wang, J. (2020). Toxicological effects of microplastics and heavy metals on the Daphnia magna. *Science of the Total Environment*, *746*, 141254. https://doi.org/10.1016/j.scitotenv.2020.141254

Zhang, L., Xiao, D., Lu, S., Jiang, S., & Lu, S. (2019). Effect of sedimentary environment on the formation of organic-rich marine shale: Insights from major/trace elements and shale composition. *International Journal of Coal Geology*, *204*, 34-50. https://doi.org/10.1016/j.coal.2019.01.014

Zoller, W. H., Gladney, E. S., & Duce, R. A. (1974). Atmospheric concentrations and sources of trace metals at the South Pole. *science*, *183*(4121), 198-200. https://doi.org/10.1126/science.183.4121.198