Global J. Environ. Sci. Manage. 9(2): 309-322, Spring 2023, Serial #34

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH ARTICLE

Geospatial visualization and seasonal variation of heavy metals in river sediments

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ARTICLE INFO

Article History:
Received 14 June 2022
Revised 19 August 2022
Accepted 22 October 2022

Keywords:
Contamination factor
Contamination degree
Geographical information system
Heavy metals
Pollution load index

DOI: 10.22034/gjesm.2023.02.10

ABSTRACT

BACKGROUND AND OBJECTIVES: Heavy metals can enter the food chain in the aquatic environment and become available for accumulation in biota. Industrialization and agricultural developments are progressively causing ecological concerns, which must be addressed. This study aimed to ascertain the heavy metals in Tamiraparani River sediments using contamination factor and contamination degree, which would help administrative bodies implement control measures. For heavy metal analysis, this study is unique in that it focuses on the far downstream, where the sediment deposition is higher.

METHODS: Using an atomic absorption spectrophotometer, the abundance of iron, manganese, copper, and chromium was determined in this study. In this study, the heavy metals in the sediments are selected on the basis of previous studies. Additionally, to assess sediment pollution status, contamination factor, contamination degree, and pollution load index were used. Furthermore, a geographical information system was used to analyse the temporal variations of heavy metals in the sediments for different spatial locations downstream of the river.

FINDINGS: The study revealed that iron > manganese > chromium > copper concentration ranges from 3838 to 853, 68 to 7.8, 8.3 to 0.5, and 5.6 to 0.26 milligram per kilogram, respectively. The contamination factor ranges from 0.006 to 0.093 among all the sampling locations, heavy metals, and seasons, indicating that the pollution is in a low-level category. The contamination degree ranges from 0.039 to 0.378 among sampling stations and seasons, also indicating low-category pollution. The pollution load index value ranges from 0.004 to 0.092, which is less than 1 (guideline value), indicating less pollution impact. The seasonal variation shows that the post-monsoon is highly polluted because of the excessive sediment deposit from upstream after monsoon rainfall.

CONCLUSION: The contamination factor and contamination degree are within the acceptable limit. However, they are in an increasing phase during monsoon seasons, which indicates that heavy metals are from industries and are built up along the river banks upstream. Additionally, chromium and copper are in high concentrations during post-monsoon (chromium = 6.643, copper = 5.636) than during pre-monsoon because of anthropogenic activities and industrial waste discharge into the river stream.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
40	7	5

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Note: Discussion period for this manuscript open until July 1, 2023 on GJESM website at the “Show Article”.

INTRODUCTION

The accumulation of heavy metals in sediments in rivers is drastically increasing because of various industrial and anthropogenic activities on the river banks. Pollution due to heavy metal sediments in water is a serious issue, and it is drawing international attention. Hence, sediments have been widely considered a heavy metal source because of their biogeochemical association (Annammala *et al.*, 2021). These complex biogeochemical association mechanisms indicate pollutant availability, mobility, and toxicity in sediments. Therefore, heavy metals are bioaccumulated in sediments because of their slow removal rates and in turn biomagnified, which is posing serious health risks to humans and aquatic organisms (Ramesh and Nagalakshmi, 2022). It is known that there are various sources for the generation of heavy metals, in which weathering of rocks (Hu *et al.,* 2013), untreated sewage, untreated industrial effluents, agricultural runoff, metal leaching from garbage (Michael *et al.,* 2022), and solid waste heaps are the major sources for the same (Reymond and Sudalaimuthu, 2021). The discharge of sewage, untreated or partially treated industrial effluent, and agricultural waste accumulated in the river, which disturbs the natural balance of the riverine system and eventually creates problems across the globe (Kumar *et al.*, 2013). Various researchers have been using advanced instruments such as inductively coupled plasma–optical emission spectrometry and graphite furnace atomic absorption spectroscopy (AAS) and AAS for analyzing heavy metal pollution in sediments for more than decades. Magesh and Chandrasekar (2014) have used AAS in their study for the detection and quantification of chemical elements relying on the absorption of optical radiation (light) by gaseous atoms. The aforementioned high-end sophisticated instruments are used extensively to determine the presence of toxic metal in sediment from the river sample. In the current scenario, the advent of remote sensing and geographical information system (GIS) is inevitable for analysing the spatiotemporal variation of heavy metals in the water body. Skordas *et al.* (2015) have used GIS in their study to analyse the spatial distribution of heavy metal concentration in sediments. Recently, GIS software has been used in the spatial modelling field, and several studies in interpolation analyses for zoning contamination sites have been conducted (Brady *et al.*, 2015). GIS is evolving as the most essential tool for researching environmental geochemistry issues (Kuchelar *et al.*, 2022). Using GIS, numerous studies have directly addressed whether reported contamination is a result of natural sources or anthropogenic (Sojka *et al.*, 2018). The indices contamination factor (CF) and contamination degree (CD) are used to evaluate the impact of anthropogenic activities. The CF is clear and concise, and a single-index indicator was used to assess metal contamination. It gives a ratio of an element at the sampling site to the same element at a background site, as well as a reference value (Said *et al.*, 2019). Generally, sediments have been used as environmental indicators, in which, their ability to monitor contaminants and identify heavy metal contamination sources is well documented. Additionally, the pollution load index (PLI) is used to determine the overall toxicity and quality of the sediments; moreover, it is utilized effectively to determine the consequence of the contribution of the metals like chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) (Khorasani *et al.*, 2013). According to the literature, metal accumulation in sediments is strongly influenced by the nature of the substrate as well as the physiochemical characteristics controlling dissolution and precipitation (Vaezi *et al.*, 2015). The Tamiraparani River receives a significant quantity of effluents from numerous industries like fertilizer production, petrochemicals, rice mills, copper smelting plants, mineral-based industries, coal-fired power stations, and other sources as it flows through the industrial area. The literature shows that although few studies were conducted to determine the heavy metal sediments in the Tamiraparani River, no studies have been done downstream of the river (Bai and Reji, 2015). Generally, the heavy metals in the sediments especially in the flood plains interact with the surrounding ecosystem and accumulate in it. Most times directly or indirectly it affects human health by creating skin diseases, cancers, and other harsh diseases. Hence, this study primary focused on the heavy metal analysis at the downstream delta region of Tamiraparani River where the sediment deposits are at their maximum. The catchment region has many industries and cities discharging untreated effluent into the Tamiraparani River, creating the dissolving of heavy metals and gradually it is adsorbed by the sediments and get deposited in the downstream deltaic regions. Therefore, this study focused on the spatiotemporal analysis of the heavy metals in the sediments of the deltaic region of the Tamiraparani River using various pollution assessment indices such as CF, CD, and PLI. The visual representation and spatial analysis are carried out using GIS techniques (Vaezi *et al*., 2014). To fulfill the expected outcome of the study, the following objectives are framed: i) sampling and laboratory analysis to derive the toxic metals of the study area; ii) assessment of the contamination levels through indices such as CF, CD, and PLI; and iii) spatiotemporal variation analysis using geospatial techniques to monitor the heavy metal pollution levels in sediments for Tamiraparani River. This study has been carried out in the Tamiraparani River of India in 2020 and 2021.

Study area

The study area is the Tamiraparani River (Fig. 1), which is the only perennial river providing drinking water for Tirunelveli and Tuticorin districts. It lies between 78°4′8.4″ and 78°5′20.4″E longitudes and 8°37′33.6″ and 8°38′13.2″N latitudes of Thoothukudi, Tamil Nadu. Thoothukudi is well known for pearl fishing, coral reefs, industries, minerals, and salt pans (Okedeyi *et al*., 2014). It has one of the oldest ports in the world. The river extends approximately 126 km in the mountains and plains, covering a catchment area of 5369 km^2. For the present study, 6 km from the downstream was considered. This area has a semiarid tropical wet climate and is characterized by South West and North East monsoons, with the annual rainfall ranging from 1000 to 1100 mm. The temperature and wind velocity vary from 20°C to 38°C and 2.8 to 35.5 km/h, respectively (Mukesh *et al*., 2018). The major rock types found in the area are garnet–biotite–sillimanite gneiss, calc–granulite, quartzite, and charnockite groups; limestone of the khondalite group; and migmatite complex of the Eastern Ghats super group. The area has four dominant soil textures, namely, loamy, fine loamy, coarse loamy, sandy, and fine sandy. The main sources of pollution in the study area includes wastewater from residence, industries, agricultural activities, and sand mining (Nayagam

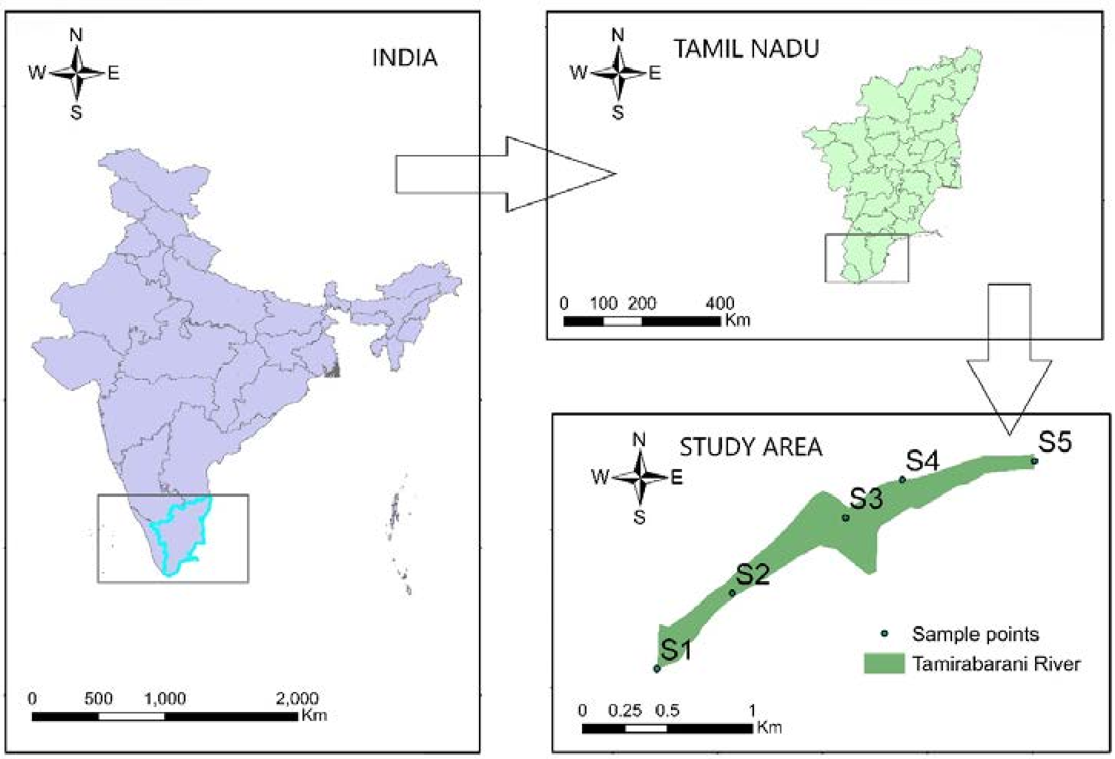

Fig. 1: Geographic location of the study area in the Tamiraparani River in India

et al., 2019). Fig. 1 shows the downstream of the Tamiraparani River as a study area.

MATERIALS AND METHODS

Sample collection

Study area delineation was carried out from the Top sheet, a scale of 1:50,000 with the help of the Aeronautical Reconnaissance Coverage Geographic Information System. Delineation of the study area includes geo-referencing of top sheet followed by onscreen digitization. Successively, sediment sampling from the field was carried out as per the standard procedures, and their locations were marked using global positioning system. The sampling primarily focused on downstream, and the location was chosen based on reconnaissance surveys such as potential pollutant sources, sites with inhabitants, and significant human activities (Pandey *et al.,* 2015). Eventually, the sediment samples are collected from Authoor, Mukkani, and Sernthamangalam from the study area. The Sernthamangalam area contains the mineral separation industry at a distance of 1.2 km from the riverbank (Singh *et al.,* 2017). To study the seasonal variation of heavy metals in river sediments, the sampling was carried out in three stages, namely, pre-monsoon, post-monsoon, and monsoon seasons. Hence, samples were collected during pre-monsoon (July 2020), monsoon (November 2020), and post-monsoon (March 2021). The Van Veen grab sampler was used for sampling the sediments from the river bed, and the samples were packed and tagged properly before laboratory analysis. The collected samples were refrigerated at 4°C for further analysis (Perumal *et al.,* 2021). Table 1 presents the details of the sampling stations along with the observed activities.

In the three seasons, a total of 75 surface sediment samples were collected. Additionally, five composite samples were collected at each station in the respective season to reduce sampling error.

Sediment digestion and heavy metals analysis

The sediments were air dried in a hot air oven at 60°C for 24 h and powdered using mortar and pestle and sieved through a 63 µm sieve. The fraction that settled was referred to as sand, whereas the fraction that passed through the sieve was referred to as clay and silt. The samples were placed on a clean and waterproof board and divided into four parts, with the diagonal portions mixed and quartered again until a homogeneous sample was obtained (Chen *et al.*, 2012). Homogenized subsamples of 1 g were subjected to the digestion process. In a Teflon bomb, 1 g homogenized subsample and 1 mL aqua regia (mixed concentrated acid of HNO_3 and HCl in a ratio of 1:3) were mixed with 6 mL hydrogen fluoride; the Teflon bomb was kept in a 95°C hot water bath for approximately 2.5 h. During the digestion process, fluorides from unreacted hydrogen fluoride precipitate were added to the solution, to re-dissolve the precipitated boric acid crystals (Guo *et al.*, 2016). Then, distilled water was added to the digested samples in a 100 mL volumetric flask and filled to the mark. After centrifuging, the heavy metals were determined via AAS, Thermo Fisher Scientific, designed in the United Kingdom and manufactured in China (Model-ICE 3300). All the chemicals used were of analytical grade. The reagent blanks were included in each analysis. All absorbance readings were taken thrice. The results were presented in milligrams per kilogram of the dry mass of sediments (Jaishankar *et al.*, 2014). The experimental analysis of the sediment samples was conducted using the AAS instrument. Samples were analysed for heavy metal concentrations such as Cr, Cu, Mn, and Fe for the pre-monsoon, post-monsoon, and monsoon months.

Pearson's correlation matrix

Pearson's correlation was performed for the different metals under consideration to see if there was any correlation between them. Table 2 shows the outcomes.

Table 1: Details of the sampling places in the Tamiraparani River

Sampling station	Place	Latitude	Longitude	Observations/activities
S1	Authoor	8.626°	78.069°	Agricultural, bathing and washing, sewage outfall, and solid waste dumping
S2	Mukkani	8.630°	78.073°	Agricultural, sewage outfall, and Brick kiln
S3	Shasta Thirukkovil	8.634°	78.079°	Agricultural, sewage outfall, and Brick kiln
S4	Sernthamangalam	8.636°	78.082°	Mineral separation industry
S5	Sri Pathirakali ammankovil	8.637°	78.089°	Mineral separation industry

Table 2: Correlation matrix of heavy metals

Heavy metal	Cr	Fe	Mn	Cu
Cr	1			
Fe	0.979849	1		
Mn	0.993816	0.969517	1	
Cu	0.982353	0.942409	0.986026	1

Table 3: Sediment quality according to contamination factor and contamination degree

C_f	C_d	Class	Quality of sediment
$C_f < 1$	$C_d < 6$	1	Low pollution
$1 \geq C_f \geq 3$	$6 \geq C_d \geq 12$	2	Moderate pollution
$3 \geq C_f \geq 6$	$12 \geq C_d \geq 24$	3	Considerable pollution
$C_f > 6$	$C_d > 24$	4	Very high pollution

In this study, Cr, Fe, Mn, and Cu all had significant correlation coefficients, indicating that they have closely associated origins and may be influenced by an exclusive factor. Cu had a strong positive relationship with Cr and Mn and, to a lesser extent, Fe. Heavy metals are present due to anthropogenic sources such as municipal and industrial wastewater, but agricultural wastewaters are the original sources of copper.

Contamination factor and contamination degree

Followed by the experimental analysis, contamination factor (C_f) and contamination degree (C_d) were estimated to analyse the intensity of the pollution in the study area. CF and CD were calculated by using Eqs. 1 and 2, respectively (Islam *et al*., 2015).

$$C_f = \text{Sediment metal content/Background metal content} \quad (1)$$

The evaluation of contamination of sediments by heavy metals is generally carried out by determining CF and CD. The sum of all contamination factors is used to calculate the contamination degree (Islam *et al*., 2015). Sediment quality is categorized according to CF and CD values represented in Table 3.

$$C_d = C_{f1} + C_{f2} + C_{f3} \quad (2)$$

Eventually, spatial analyst tools named the Inverse Distance Weighted Interpolation Techniques from GIS techniques were used to prepare the geospatial pollution vulnerability map of the study area.

Pollution load index

The PLI is a popular approach for determining the toxicity level of sediment. The succeeding formula was employed to calculate PLI using Eq. 3 (Islam *et al*., 2015).

$$PLI = (CF_1 \text{ X } CF_2 \text{ X } CF_3 \text{ X} \ldots \text{X } CF_n)^{1/n}, \quad (3)$$

Where, CF denotes the contamination factor and n denotes the number of metals considered for the derivation of the resultant. PLI values greater than 1 indicate heavy metal pollution, whereas PLI values less than 1 indicate no pollution (Rakib *et al*., 2021).

RESULTS AND DISCUSSION

Heavy metal concentration

AAS instrument was used to analyse trace metal concentrations in sediments for the various season such as pre-monsoon, post-monsoon, and monsoon seasons, and Fig. 2 presents the results. It was revealed that the highest concentration as 3837 milligram per kilogram (mg/kg) and the lowest concentration (2275 mg/kg) of Fe were found in Station 5 at post-monsoon and Station 1 at pre-monsoon, respectively. The reason behind the higher concentration of Fe was due to lithogenic and detrital components in the sand. The experimental analysis shows that Mn levels were higher (68.1 mg/kg) at Station 5 during post-monsoon and lower (48.1 mg/kg) at Station 1 during the pre-monsoon. It is caused by the influence of industrial effluent and farming activities near the study area. The aforementioned sampling location recorded the highest (5.6 mg/kg) and lowest (4.4 mg/

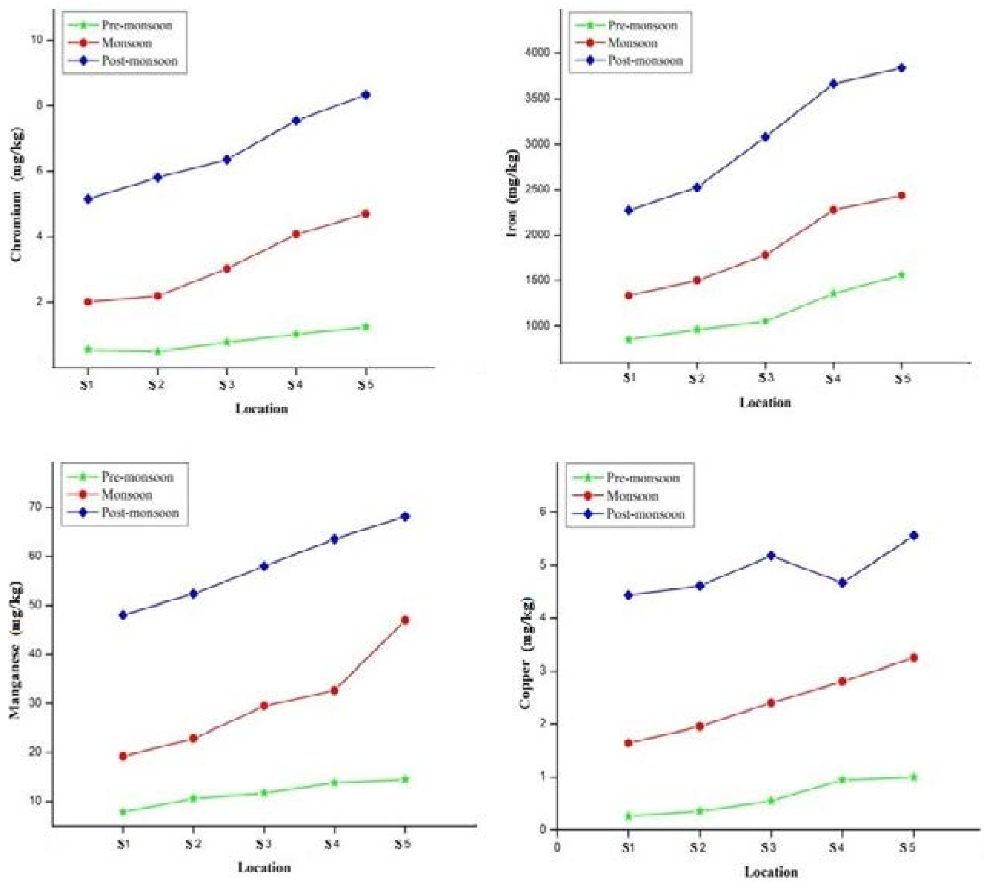

Fig. 2: Seasonal variation of Cr, Fe, Mn, and Cu in sediments

kg) concentration of Cu during post-monsoon and pre-monsoon respectively. Additionally, the highest (8.3 mg/kg) and lowest (5.2 mg/kg) concentrations of Cr were at Stations 5 and 2, respectively. All the heavy metal values are within the acceptable range, in comparison with Indian, European, and American standards.

In terms of the ratio of concentrations between pre-monsoon and post-monsoon, the result shows that Cr has the highest increase rate, which is 6.643, followed by Cu with a rate of 5.636. The other two heavy metals, i.e., Fe and Mn, showed mild increases of 2.456 and 4.696, respectively. The finer sediment deposits in the farthest downstream end and thus have higher adsorbed heavy metals. This becomes the reason for higher concentrations of heavy metals in the downstream and least in the upstream. In this study, Cr, Fe, Mn, and Cu all had significant correlation coefficients, indicating that they have closely associated origins and may be influenced by an exclusive factor. Cu had a strong positive relationship with Cr and Mn and, to a lesser extent, Fe. Heavy metals are present due to anthropogenic sources such as municipal and industrial wastewater, but agricultural wastewaters are the original sources of copper. Table 4 shows comparative concentrations of elements in Tamiraparani River sediments.

Spatial distribution analysis

GIS technology has been used in this study to understand the geospatial variation of heavy metals in sediments. A GIS-based kriging tool has been used to interpolate the heavy metals in sediments for analysing and developing spatial variation maps of the same at the study area. Fig. 3 depicts a spatial variation concentration map for various seasons. It was revealed that the concentrations increase from upstream to downstream and the dry season had

Table 4: Trace metal presence in Tamiraparani river sediment with statistical analysis (Bhaskar *et al*., 2016)

Data	Heavy metals (mg/kg)			
	Cr	Fe	Mn	Cu
Mean	3.6	2033.1	33.3	2.64
Deviation	2.92	970.2	23.3	2.2
Minimum	0.5	853	7.8	0.26
Maximum	8.3	3837	68.1	5.6
IRSA*	87	29000	605	28
WRSA*	100	48000	1050	100

*Indian river sediment average (IRSA); world's river sediment average (WRSA)

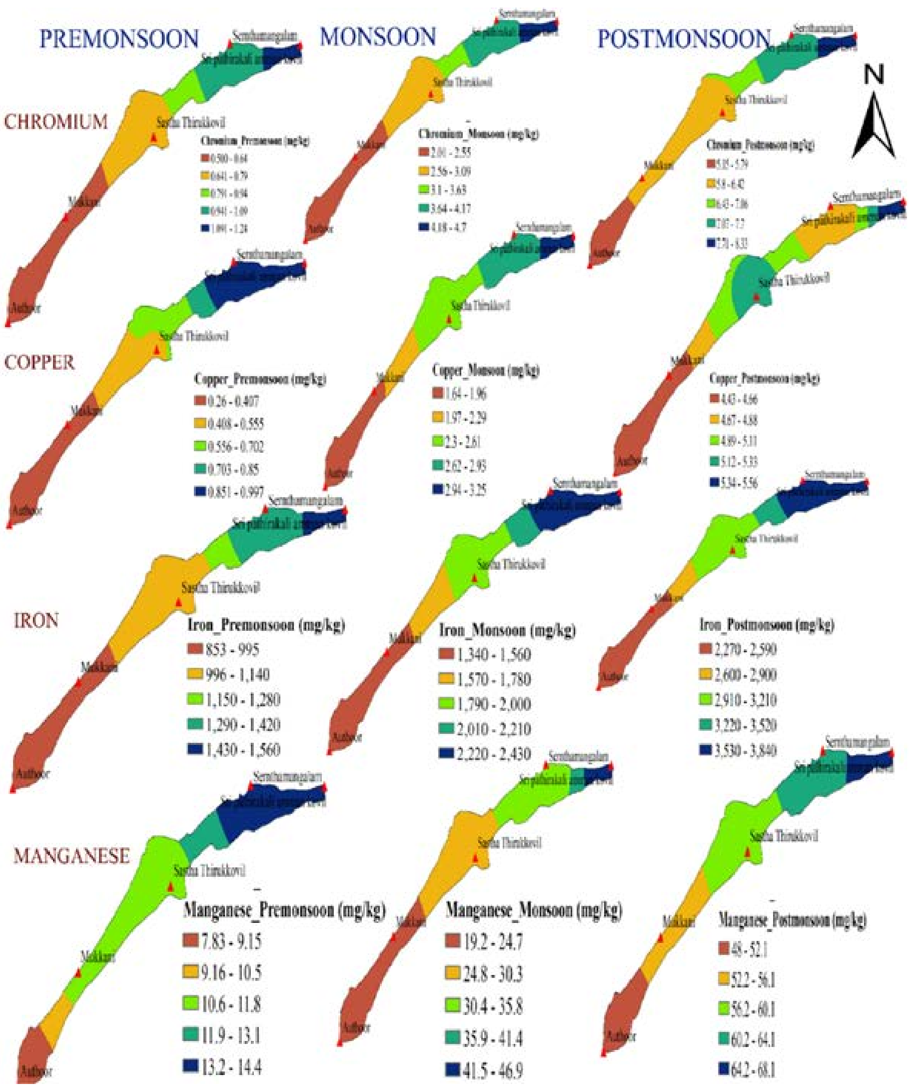

Fig. 3: Seasonal variations of heavy metals in sediments

Table 5: Contamination factor of collected samples during various seasons

Station number	Pre-monsoon				Monsoon				Post-monsoon			
	Cr	Mn	Fe	Cu	Cr	Mn	Fe	Cu	Cr	Mn	Fe	Cu
1	0.006	0.009	0.018	0.006	0.022	0.023	0.028	0.037	0.057	0.057	0.048	0.098
2	0.006	0.012	0.020	0.008	0.024	0.027	0.032	0.043	0.065	0.062	0.054	0.102
3	0.009	0.014	0.022	0.012	0.034	0.035	0.038	0.053	0.071	0.068	0.065	0.115
4	0.011	0.016	0.029	0.021	0.045	0.038	0.048	0.062	0.084	0.075	0.078	0.104
5	0.014	0.017	0.033	0.022	0.052	0.055	0.052	0.072	0.093	0.080	0.081	0.124

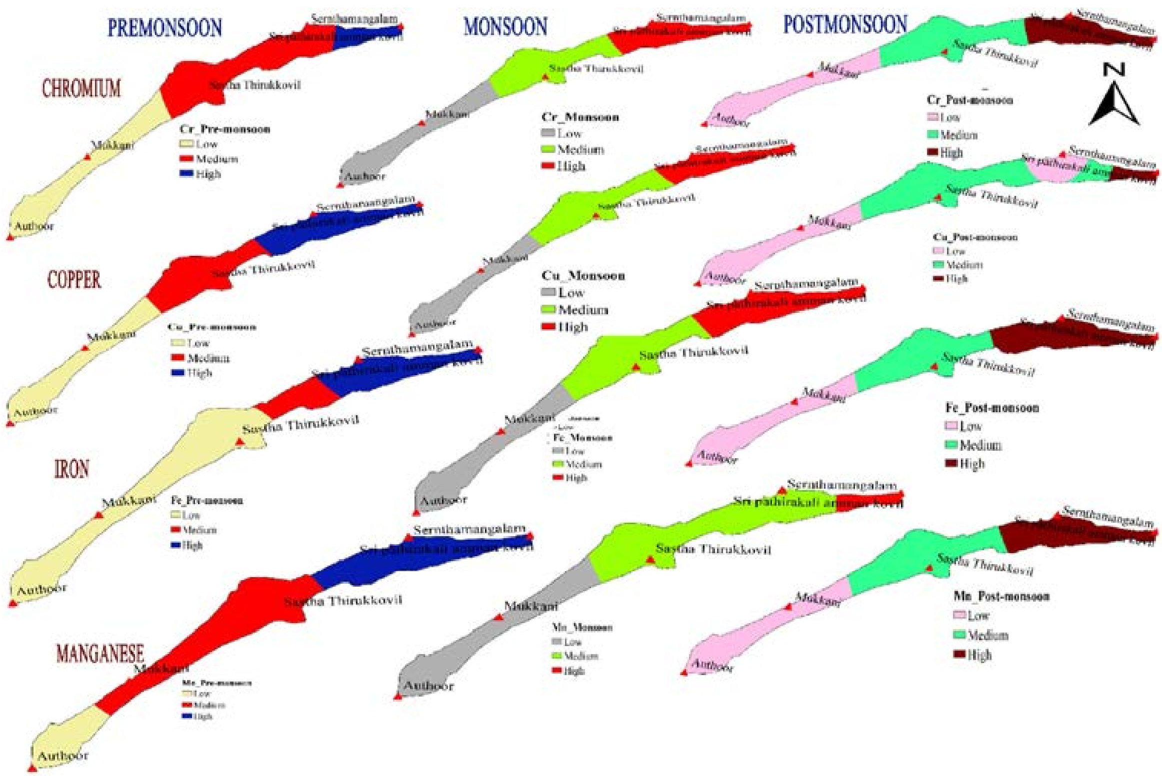

Fig. 4: Contamination factor of Cr, Cu, Fe, and Mn in sediments

the largest concentration, followed by the monsoon and pre-monsoon seasons. Furthermore, the figure revealed that all the heavy metals such as Fe, Cr, Cu, and Mn in the sediments have higher concentrations at the estuary of the river. It was also observed that the patterns are similar for all the metals in all the seasons. The least values are observed at Station 1 and average from Stations 2 to 4 and the maximum at Station 5. Generally, it was observed from the study that hydrodynamic conditions impact the spreading of heavy metals in the sediments downstream of the study area.

Contamination factor

C_f has been used to determine heavy metal concentrations in sediments. With the reference to CF-derived concentrations as shown in Table 5, the concentrations are less than 1. As per the study, $C_f < 1$ is considered no contamination (Aradpour *et al*., 2020).

The CF values for all the elements in the monsoon season ranged over the interval of 0.022–0.072. The highest value of 0.022 for Cu at Station 5 and the least value of 0.006 for Cr and Cu at Station 1 were detected in the pre-monsoon season. The maximum value of 0.072 for Cu at Station 5 and the least value of 0.022 for Cr at Station 1 were observed in the monsoon season. The highest value of 0.124 for Cu at Station 5 and the least value of 0.048 for Fe at Station 1 were observed in the post-monsoon season. The CF for Cu is higher than the other elements in all the stations.

Additionally, Fig. 4 presents the CF on different heavy metals for various seasons. It was revealed from the figure that heavy metal concentration is increasing downstream in all three seasons. The post-monsoon season had higher heavy metal concentrations than the other two seasons due to higher deposition of heavy metals. It is also revealed that due to the disintegration of rocks and anthropogenic activities, downstream had higher trace metals accumulation in sediments.

Contamination degree

The contamination degree (C_d) is derived with reference to CF and depicted in Fig. 5. It was understood that the CD values for Cr, Mn, Fe, and Cu in all the studied locations are <6 and fall in the low pollution category. The maximum values of CD for all the heavy metals were observed at Sernthamangalam in the post-monsoon season, and the minimum values were recorded at Authoor in the pre-monsoon seasons.

All the stations in the pre-monsoon season revealed a low contamination degree. The maximum CD was observed in post-monsoon at Station 5. The highest value of 0.378 was observed at Station 5 in the post-monsoon season, and the lowest value of 0.039 at Station 1 was detected in the pre-monsoon season. The resultant was the same as downstream showing higher concentrations of heavy metals in post-monsoon than the rest of the season.

Fig. 6 shows the CD spatial variation map of the study area. This figure shows that the lowest CD was found at Stations 1 and 2, the medium CD was shown at Station 3, and the highest CD was identified at Stations 4 and 5, regardless of the season.

Pollution load index

Fig. 7 displays the PLI results for each sampling station. It was indicated that the heavy metals are increased in sediments during post-monsoon than in other seasons. However, the overall impact is less as per the guideline's values of PLI is less than 1 in sampling locations. The compaction factor, contamination degree, and PLI all show an increasing trend from pre-monsoon to post-monsoon through monsoon seasons. The reason behind this is that the sediments are lowered during pre-monsoon and start to increase in the flood of monsoon. Later in the post-monsoon, all the sediments started to settle down, which arrived freshly from the upstream of the Tamiraparani River.

Interpretation

This study intends to determine the presence of toxic metals in sediment through CF, CD, and PLI from downstream of the Tamiraparani River. As per Magesh *et al.* (2016), due to channel topography

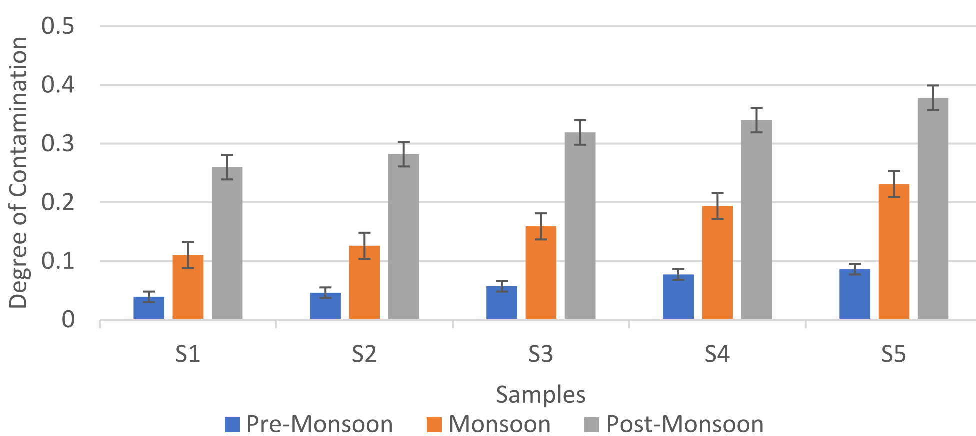

Fig. 5: Contamination degree in various seasons

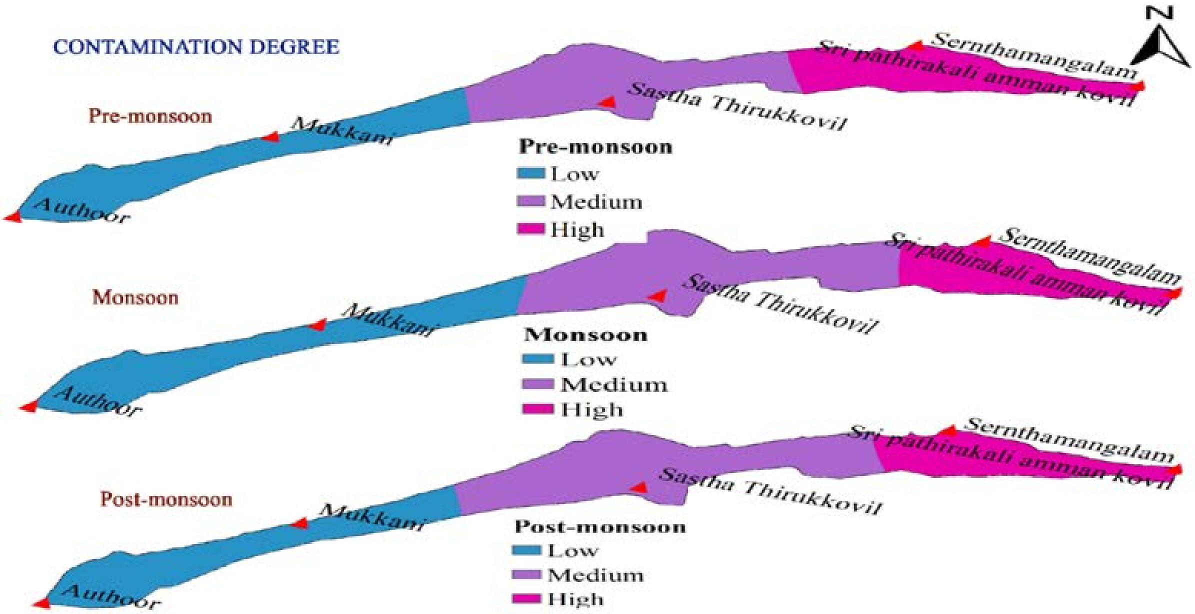

Fig. 6: Contamination degree in sediments during various seasons

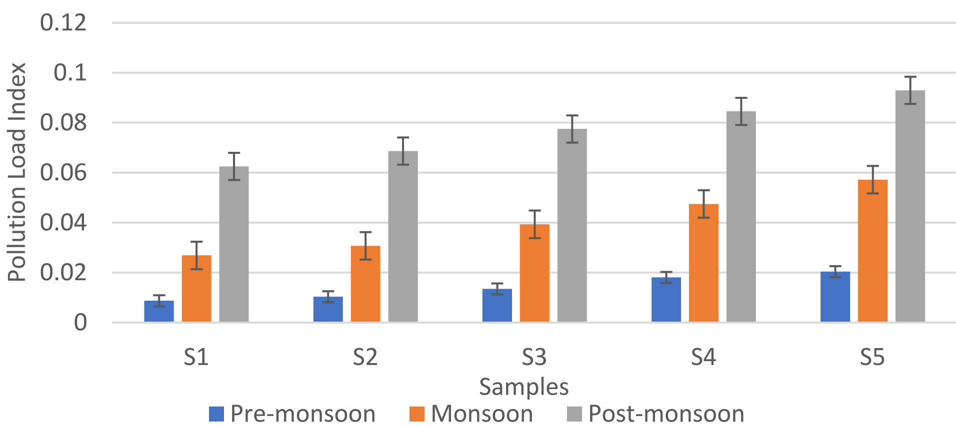

Fig. 7: Pollution load index in various seasons

and soil erodibility, the deposition of sediment is higher downstream of the study site. According to the derived contamination factor, in the study region, the highest index was 0.124 for Cu at Station 5. Magesh *et al*. (2017), in their study carried out in the Tamiraparani River, have identified that Cu concentration is contributed higher because it is rich in calcareous in nature and observed that the elevated lead (Pb) is due to port activities and nearby thermal power plant. Shanbehzadeh *et al*. (2014), in their study carried out in the same area, have determined the contamination factor specified as low to moderately contaminated except for CD at Tamiraparani River. The maximum concentrations of heavy metals such as Fe, Mn, Cu, and Cr were detected in sample areas amassed immediately downstream of the Station 5, where approximately 58% of the industrial activities are located, as well as the lower portions of the river's Station 4 (Bhuyan *et al*., 2017). However, it was observed from another study, that higher concentrations of Cd and Pb were found in the downstream direction of the Tamiraparani River due to high pH, salinity, and anthropogenic pollution during the winter season (Silva *et al*., 2014). According to the research carried out by Feng *et al*. (2012), the pollution intensity determined using enrichment factor exhibited that Zn, Pb, and cadmium (Cd) were found at the estuary of Tamiraparani River due to unrestricted anthropogenic activities. The analysis revealed that heavy metal concentrations of Fe range from 853 to 3837 mg/kg in the study area, whereas the result obtained from the Benin River in Nigeria showed that the values range from 867.8 to 7195.0 mg/kg (Tao *et al*., 2012). Furthermore, Arisekar *et al*. (2020) from Nigeria completed their analysis of sediments in soil, in which they observed that Fe concentration is higher. Additionally, they revealed that a high quantum of chromium reaches rivers and streams mainly because of wastewater and metal-containing products in the river. The quantity of these metals is predicted to reveal long-term exposure of sediments to several activities, such as organic waste and the surrounding chemical plants. Tuticorin is well known for chemical-, fertilizer-, and mineral-based industries (Zhang *et al*., 2019). The release of industrial wastes from surrounding petrochemical and copper smelting industries into the river has amplified the concentration of these metals in sediments. Fertilizers, pesticides from agricultural activities, municipal sewage, and fly ash from nearby industries have worsened the problem (Ma *et al*., 2015). Heavy metal pollution endangers humans, fish, and vertebrates alike. Contaminants bioaccumulated in water and sediments and then biomagnified in aquatic animals, trying to pose a risk of certain cancers once they enter the food chain (Shafie *et al*., 2013). The above results show that the river sediments fall in the "Class 1—low contamination" zone. The concentration of copper is observed to be high downstream during the post-monsoon season. The values of C_f and C_d were low at Station 1 and high at Station 5. All stations in the present study recorded low CF, CD, and PLI for Cr, Mn, Fe, and Cu.

CONCLUSION

The study evaluated the heavy metal concentration from the sediments at the Tamiraparani River delta with the help of CF, CD, and PLI. The results show that there is the existence of heavy metals such as Cr, Cu, Fe, and Mn at a detectable level. These are the constitutes of various industrial, agricultural, and domestic sewage discharges. Cr concentration ranged from 0.5 to 8.3 mg/kg with a mean of 3.6 mg/kg, Fe concentration ranged from 853 to 3837 mg/kg with a mean of 2033.1 mg/kg, Mn concentration ranged from 7.8 to 68.1 mg/kg with a mean of 33.3 mg/kg, and Cu concentration ranged from 0.26 to 5.6 mg/kg with a mean of 2.64 mg/kg. All four metals are in an increasing trend between pre-monsoon and post-monsoon through monsoon seasons. This is due to the increase in lower sediment deposits in the prior and subsequent increase of sediment deposit in monsoon and post-monsoon. Spatially, the upstream sampling Station S1 experienced a lower concentration, and the downstream station S5 experienced the highest concentration indicating that the sedimentation rate had been increasing from the upstream to the downstream. CF and CD show that the study area lies in the low pollution category. However, there was an increasing trend of pollutants and should be checked in the early stage as a prevention measure. This increase was due to anthropogenic activities, industrial effluent discharge, agricultural discharge, and untreated sewage discharge in the rivers. Moreover, the PLI, which was less than 1, indicates the low impact of pollution in the deltaic region. However, naturally, copper concentration was higher in sediment throughout Tamiraparani River because of the higher deposits in the Agasthiyar hill ranges where the river originates; moreover, because the river is highly calcareous in nature, Fe was high at the estuary of the study area due to lithogenic and anthropogenic activities along the river. With the reference to the field investigation, the major heavy metal pollutants identified were from industries, sand mining activities, agricultural runoff, and untreated sewage wastewater. Aside from the abovementioned reasons, soil erosion and flooding also transport heavy metals from upstream to downstream. To understand the increasing pattern of heavy metal concentration, the study recommended temporal monitoring of the pollution concentrations at the river to refrain from the activities influencing or increasing the concentration level in the study area. The need for the study is to identify the analysis of heavy metals due to their toxicity effect on the ecosystem, especially due to the impact of industries and urbanization around the river banks. Spatiotemporal analysis downstream is focused due to higher deposits of sediments in the floodplain delta. The study is considered essential as per the Water Act 1974 to prevent and control water pollution at the river. Additionally, the identified higher concentration stations should be observed closely by government authorities such as the District Collectorate Office and municipal corporations to impose legal actions against default polluters to avoid pollution in the study area. Heavy metal controlling and monitoring activities are required in the study region because of metal bioaccumulation characteristics and the potentially harmful effects of long-term exposure to biota and humans. Illegal discharges into the river system should be closely monitored to protect the river ecosystem, and wastewater from industries, municipalities, and households should be treated before being discharged into the river. The findings could serve as a basis for the predictions of human-induced effects, which could be used to examine and define an effective management decision policy to reduce heavy metal contamination.

AUTHOR CONTRIBUTIONS

J.D. Reymond performed the literature review and analysed and interpreted the data. K. Sudalaimuthu prepared the manuscript text and manuscript edition.

ACKNOWLEDGEMENT

The authors thank the head of the Department of Civil Engineering, SRM Institute of Science and Technology (SRMIST), Kattankulathur, Chengalpattu, Tamil Nadu, India, and the Management of SRMIST for providing the opportunity to carry out this extensive research work.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. Additionally, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely addressed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

°C	Degree Celsius
C_d	Degree of contamination
C_f	Contamination factor
%	Percentage
µm	Micrometre
AAS	Atomic absorption spectrophotometer
ArcGIS	Aeronautical reconnaissance coverage geographic information system
CD	Degree of contamination
Cd	Cadmium
CF	Contamination factor
Cr	Chromium
Cu	Copper
Fe	Iron (Ferrous)
g	Gram
GFAAS	Graphite furnace atomic absorption spectroscopy
GIS	Geographical information system
GPS	Global positioning system
h	Hours

ICP-OES	Inductively coupled plasma - optical emission spectrometry
IRSA	Indian river sediment average
kg	Kilogram
km	Kilometre
km	Kilometre
km²	Square kilometre
mg	Milligram
mL	Millilitre
mm	Millimetre
Mn	Manganese
Pb	Lead
PLI	Pollution load index
WRSA	Worlds River sediment average
Zn	Zinc

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HOW TO CITE THIS ARTICLE

Justus Reymond, D.; Sudalaimuthu, K., (2023). Geospatial visualization and seasonal variation of heavy metals in river sediments. Global J. Environ. Sci. Manage., 9(2): 309-322.

DOI: 10.22034/gjesm.2023.02.10

url: https://www.gjesm.net/article_696644.html