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REVIEW

Occurrence, Spatial Distribution and Ecological Impact of Heavy Metals in Rivers, Lakes and Marine Environments of Tamil Nadu, India

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The importance of a clean environment is recognized as a "pillar" of sustainable development. There is, however, a serious public health threat associated with heavy metal releases into the environment. Aquatic environments in Tamil Nadu state of India lack heavy metals monitoring data. From year 2008 to 2022, research articles were assessed that focused at heavy metal concentrations in freshwater and marine ecosystems. It has been shown that elevated levels of heavy metals in sediments of aquatic ecosystems contribute to an increase in their abundance, which may further enter the food chain through bioaccumulation. In addition, intensifying human exploitation of the South East Coastal region (SEC) in Tamil Nadu state of India through industries, tourism, aquaculture and recreation further complicates the situation by providing ever-changing sources of contamination. As a result of analyzing all heavy metals, the levels of Cd in biota collected from ocean environments were higher. Rivers and lakes have shown increased levels of heavy metals such as Zn, Cu and Pb as a result of localized anthropogenic activities. In accordance with sediment guidelines and human health risk assessments, most of the heavy metals concentrations in sediments and aquatic biota exceeded the permissible limits. It is highly recommended that more monitoring studies are conducted to monitor the levels of heavy metals in organisms and in urban rivers, lakes and marine environments in the future, with extreme importance both for environmental health and economics. By identifying the sources of pollutants and implementing strict policies to abate pollution, local governments can implement better control measures to decrease pollution levels.

Keywords: Rivers, Lakes, Marine environments, Biota, Heavy metals, Tamil Nadu.

INTRODUCTION

Heavy metal contamination of aquatic environments has grown significantly in recent decades and is now regarded as usually harmful [1]. Rivers, lakes, coastal and marine environments are the ultimate destinations of contaminants for the receiving systems [2-4]. Heavy metals can persist in aquatic environments for a long time and have negative impacts on benthic organisms and are therefore able to substantially affect the food web [5-7]. Moreover, exposure through environmental media could cause human-associated health risks [8-10]. Water and sediment contamination of with heavy metals can be of both natural weathering processes and human linked anthropogenic activities [11]. Sediments are considered as a sink for inorganic pollutants such as metals in aquatic ecosystems and present many times higher than in the overlying water [11-14]. The punctual and diffusion sources including untreated urban effluents, hospital effluents, industrial effluents, leachate draining, landfilling, dumping urban waste, surface runoff and atmospheric depositions have been reported to contaminate the emerging heavy metal contamination globally [15-18]. Heavy metals can be associated with sediments and present mostly in dissolved phases [19,20]. Sediment bound metals can also be dissociated to the water column [14]. The accumulations of heavy metals in sediments have been influenced by various physical and chemical parameters including grain size, density, pH, organic matter, carbonates and chemical fractionation [20,21].

Tamil Nadu (southern state of India) has many commercial zones with growing industries and undergone rapid urbanization. Economically, Tamil Nadu plays a significant role in India and has over 70 million populations. Nevertheless, over the years the contamination of the aquatic system with heavy metals has become a serious concerns [22-24]. An important problem of river contamination is also associated with transboundary river between Tamil Nadu and nearby states. This review highlights the extent of metal contamination in aquatic systems in a tropical climate system and will help to identify the sources of heavy metal contamination and its impact on aquatic ecosystems. Furthermore, it will redress the decreasing inorganic pollutants. Most of the studies primarily focussed on their contamination in the water column and surface sediments. Among the marine environments, the estuarine and coastal zone has been known to receive a huge part of heavy metals and act as sinks [21,25]. Besides, coastal regions are playing an economically crucial role, with 70% of the human population livelihood [26]. Thus, southeast coastal regions provide strong services to the regional population that need to be preserved but are undergoing gradual changes that have been monitored for years.

The coastal area of Tamil Nadu is situated in the tropical zone of Bay of Bengal and the Indian Ocean (Fig. 1). The Bay of Bengal supports diverse coastal and marine habitats including mangroves, coral reefs, seagrass and swamps. Over the years, Tamil Nadu has witnessed several industrial developments and caused serious pollution problems. The east coast regions (ECR) have many industries in Pondicherry and Chennai territories. Besides, Chennai and Pondicherry are one of the important tourist destinations in India. Urban and industrial effluents and petroleum refinery industrial effluents are the major sources of pollutants and can contribute marine environment degradation along the east coast regions in Chennai. This is evident from innumerable classic studies documenting heavy metal pollution and associated impacts [27-29]. However, heavy metal contamination is progressively increasing in the south-east coastal regions of Tamil Nadu largely due to the continuous economic development in the past decades

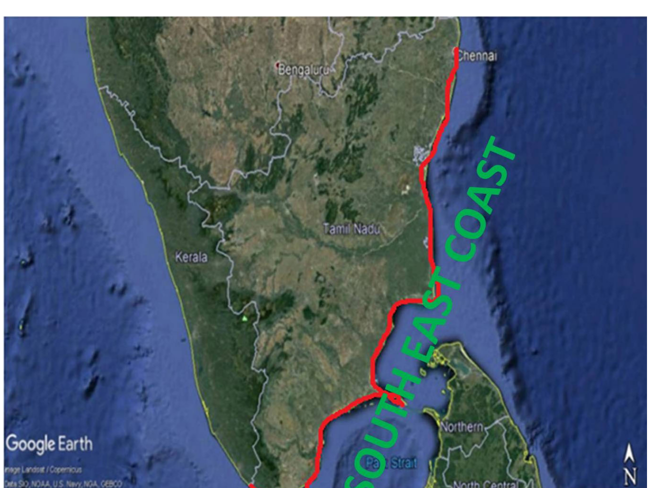

Fig. 1. Satellite map representing Tamil Nadu state of India and southeast coast regions

including rapid increase of industries, land reclamation, dredging and aquaculture. The option of controlling or managing heavy metals pollution requires knowledge on spatial distribution, sources and impact in order to counter the environmental threat. Therefore, the present review is aimed to address the current status of heavy metal pollution and sources in sediments of the river, lakes, marine environments and organisms from Tamil Nadu state, India.

Search criteria: A critical review of studies on heavy metals contents in biota and sediments from freshwater and marine environments in Tamil Nadu, India is conducted. Using the keywords heavy metals contents in Southeast coast Tamil Nadu, Rivers and Lakes and marine ecosystems of Tamil Nadu, we carried out a survey on the Clarivate Web of Science (WOS), Science Direct and Google Scholar. Only heavy metals research studies were selected. Other literature (data study, review and others) were not considered and thus only research articles having impact factors were considered. When examining the studies, the marine environment has the most (55%) and Lake has the second-most (22%) (Fig. 2a). Biomonitoring studies in marine ecosystems were higher than in freshwater aquatic systems, representing 69% of all studies (Fig. 2b).

Heavy metal concentrations in sediments, fishes from rivers and lakes: Heavy metals analyzed in sediments and fishes from various rivers in Tamil Nadu are shown in Table-1. Previous study determined that the metal concentrations have a higher concentration in urban lakes than lakes in the countrysides [30]. The primary sources of heavy metal contamination to lake sediments are urban sewage and industrial effluents. Heavy metals including Pb Cu, Zn, Cr, Pb and Cd were above the permissible level in urban lake sediments and posed a risk to the aquatic organisms. Arisekar *et al.* [31] reported that the downstream region from the river Thamirabarani river was at risk of increased heavy metals pollution and had a significant effect on children health. According to Arisekar *et al.* [31], the heavy metal contents in river sediments and fish was ranged between 0.294 and 106.25 mg kg^{-1} and 0.001 to 9.505 mg kg^{-1}, respectively. They proposed that heavy metals are higher in sediments of downstream regions due to the mixing of sewage, agricultural runoff and waste. Dhanakumar *et al.* [32] investigated the concentrations of Cu, Zn, Ni, Cr and Pb in sediments from upper Anicut were 22.8, 50.8, 2.2, 153.1 and 1.14 7 mg kg^{-1}, respectively. The levels of Cu, Zn, Ni, Cr and Pb in sediments from Grand Anicut were 39.9, 85.6, 7.7, 139.4 and 5.4 mg kg^{-1}, respectively. Grand Anicut is located downstream of urban location and had shown elevated levels of heavy metals in sediments, which indicate the impact of urban effluents into the upstream of Cauvery river. The concentrations of heavy metals in lower anicut sediments were generally lower than the sediment quality guidelines (SQGs) level except Cr with the value of 45.4 mg kg^{-1}. Accumulation of Cu in fish species varied between BDL and 6.45 µg/g, dry wt. *Catlacatla* had the highest accumulation of Cu with the value of 6.45 µg/g. Zn levels in fish tissues varied between 11.57 and 182.56. The highest Zn concentration was found in *Cirrhinus mrigala* (182.56 µg/g). On the whole, Zn concentrations in tissues of fish species analyzed are higher compared to other metals,

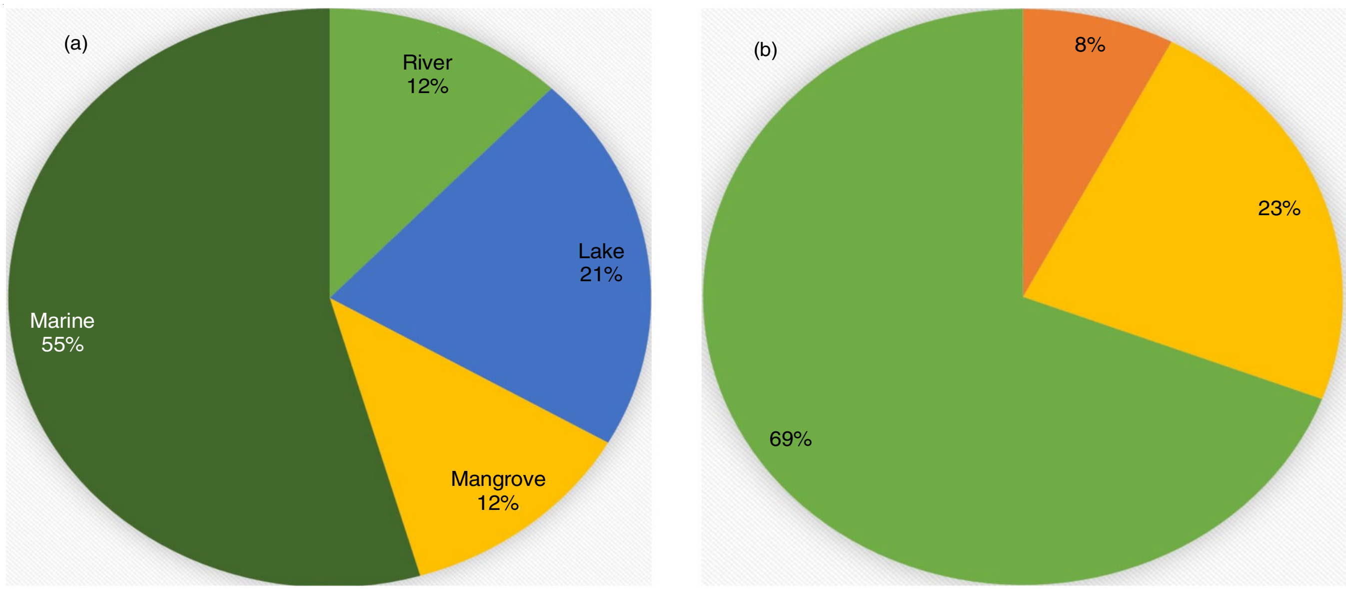

Fig. 2. Frequency (%) of studies (a) and accumulation (b) on heavy metal contents in sediments of river, lakes, mangroves and marine environments from Tamil Nadu between year 2008-2022 (research articles collected from Clarivate Web of Science (WOS), Science Direct and Google Scholar)

TABLE-1
HEAVY METAL CONCENTRATION MEASURED IN THE SEDIMENT AND FISHES OF DIFFERENT RIVERS, LAKES ECOSYSTEM IN TAMIL NADU

	Concentration (mg kg^{-1})								Ref.
	Cu	Zn	Co	Ni	Cr	Pb	Cd	As	
Reservoirs of river Cauvery									
Sediments									
Upper Anicut	22.8	50.8	n.a	2.2	153.1	1.14	n.a	n.a	[32]
Grand Anicut	39.9	85.6	n.a	7.7	139.4	5.4	n.a	n.a	[32]
Anaikarai	10.3	24.7	n.a	2.0	45.4	2.2	n.a	n.a	[32]
Fish sp. (µg/g, dry wt.)									
Channa striata	BDL-0.03	14.73-45.93	n.a	0.42-0.95	0.50-3.06	0.29-1.93	n.a	n.a	[32]
Catlacatla	0.03-6.45	19.63-123.33	n.a	0.29-2.39	1.27-10.83	1.04-17.50	n.a	n.a	[32]
Oreochromismossambicus	0.05-3.69	12.50-57.47	n.a	0.24-0.93	1.10-6.33	0.42-6.50	n.a	n.a	[32]
Etroplussuratensis	0.33-3.55	37.0-169.32	n.a	0.20-2.14	1.10-6.97	1.67-15.95	n.a	n.a	[32]
Mystusvittatus	0.04-1.80	16.87-47.23	n.a	0.24-0.74	1.56-2.87	1.61-11.97	n.a	n.a	[32]
Cirrhinus mrigala	0.02-0.46	11.57-182.56	n.a	0.19-2.31	0.33-1.93	0.53-14.45	n.a	n.a	[32]
Cauvery river sediments	2.7-906.3	4.9-649.8	2.7-9.7	6.4-51.4	13.9-74.6	1.1-111.4	0-6.30	0.20-2.80	[16]
Vaigai river sediments	16.00-96.08	39.24-418.80	n.a	14.44-259.16	17.36-215.60	28.28-375.20	0.65-1.52	n.a	[22]
Thamirabarani river sediments	0.44-35.23	18.02-93.27	1.27-15.59	14.79-34.60	1.36-16.13	1.05-2.96	0.29-3.12	0.94-2.06	[31]
Fish sp. Thamirabarani river									
Labeo rohita	0.22-1.07	1.49-5.87	0.002-0.15	0.003-0.14	0.002-0.47	0.15-1.03	0.001-0.16	0.002-0.26	[31]
Oreochromis niloticus	0.39-1.64	2.45-4.08	0.05-0.32	0.05-2.11	0.07-1.02	0.12-0.51	0.04-1.13	0.02-0.53	[31]
Noyyal River water	0.02-0.12	1.4-5.01	n.a	0.01-0.17	0.08-0.61	0.01-0.08	0.00-0.16	n.a	[70]
Veeranam Lake sediments	65-125	69-599	n.a	34-95	40-150	20-41	0.2-3.9	n.a	[31]
Emerald Lake sediments	314-462	20.1-53.21	91-129.9	128-215	336-523	151-158	n.a	n.a	[23]
Perur Lake sediments	30.52-52.68	58.74-100.00	16.79-22.66	58.40-88.58	79.82-127.21	17.60-21.94	0.08-1.35	1.13-1.74	[30]
Senkulam Lake sediments	39.66-58.82	86.83-134.94	17.51-29.24	61.79-98.76	96.01-177.22	17.91-25.70	0.05-0.10	0.91-1.89	[30]
Settipalayam Lake sediments	23.02-28.54	51.42-87.68	13.49-18.53	40.06-50.44	55.64-68.44	10.29-13.81	0.06-0.14	1.11-2.15	[30]
Ukkadam Lake sediments	42.99-203.32	24.63-241.25	3.57-18.05	11.11-66.20	22.32-107.52	34.45-92.09	0.08-1.55	0.48-2.37	[30]
Singanallur Lake sediments	95.43-383.69	75.99-747.42	6.77-18.95	38.37-78.23	57.78-267.30	17.78-45.05	0.18-4.40	1.12-3.68	[30]
River sediments (n = 6)									
Minimum	0.44	4.9	1.27	2.0	1.36	1.1	0.29	0.20	
Maximum	906.3	649.8	15.59	259.16	215.60	375.20	3.12	2.80	
Lake sediments (n = 7)									
Minimum	23.02	20.1	3.57	11.11	22.32	10.29	0.05	0.48	
Maximum	462.00	747.42	129.9	215	523.00	158.00	4.40	3.68	
[a]ERL	70.00	120		30	80	35	5.00		[31]
[a]ERM	390	270		50	145	110	9.00		[31]
[b]TRV	16	110		16	26	31	0.60		[31]
[c]WSA	32	129		49	26	20	0.30		[64]
[d]WCTMRL	20-90	50-250	–	30-250	20-190	10-100	0.1-1.5	–	[65]
[e]TEL	35.7	123	–	35	37.3	18	0.59	5.9	[66]
[e]PEL	197	315	–	91.3	90	36	3.53	17	[66]

[a]Effect range low (ERL) and effect range medium (ERM) for freshwater ecosystem; [b]Toxicity reference value (TRV); [c]World surface rock average (WSA) [64]; [d]World Common Trace Metal Range in lake (WCTMRL) sediment [65]; [e]Threshold Effect Level (TEL) or Probable Effect Level (PEL) for freshwater ecosystems [66]

indicating that increased bioavailability of Zn to their tissues. Among the fish species studied, the lowest concentration of Ni was observed in *Cirrhinus mrigala* (0.19 µg/g), while *Catlacatla* has the highest concentration (2.39 µg/g). The maximum concentration of Cr recorded was 10.83 µg/g in *Catlacatla* and a similar trend was observed for Pb with the value of 17.50 µg/g. The levels of Cu (6.45 µg/g, DW), Zn (123.33 µg/g, DW), Ni (2.39 µg/g, DW), Cr (10.83 µg/g, DW) and Pb (17.50 µg/g, DW) in *Catlacatla* were remarkably higher than other fish species suggesting its trophic levels and pose significant human health associated risk. Devarajan *et al.* [16] investigated selected heavy metals in surface sediment samples collected from the Cauvery river in Tiruchirappalli city. The concentration of Cu, Zn, Co, Ni, Cr, Pb, Cd and As in sediments were ranged from 2.7 to 906.3, 4.9 to 649.8, 2.7to 9.7, 6.4 to 51.4, 13.9 to74.6, 1.1 to 111.4, 0 to 6.30 and 0.20 to 2.80 (mg kg^{-1}), respectively. Generally, the levels of heavy metals in surface sediments from the vicinity of effluent discharge site were significantly higher than upstream sites. The results suggest that the sewage effluents, industrial effluents and surface runoff could be sources of heavy metal contamination.

Concentrations of heavy metals in sediments collected from Vigai river, Madurai city were investigated by Paramasivam *et al.* [22]. Madurai, the third-largest city in Tamil Nadu and Vaigai river is flowing across the city and ends in Bay of Bengal. The authors measured the higher levels of heavy metal in polluted city cites. Accumulation patterns of heavy metals in Vaigai river sediments from city sites were similar to those reported in the Cauvery river, Tiruchirappalli city [16]. Heavy metals concentration (ppm) were in the range of 16.00-96.08, 39.24-418.80, 14.44-259.16, 17.36-215.60, 28.28-375.20 and 0.65-1.52 for Cu, Zn, Ni, Cr, Pb and Cd, respectively. Heavy metal concentrations in sediment showed increasing trend within urban site of sample collection suggesting the impact of the heavy discharge of untreated urban and industrial effluents.

The heavy metals proportion level in different lakes studied are shown in Fig. 3b. A recent field study revealed that depending on the human influence, the lakes in Coimbatore city are contaminated and showed the highest toxic metal accumulation in urban lakes, mainly Singanallur and Ukkadam [30]. A study of Emerald lake indicated that the sediments receiving wastewater show an elevated level of heavy metals in sediments [23]. Highest concentrations of Cu (462 µg/g), Co (129.9 µg/g), Ni (215 µg/g), Cr (523 µg/g) and Pb (158 µg/g) suggest that sediments in Emerald Lake are characterized by heavy anthropogenic pressure with point sources contamination (Table-1). Suresh *et al.* [33] measured the concentrations of Cu, Zn, Ni, Cr, Pb and Cd in sediments collected from Veeranam lake. Their study indicated that serious contamination of Cd, Zn, Cu and Cr in Veeranam lake sediments is due to the primary runoff from point sources such as metal processing industries, agriculture runoff and garbage landfilling and living residents [33]. Despite being a limited number of studies from rivers and lakes, the concentrations of Zn and Pb reached higher than the permissible limit, which could be the apparent link of heavy anthropogenic activities. However, a more number of studies on other rivers, lakes and biota across Tamil Nadu region are warranted. Besides, biomonitoring studies to assess human health risks are needed from these environments.

Heavy metals in mangrove plants and sediments: Mangrove forests are a highly productive ecosystem located in the tidal zones of tropical and subtropical regions [34]. They are home a diverse flora and fauna of marine, freshwater and terrestrial species [35]. The Pichavaram mangrove is the second largest mangrove ecosystem in the world. Pichavaram mangrove forest (Latitude of 11° 4′ N-Longitude of 79° 8′ E), located in the east coast of Tamil Nadu between the Vellar and Coleroon estuaries. This forest consists of 51 islets ranging in size from 10 m^2 to 2 km^2 [36]. It is estimated to have an area about 1100 hectares. It is home to woody plants that grow at the interface between land and sea in tropical and subtropical latitudes. Pichavaram mangrove forest exists under conditions such as high salinity, extreme tides, strong winds, high temperature and muddy, anaerobic soils [36].

Table-2 presents the results of heavy metals accumulation sediments and various plants associated with mangrove forests in Tamil Nadu state. Agoramoorthy *et al.* [37] reported the accumulation of toxic metals (µg/g) including Cu, Zn and Pb in *Avicennia officinalis*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Bruguiera cylindrical*, *Ceriops decandra*, *Aegiceras corniculatum* and *Acanthus ilicifolius* from Pichavaram mangrove. The accumulation of metals by plants significantly varied according to the species. The highest accumulation of Cu (95.05 µg/g), Zn (116.9 µg/g) and Pb (27.35

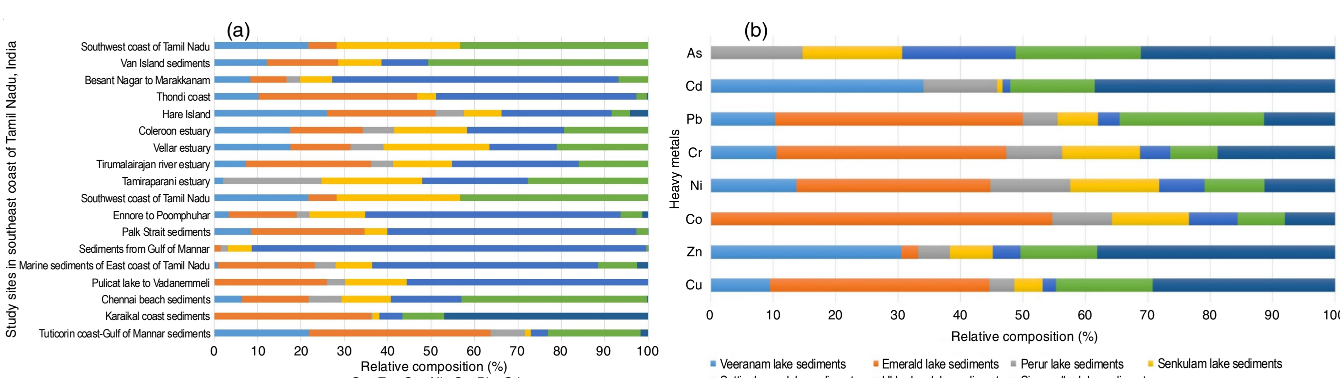

Fig. 3. Relative distribution of heavy metal contents in sediments from different sites (a) and different lakes (b) of the Southeast coast, Tamil Nadu, India between year 2008-2022

TABLE-2
HEAVY METAL CONCENTRATIONS RECORDED IN THE PLANTS AND SEDIMENTS OF DIFFERENT MANGROVE ECOSYSTEM IN TAMIL NADU

	Concentration (µg g^{-1})						Ref.
	Cu	Zn	Ni	Cr	Pb	Cd	
Pichavaram Mangrove Plants (mg kg^{-1})							
Avicennia officinalis	14.78	107.8	n.a	n.a	23.21	n.a	[37]
Rhizophora apiculata	10.25	16.8	n.a	n.a	12.23	n.a	[37]
Rhizophora mucronata	19.9	40.3	n.a	n.a	12.61	n.a	[37]
Excoecaria agallocha	8.12	76.6	n.a	n.a	27.35	n.a	[37]
Bruguiera cylindrica	17.46	116.9	n.a	n.a	17.39	n.a	[37]
Ceriops decandra	95.05	9.3	n.a	n.a	11.82	n.a	[37]
Aegiceras corniculatum	13.39	12.8	n.a	n.a	12.91	n.a	[37]
Acanthus ilicifolius	13.79	67.5	n.a	n.a	15.99	n.a	[37]
Pichavaram Mangrove Sediment (mg kg^{-1})	21.56-33.88	10.48-38.32	3.24-25.16	12.56-45.56	8.44-29.24	0.28-1.68	[24]
Muthupet mangrove Plants (mg kg^{-1})							
Rhizophora mucronata	0.76-4.35	1.75-61.67	n.a	n.a	6.20-26.57	0.10-0.62	[29]
Avicenia marina	2.25-18.64	0.66-37.99	n.a	n.a	0.41-23.73	0.07-0.83	[41]
Sediment (mg kg^{-1})	2.88-14.87	7.80-38.37	n.a	n.a	0.43-17.49	0.43-17.49	[29]
Sediment	12.34	20.2	n.a	n.a	11.35	0.31	[41]
Sediment	4.46-20.59	4.41-39.18	n.a	n.a	2.90-21.35	0.06-0.57	[40]
Hare Island mangrove Plant (mg kg^{-1})							
Avicennia marina	4.03-8.42	1.66-3.21	1.07-1.98	0.10-0.45	0.09-0.25	0.01-0.32	[38]
Pemphis acidula	7.24-12.10	2.96-4.85	1.08-2.21	0.12-1.12	0.69-1.34	0.32-1.05	[38]

µg/g) were found in *Ceriops decandra*, *Bruguiera cylindrical* and *Excoecaria agallocha*, respectively. The authors ascertain that the concentration of Pb in all studied plants was above the recommended level (5.0-10 µg/g). Higher content of Pb in plants was probably due to environmental contamination into mangrove forests [37]. Besides, the higher accumulation of heavy metals by these plants could impact human health upon consumption as they are proved to have medicinal properties [37].

Recently, Arisekar *et al.* [38] conducted a maiden study to determine the heavy metal contamination level in Hare Island, Gulf of Mannar marine biosphere. According to the metal accumulation in mangrove plants was below the threshold levels, indicating heavy metals are not contaminating this biosphere environment. Levels of selected toxic metals in sediments collected from Pichavaram were measured by Shanmugam *et al.* [24]. This study revealed that the measured heavy metal concentrations (µg g^{-1}) in sediment samples ranged from 21.56 to 33.88 for Cu, 10.48 to 38.32 for Zn, 3.24 to 25.16 for Ni, 12.56 to 45.56 for Cr, 8.44 to 29.24 for Pb and 0.28 to 1.68 for Cd. This study indicated that concentrations of heavy metals were lower than the reference limit values established by CSQG (Canadian Sediment Quality Guidelines) for the Protection of Aquatic Life (CCME EPC-98E, 1999) except for cadmium. An elevated level of cadmium might be attributed to surrounding anthropogenic activities.

Muthupet mangrove forest (Latitude, 10º 25′ N; Longitude 79º 39′ E) is located in the Southeast coast of India [39]. This mangrove forest is being one of the prominent tourist destinations in Tamil Nadu and contributing major fishing and agriculture activities on the east and west side [40]. Heavy metals of Cu, Zn, Pb and Cd were measured in tissues of *Rhizophora mucronata* collected from Muthupet mangrove. The levels of heavy metals in examined plant tissues ranged between 0.76 to 4.35, 1.75 to 61.67, 6.20 to 26.57 and 0.10 to 0.62 mg kg^{-1} for Cu, Zn, Pb and Cd, respectively. The Pb levels in *Rhizophora mucronata* tissues were generally higher and similar to those reported earlier in mangrove plants [37,41]. The high level of Pb was probably due to the human linked industrial activities, agricultural runoff and stormwater runoff. This study also reported elevated levels of Zn (61.67 mg kg^{-1}) and Cd (0.62 mg kg^{-1}) that exceeded the safe level in plants. Similarly, the authors measured the levels of heavy metal in the surface sediments collected from Muthupet Mangrove. The results showed elevated levels of Cd that ranged between 0.43 and 17.49 mg kg^{-1}. However, Cu, Zn and Pb levels were not exceeded the SQGs. Arumugam *et al.* [41] analyzed the heavy metals in both plant and sediments from Muthupet. Notably, the level of Cd in surface sediments radically increased from 0.31 to 17.49 (mg kg^{-1}) between year 2018 and 2019. Relatively high levels of Zn, Pb and Cd in plant tissues may be ascribed to increased intensive human linked activities. Sediments collected from the Muthupet mangrove ecosystem were analyzed for heavy metals by Rajaram *et al.* [40]. In this study, the concentrations (mg kg^{-1}) of Cd, Cu, Pb and Zn were ranged from 0.06 to 0.57, 4.46 to 20.59, 2.90 to 21.35 and 4.41 to 39.18, respectively. The heavy metal levels were found to be low in all samples from mangrove sediment. Municipal wastes, idol immersion, agricultural based drainages, agriculture activities, aqua farm wastages and industrial activities are the major sources of metal pollution [40].

Heavy metals distribution in marine sediments: The comparison of heavy metals levels in sediments from different regions of the Southeast coast is presented in Table-3. The spatial distribution of heavy metal levels in sediments from Beach sediments in Chennai Metropolitan City was investigated by Santhiya *et al.* [27]. Although the distribution of metals varied among the sediment samples, the concentrations of Cu, Pb and Cr in sediments from northern sites were relatively higher than the southern part (Fig. 3a). The primary sources of heavy metals in the northern part are industrial activities associated with chromite processing, atmospheric deposits from rocket/missile launching testing centre, wastes from Thermal power plant, petrochemical industries and harbour. With the increasing industrialization in marine environments, heavy metals deterioration of the biosphere has become increasingly serious due to accumulation in sediments. Tholkappian *et al.* [29] reported the status of pollution by heavy metals in sediments collected from Pulicat lake to Vadanemmeli along with the southeast coast of India. In this study, the concentrations of heavy metals ranged from 16.20 to 93.00, 1.20 to 7.10, 15.60 to 23.60 and 18.60 to 45.30 mg kg^{-1} for Cr, Co, Ni and Zn, respectively. The high level of metals found in sediments possibly due to discharge of urban wastewaters, aquaculture and shipping activities. The levels of heavy metals in sediments collected from the Periyakalapet to Parangipettai coast, east coast of Tamil Nadu state were investigated by Harikrishnan *et al.* [42]. It was observed that the concentration of Cu, Zn and Pb generally low in all sediments as compared to world crustal average. However, chromium and cadmium reached the maximum values of 207.3 mg kg^{-1} and 10.2 mg kg^{-1} at some sites cause initial threat and indicating the strong influence of human activities. Kasilingam *et al.* [43] studied the levels of heavy metals in surface sediments collected from the Palk Strait, Southeast coast of Tamil Nadu. Compared with other coastal sediments from southeast coast regions of Tamil Nadu, Cd levels in Palk Strait were relatively low. The concentrations (µg/g) of Cu, Zn, Ni, Cr, Pb and Cd were found to be in the range of 27.00-99.00, 220.0-305.0, 17.7-60.6, 213.0-668.0, 10.10-31.30 and 0.14-0.68, respectively.

The concentrations of Pb, Ni, Cr and Zn were generally higher than the crustal average. According to their findings, the high levels of Cu, Pb, Ni and Cd observed on the north study sites may be attributed by riverine runoff and discharge of industrial effluents into rivers. A recent investigation determined the spatial distribution of heavy metals in the surface sediment of the southeast coast of India [44]. Concentrations (in mg/kg) of Cu, Zn, Co, Ni, Cr, Pb and Cd heavy metals were ranged from 1.35 to 15.75, 39.73 to 72.68, 5.85 to 13.55, 39.11 to 59.76, 108.14 to 273.20, 11.85 to 23.05 and 0.59 to 6.41 for Cu, Zn, Co, Ni, Cr, Pb and Cd, respectively. The highest accumulation of Pb, Cd and Cr in surface sediments might be the result of human activities such as industrial discharges, urban waste disposals and agricultural runoff and upstream contamination from river Cauvery. Another pioneering study by Godson *et al.* [45], who investigated the levels of heavy metals in sediments collected from the Southwest coast of Tamil Nadu. The concentrations (µg/g) of heavy metals in sediments were in the range of 14.00 to 458.44 for Cu, 10.05 to 135.93 for Zn, 14.24 to 599.99 for Ni and 101.29 to 913.39 for Pb. According to their results, elevated levels of Cu, Ni and Pb at some sites were primarily attributed to the fishing harbour, longshore sediment transport, the confluence of river and the application of anti-biofouling paints. Magesh *et al.* [46] reported that the distribution and levels of Cu, Co, Ni, Cr and Pb in sediments collected from the Tamiraparani estuary, Southeast coast of India. The concentrations (ppm) of heavy metals in the analyzed sediment samples were 05.00-68.00, 119-750, 130-769, 30-805 and 43.0-919.0 for Cu, Co, Ni, Cr and Pb, respectively. The elevated levels of Pb, Co, Ni and Cr, were found to be in sediments that mostly associated with a

TABLE-3
HEAVY METAL LEVELS MEASURED IN SEDIMENTS OF MARINE ECOSYSTEMS IN TAMIL NADU

	Concentration (mg kg^{-1})							Ref.
	Cu	Zn	Co	Ni	Cr	Pb	Cd	
Tamiraparani estuary	13.41-95.24	72.0-300.00	BDL-15.21	10.63-35.65	BDL-16.98	16.30-53.35	4.50-17.34	[53]
Chennai beach sediments	4.05-7.51	9.89-18.07	5.05-8.82	9.17-13.31	14.10-19.16	19.77-50.08	0.27-0.31	[27]
Tuticorin coast-Gulf of Mannar sediments	13.40-178.20	60.0-340.0	13.0-64.5	0.2-11.0	2.1-31.50	13.5-173.9	1.40-14.60	[50]
Karaikal coast sediments	n.a	2.15-3.0	0.02-0.03	0.05-0.13	0.17-0.44	0.0536-0.8	1.12-3.9	[51]
Besant Nagar to Marakkanam	10.8-211.00	75.4-210.40	16.4-79.20	12.60-186.80	227.6-1665.00	23.60-173.60	n.a	[54]
Tirumalairajan river estuary	BDL-0.039	0.012-0.153	BDL-0.027	BDL-0.072	BDL-0.155	BDL-0.085	n.a	[49]
Palk Strait sediments	27.00-99.00	220.0-305.0	n.a	17.7-60.6	213.0-668.0	10.10-31.30	0.14-0.68	[43]
Marine sediments of east coast of Tamil Nadu	BDL-3.60	14.00-89.00	1.1-19.0	15.2-33.63	12.50-207.3	BDL-35.7	BDL-10.2	[42]
Sediments from Ennore to Poompuhar	1.35-15.75	39.73-72.68	5.85-13.55	39.11-59.76	108.14-273.20	11.85-23.05	0.59-6.41	[44]
Tamiraparani estuary	05.00-68.00	n.a	119-750	130-769	30-805	43.0-919.0	n.a	[46]
Vellar estuary	78.0-157.0	78.0-123.0	18.0-68.0	60.0-218.0	56.0-138.0	34.0-188.0	n.a	[47]
Coleroon estuary	96.0-162.0	86.0-156.0	39.0-66.0	50.0-156.0	106.0-207.0	58.0-180.0	n.a	[47]
Chennai Coast	37.20-599.90	48.20-267.10	5.00-67.90	2.20-151.30	8.50-853.20	6.50-3935.5	n.a	[55]
Van Island sediments	0.008-494.27	9.89-660.83	n.a	35.30-405.31	0.03-435.94	0.18-2053.20	n.a	[48]
Pulicat Lake to Vadanemmeli	n.a	18.60-43.40	1.20-7.10	16.40-23-60	16.20-93	n.a	n.a	[29]
Southwest coast of Tamil Nadu	14.00-458.44	10.05-135.93	n.a	14.24-599.99	n.a	101.29-913.39	n.a	[45]
Sediments from Hare Island	0.11-6.49	0.01-6.24	0.16-1.64	0.32-2.15	1.64-6.34	0.01-1.05	0.00-1.05	[38]
Sediments from Thondi coast	31-84	214-298	n.a	20.1-35.6	231-378	10.2-19.5	0.6-2.5	[57]
Sediments (n = 18)								
Minimum	BDL	n.a	BDL	BDL	n.a	BDL	BDL	
Maximum	599.90	660.83	750	599.99	1665.00	3935.5	17.3	
Upper continental crust	55.00	70.00	25.00	75.00	100.00	12.50	0.2	[67]

n.a: not analyzed. BDL: Below detection limit confluence of rivers and industrial activities. This enhanced concentration of Co, Ni, Cr and Pb was possibly due to the influence of paint industries, heavy water plant, alkali chemical and fertilizer industries, thermal power plants and port activities [46].

The concentrations of heavy metals in surface sediments collected from the Vellar and Coleroon estuaries, southeast coast of India were determined by Nethaji *et al.* [47]. The concentrations (µg g^{-1}) were in the range of 78.0 to 157.0, 78.0 to 123.0, 18.0 to 68.0, 60.0 to 218.0, 56.0 to138.0, 34.0 to 188.0 for Cu, Zn, Co, Ni, Cr and Pb, respectively in Vellar estuary. The levels of Cu, Zn, Co, Ni, Cr and Pb in sediments from Coleroon estuary were ranged from 96.0-162.0 (µg g^{-1}), 86.0-156.0 (µg g^{-1}), 39.0-66.0 (µg g^{-1}), 50.0-156.0 (µg g^{-1}), 106.0-207.0 (µg g^{-1}) and 58.0-180.0 (µg g^{-1}), respectively. The authors ascertained that heavy metal contamination in the study sites were primarily attributed to upstream river contamination with human liked anthropogenic activities. When comparing, the concentrations of heavy metals was significantly higher in the Coleroon estuary sediments than the Vellar estuary suggesting riverine input to the coastal regions during its course. Both rivers are affected primarily by industrial and urban effluents and agricultural runoff. Krishnakumar *et al.* [48] investigated the levels of heavy metals in sediments collected from the Van Island. Concentrations of Cu, Zn, Ni, Cr and Pb in sediments varied from 0.008 to 494.27, 9.89 to 660-83, 35.30 to 405.31, 0.03-435.94 and 0.18-2053.20 ppm, respectively. According to their findings, the concentration of Pb was found to be uniformly higher in most of the sediments. Urban activities in Tuticorin, industrial outfall locations such as coal incineration power plants and port activities acted as the primary sources of heavy metal pollution in the study regions with consistent upstream pressure [48,49] measured heavy metals in sediment samples collected from Tirumalairajan estuary. The results revealed that the measured levels of Cu, Zn, Co, Ni, Cr and Pb in Tirumalairajan estuary was ranged from BDL to 0.039, 0.012 to 0.153, BDL to 0.027, BDL to 0.072, BDL to 0.155 and BDL to 0.085 µg g^{-1}, respectively. These values were found to be relatively low and Tirumalairajan River estuary considered as unpolluted.

Magesh *et al.* [50] analyzed the heavy metals in sediments collected from the estuarine along Tuticorin coast-Gulf of Mannar, southeast coast of India. The levels of heavy metals sediments in this study were ranged between 13.40-178.20, 60.0-340.0, 13.0-64.5, 0.2-11.0, 2.1-31.50, 13.5-173.9 and 1.40-14.60 µg g^{-1} for Cu, Zn, Co, Ni, Cr, Pb and Cd, respectively. Findings from this study indicated that the concentrations of heavy metals were significantly higher than that of other coastal regions in Tamil Nadu state [51]. The authors the inferred that the heavy metals might have resulted from the industrial effluents such as discharge from Tuticorin alkali chemicals, thermal power plant, petrochemical industries, copper smelting and shipping activities. The findings also revealed that among the study sites, Korampallam Creek's sediments had the highest and most dangerous levels of heavy metal contamination [50]. In the same year, Lakshmanasenthil *et al.* [51] investigated concentrations of heavy metals in sediments collected from estuaries located in Bay of Bengal in Tamil Nadu, southeast coast regions. According to the authors the levels of heavy metals (µg/g) in sediments varied between 2.15 and 3.0, 0.02 and 0.03, 0.05 and 0.13, 0.17 and 0.44, 0.0536 and 0.8, 1.12 and 3.9 for Zn, Co, Ni, Cr, Pb and Cd, respectively. The results indicated that the impact of waste disposal and industrial effluents through the study regions on heavy metal contamination in sediments. The metal contents in sediments collected from the Pichavaram mangrove ecosystem after the impact of December 2004-Tsunami was investigated by Ranjan *et al.* [52]. The results indicated that high accumulation of Cd, Cu, Cr, Pb and Ni in sediments. Alarming level of Cd in sediments was recorded. Magesh *et al.* [53] determined heavy metal contents in sediments collected from Tamiraparani estuary; southeast coast of India. The concentrations of metals were in the range of 13.41 to 95.24, 72.0 to 300.00, BDL to 15.21, 10.63 to 35.65, BDL to 16.98, 16.30 to 53.35 and 4.50 to 17.34 for Cu, Zn, Co, Ni, Cr, Pb and Cd, respectively. The metal contents in sediments were found to be significantly higher and could pose a potential threat to the ecosystem. The authors ascertained that the harbour activities and industrial discharge around the study sites might attribute the contamination of sediments. Gandhi & Raja [54] studied the heavy metal pollution levels in sediments collected between the Besant Nagar to Marakkanam, southeast coast India. According to authors, the municipal sewage and dumping of urban wastes were found to be the major sources of heavy metals. Gopal *et al.* [55] reported that the concentrations of heavy metals in sediments collected from the off Chennai coast impacted by a major flood. The concentrations of heavy metals in sediments were in the range of 37.20-599.90, 48.20-267.10, 5.00-67.90, 2.20- 151.30, 8.50-853.20 and 6.50-3935.5 for Cu, Zn, Co, Ni, Cr and Pb, respectively. The authors proposed that Pb levels in sediments from the study sites were higher than that of the global average level. The pollutants could have originated from urban runoff through Adyar and Cooum rivers. A fascinating maiden study investigated the metal contents in the sediments of Hare Island and determined below threshold levels, suggesting that the concentration of metals did not contaminate the sediments [38]. In a study investigating *Scylla serrata* from Tuticorin, southeast coast of India, heavy metal accumulation is influenced by industrial effluents and domestic sewage discharge [56]. Another important study has been published by Perumal *et al.* [57]. Their results implied that Cd was contaminated higher among metals in surface sediments from the Thondi coast, Palk Bay, which may be associated with municipal wastewater, domestic sewage, fishing harbour activities and industrial activities.

Heavy metals level in marine edible algae, crabs and fishes: A tropical climate characterizes the southeast coast region in Tamil Nadu. This coastal region is supported different natural diversity and economic, recreational and agricultural activities to Tamil Nadu. Several industries and international ports have also dominated this coastal region. During recent years anthropogenic activities are highly pronounced in this coastal region. Thus, over the years, increased anthropogenic activities had led to the degradation of its biodiversity and marine organism's abundance. Besides, heavy metals originated from urban and industrial discharge mostly affected the food web chain in terms of bioaccumulation in living organisms such as edible algae, fish and crabs. Few studies have been conducted to measure heavy metal contamination in marine organisms. Studies have shown that heavy metals concentrations in sediments are continuously increasing in the southeast coast regions. More recently, Partheeban *et al.* [58] investigated the heavy metal accumulation in the demersal flatfishes collected from the Gulf of Mannar biosphere reserve, Tamil Nadu, India. Zinc was the most predominant accumulated metal in the bottom-dwelling flatfishes, suggesting habitat behaviour. Bioaccumulation was associated with metal contents measured in sediments.

Arisekar *et al.* [38] reported the bioaccumulation of heavy metals in two crabs collected from Hare Island. The levels of heavy metals were below the permissible levels set by the FDA, EC and FSSAI. The concentrations heavy metals were measured in several species of edible marine algae collected from the Thondi coast of Palk Bay [59]. According to their result, levels of Cu, Zn and Cd in several species exceeded safety level set by National and international standard regulatory limits. For instance, *Ulva reticulate* had the highest accumulation of cadmium with a value of 8.62 mg kg^{-1}. The higher concentrations of Cu (17.33 mg kg^{-1}), Pb (5.24 mg kg^{-1}) and Zn (23.45 mg kg^{-1}.) were recorded in *Sargassum whitti*, *Chaetomorpha linum* and *Kappaphycus alverizii*, respectively. The result indicates that seaweeds from Thondi coast were heavily contaminated by Cu, Zn and Cd. Vasanthi *et al.* [60] measured the concentrations of heavy metals in the tissues of *Mugil cephalus* collected from Ennore estuary in the eastern coast region. According to their results, the heavy metals accumulation had shown significant variation in the tissues of fish. The heavy metal concentrations (µg g^{-1}) ranged from 3.346 to 6.068 for Cu, 4.132 to 8.058 for Zn, 1.15 to 5.253 for Pb and 0.953to 3.146 for Cd. The concentration of Cd in the fish was high and exceeded the safe level for human consumption. The higher concentrations recorded in tissue reflected tissue morphological changes such as Lesions, increased lipid droplets, epithelial hypertrophy and hyperplasia, lamellae deformity and chronic changes in hepatocytes [60].

Karunanidhi *et al.* [61] determined the heavy metal levels in edible fishes collected from the Gulf of Mannar. A significant difference found in heavy metal concentrations among fish species. The heavy metal concentration (mg kg^{-1}) in the fish tissues ranged between 0.42 and 6.31 for Cu, 6.75 and 65.08 for Zn, 5.80 and 19.87 for Pb and 0.01and 0.79 for Cd. This study reported high values for Zn and it could be due to the bioavailability of Zn in the environment. The highest levels of Zn (65.08 mg kg^{-1}), Cd (0.79 mg kg^{-1}) and Pb (19.87 mg kg^{-1}) exceeded the safe limit set for human consumption established by FAO/WHO. The reported high a accumulations of Zn, Pb and Cd, might be attributed to the heavy industrial activities in the region of Gulf of Mannar and should receive special attention to prevent contaminants from industries such as Chloralkali plants, Sterlite copper and thermal power plants [61]. Seedevi *et al.* [62] determined the concentrations o heavy metals in *Sepiella inermis* collected from the Mudasalodai Landing Centre. The concentrations (mg kg^{-1}) of heavy metals Cu, Zn, Co, Ni, Cr, Pb and were in the range of 8.12-71.15, 10.54-54.42, 0.01-0.55, 0.62-3.66, 2.49-9.11, 1.75-27.77 and 0.24-26.65, respectively. The Cd value was found higher than the permissible level recommended by FAO/WHO. Similarly, Pb value was found to be higher than the FAO acceptable limits for fish. However, Cu and Zn concentrations did not exceed the safe level for human consumption. The concentrations (mg/kg) of Cu, Co, Ni, Cr, Pb and Cd in the marine crab's tissues of *Portunus pelagicus* and *Portunus sanguinolentus* collected from the southeast coast of India were studied by Barath Kumar *et al.* [28]. The metal contents (mg kg^{-1}) in *Portunus pelagicus* tissues varied from 58.25 to 267.26 for Cu, BDL to1.66 for Co, BDL to 32.77 for Ni, BDL to 81.69 for Cr, BDL to 8.68 for Pb and BDL to 30.23 for Cd. The concentrations (mg kg^{-1}) of Cu, Co, Ni, Cr, Pb and Cd in *Portunus sanguinolentus* tissues were in the range of BDL to 375.94, BDL to 6.32, BDL to 86.41, BDL to 163.23, BDL to 6.50 and BDL to 46.47, respectively. According to their results, high levels of metals were found in *P. sanguinolentus* with the exception of as compared to *Portunus pelagicus*. The Cr levels were found to be higher than permissible limits for human consumption. Markedly increased levels of Cu were found in both species studied that exceeded the permissible limits for human consumption (Table-4). This study also showed that a higher level of Cd in tissues of analyzed crabs, which were above the recommended level. With the highest recorded levels of Cd, Cu and Cr in tissues would cause human-associated health risks upon regular consumption. Recently, Rajaram *et al.* [63] investigated the heavy metal contents in edible green sea weeds collected from the Palk Bay, southeastern India. According to them, among the sea weeds investigated *Caulerpa scalpelliformis* and *Ulva lactuca* were reported to the highest accumulators of heavy metals. In general, the measured metal contents in edible seaweeds were above the permissible limits set by WHO standards. In recent study, Vinothkannan *et al.* [68] examined the heavy metal contents in shellfish species collected from the Cuddalore coast in Southeastern India. Overall metal concentrations were found to be Zn > Cu > Pb > Cd. The study found that due to Cd levels in shellfish species were over threshold levels and thus posed a harm to consumers' health. Also, Vinothkannan *et al* [69] indicated that the concentrations of Cu and Zn in pelagic and benthic fish collected from Cuddalore coast in Tamil Nadu, India were higher, which may pose health risks to humans. The level of heavy metals (Cr, Pb, Ni, Cd, Cu and Zn) in water samples from Noyyal river was also evaluated [70]. Based on the authors' findings, the quality of water in terms of metal contents was poor.

Conclusion

Even though there haven't been many studies into heavy metal contamination in lakes and rivers, it's become clear that human activity has a big influence on pollution levels. It should be noted that concentration of Zn, Pb and Cu mostly accumulated in sediments collected from the river and lakes and are relatively higher than the permissible level set by Canadian Sediment Quality Guidelines (CSQG), indicating that adverse

TABLE-4
CONCENTRATIONS OF HEAVY METALS ANALYZED FROM EDIBLE ALGAE, CRABS AND FISHES COLLECTED FROM TAMIL NADU MARINE ECOSYSTEMS

	Concentration (mg kg^{-1})							Ref.
	Cu	Zn	Co	Ni	Cr	Pb	Cd	
Edible marine algae from Thondi Coast								
Hypnea musciformis	16.57	14.28	n.a	n.a	n.a	2.36	5.59	[59]
Gracilaria edulis	15.58	11.53	n.a	n.a	n.a	0.86	4.56	[59]
Gracilaria verrucosa	16.64	18.69	n.a	n.a	n.a	1.55	2.66	[59]
Gracilaria corticata	14.2	16.49	n.a	n.a	n.a	0.9	2.39	[59]
Sarconema filiforme	16.3	15.28	n.a	n.a	n.a	0.94	4.7	[59]
Kappaphycus alverizii	16.42	23.45	n.a	n.a	n.a	2.58	5.68	[59]
Acanthophora muscoides	15.63	7.49	n.a	n.a	n.a	2.46	1.85	[59]
Ulva lactuca	15.48	15.52	n.a	n.a	n.a	1.49	0.87	[59]
Ulva reticulata	16.37	19.69	n.a	n.a	n.a	0.4	8.62	[59]
Caulerpa scalpelliformis	16.28	7.65	n.a	n.a	n.a	0.58	3.54	[59]
Chaetomorpha linum	15.38	22.34	n.a	n.a	n.a	5.24	8.51	[59]
Sargassum whitti	17.33	19.59	n.a	n.a	n.a	2.68	7.67	[59]
Turbinaria conoides	15.64	5.49	n.a	n.a	n.a	2.09	1.92	[59]
Fish								
Mugil cephalus from Ennore estuary	3.346-6.068	4.132-8.058	n.a	n.a	n.a	1.15-5.253	0.953-3.146	[60]
Edible fishes from Gulf of Mannar	0.42-6.31	6.75-65.08	n.a	n.a	n.a	5.80-19.87	0.01-0.79	[61]
Sepiella inermisfromMudasalodai	8.12-71.15	10.54-54.42	0.01-0.55	0.62-3.66	2.49-9.11	1.75-27.77	0.24-26.65	[62]
Flatfishess (µg/g dw) Gulf of Mannar	0.96-13.83	8.93-44.05	n.a	n.a	n.a	ND-12.68	0.18-2.76	[58]
Marine Crab (Scylla serrata)	0.21-10.60	14.26-44.94	n.a	n.a	n.a	0.09-0.72	0.13-1.10	[56]
Marine crabs (SE coast Tamil Nadu)								
Portunus pelagicus	58.25-267.26	n.a	BDL-1.66	BDL-32.77	BDL-81.69	BDL-8.68	BDL-30.23	[28]
Portunus sanguinolentus	BDL-375.94	n.a	BDL-6.32	BDL-86.41	BDL-163.23	BDL-6.50	BDL-46.47	[28]
Marine crabs (Gulf of Mannar)								
C. clibanarius	26.9-28.1	29.8-36.9	0.14-0.71	0.02-0.39	0.21-1.50	0.09-0.25	0.02-0.65	[38]
U. annulipes	0.01-0.45	1.54-2.78	0.06-0.56	0.21-0.96	0.13-0.97	0.06-0.16	0.01-0.19	[38]
Palk Bay Coast								
Ulva lactuca	11.54	7.18	n.a	n.a	n.a	10.75	0.24	[63]
Chaetomorpha linum	6.46	4.24	n.a	n.a	n.a	8.16	0.66	[63]
Caulerpa scalpelliformis	10.83	11.77	n.a	n.a	n.a	11.20	0.96	[63]
Enteromorpha compressa	6.46	4.24	n.a	n.a	n.a	6.19	0.71	[63]
Shellfish spp.	BDL-49.67	10.9-55.9	n.a	n.a	n.a	BDL-4.01	BDL-3.32	[68]
Fish spp.	2.37-29.1	23.09-30.78	n.a	n.a	n.a	0.39-2.21	0.06-0.46	[69]

biological effects could occur. *Catlacatla* accumulated high concentrations of Cu, Zn, Cr and Pb when compared to other fish species, indicating its trophic level-dependent accumulation behaviour. Also, it can have human-associated health risks upon regular consumption. Unlike rivers and lakes, heavy metal levels in sediments and organisms from southeast coast regions were extensively investigated. The spatial analysis indicated that increasing trend of heavy metals nearby river confluences, at the waste discharging points, industrial activities such as ship activities, coastal anthropogenic activities, thermal power stations and other intensive diffusing sources. Also, results of data indicated that some hotspots with greater accumulation of Cd, Zn and Pb were found in marine environments. Accordingly, Palk Strait and Gulf of Mannar were identified to be the hot spot regions for increased heavy metal pollution. Besides in sediments, levels of heavy metals such as Cu, Zn, Pb and Cd in seafoods were considerably high, suggesting potentially harmful effects for human consumption. Therefore, this study calls for special attention to coastal area protection along the southeast coast regions since the elevated levels of heavy metals found in sediments and organisms contribute to the potential risk to ecosystems and human health. Studies focusing on heavy metals in freshwater ecosystems in Tamil Nadu state were still minimal when compared to marine environments. In this regard, this review will guide the identification of priority areas to assess the heavy metal pollution along with other pollutants and implement better management practices, design ecoremediatiron strategies and effective policies in Tamil Nadu state of India. Besides, more future studies and correlation with additional environmental parameters are needed to fill the knowledge gaps in order to explore the effect of heavy metals on biota and providing opportunities to limit the sources of pollutants.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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