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AN ECLECTIC POLLUTANTS ON THERMAL POWER PLANT ENVIRONS OF TUTICORIN COASTAL ZONE

S. VIGNESH

Department of Marine Science, Bharathidasan University, Tiruchirappalli - 620 024, Tamil Nadu, India.

Abstract

The presence of microbiological, heavy metal and physiochemical parameters and its relationship with each others, were studied at five different Thermal power plant influenced marine zones in Tuticorin during two different seasons. The Temperature, EC, TDS and salinity in monsoon and post monsoon ranged from 29 – 33 and 28 – 31; 29244 – 46842 and 30566 – 54128 µS/cm, 18424 – 29510 and 19257 – 34101 mg/kg and, 19 – 27 and 18 – 32 ppt, respectively. In both seasons, high counts of all bacterial parameters were noticed in Tuticorin Muthu Nagar Beach (S1) due to frequent public visit and dense human populations and illegal settlement activities while less count in Tuticorin saltpan area (S3) due to high saline in nature. The pollution index (PI) ratio were above 1 indicated that these sites were contaminated with human influences. The ranges of Cd, Cr, Cu, Fe, Ni, Pb and Zn metals in sea sediment samples at monsoon and post monsoon season were 0.13 – 0.28 and 0.1 – 0.25, 0.08 – 0.2 and 0.08 – 0.15, 0.15 – 0.58 and 0.11 – 0.38, 3268 – 7346 and 2614 – 5876, 0.09 – 0.18 and 0.08 – 0.23, 0.11 – 0.37 and 0.1 – 0.24, and 3.45 – 8.64 and 2.17 – 6.13 mg kg^{-1}, respectively. According to the results of pollution load index (PLI), the stations were slightly polluted with trace metals. Interestingly, high positive correlations were observed between each groups such as physiochemical, heavy metals and bacterial parameters. Mostly, the negative correlation was observed between physiochemcial and microbiological parameters except, PI. This results indicated that the microbiological parameters were unique and it may change themselves due to the environmental factors and those studied regions are affected by microbial pollution.

Keywords: Pollution index, Heavy metal pollution, Tuticorin coast, Thermal power plant, Sea sediment.

INTRODUCTION

Among the myriad of organic and inorganic substances released into aquatic ecosystems, heavy metals have received considerable attention due to their toxicity and potential bioaccumulation in many aquatic species (Blevins, 1985; Salah et al., 2012). In the marine environment toxic metals are potentially accumulated in sediments and marine organisms, and subsequently transferred to man through the food chain. Thus, it has become increasingly important to determine and assess levels of heavy metals in marine organisms because of nutritional and safety conditions, as well as their use as indicators of marine pollution and detection of point sources of pollutants (Sadiq et al., 1995; Vignesh et al., 2016). Rapid urbanization and industrialization led to increase in air pollution level of cities worldwide. The population of megalopolis cities, motor vehicles, motor fuel consumption increases and finally air pollution level increased (Ghose et al., 2004). Urban air pollution problems are aggravated by meteorological and topographical factors that often accumulate pollutants in the city and prevent proper dispersion and dilution.

Pathogen levels in the water and sediment can be estimated by measuring the pathogen indicator organism concentration. Pathogen indicator organisms, often called indicator organisms, refer to pathogen associated microorganisms, typically chosen for easier isolation and identification of contamination. The indicator organism (1) should be easily detectable using simple laboratory tests; (2) should not generally be present in unpolluted water; (3) should appear in concentrations that can be correlated with the extent of contamination; (4) should have a die-off rate that is not faster than the die-off rate for the pathogens of concern (U.S. Environmental Protection Agency, 2001). The presence of *Escherichia coli*, a more common microbial constituent used for water quality examination, indicates fecal contamination, since *E. coli* is the subset of fecal coliform. Fecal *Streptococci* are also often used as an indicator. Vignesh and his group (2014) investigated the potential risk of fecal contamination and other pathogens due to diffuse pollution on coastal bathing waters using indicator organisms. Indicator organisms are often used as a tool to identify the contaminant sources (Vignesh et al., 2015). Pathogen levels of surface water are sunlight sensitive and are related to many other factors including temperature, salinity, moisture, soil condition, water body condition, and encystations (U.S. Environmental Protection Agency, 2001).

The main objective of this study was to determine the levels of heavy metal and microbiological parameters in sea sediments from the Thermal power station environs of Tuticorin coastal zone. Moreover, the results have been compared with already existing guidelines and limits. The other purposes of the research are: (a) to evaluate the possible relationships among the metals and microorganisms in sea sediment from the study regions; (b) to determine inter-elemental / microbial relationships; (c) to study the possibility of using the indicator organisms for assessing diffuse pollution.

MATERIALS AND METHODS

STUDY AREA

Tuticorin (Thoothukudi) is a port city and an industrial city in the Indian state of Tamil Nadu. The city lies in the Coromandel Coast of Bay of Bengal and is located at 8.53°N 78.36°E. According to Confederation of Indian Industry, Thoothukudi has the second highest Human Development Index in Tamil Nadu next to Chennai. Tuticorin Port is one of the Fastest growing Major Ports in India. Tuticorin is an 'Emerging Energy and Industrial hub of South India'. The city is administered by a Thoothukudi Municipal Corporation covering an area of 353.07 km^2 (136.32 sq mi) and had a population of 237,830 in 2011. The urban agglomeration had a population of 410,760 as of 2011. The majority of the people of the city are employed in salt pans, sea-borne trading, fishing, and tourism. The 21 islands between Thoothukudi and Rameswaram shores in the Gulf of Mannar are noted as the first Marine Biosphere Reserve of India, and have around 36,000 species of flora and fauna. The city mostly has a flat terrain and roughly divided into two by the Buckle channel. Being in coastal region, the soil is mostly clay sandy and the water table varies between 1 and 4 m (3.3 and 13.1 ft) below ground level. The city has loose soil with thorny shrubs in the north and salt pans in the south. The city experiences tropical climatic conditions characterized with immensely hot summer, gentle winter and frequent rain showers (https://en.wikipedia.org/wiki/Thoothukudi).

Tuticorin Thermal Power Station (TTPS) is a power plant situated near new port of Thoothukudi in Tamil Nadu, India, on the sea shore of Bay of Bengal. It has 5 units with a total installed capacity of 1,050 MW and spread over 160 hectares (400 acres). All the unit are coal based. Coal is transported by sea through ship Coal transported by ship is given to crushers which crush the coal particles to 10-20mm dia. The crushed coal is fed to coal grinding mills with bowl roller via coal bunkers. The powdered coal is given to pulverized and to furnace through forced draft fans. There are four mills around the furnace as well as oil injecting nozzles from oil storage for tangential firing. The average coal consumption is around 5 million tonnes per annum. Raw water required for DM water production and use in boiler and for other use is tapped off from the 20 MGD water mains laid by TWAD Board from Thamirabarani river to Tuticorin Industrial complex. The requirement of raw water is 6000 KL per day (Tuticorin thermal power station report, 2017). The sampling locations are follows: Tuticorin Muthu Nagar Beach (S1), Tuticorin Roche Park Beach (S2), Tuticorin Saltpan (Very Near to Thermal plant) (S3), Tuticorin Rabbit Island Beach (S4) and Tuticorin Harbor Park Beach (S5) (Figure 1) (Table 1). The sampling locations were demarcated by using a geographical positioning system (GPS) (Garmin GPS 60).

SAMPLING

The sampling seasons are divided into four groups: post monsoon (January – February), summer (March - May), premonsoon (June - August), and monsoon (September - December) (Vignesh et al., 2014). The sediment samples from five different locations belonging to different eco-niches in Tuticorin coastal zone which is surrounded by Thermal power plant were collected during monsoon 2017 and post monsoon 2018. Physicochemical parameters i.e., Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity were measured using a field kit (EUTECH - PCSTestr 35 Multi Meter) at the each sampling site. Nearly, 250 g of sea surface sediment samples were collected (0–5 cm depth) with a sterile spatulum and stored in aseptic sterile containers. All samples were kept in iceboxes and processed within 15 h of collection (Vignesh et al., 2013).

ASSESSMENT OF HEAVY METALS

The marine sediment samples were shadow dried and homogenized using an agate mortar and pestle, and sieved using a 63 µm sieve. Then, one gram of sediment particles (> 63 µm in size) were added to 10 ml of 'aqua regia' (i.e. $HCl:HNO_3 = 3:1$) in Teflon PTFE vessels and treated with 100 °C for 24 h in a hot air oven. After incubation, the residue was dissolved with 20 ml of HNO_3 and filtered in a Millipore filtration unit with 0.45 µm Millipore filter paper. The final volume was made up with HNO_3 to 25 ml and the concentration of heavy metals were determined by atomic absorption spectrophotometry (GBC SenSAA - AAS, Australia) by a flame method. According to evaluate the degree of trace metal pollution in the study area, four different parameters were used such as Enrichment Factor (EF), Contamination Factor (CF), Pollution Load Index (PLI) and Geo-Accumulation Index (I_{geo}) (Salah et al., 2012; Vignesh et al., 2016).

BACTERIOLOGICAL ANALYSIS

The marine bacterial populations i.e. TVC - total viable count; TC – total coliforms; TS – total *Streptococci*; FC – fecal coliforms; FS – fecal *Streptococci*; VC – *Vibrio* count; SAC – *Salmonella* count; SHC – *Shigella* count; PC – *Pseudomonas* count and AC – *Aeromonas* count from sea sediment samples were studied by the pure culture technique (spread plating method) on selective agar plates such as nutrient agar, MacConkey agar, M Enterococcus agar, MFC agar, KF *Streptococcus agar*, TCBS agar, XLD agar, XLD agar, Cetrimide agar and *Aeromonas* isolation agar, respectively. Then, the plates were incubated at 37 ± 1°C for 24 to 48 h and all the trials were performed triplicate. The average final counts of colonies were noted. The Pollution Index (PI) was calculated by using of standard formula (Vignesh et al., 2012). The bacterial colonies were partially identified through Rapid Microbial Limit Test kits (Vignesh et al., 2015). The culture media were obtained from Hi-Media Pvt. Ltd., Bombay, India.

STATISTICAL ANALYSIS

Pearson correlation coefficient was employed for finding the relationship between the variables (trace metals, physiochemical, and bacteriological parameters) and the descriptive statistics was also performed by using the statistical package ORIGIN8.0 (Vignesh et al., 2014, 2015, 2016). Descriptive statistics is distinguished from inferential statistics and is used to summarize a sample, rather than use the data to learn about the population that the sample of data is thought to represent.

RESULTS AND DISCUSSION

The average mean value of pH was 7.98, 8.21, 8.89, 8.32 and 8.04 in S1, S2, S3, S4 and S5 in monsoon season respectively. The EC in sample was due to ionization of dissolved inorganic solids and became a measure of calculated TDS. The Temperature, EC, TDS and salinity in monsoon and post monsoon ranged from 29 – 33 and 28 – 31; 29244 – 46842 and 30566 – 54128 µS/cm, 18424 – 29510 and 19257 – 34101 mg/kg and, 19 – 27 and 18 – 32 ppt, respectively (Figure 2 and 3). The physiochemical parameters levels were highly fluctuating during both seasons and the monsoon is highly contaminated season than post monsoon due to heavy rain. The skewness and kurtosis level in Temperature, pH, EC, TDS and salinity in monsoon season were 0.00 and -1.20, 1.51 and 2.45, 1.70 and 3.10, 1.70 and 3.10 and 1.52 and 2.61, respectively (Table 2).

In sediment samples, the mean TVC ranged from 198.0 – 2210.0 [$\times 10^4$] g^{-1} during monsoon and 104.0 – 1240.0 [$\times 10^4$] g^{-1} during post monsoon (Figure 2 and 3). The microbiological parameters are high in monsoon season than post monsoon season. Because, the severe rain brought land materials and different waste materials to sea and local municipal waste/ fisher folks house hold waste directly mixed into sea without sort of any treatment. Mainly, the open defecation and septic tank waste are direct threat to the quality of seawater. Apart from that, the thermal power station coolant waste water may develop the resistance in the microorganisms especially *Enterobacteriaceae* family organisms. The extremophiles may develop due to the release of heat water into the coast.

In both seasons, high counts of all bacterial parameters were noticed in Tuticorin Muthu Nagar Beach (S1) due to frequent public visit and dense human populations and illegal settlement activities while less count in Tuticorin saltpan area (S3) due to high saline in nature. Similar observations were made by Vignesh and co-workers (2014) at Tamil Nadu beaches, Vignesh et al (2016) Pondicherry and Cuddalore, Nagvenkar and Ramaiah (2009) at Goa water, April Clark (2003) at Visakhapatnam water and Kumarasamy et al (2009) in the Cauvery estuary.

The TC, TS, FC, FS, VC, SAC, SHC, PC and AC in monsoon and post monsoon ranged from 31000 – 141000 and 17100 – 98000, 2130 – 16100 and 2210 – 10200; 1500 – 10200 and 1240 – 8800, 370 – 1210 and 240 – 950, 5700 – 10100 and 2810 – 8700, 170 – 640 and 120 – 440, 310 – 910 and 220 – 640, and 1170 – 4100 and 940 – 3100 CFU/g, respectively. The pollution index (PI) ratio were above 1 indicated that these sites were contaminated with human influences (Figure 2 and 3). Sewage contamination of aquatic habitats is detected by enumerating the coliform groups of bacteria (Fujioka, 2002). For instance, information on occurrence, abundance and distribution of potent human pathogens, *Vibrio cholerae* (causing cholera in humans), *Vibrio parahaemolyticus* (gastroenteritis), Salmonella and *Shigella* sp (typhoid fever; food poisoning), *Streptococcus* sp (meningitis and skin infections) and *Aeromonads* (septicaemic conditions) in aquatic ecosystems may prove useful in public health management.

The standard deviation, standard error, lower 95% CI of mean, upper 95% CI of mean, variance, skewness, kurtosis, uncorrected sum of squares, corrected sum of squares, coefficient of variation, mean absolute deviation, geometric mean, minimum value, median value and maximum value of FC and FS in post monsoon season were 4112 and 572, 2871.12 and 287.35, 1284.0 and 128.51, 547.16 and 215.22, 7676.84 and 928.78, 8243320.0 and 82570.0, 1.34 and 0.28, 2.21 and -1.49, 117516000.0 and 1966200.00, 32973300.0 and 330280.0, 0.70 and 0.50, 2030.40 and 226.40, 3379.40 and 510.35, 2.05 and 1.74, 1240 and 240, 3300 and 540, and 8800 and 950, respectively (Table 2). The ranges of Cd, Cr, Cu, Fe, Ni, Pb and Zn metals in sea sediment samples at monsoon and post monsoon season were 0.13 – 0.28 and 0.1 – 0.25, 0.08 – 0.2 and 0.08 – 0.15, 0.15 – 0.58 and 0.11 – 0.38, 3268 – 7346 and 2614 – 5876, 0.09 – 0.18 and 0.08 – 0.23, 0.11 – 0.37 and 0.1 – 0.24, and 3.45 – 8.64 and 2.17 – 6.13 mg kg^{-1}, respectively (Fig 2 and 3).

The standard deviation, standard error, lower 95% CI of mean, upper 95% CI of mean, variance, skewness, kurtosis, uncorrected sum of squares, corrected sum of squares, coefficient of variation, mean absolute deviation, geometric mean, minimum value, median value and maximum value of Cu in monsoon were 0.322, 0.16, 0.07, 0.12, 0.53, 0.03, 1.08, 1.22, 0.63, 0.11, 0.51, 0.12, 0.29, 1.66, 0.15, 0.27 and 0.58, respectively (Table 2). Shortness of breath, coughing, wheezing, septum, bronchitis, decreased pulmonary function, pneumonia, and other respiratory disorders have been observed from chronic exposure of chromium (Cr) (Mugica et al., 2002). Lead (Pb) can affect adversely to nervous system, the hemo group syntheses and the vascular system, especially to children (Mugica et al., 2002). Cadmium (Cd) is a possible carcinogen and its chronic exposition to high concentrations can result in respiratory illness.

Continuous and prolonged exposure to Nickel (Ni) may produce dermatitis and disorders to respiratory system. Zinc and iron deteriorates human metabolism. Iron is a potentially toxic element that acts as a catalyst in the development of the highly poisonous free oxygen radicals in living organisms (Hemminki et al., 1995).

According to the results of pollution load index (PLI), the stations were slightly polluted with trace metals. The variations in CF values are indicating that contamination with Cd in the sediment was highest in comparison with other metals. Similar to CF, the EF value denoted that among the trace metals, Cd were highly influenced in study area. Interestingly, the results of I_{geo} values revealed that a certain portion of metals originated from geological sources (Table 3a and b). Heavy metals are important potentially hazardous pollutants, and what makes them different from other pollutants is that they cannot be decomposed by microbial means. On the contrary, they can be enriched in the biologic body and become persistent pollutants, and harm human health through the food chain. Interestingly, high positive correlations were observed between each groups such as physiochemical, heavy metals and bacterial parameters. Mostly, the negative correlation was observed between physiochemcial and microbiological parameters except, PI (Table 4). Similar results were observed between heavy metal and microbiological parameters while positive correlation was observed between physiochemical and heavy metal parameters.

CONCLUSION

Analysis of sea sediment samples from the study area indicated signs of deterioration and the stations were poor microbiological quality as per the TNPCB (2000) standard. Thermal power plant environmental zones requires continuous monitoring, due to its waste, the normal microbes will become thermo-tolerable. Additional study should also focus on identifying the local sources (apart from point sources) of contamination and a determination of bacteria source tracking study. On the other hand, the heavy metal pollution was moderately affected the study area. Hence, this study also recommends the necessity of proper sanitation and waste disposal to sustain the coastal quality.

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FIGURE 1
SAMPLING SITES AT THERMAL POWER PLANT ENVIRONS IN TUTICORIN

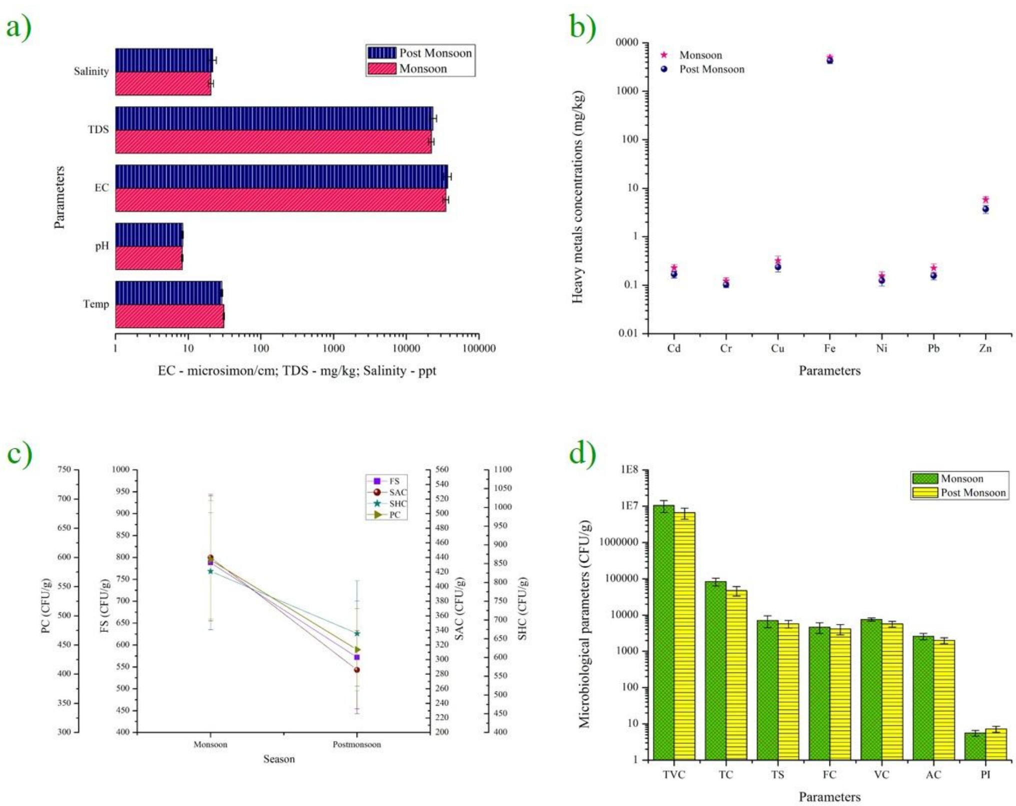

FIGURE 2
TEMPORAL VARIATIONS OF PHYSIOCHEMCIAL, HEAVY METAL AND MICROBIOLOGICAL PARAMETERS

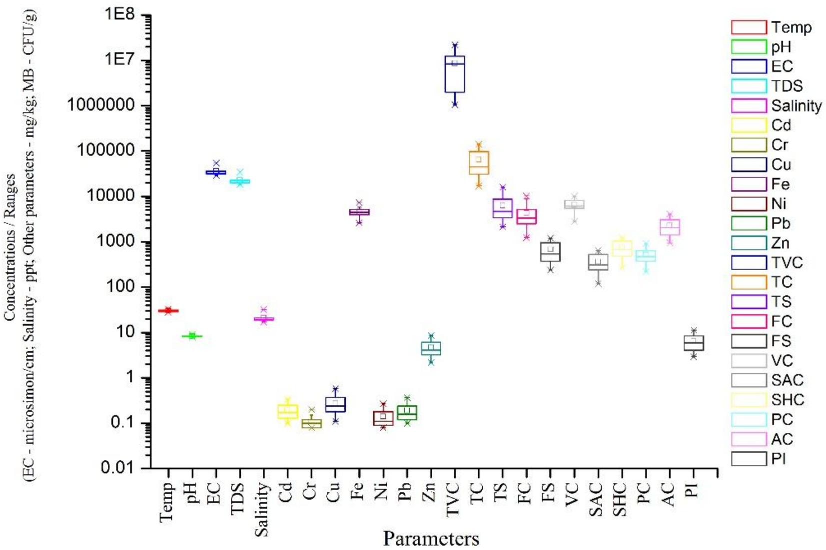

FIGURE 3
BOX-WHISKER PLOT SHOWING VARIATION OF PHYSIOCHEMCIAL, HEAVY METAL AND MICROBIOLOGICAL PARAMETERS

TABLE 1
DETAILS OF THE STUDY AREA

S. No	Sampling Station	Sampling Code	Latitude	Longitude	Source of Pollution
1	Tuticorin Muthu Nagar Beach	S1	8˚48'26.61 N	78˚09'46.56 E	Regular public visit / Human and animal waste / Recreational area / Fishing activity
2	Tuticorin Roche Park Beach	S2	8˚47'07.66 N	78˚09'42.15 E	Regular public visit / Human and animal waste / Recreational area
3	Tuticorin Saltpan (Near Thermal plant)	S3	8˚46'15.35 N	78˚10'11.92 E	Canal confluenicng to sea (Points source) / Saltpan area
4	Tuticorin Rabbit Island Beach	S4	8˚47'07.93 N	78˚11'57.27 E	Rare public visit / Human and animal waste
5	Tuticorin Harbor Park Beach	S5	8˚44'35.93 N	78˚10'14.18 E	Regular Public visit / Human and animal waste / Recreational area

TABLE 2

DESCRIPTIVE STATISTICS FOR PHYSIOCHEMCIAL, HEAVY METAL AND MICROBIOLOGICAL PARAMETERS AT MONSOON AND POST MONSOON SEASONS OF TUTICORIN SEA SEDIMENT

Parameters	Mean	SD	SE	L 95% M	U 95% M	Var	Ske	Kur	USS	CSS	CV	MAD	GM	GSD	Mini	Med	Max
Monsoon																	
Temp	31	1.58	0.71	29.04	32.96	2.50	0.00	-1.20	4815.00	10.00	0.05	1.20	30.97	1.05	29	31	33
pH	8.288	0.36	0.16	7.84	8.74	0.13	1.51	2.43	343.98	0.53	0.04	0.25	8.28	1.04	7.98	8.21	8.89
EC	35130.8	6904.84	3087.94	26557.61	43703.99	47676800.00	1.70	3.10	6361570000.00	190707000.00	0.20	4803.36	34644.97	1.20	29244	32264	46842
TDS	22132.404	4350.05	1945.40	16731.30	27533.51	18922900.00	1.70	3.10	2524910000.00	75691700.00	0.20	3026.12	21826.33	1.20	18423.72	20326.32	29510.46
Salinity	20.6	3.85	1.72	15.82	25.38	14.80	1.52	2.61	2181.00	59.20	0.19	2.72	20.34	1.19	17	19	27
Cd	0.228	0.08	0.04	0.12	0.33	0.01	0.29	-1.29	0.29	0.03	0.37	0.07	0.22	1.47	0.13	0.22	0.34
Cr	0.122	0.05	0.02	0.06	0.18	0.00	1.66	3.23	0.08	0.01	0.38	0.03	0.12	1.40	0.08	0.11	0.2
Cu	0.322	0.16	0.07	0.12	0.53	0.03	1.08	1.22	0.63	0.11	0.51	0.12	0.29	1.66	0.15	0.27	0.58
Fe	4986.40	1491.06	666.82	3135.07	6837.73	2223250.00	0.99	2.06	133214000.00	8893020.00	0.30	1006.08	4818.13	1.34	3268.00	4712.00	7346.00
Ni	0.156	0.07	0.03	0.07	0.25	0.01	1.10	0.72	0.14	0.02	0.47	0.06	0.14	1.56	0.09	0.14	0.27
Pb	0.226	0.11	0.05	0.09	0.36	0.01	0.52	-1.99	0.30	0.05	0.48	0.09	0.21	1.64	0.11	0.18	0.37
Zn	5.796	1.99	0.89	3.33	8.26	3.94	0.54	-0.17	183.74	15.78	0.34	1.54	5.53	1.42	3.45	5.12	8.64
TVC	1.05E+07	8559680.00	3828010.00	-87874.67	21167900.00	73268200000000.00	0.33	-1.52	848531000000000.00	293073000000000.00	0.81	6632000.00	7117800.00	2.98	1.98E+06	1.09E+07	2.21E+07
TC	83400	44992.22	20121.13	27536.76	139263.24	2024300000.00	0.00	-1.63	42875000000.00	8097200000.00	0.54	36320.00	72231.05	1.88	31000	98000	141000
TS	7006	5649.48	2526.53	-8.51	14020.51	31916700.00	1.34	1.34	373087000.00	127667000.00	0.81	4315.20	5440.77	2.21	2130	4700	16100
FC	4622	3399.47	1520.29	401.15	8842.85	11556400.00	1.41	2.14	153040000.00	46225700.00	0.74	2422.40	3752.70	2.06	1500	3800	10200
FS	788	341.57	152.75	363.90	1212.10	116670.00	-0.10	-1.68	3571400.00	466680.00	0.43	274.40	722.01	1.63	370	860	1210
VC	7580	1739.83	778.07	5419.80	9740.20	3027000.00	0.54	-0.29	299390000.00	12108000.00	0.23	1304.00	7423.92	1.26	5700	7800	10100
SAC	440	193.65	86.60	199.56	680.44	37500.00	-0.68	-1.41	1118000.00	150000.00	0.44	160.00	396.76	1.73	170	530	640
SHC	830	348.86	156.01	396.85	1263.15	121700.00	-0.40	-0.46	3931300.00	486800.00	0.42	260.00	758.77	1.66	340	840	1240
PC	596	227.22	101.62	313.88	878.12	51630.00	0.20	-0.12	1982600.00	206520.00	0.38	168.80	559.26	1.51	310	620	910
AC	2616	1185.76	530.29	1143.74	4088.26	1406030.00	0.03	-1.61	39841400.00	5624120.00	0.45	916.80	2379.06	1.66	1170	2640	4100
PI	5.58284	2.27	1.02	2.76	8.40	5.16	0.20	-1.89	176.50	20.66	0.41	1.83	5.20	1.54	2.9186	5.20408	8.42975
Post Monsoon																	
Temp	29.2	1.30	0.58	27.58	30.82	1.70	0.54	-1.49	4270.00	6.80	0.04	1.04	29.18	1.05	28	29	31

pH	8.39	0.41	0.18	7.88	8.90	0.17	1.99	4.10	352.64	0.68	0.05	0.29	8.38	1.05	8.1	8.23	9.11
EC	37101.6	9760.47	4365.01	24982.81	49220.39	95266800.00	1.98	3.99	7263710000.00	381067000.00	0.26	6810.56	36235.05	1.26	30566	32674	54128
TDS	23374.01	6149.10	2749.96	15739.17	31008.85	37811400.00	1.98	3.99	2882970000.00	151246000.00	0.26	4290.65	22828.08	1.26	19256.58	20584.62	34100.64
Salinity	21.8	5.81	2.60	14.59	29.01	33.70	2.05	4.28	2511.00	134.80	0.27	4.08	21.28	1.26	18	19	32
Cd	0.168	0.06	0.03	0.09	0.25	0.00	0.35	-1.74	0.16	0.02	0.37	0.05	0.16	1.46	0.1	0.16	0.25
Cr	0.102	0.03	0.01	0.07	0.14	0.00	1.58	2.74	0.06	0.00	0.28	0.02	0.10	1.29	0.08	0.1	0.15
Cu	0.236	0.11	0.05	0.10	0.37	0.01	0.39	-1.31	0.33	0.05	0.46	0.09	0.22	1.63	0.11	0.2	0.38
Fe	4279.20	1188.23	531.39	2803.86	5754.54	1411900.00	-0.12	0.93	97205400.00	5647600.00	0.28	828.64	4137.51	1.35	2614.00	4168.00	5876.00
Ni	0.124	0.06	0.03	0.05	0.20	0.00	1.79	3.40	0.09	0.02	0.50	0.04	0.11	1.54	0.08	0.11	0.23
Pb	0.156	0.06	0.03	0.08	0.23	0.00	0.76	-1.84	0.14	0.01	0.39	0.05	0.15	1.46	0.1	0.12	0.24
Zn	3.702	1.53	0.68	1.80	5.60	2.34	1.17	1.34	77.88	9.36	0.41	1.14	3.47	1.48	2.17	3.24	6.13
TVC	6.62E+06	4947450.00	2212570.00	481145.32	12766900.00	24477300000000.00	-0.21	-2.45	317296000000000.00	97909100000000.00	0.75	4131200.00	4533190.00	3.01	1.04E+06	8.40E+06	1.24E+07
TC	47220	31051.44	13886.63	8665.91	85774.09	964192000.00	1.37	2.15	15005400000.00	3856770000.00	0.66	22224.00	40019.73	1.91	17100	38000	98000
TS	5722	3003.23	1343.09	1993.12	9450.88	9019420.00	0.66	0.64	199784000.00	36077700.00	0.52	2182.40	5068.14	1.77	2210	5400	10200
FC	4112	2871.12	1284.00	547.16	7676.84	8243320.00	1.34	2.21	117516000.00	32973300.00	0.70	2030.40	3379.40	2.05	1240	3300	8800
FS	572	287.35	128.51	215.22	928.78	82570.00	0.28	-1.49	1966200.00	330280.00	0.50	226.40	510.35	1.74	240	540	950
VC	5662	2213.31	989.82	2913.92	8410.08	4898720.00	0.18	0.01	179886000.00	19594900.00	0.39	1630.40	5290.35	1.53	2810	5500	8700
SAC	286	119.92	53.63	137.11	434.89	14380.00	-0.18	0.12	466500.00	57520.00	0.42	87.20	262.31	1.64	120	280	440
SHC	664	313.42	140.16	274.86	1053.14	98230.00	0.01	-1.67	2597400.00	392920.00	0.47	248.80	597.33	1.72	270	620	1040
PC	442	157.38	70.38	246.59	637.41	24770.00	-0.34	0.18	1075900.00	99080.00	0.36	117.60	416.19	1.50	220	470	640
AC	1996	850.08	380.17	940.53	3051.47	722630.00	0.04	-1.08	22810600.00	2890520.00	0.43	656.80	1837.33	1.60	940	2080	3100
PI	7.196	3.12	1.40	3.32	11.07	9.74	0.27	-0.97	297.89	38.97	0.43	2.48	6.62	1.60	3.35	6.11	11.33

SD - standard deviation; SE - standard error, L 95% M - lower 95% CI of mean; U 95% M - upper 95% CI of mean; Var – variance; Ske – skewness; Kur – kurtosis; USS - uncorrected sum of squares; CSS - corrected sum of squares; CV - coefficient of variation; MAD - mean absolute deviation; GM - geometric mean; Mini - minimum value; Med - median value; Max - maximum value.

TABLE 3A.
THE DEGREE OF TRACE METAL CONTAMINATIONS IN SEDIMENT SAMPLES OF THERMAL POWER PLANT ENVIRONS AT TUTICORIN COASTAL ZONE

S.S	EF value						I_{geo} value							CF value							PLI
	Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Cd	Cr	Cu	Fe	Ni	Pb	Zn	
Monsoon																					
S1	8.57	0.01	0.08	0.02	0.14	0.66	0.00	0.00	-7.51	-3.78	0.00	-6.60	-4.39	0.93	0.00	0.01	0.11	0.00	0.02	0.07	0.039
S2	5.68	0.01	0.06	0.02	0.09	0.54	-1.40	0.00	-7.97	-3.91	0.00	-7.38	-4.80	0.57	0.00	0.01	0.10	0.00	0.01	0.05	0.035
S3	7.28	0.01	0.08	0.03	0.12	0.58	0.00	0.00	-6.86	-3.27	0.00	0.00	-4.04	1.13	0.00	0.01	0.16	0.00	0.02	0.09	0.030
S4	6.26	0.01	0.05	0.02	0.08	0.52	0.00	0.00	-8.81	-4.44	0.00	0.00	-5.37	0.43	0.00	0.00	0.07	0.00	0.01	0.04	0.025
S5	7.75	0.01	0.06	0.01	0.08	0.55	-1.03	-10.26	-8.14	-3.99	0.00	-7.55	-4.84	0.73	0.00	0.01	0.09	0.00	0.01	0.05	0.020
Post Monsoon																					
S1	6.95	0.01	0.07	0.02	0.10	0.43	0.00	0.00	-7.77	-3.90	0.00	-7.23	-5.11	0.70	0.00	0.01	0.10	0.00	0.01	0.04	0.011
S2	4.53	0.01	0.05	0.02	0.07	0.39	-1.91	0.00	-8.40	-4.09	0.00	-7.97	-5.46	0.40	0.00	0.00	0.09	0.00	0.01	0.03	0.006
S3	6.69	0.01	0.07	0.03	0.10	0.52	0.00	0.00	-7.47	-3.59	0.00	0.00	-4.54	0.83	0.00	0.01	0.12	0.00	0.01	0.06	0.001
S4	6.02	0.02	0.04	0.02	0.09	0.41	0.00	0.00	-9.26	-4.76	0.00	0.00	-6.04	0.33	0.00	0.00	0.06	0.00	0.01	0.02	-0.004
S5	6.32	0.01	0.05	0.01	0.07	0.36	-1.49	-10.40	-8.55	-4.15	0.00	-7.97	-5.64	0.53	0.00	0.00	0.08	0.00	0.01	0.03	-0.009

S.S – Sampling stations; EF value – Enrichment factor value; I_{geo} value – Geo-accumulation indices value; CF value – Contamination factor value; PLI – Pollution loading index

TABLE 3B
DIFFERENT CLASSIFICATION FOR FINDING THE CONTAMINATION LEVEL OF TRACE METALS IN SEDIMENTS

S.No	Categories	Prescribed levels	Class / Division	Quality level
1.	**Geo-accumulation index (I_{geo})**	≤ 0	0	Unpolluted
		0 – 1	1	From unpolluted to moderately polluted
		1 – 2	2	Moderately polluted
		2 – 3	3	From moderate to strongly polluted
		3 – 4	4	Strongly polluted
		4 – 5	5	From strongly to extremely polluted
		> 6	6	Extremely polluted
2.	**Enrichment factor (EF)**	EF < 2	--	Deficiency to minimal enrichment
		2 ≤ EF < 5	--	Moderate enrichment
		5 ≤ EF < 20	--	Significant enrichment
		20 ≤ EF < 40	--	Very high enrichment
		EF ≥ 40	--	Extremely high enrichment
3.	**Contamination factor (CF)**	CF < 1	--	Low contamination
		1 ≤ CF < 3	--	Moderate contamination
		3 ≤ CF < 6	--	Considerable contamination
		CF > 6	--	Very high contamination
4.	**Pollution load index (PLI)**	< 1	--	Baseline pollution
		> 1	--	Polluted

TABLE 4
CORRELATION COEFFICIENT MATRIX IN TUTICORIN SEA SEDIMENT

	Temp	pH	EC	TDS	Salinity	Cd	Cr	Cu	Fe	Ni	Pb	Zn	TVC	TC	TS	FC	FS	VC	SAC	SHC	PC	AC	PI
Temp	1.00	**-0.44**	**-0.24**	**-0.24**	**-0.22**	**0.13**	**-0.13**	0.00	**-0.11**	**-0.03**	0.20	0.20	0.60	0.75	0.61	0.55	0.61	0.61	0.73	0.56	0.69	0.63	**-0.10**
		0.20	*0.50*	*0.50*	*0.55*	*0.71*	*0.73*	*1.00*	*0.76*	*0.93*	*0.58*	*0.57*	*0.07*	*0.01*	*0.06*	*0.10*	*0.06*	*0.06*	*0.02*	*0.09*	*0.03*	*0.05*	*0.79*
pH		1.00	0.90	0.90	0.89	0.50	0.73	0.62	0.65	0.76	0.48	0.51	**-0.64**	**-0.62**	**-0.58**	**-0.57**	**-0.70**	**-0.67**	**-0.76**	**-0.75**	**-0.75**	**-0.71**	0.40
			0.00	*0.00*	*0.00*	*0.14*	*0.02*	*0.06*	*0.04*	*0.01*	*0.16*	*0.13*	*0.05*	*0.05*	*0.08*	*0.09*	*0.02*	*0.03*	*0.01*	*0.01*	*0.01*	*0.02*	*0.25*
EC			1.00	1.00	1.00	0.68	0.81	0.76	0.78	0.87	0.68	0.68	**-0.36**	**-0.36**	**-0.30**	**-0.30**	**-0.46**	**-0.48**	**-0.53**	**-0.55**	**-0.52**	**-0.47**	0.47
				0.00	*0.00*	*0.03*	*0.00*	*0.01*	*0.01*	*0.00*	*0.03*	*0.03*	*0.30*	*0.31*	*0.40*	*0.40*	*0.18*	*0.16*	*0.11*	*0.10*	*0.12*	*0.17*	*0.17*
TDS				1.00	1.00	0.68	0.81	0.76	0.78	0.87	0.68	0.68	**-0.36**	**-0.36**	**-0.30**	**-0.30**	**-0.46**	**-0.48**	**-0.53**	**-0.55**	**-0.52**	**-0.47**	0.47
					0.00	*0.03*	*0.00*	*0.01*	*0.01*	*0.00*	*0.03*	*0.03*	*0.30*	*0.31*	*0.40*	*0.40*	*0.18*	*0.16*	*0.11*	*0.10*	*0.12*	*0.17*	*0.17*
Salinity					1.00	0.67	0.80	0.74	0.76	0.86	0.67	0.67	**-0.36**	**-0.36**	**-0.30**	**-0.30**	**-0.46**	**-0.49**	**-0.52**	**-0.56**	**-0.51**	**-0.47**	0.47
						0.03	*0.01*	*0.01*	*0.01*	*0.00*	*0.04*	*0.03*	*0.31*	*0.31*	*0.41*	*0.39*	*0.18*	*0.15*	*0.12*	*0.10*	*0.13*	*0.17*	*0.17*
Cd						1.00	0.91	0.95	0.92	0.84	0.96	0.95	0.15	0.20	0.12	0.12	0.07	0.16	0.02	**-0.10**	0.05	0.03	0.20
							0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.68*	*0.58*	*0.74*	*0.74*	*0.84*	*0.67*	*0.97*	*0.79*	*0.89*	*0.93*	*0.59*
Cr							1.00	0.94	0.93	0.91	0.88	0.90	**-0.22**	**-0.19**	**-0.24**	**-0.26**	**-0.30**	**-0.21**	**-0.35**	**-0.46**	**-0.33**	**-0.34**	0.08
								0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.55*	*0.60*	*0.50*	*0.46*	*0.39*	*0.55*	*0.32*	*0.19*	*0.35*	*0.34*	*0.83*
Cu								1.00	0.98	0.93	0.97	0.95	0.04	0.06	0.04	0.03	-0.03	0.06	**-0.12**	**-0.17**	**-0.08**	**-0.07**	0.20
									0.00	*0.00*	*0.00*	*0.00*	*0.92*	*0.86*	*0.92*	*0.93*	*0.94*	*0.87*	*0.74*	*0.64*	*0.82*	*0.86*	*0.58*
Fe									1.00	0.91	0.91	0.93	0.02	0.02	**-0.03**	**-0.04**	**-0.05**	**0.00**	**-0.15**	**-0.19**	**-0.13**	**-0.09**	0.22
										0.00	*0.00*	*0.00*	*0.95*	*0.97*	*0.93*	*0.91*	*0.89*	*1.00*	*0.68*	*0.59*	*0.72*	*0.80*	*0.55*
Ni										1.00	0.90	0.91	**-0.14**	**-0.13**	**-0.09**	**-0.14**	**-0.22**	**-0.17**	**-0.30**	**-0.34**	**-0.26**	**-0.24**	0.32
											0.00	*0.00*	*0.71*	*0.72*	*0.81*	*0.70*	*0.54*	*0.63*	*0.40*	*0.34*	*0.46*	*0.50*	*0.37*
Pb											1.00	0.96	0.18	0.21	0.21	0.18	0.10	0.18	0.02	**-0.05**	0.08	0.07	0.21
												0.00	*0.62*	*0.56*	*0.56*	*0.62*	*0.79*	*0.61*	*0.96*	*0.89*	*0.83*	*0.85*	*0.56*
Zn												1.00	0.13	0.19	0.09	0.04	0.07	0.15	0.03	**-0.08**	0.04	0.03	0.14
													0.71	*0.59*	*0.81*	*0.90*	*0.84*	*0.69*	*0.93*	*0.82*	*0.91*	*0.93*	*0.70*
TVC													1.00	0.94	0.93	0.89	0.96	0.90	0.93	0.93	0.96	0.98	0.09
														0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.80*
TC														1.00	0.87	0.88	0.97	0.95	0.97	0.92	0.97	0.96	0.03
															0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.93*
TS															1.00	0.97	0.89	0.84	0.82	0.89	0.92	0.92	0.26
																0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.47*
FC																1.00	0.89	0.87	0.80	0.89	0.89	0.90	0.28
																	0.00	*0.00*	*0.01*	*0.00*	*0.00*	*0.00*	*0.43*
FS																	1.00	0.96	0.97	0.98	0.98	0.99	0.03

	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.94*
VC	1.00	0.93	0.93	0.95	0.94	**-0.07**
		0.00	*0.00*	*0.00*	*0.00*	*0.86*
SAC		1.00	0.94	0.97	0.96	**-0.10**
			0.00	*0.00*	*0.00*	*0.79*
SHC			1.00	0.96	0.98	0.06
				0.00	*0.00*	*0.88*
PC				1.00	0.98	0.01
					0.00	*0.99*
AC					1.00	0.06
						0.86
PI						1.00

High positive correlation level is > 0.60; Significant levels are given by Italic forms; Negative correlation value shown in bold form