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POTENTIAL ECOLOGICAL AND GEOCHEMICAL RISK ASSESSMENT ALONG THE COAST TRACK OF TUTICORIN BAY, TAMIL NADU, SOUTHEAST COAST OF INDIA

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Abstract

Geochemical hold associated with ecological risk were assessed along the coast track of Tuticorin Bay with the aid of outward sediments. The circulation of $CaCO_3$ in the study area is derived from the terrigenous materials from the land side, major source of carbonate materials is the shell fragments and input from adjacent land mass. The concentration of organic matter is derived from the adjoining area mass and industrial effluents nearby. Accounting the major concentrations, Calcium upholds the role next to Silica and is because of both biogenic and lithogenic contributions. The level of Cr, Cu, Pb and Sr shows elevated concentrations which might be due to anthropogenic and industrial provenances. The main sources of most of these trace attributes are from power plants and coal handling operations from harbors.

Keyword: Geochemical, Ecological, Terrigenous, Biogenic, Antropogenic, Lithogenic

1.INTRODUCTION

The cloud of Tuticorin Bay engulfed with rich biodiversiry are at the verge of extinction. This sector of Gulf of Mannar are impacted by both southeast and northwest monsoon and serve as sustaining platform for ecologically and economically important species. This piece of work highlights the influences induced on the marine sediments and its expression with ecological modifications. The industrial refuses marks an alarming role in sea sediments, as they have an inclination to act as sinks for fine, contaminants reactive sediments. This study with the aid of various geochemical and ecological indices like, enrichment factor (EF) (Tang et al. 2010), Contamination Factor and index of geo-accumulation (Igeo) (Müller 1981; Lin et al. 2011) Metal Pollution Index(MPI) (Usero et al. 1997), Sediment Pollution Index(SPI) (Singh et al. (2002) and Potential Ecological Risk Index (PERI) (Hakanson (1980) predict the destiny of Tuticorin Bay and its adjoining biologically supplemented backdrops.

The Gulf of Mannar Marine Biosphere Reserve (GoMMBR) extending from Tuticorin to Rameswaram, off southeast coast of India asserted as a bio-reserve, lacks geochemical characters and elaborate description in relevancy with the ecological proxies concerning the surface sediments within the inner shelf of Gulf of Mannar (GoM).This study marks the purpose by point so much reaching record of the key and trace element geochemistry of the marine sediments off Gulf of Mannar.

2.MATERIALS & METHODS

Tuticorin Bay presents nice interest as a result of its industrial belt covering chemicals production, petrochemicals, plastics harbor activities, thermal power plant and human activities from around Tuticorin. Taking in to account the earth science of the study area,

Gneisses, charnockites, and quartzites of archaean age, chalky arenaceous rock and shell limestone of tertiary age, and alluvial deposit of recent age underlie the realm. The formations, together with quartzites as ridges within the western half, are weather worn, articulated and broken. Recent to sub-recent sand occupies coastal areas. It consists of coarse and carbonate grits arenaceous rock and shell limestone. Addressing the morphology and soils, the outstanding geomorphic units known within the district are 1) fluvial, 2) Marine, 3) Fluvio-marine, 4) Aeolian and 5) Erosional landforms relying upon the earth of development. Taruvaikulam-Tuticorin surface, Kulattur surface, Vaippar surface, Nagalapuram-Vedanattham surface and Volinokkam-Vembar surface are a number of the erosional geomorphic units within the northern part of the study area. The area is roofed with black soils in western half, red soil in central half and alluvial sandy
soils in eastern part. The sandy soils originated from sandstones have low moisture impermeability whereas the alluvial deposits are wind-blown sands and shells representing beach and coastal dunes, having terribly low moisture retentiveness. This bay was hand-picked, since it is holding the credibility of water course near the mouth which might decipher the influence of coastal region.

Accordingly surface sediment samples were collected along the coastal stretch off Tuticorin Bay at seventeen locations during July 2016 (Table 1.1 and Figure1.1), signifying the bay environment to evaluate the marine geochemistry. The sampling sites were fixed using Trimple Juno SB outdoor handheld GPS. Sediment samples were retrieved from the sampling locations with the aid of Peterson grab surface sediment sampler. The collected surface sediments were systematically numbered and shifted to the laboratory for further analysis. The sediment samples were kept in a hot air oven at 60 °C to remove the moisture content and powdered (< 63 µm), using Agate mortar at Institute for Ocean Management, Anna University, Chennai. Calcium Carbonate ($CaCO_3$) and trace element investigation was executed by means of the procedure formulated by Loring and Rantala (1992). Organic Carbon availability was aided through exothermic warming tracked by oxidation of potassium dichromate and concentrated sulfuric acid followed by titration of excess dichromate salts with ferrous ammonium sulfate (Gaudette et al., 1974). 0.5 g pulverized fine grained sediment (< 63 µm) was completely digested in a Teflon beaker using aqua regia (2 h at 120 °C; HNO3:HClO4:HF - 3:2:1). The final digested solution was centrifuged at 500 RPM and made up to 30 ml with double distilled water (Yang et al., 2012). The concentrations of the trace elements were estimated with the help of a Graphite Furnace Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst 800) at Institute for Ocean Management, Anna University, Chennai. The geospatial distribution of marine geochemistry was plotted using an inverse distance weighted (IDW) algorithm in ArcGIS 10.3. The statistical analysis was performed using SPSS 21 software package.

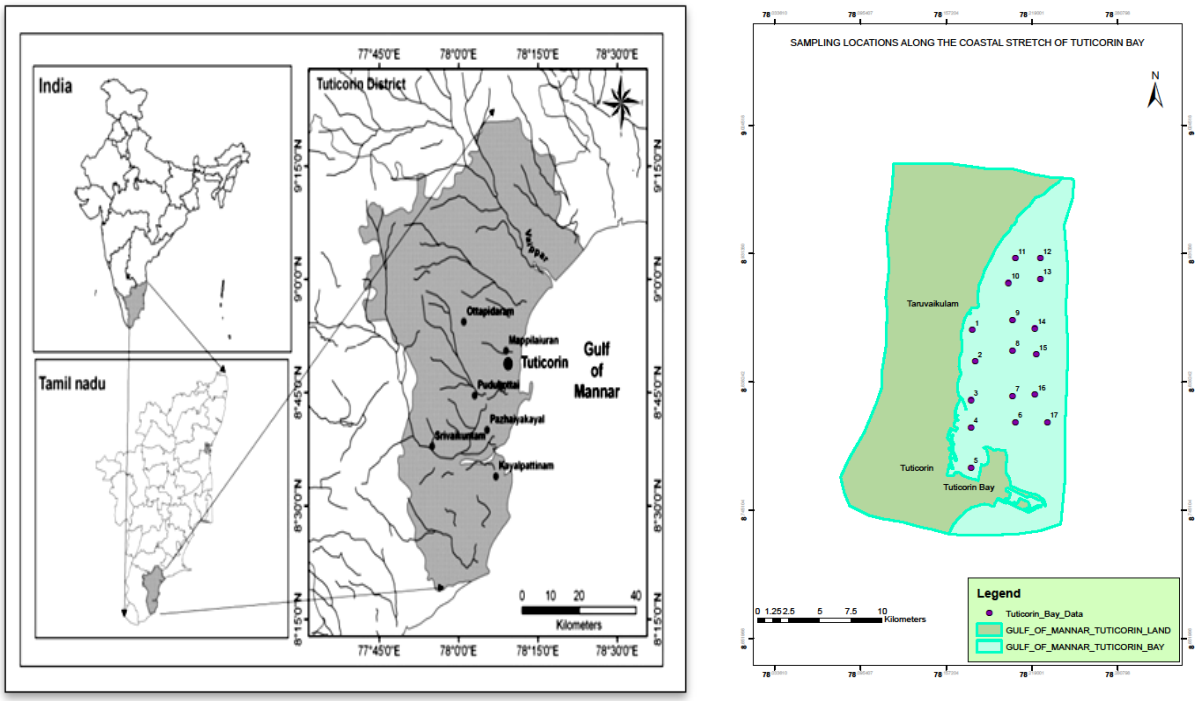


Figure :1.1 Study Area Map Off GoM, Southeast Coast of India

3.RESULTS AND DISCUSSIONS

The sediment composition within the study area exemplify a heterogeneous assortment principally created out of quartz sand, biogenic carbonate and shell fragments (Table1.1). The textural characters of the sediments collected express with 27.41 to 98.49% of sand, 0.01 to 65.01% of silt and 0.01 to 72.58% of clay (Figure 1.2).Significant exercises prompting marine contamination in Gulf of Mannar are unleash and disposal of domestic wastes, discharge and disposal of biodegradable pollution and industrial wastes, Harbour activities and maritime transport, sport fishing exercises and salt production. Except some of the industries, the effluents popping out of the industries are disposed off within the coastal space. The sediments along the coastal stretch of Tuticorin bay are enriched with chalky sand stones and chippings, acquired from coral reefs and remnants of algal/ benthic macro fauna.

Table 1.1 Sample locations Lat/Long, Textural characters, $CaCO_3$, Organic Matter & SI distribution along the coastal stretch of Tuticorin Bay

S.No	Longitude	Latitude	Sand	Silt	Clay	OM	CaCO3	SI	Sediment Type
1	78°10'34,35"	8°52'34.61"	83.61	16.36	0.03	0.24	39.81	0.00221	Silty Sand
2	78°10'40.67"	8°51'9.23"	86.60	0.01	13.39	0.66	30.83	0.00032	Clayey sand
3	78°10'31.38"	8°49'30.47"	98.20	0.80	1.00	0.44	44.70	0.00030	Sand
4	78°10'31.45"	8°48'16.82"	87.60	12.39	0.01	3.94	47.05	0.00034	Silty sand
5	78°10'28.44"	8°46'34.59"	34.98	65.01	0.01	0.97	25.35	0.00267	Silty sand

6	78°12'26.43"	8°48'33.66"	98.49	1.50	0.01	0.12	42.30	0.00036	Sand
7	78°12'17.29"	8°49'41.24"	81.90	18.09	0.01	1.14	36.55	0.00032	Silty sand
8	78°12'17.60"	8°51'40.21"	75.00	0.01	24.99	2.75	32.33	0.00190	Clayey Sand
9	78°12'16.24"	8°52'57.97"	86.20	0.01	13.79	1.65	36.23	0.00035	Clayey Sand
10	78°12'8.63"	8°54'34.95"	94.60	5.39	0.01	1.57	39.44	0.00097	Sand
11	78°12'26.13"	8°55'39.43"	88.00	11.99	0.01	0.94	33.20	0.00163	Silty sand
12	78°13'30.76"	8°55'39.43"	27.41	0.01	72.58	2.07	12.00	0.00032	Sandy clay
13	78°13'30.49"	8°54'47.51"	94.80	0.01	5.19	1.33	36.32	0.00046	Sand
14	78°13'14.16"	8°52'37.71"	83.80	16.19	0.01	0.85	29.24	0.00031	Silty Sand
15	78°13'18.53"	8°51'27.80"	80.60	19.39	0.01	1.67	28.33	0.00043	Silty Sand
16	78°13'14.93"	8°49'44.31"	87.00	0.01	12.99	0.78	22.48	0.00039	Clayey sand
17	78°13'47.24"	8°48'32.11"	61.00	0.01	38.99	0.87	19.95	0.00036	Clayey sand
AVG			**79.40**	**9.83**	**10.77**	**1.29**	**32.71**	**0.00080**	
MIN			**27.41**	**0.01**	**0.01**	**0.12**	**12.00**	**0.00030**	
MAX			**98.49**	**65.01**	**72.58**	**3.94**	**47.05**	**0.00267**	

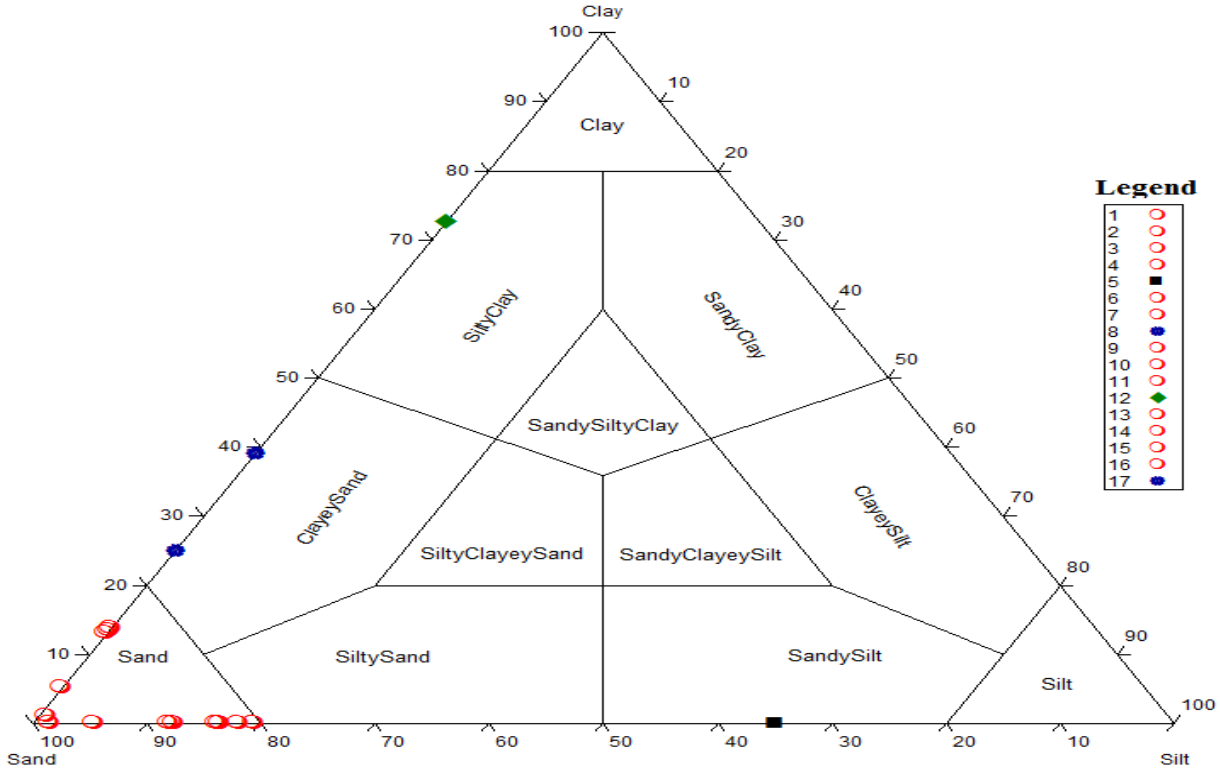


Figure 1.2 Trilinear plots

Huge aeolian sand deposits favours sand increment in the entire study area and the deposition of fine sediments indicates that the currents from the abrasion zone transport fine fractions which might be due to sediment re-suspension from the adjacent sources (P.Saravanan et.al 2018). The concentration of clay is high in sampling location 12 whereas silt dominates in location 5. The circulation of $CaCO_3$ in the study area ranges from 12% to 47.05% indicating the high input of terrigenous materials from the land side, major source of carbonate materials is the shell fragments and input from adjacent land mass where Tertiary limestones and calcareous sandstones reach out in the southern locale (Ray and others 1990). The concentration of organic matter ranges from 0.12% to 3.94% (Figure 1.3).The non availability of direct carbon sources inhibits the addition of organic matter.

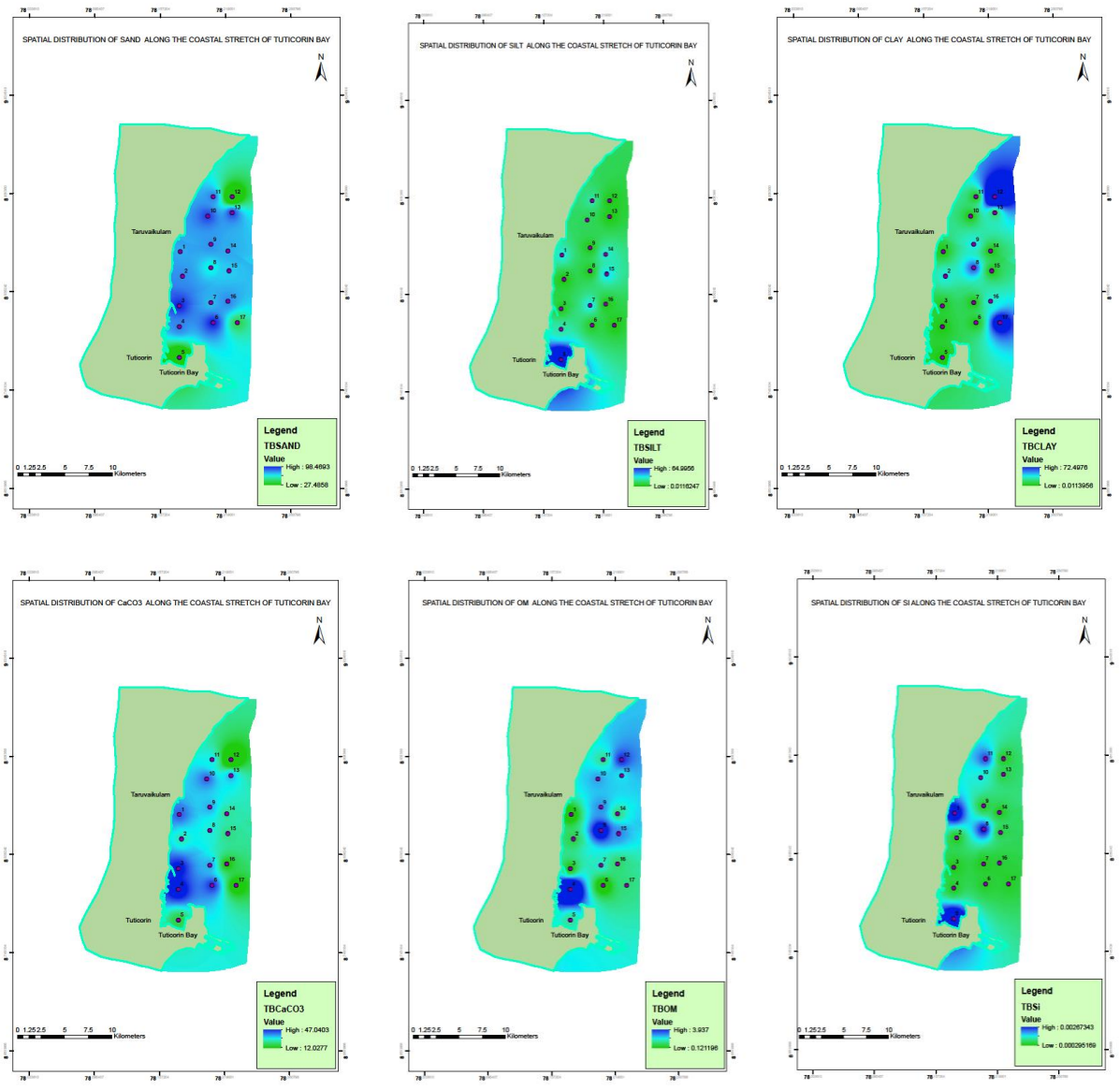
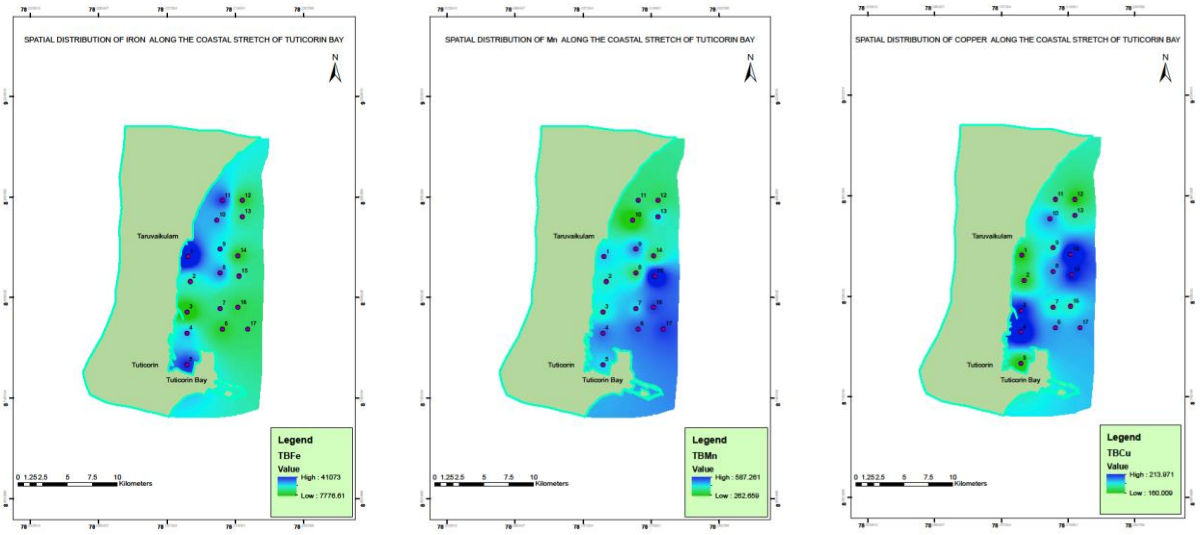


Figure 1.3 Spatial distribution of Sand, Silt, Clay, OM, CaCO3 & SI

Taking in to record the convergence of major oxides silica demonstrates a greatest scope of 33.17% and a minimum estimation of 24.67% with the average

concentration of 27.35%.In its oxide form SiO_2 ranges from 52.85% - 71.08%. The concentration of alumina ranges from 1.09 – 3.52% with an average of 1.92% and its oxide form ranges from 2.07– 6.65% with a mean value of 3.63%. Fe_2O_3 ranges from 1.11 – 5.87%. The iron content doesn't demonstrate any consistency in distribution. The concentration of CaO is much higher than all other major oxides except silica. CaO ranges from 7.44 – 24.57% with an average value of 17.43%. Bounteous concentration of calcium deposits in the sediment fractions reveals the domination of calcareous phase enriched lithoclastst and shell debris (P.Saravanan et.al 2018). The concentration of MgO ranges from 1.17– 1.43% with an average of 1.28% and the concentration Na_2O ranges from 2.05 – 3.99%. Taking in to record the concentration of K_2O, P_2O_5 and MnO, they are extremely poor in the study area. The concentrations of these elements are engaged by fluvial deposition and sediment fractions (Figure 1.4).

Tuticorin Bay explicit a very high concentrations of trace elements (Figure 1.4 &1.5) in most stations with noteworthy blending at the shallowest profundity and the comparative grouping of metals in different sampling stations show the sandy nature. Elevated concentration of certain trace elements viz. Cr, Cu, Pb, Sr and Zr were observed along the coastal track off Tuticorin Bay which might be due to harbor undertakings associated with anthropogenic contribution. The contributors of chromium along Tuticorin Bay are corrosive building materials and effluents from industrial and domestic sewage. Handling of copper scraps in the Tuticorin Harbour, Sterlite Industries (India's biggest copper smelter)(http://www.rediff.com/money/report/slide-show-1-special-why-sterlite-industries-is-in-trouble/20130421.htm)are the main contributors of copper along the coastal stretch of Tuticorin. The toxicity of lead along the coastal trail of Tuticorin are due to the handling of cargo and dredging activities, antifouling paints used in aquatic vessels,fuel discharges, power plant activities etc. (James Balgan Anand D and Mary Jelastin Kala, 2015). The elevated concentration of Strontium could be from fossil deposits (Nepal C. Mondal et.al.,2011)



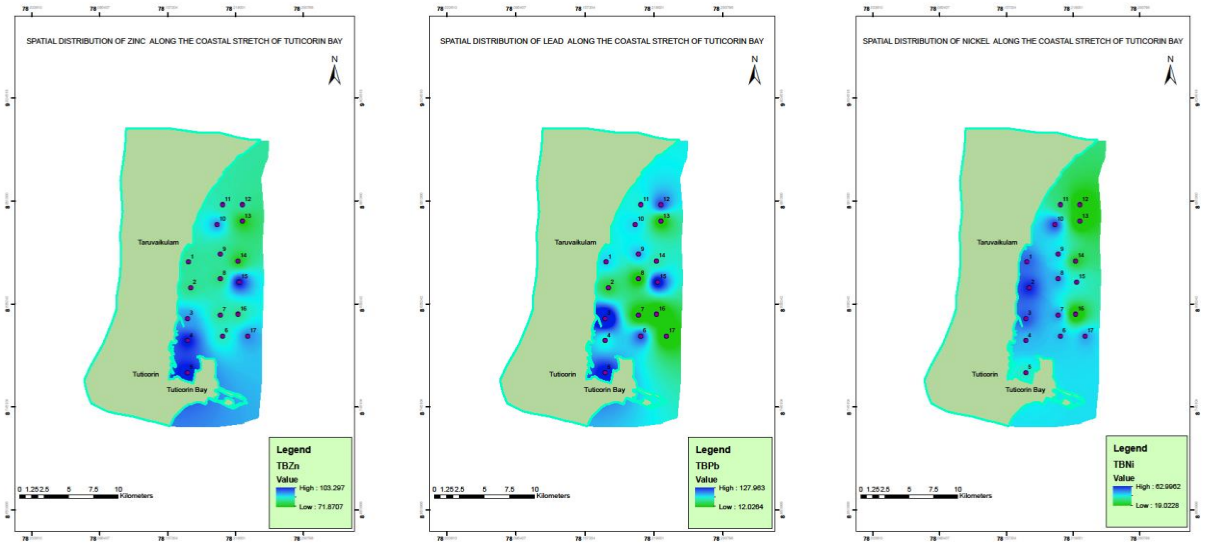


Figure 1.4 Spatial distribution of Fe, Mn, Cu, Zn, Pb .& Ni

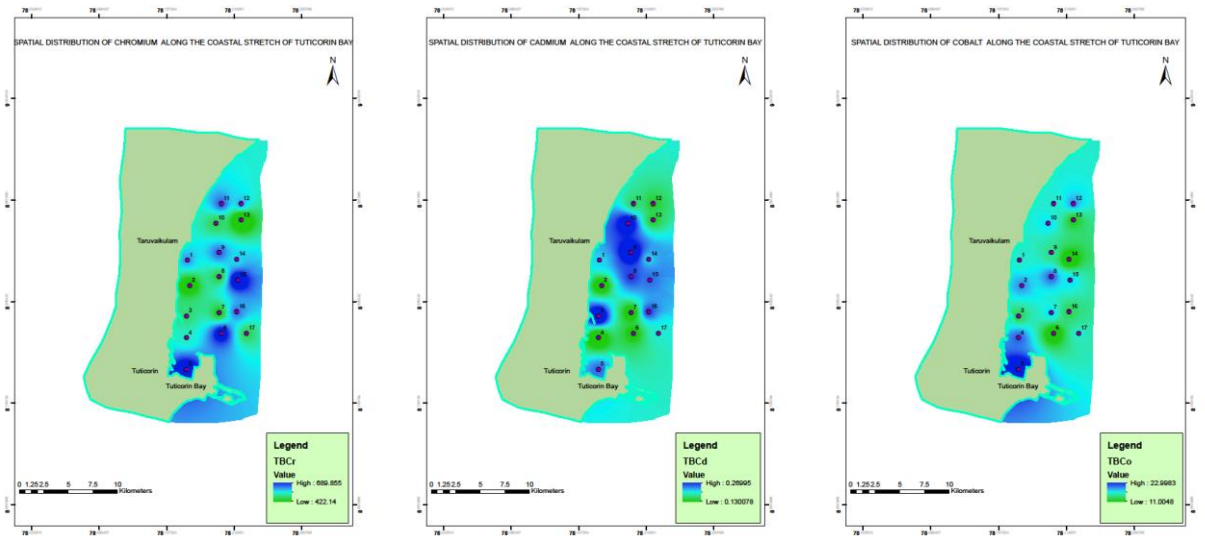


Figure 1.5 Spatial distribution of Cr, Cd .& Co

Loring (1991) showed that the regular mineralogical and granular variability is best remunerated by the geochemical standardization of major and trace metal information. Al remains the best and generally utilized normalizer and makes up for varieties in grain size and structure on the grounds that it speaks to the nature of alumino silicate, which is the most vital bearer for adsorbed metals in close shore residue. Also, in the hull, metal to aluminum proportions are less influenced by human exercises (Schropp and others 1990). The current study utilizes Al for normalization and the silica with Al

normalization imparts an average of 15.43 (Figure 1.6). Si concentrations in the surface sediments are pretty much uniform and the whole area demonstrates the vicinity of higher quartz content (Jonathan et al. 2004) Next to silica, CaO frames the second major oxide in the present study and the convergence of high CaO is because of both biogenic and lithogenic material. The average concentration of Fe/Al ratio is 1.18% and the

mean Mg/Al ratio is 0.71%.Sodium and potassium concentrations in the area are low with mild enrichment. Sodium and potassium concentrations values ranges from 1.52 to 2.96 and 0.45 to 1.34%, respectively.

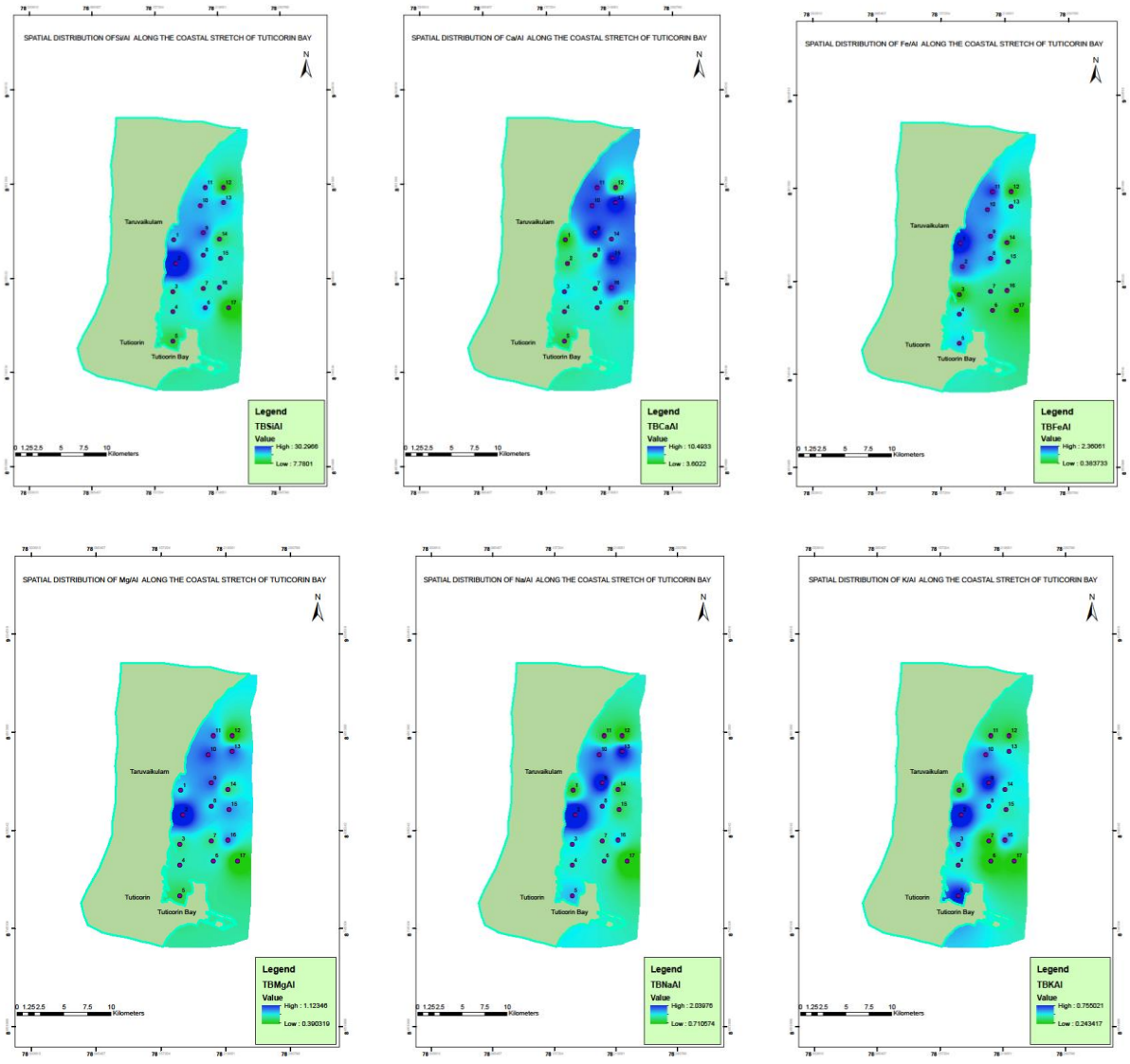


Figure 1.6 Spatial distribution of Al normalization for Si, Ca, Fe, Mg, Na & K

Potassium and Plagioclase feldspar distribution in the sediments are largely reflected in potassium and sodium behaviours. The P/Al and Mn/Al proportions don't demonstrate much contrasts and their average concentrations are 0.04 and 0.02% respectively.

Enrichment Factor (EF) is a popular strategy to explicit the enrichment of metals in marine configuration with the aid of Aluminium or Iron normalization. EF marks its role as a valuable key ciphering the enrichment of metals in sediment by anthropogenic or natural sources (Bastami et al. 2012). The enrichment factor indicating the polluted nature is mathematically expressed by EF = (Me/Al) Sample/ (Me/Al)

{shale Value} where (Me/Al) sample is that the metal to Aluminium (Al) quantitative relation within the sample of interest, (Me/Al) shale value is that the ratio of metal to Al within the Wedopohl shale value (1995).Since particulate metals from natural and evolution sources accumulate together, it may be tough to work out what portion is anthropogenetic. The naturally available

metal concentrations in sediments should be standardized so that anthropogenic add-ons could be detected and quantified. (Loring 1991). The EF is further classified into seven classes (Table 1.2) (P.Saravanan et.al 2018). EF values > 10 are considered to be non-crustal source. Accordingly 12% of the samples are grouped under moderate enrichment, 53% falling under moderately severe enrichment and 35 % under severe enrichment category.

Table 1.2 Enrichment Factor Classification

Enrichment Factor	Range	Classification
1	0-1	background concentration or no enrichment
2	1-3	minor enrichment
3	3-5	moderate enrichment
4	5-10	moderately severe enrichment
5	10-25	severe enrichment
6	25-50	very severe enrichment
7	>50	extremely severe enrichment

In order to know the extent of contamination, the values of trace metals were accustomed for contamination issue, calculated as Contamination factor (CF) = C metal/C shale worth where C metal is that the metal concentration and c shale value is that the globe average concentrations of the thought-about parts reportable for shale (Wedopohl 1995). The pollution level in trace metals were calculated directly based on Pollution Load Index (Tomlinson et al. 1980).
Pollution Load Index (PLI) = n√(CF1XCF2XCF3X...XCFn)
where CFn = contamination factor and n = range of metals.

The PLI index represents the number of times by that the heavy metal concentration within the sediment exceeds the background concentration and provides an accumulative indication of the overall level of significant metal toxicity in an exceedingly explicit sample. The pollution load index ranges from 0.75 to 1.55.Except station 7,8, 13,16 & 17, all other locations falls in polluted category (Figure 1.7).The contamination factor values are in the track of Cr > Cu >Pb>Sr>Zr> Zn > Ba > Co > Ni > Cd > Ti >Mn> V >Rb. The CF values for Cr, Cu, Pb, Sr and Zr are more prominent than 2 and may be because of industrial pollution.

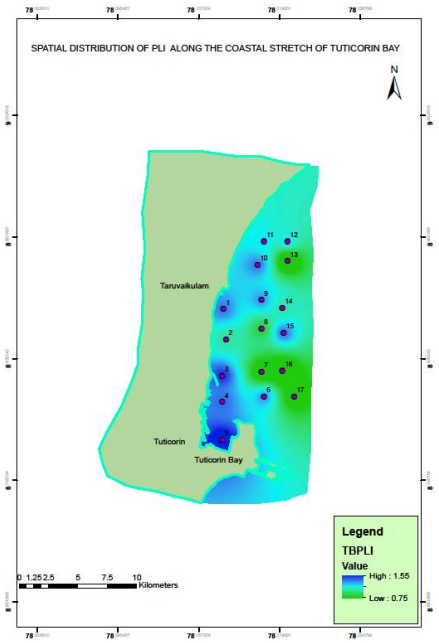


Figure 1.7 Spatial distribution map of the Pollution Load Index (PLI)

Geoaccumulation Index (Igeo Index) again categorizes the samples into six classes based on their severity. The highest category (Class 6) reflects at least a 100-fold enrichment above background values (Barbieri M (2016) . Igeo Index is calculated with Igeo = $\log_2$ (Cn/1.5*Bn) (Wedepohl 1995) and factor 1.5 curtails the impact of attainable deviations within the background values which can be attributed to lithogenic variations within the sediments (Stoffers et al. 1986).Igeo Index spread a moderate contamination in Tuticorin Bay except Cr which demonstrated an elevated enrichment of 114.58

Metal Pollution Index (MPI) is used to find out the mutual pollution effect from different locations by various elements. MPI is calculated based on (Usero et al. 1997) equation:
$MPI = (Cf_1, \times Cf_2, \ldots .Cf_{n,})^{1/n}$
Where Cf_n is the concentration of metal n in the sample. The MPI values of the trace components studied are conferred in Table 1.3.

The lowest metal pollution index was recorded in station 13 and higher index in station 5, indicating the confluence of contamination from industries and other sources into this environment (Figure 1.8). Broadly, the results of MPI index powerfully recommend that the study area is contaminated by phylogeny activities.

Table 1.3 Metal Pollution Index along the coastal stretch of Tuticorin Bay off Gulf of Mannar, SE coast of India

S. No	Ba	Zr	Sr	Rb	Pb	Zn	Cu	Ni	Co	Cr	V	Cd	Fe	Mn	MPI
1	463	1345	379	26	69	81.02	161	57	16	588	54	0.2	41080	427.46	133.21
2	350	209	334	45	39	80.02	162	63	18	469	77	0.14	19230	390	106.50
3	630	141	1329	36	128	92.66	201	59	14	523	67	0.27	7770	390	125.45
4	443	728	872	37	61	102.70	213	50	19	549	43	0.13	24030	470	131.35
5	652	477	778	67	99	103.30	160	43	23	664	41	0.22	30370	420	146.10
6	612	304	883	35	87	83.52	187	50	11	662	55	0.15	13210	480	121.25
7	508	139	106	35	24	81.01	175	53	17	491	23	0.14	17710	420	84.53
8	570	228	158	26	25	79.02	186	52	19	503	34	0.23	26540	340	97.34
9	579	557	672	24	73	81.57	175	49	15	608	35	0.27	21920	460	125.06
10	378	795	958	24	69	92.16	188	59	17	512	30	0.26	24680	262.54	124.50
11	495	749	523	29	61	82.81	172	37	16	611	33	0.17	29990	360	118.43
12	601	132	1063	35	88	81.91	160	23	18	585	67	0.16	13110	340	110.31
13	469	122	68	28	26	71.86	174	22	13	422	41	0.16	17140	410	75.53
14	334	112	1871	46	55	72.88	214	30	11	571	39	0.2	12580	340	103.97
15	590	288	1169	25	104	102.97	201	44	17	690	30	0.22	17790	587.46	129.62
16	460	128	95	35	12	80.99	175	19	14	603	28	0.23	14630	497.46	76.91
17	480	124	103	25	23	93.46	187	52	16	513	41	0.19	15990	500	87.93
AVG	**506.71**	**386.94**	**668.29**	**34**	**61.35**	86	**182**	**44.82**	**16.12**	**562.59**	**43.41**	**0.20**	**20457.06**	**417.35**	**111.65**
MIN	**334**	**112**	**68**	**24**	**12**	72	**160**	**19**	**11**	**422**	**23**	**0.13**	**7770**	**262.54**	**75.53**
MAX	**652**	**1345**	**1871**	**67**	**128**	103	**214**	**63**	**23**	**690**	**77**	**0.27**	**41080**	**587.46**	**146.10**

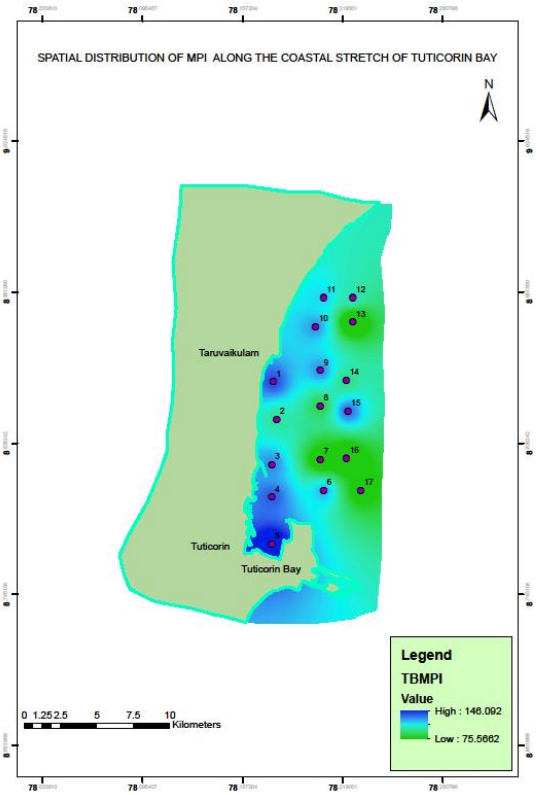


Figure 1.8 Spatial distribution map of the Metal Pollution Index (MPI)

The Sediment Pollution Index (SPI) aids in estimating the adulteration level in the natural setting. Singh et al. (2002) proposed the approach to estimate the Sediment Pollution Index level of the bay associated sediments.

$SPI = \Sigma(EFm \times Wm)/\Sigma Wm$

$EFm = Cn/Cr$

(EFm refers to the ratio between the observed elemental concentration (Cn), the background elemental concentration of the continental crust (Cr) and Wm is the toxicity weight in the SPI equation)

Based on the SPI values, the toxicity value of elements was allocated based on their toxic effect to the environment. Each studied elements were assigned with a toxicity weight. Toxicity weight 40 for Hg, 30 for Cd, 10 for As, 5 for Pb and Cu, 2 for Cr and 1 for Zn was assigned by Hakanson (1980). The Sediment Pollution Index (Table 1.4) of Tuticorin Bay falls under moderately polluted sediments category (Figure 1.9).).Altogether 76% of samples are moderately polluted, 18% low polluted sediments and 6% highly polluted sediments

Table 1.4 Classification of sediments based on SPI calculation

SPI	Range	Classification
1	0-2	natural sediment
2	2–5	low polluted sediment
3	5–10	moderately polluted sediment
4	10–20	highly polluted sediment
5	>20	dangerous sediment

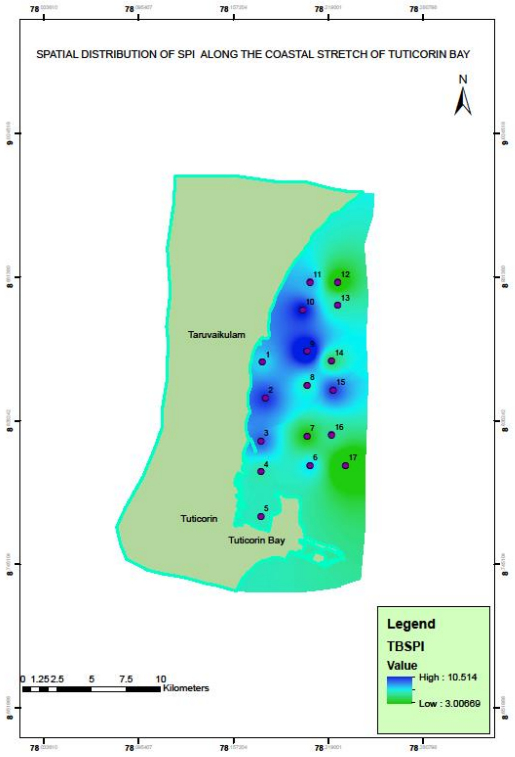


Figure 1.9 Spatial distribution map of the Sediment Pollution Index (SPI)

Ecological risk index (ER) coined by Hakanson (1980) generally aids in natural threat valuations of sediment associated trace elements. The Potential Ecological Risk Index (PERI) was calculated with the help of the succeeding equation.

$C_f^i = C_D^i / C_B^i$

$E_r^i = T_r^i \times C_f^i$

m

$$RI = \sum_{i=1} E_r^i$$

where, RI indicates the total of the potential risk of specific elements, E_r^i indicates the potential risk of specific elements, T_r^i indicates the toxic-response factor for an element, C_f^i refers contamination factor, C_D^i discusses the current element concentration in sediments, and C_B^i is the background concentration in sediments. Based on Hakanson's approach, the toxic-response factor is 2 for Cr and Ni, 5 for Cu and Pb and 1 for Zn and Mn respectively (S.Krishnakumar et.al,2017) (Singh et al., 2002) .The background value (crustal average) used for this calculation was derived from Taylor (1964) and Li et al. (1986). Hakanson endorsed five groups of ecological risk index (E_r^i), and four groups of RI (Table1.5). The ecological risk grade for each metal (E_r^i)suggests that all the elements fall under the low risk category.Whereas in potential ecological risk grades , Cd and Cu falls with considerable risk ,Pb and Cr falls with moderate risk and Zn and Ni with low risk category.

Table 1.5 Indices and corresponding degrees of potential ecological risk (Hakanson, 1980).

S.No	E_r^i value	Grades of ecological risk of single metal	RI value	Grades of potential ecological risk of the environment
1	$E_r^i < 40$	Low risk	RI < 150	Low risk
2	$40 \le E_r^i < 80$	Moderate risk	150≤RI < 300	Moderate risk
3	$80 \le E_r^i < 160$	Considerable risk	300≤RI < 600	Considerable risk
4	$160 \le E_r^i < 320$	High risk	RI≥600	Very high risk
5	$E_r^i > 320$	Very high risk		

Table 1.6 Comparison of trace elements in sediments with various other coastal regions around the State

STUDY AREA	Fe	Mn	Cu	Zn	Pb	Cd	Cr	Ni	Co	As	Hg
Surface sediment of Pitchavaram Estuary (Ramanathan et al. 1999)	32,482	941	43.4	93	11.2	6.6	141.2	62	35.3	NA	NA
Surface sediment of Coleroon estuary (Ramanathan et al. 1999)	23,533	326	4.3	60	4.6	8.6	49.6	24	166	NA	NA
Core sediments, 0–0.25 cm interval, Ennore Creek, S.E. Coast of India (Jonathan and Ram Mohan 2003)	NA	391	NA	105	17	0.108	643	49	11	NA	NA
Surface sediments, The Gulf of Mannar (Jonathan and Ram Mohan 2003)	NA	296	NA	73	16	0.2	167	24	7	NA	NA
Estuarine Sediments, KallarEstuary,Tuticorin Coast, GoM (Mahesh et al. 2013)	34,125	356.25	27.43	320.38	29.11	3.61	10.12	33.78	1.38	7.30	0.20
Estuarine Sediments, Korampallam Creek, Tuticorin Coast, GoM (Mahesh et al. 2013)	23,663	357.50	98.10	190.38	67.38	5.29	26.85	33.99	5.11	5.06	0.24
Estuarine Sediments, Punnakayal Estuary , Tuticorin Coast, GoM (Mahesh et al.2013)	28,363	277.63	30.98	231.00	28.13	10.40	9.34	21.20	3.65	5.69	0.33

Surface sediments, Gulf of Mannar, India (Jonathan et al. 2004)	12,600	305	57	73	16	NA	177	24	NA	NA	NA
Surface sediments, Tuticorin Coast, India (Magesh et al. 2013)	28,717	330	52	247	42	NA	15	30	NA	NA	NA
Palk Strait, southeast coast of India (Kasilingam et al. 2016)	55,680.30	661.4	69.1	244.2	19.5	NA	302.3	27.9	NA	NA	NA
Cuddalore, SE coast of India. (Jayaprakash et al. 2016)	10,982	291	40	37.7	33.9	NA	127	39.2	NA	NA	NA
Surface sediment of south east coast of India (Kumar et al. 2017)	2780	542.6	6.7	58.7	19.7	NA	191.3	50.7	NA	NA	NA
Present study	20,457	417.35	182	86	61.35	0.20	562.6	44.82	16.12	NA	NA

Element concentration µg/g; NA – data not available

Similar studies have been focused on metal levels in nearby location (Gulf of Mannar) which is presented in Table 1.6. It was found that Cu and Cr levels measured in this study were relatively higher than the sediments of Gulf of Mannar. In most marine sediments copper is listed at trace levels of concentration, well below 100 mg/g. Sources of contamination in natural sediments are usually associated with mining wastes, industrial metal manufacturing and process, corrosion products, or as a result of intensive use of protective paints in marine areas. The higher concentration of chromium in the marine sediments around the study area shows that they are the input through the industries on the banks of the marine environment.

4.FACTOR ANALYSIS AND INTER-ELEMENT RELATIONSHIP

Factor analysis contributed 61.09% aggregate variance preceded with 27 components. The component scores processed from unique raw data estimations and varimax raw rotated factor loadings delivered a completely new arrangement of smaller number composite variables. Distribution of major and trace elements demonstrated a general pattern in relation to sediment composition and calcium carbonate dissemination in the area.

On account of the first varimax raw rotated factor of major and other elements, it contributes 19.06% of the aggregate variance, 5.15 of Eigen value, and portrays the presence of carbonate shells in the sand fractions and bunch of aluminium in the clay and is textural controlled. The second varimax raw rotated factor represents for 15.92% of the aggregate variance, 34.98% of cumulative variance and 9.44% of cumulative Eigen value. This component stacking shows the vicinity of Ti demonstrating the vicinity of substantial mineral. The third varimax raw rotated factor accounts for 12.19% of the aggregate variance, 48.90% of cumulative variance and 13.20% of cumulative Eigen value. This factor loading indicates the presence of Si and V indicating the lithigenic origin. The fourth varimax raw rotated factor accounts for 13.92% of the aggregate variance, 61.10% of cumulative variance and 16.50% of cumulative Eigen value. This factor loading indicates the vicinity of Pb, Zn, Cr and Sr portraying its origin from anthropogenic activities.

5.CORRELATION MATRIX

Pearson's correlation coefficient matrix among the selected heavy metals is displayed in Table 1.7. Correlations are significant at $p < .05000$.from the correlation matrix study it is evident that Titanium shows good positive correlation with Silica, which is due to the vicinity of titanium silicates like lutile, in the sediments. Titanium is for the most part from silicates. Calcium shows negative correlation with silica which indicates higher grouping of calcium is because of the vicinity of $CaCO_3$ and as shell fragments. Vanadium and Nickel shows good positive correlations with silica indicating the presence in the mafic minerals in the sediments. The positive correlations of Ti, V and Ni indicate lithogenic origin of these elements. Iron shows positive correlation with Zr, Co and P. In this case Zr is felsic and Co is mafic. Magnesium shows positive correlation with Calcium which is because of the vicinity of $CaCO_3$ and $MgCO_3$ in

the samples. Na shows positive correlation with potassium showing the presence of marine salt origin. Potassium is negatively correlated with sand showing salt precipitation. Phosphorus, Zirconium and Iron shows good positive correlation.

Rb is available in clay fragments. Sr indicates positive correlation with Copper and Lead, Barium and Chromium additionally demonstrates positive correlation with Pb. There are no noteworthy correlations among a large portion of these metals, demonstrating they have diverse anthropogenic and natural sources. In most cases, however, there are no noteworthy correlations among the vast majority of these substantial metals, recommending that these metals are not connected with one another and their indistinguishable behavior transport in estuarine environment. Moreover, these metals may have distinctive anthropogenic and natural sources in sediments of the zone of study (Hoda et al. 2009).

Table 1.7 Correlation Matrix along the coastal stretch of Tuticorin Bay off Gulf of Mannar, SE coast of India

	Means	**Std.Dev.**	**Al**	**Si**	**Ti**	**Fe**	**Mn**	**Mg**	**Ca**	**Na**	**K**	**P**	**Rb**	**Sr**	**Ba**	**Zr**	**V**	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**Pb**	**Cd**	**TOC**	**$CaCO_3$**	**Sand**	**Silt**	**Clay**
Al	1.91	0.57	1.00																										
Si	27.35	2.00		1.00																									
Ti	0.28	0.04		**0.50**	1.0																								
Fe	2.04	0.78				1.00																							
Mn	0.04	0.01					1.00																						
Mg	0.77	0.04						1.00																					
Ca	12.45	3.50		**-0.63**		**-0.53**		**0.72**	1.00																				
Na	2.24	0.32								1.00																			
K	0.77	0.20								**0.74**	1.00																		
P	0.07	0.08				**0.57**						1.00																	
Rb	34.05	10.72								**0.54**	**0.52**	**-0.54**	1.00																
Sr	666.47	515.23												1.00															
Ba	504.71	95.14													1.00														
Zr	384.71	345.65				**0.83**				**-0.52**		**0.59**				1.00													
V	43.53	14.62		**0.75**					**-0.49**								1.00												
Cr	560.00	75.00																1.00											
Co	16.24	2.41				**0.70**										**0.48**			1.00										
Ni	44.94	14.18		**0.53**					**-0.49**											1.00									
Cu	181.98	17.00												**0.56**							1.00								
Zn	86.19	9.52																				1.00							
Pb	60.41	32.00												**0.72**	**0.54**			**0.58**					1.00						
Cd	0.20	0.04																						1.00					

TOC	1.25	0.87																	**0.50**						1.00				
$CaCO_3$	32.71	9.42	**-0.58**								**-0.48**									**0.54**						1.00			
Sand	79.40	20.17	**-0.68**								**-0.58**								**-0.49**							**0.77**	1.00		
Silt	9.90	16.08											**0.67**						**0.56**									1.00	
Clay	10.70	19.31	**0.64**																							**-0.74**	**-0.67**		1.00

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