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Application of Magnetic Susceptibility in Source Identification of Heavy Metal Pollution in Sediments of Chennai Coast, Tamilnadu Using Multivariate Statistical Analysis

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Abstract: In the present work, magnetic susceptibility and concentration of heavy metals has been determined for sediments from Pulicat Lake to Vadanemmili coastal area, Tamilnadu, India. A magnetic susceptibility (χLF, χHF, χFD) measurement was carried using dual frequency susceptibility meter and Concentration of Mg, Al, K, Ca Ti, Fe, V, Cr, Mn, Co, Ni, Zn were also determined using energy dispersive X-ray fluorescence spectrometer (EDXRF) in order to establish their presence in these sediments and their possible linkage with magnetic enhancement. The relationship between magnetic susceptibility with the heavy metal concentrations were investigated by Pearson correlation analysis. Additionally, the factor and cluster analysis were performed for magnetic susceptibility with the heavy metal concentrations to identify the sources of heavy metal pollution in sediments using multivariate statistical analysis.

Keywords: Sediment, Magnetic susceptibility, Heavy metals, EDXRF, Statistical analysis.

1 Introduction

Magnetic susceptibility (also called susceptibility) is a measure of degree of magnetization of a material in response to an applied magnetic field. It is positive for a paramagnetic or ferromagnetic and negative for diamagnetic materials. This measurement is non-destructive and cost effective method for determining presence of magnetic minerals within the sediments. The use of magnetic measurements as a proxy for chemical methods is possible because pollutants and magnetic particles are genetically related [1]. Measurement of magnetic susceptibility of coastal sediments are reflecting magnetic enhancement of sediments due to the atmospherically deposited magnetic particles of natural and industrial origin. Many researchers reported that magnetic susceptibility measurements are very useful in investigating industrial discharges and exhaust gasses in urban regions. It appears that atmospheric deposition is one of the major sources of contamination in coastal and marine sediments [2-6].

The term heavy metal generally refers to any chemical element that has a relatively high density and which is toxic at low concentrations [7]. Heavy metals such as Al, Cd, Cr, Cu, Fe, Ni, Pb, Zn, etc., are natural components of the Earth's crust. Heavy metals in the sediments cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air in the form of chemicals, food additives, pesticides, industrial wastes and the list goes on. Interestingly, small amount of heavy metals (e.g. copper, selenium and zinc) are essential to maintain the metabolism of the human body. Contaminated sediment is a significant environmental problem affecting coastal environments throughout the country. Coastal sediments are important carriers of trace metals in the hydrological cycle, because metals are partitioned with the surrounding waters, reflecting the quality of an aquatic system [8]. Heavy metals in the environment arise from both lithogenic and anthropogenic sources.

Nowadays, large quantities of industrial wastewater and domestic wastewater drain directly into the tidal regions. This makes tidal zone areas to face a tremendous environmental pressure to act as a natural purifier and storage of pollutants, especially in coastal estuaries on both

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sides of tidal regions with a more serious situation. Heavy metal content of tidal region sediments reflects the real situation of a region's environment. The amount of heavy metals in sediments also depends upon the sediment characteristics, particularly, the type and quantities of organic matter, grain size, cation exchange capacity and mineral constituents [9].

Coastal sediments are considered as intensely important component for the assessment of marine environmental pollution since they act as a sink for many materials transported from Earth crust. Most of these heavy metals are sources of toxicity to the environments [10]. Since heavy metals can have the ability to get adsorbed in to the mineral surface, sediments have high metal concentration [11].

Hence, the main objectives of the present study is (i) to find the magnetic susceptibility and heavy metal concentration in coastal sediments, (ii) to determine the relationship between magnetic susceptibility and heavy metal concentration in coastal sediments (iii) to identify the heavy metal source in sediments collected from Pulicat Lake to Vadanemmili coastal area, Tamilnadu.

2 Study Areas

The study area, which spans from Pulicat Lake to Vadanemmeli of Chennai Coast, Tamilnadu, India is located in one of the most populated regions of southeastern, India. The area is dominated by intensive industrial activities in which the discharge of their effluents into the river has been going on for a long time. This coast is a very important environmental, economical, commercial, agricultural and recreational location in southeastern India.

This study was conducted to investigate the impacts of rapid economic development along the East Coast of Tamilnadu on heavy metal contamination and to assess their potential ecological risk.

3 Materials and Methods

3.1 Sample Collection and Preparation

Sediment samples are collected from Pulicat Lake to Vadanemmili coastal area, Tamilnadu using a Peterson grab samples from a distance of 10m parallel to the shoreline during the pre-monsoon period. Fig 1 shows the sample collected location in the study area and Table 1

Table 1 : The geographical latitude and longitude for the sampling location, Pulicat Lake to Vadanemmili coastal area, Tamilnadu.

S. No	Location	Sample ID	Latitude	Longitude
1	Pulicat Lake	CPL	13°34'3.82"N	80°18'0.75"E
2	Pulicat (Koonangkuppam)	CPK	13°25'31.42"N	80°21'26.12"E
3	Kattupalli	CKP	13°19'27.33"N	80°22'51.77"E
4	Power Station	CPS	13°15'35.37"N	80°22'21.94"E
5	Nettukuppam	CNK	13°14'10.50"N	80°21'53.23"E
6	Ennore	CEE	13°12'41.88"N	80°21'18.71"E
7	Tiruchinnakuppam	CTK	13° 9'36.02"N	80°20'32.34"E
8	Chennai Harbor (Nagooranthottam)	CCH	13° 8'20.61"N	80°20'8.02"E
9	Chennai Port (KasimeduFishing Harbour)	CPT	13° 6'5.45"N	80°19'44.78"E
10	Kasimedu-Tondiarpet	CKU	13° 7'14.61"N	80°19'44.04"E
11	Neppiar Bridge	CNB	13° 4'17.77"N	80°19'34.47"E
12	Marina Beach	CMB	13° 2'34.23"N	80°18'20.02"E
13	Broken Beach (Adaiyaralamaram)	CBB	13° 0'54.40"N	80°18'21.48"E
14	Besent Nagar	CBN	13° 0'8.21"N	80°18'17.37"E
15	Thiruvanmiyur	CTR	12°59'8.39"N	80°18'0.98"E
16	Neelankarai	CNI	12°57'2.18"N	80°17'29.61"E
17	Chennai Golden Beach	CCG	12°55'3.90"N	80°17'16.44"E
18	Panaiyur	CPR	12°53'2.32"N	80°17'4.18"E
19	Kanathursunami, (Reddykuppam)	CKI	12°50'12.66"N	80°16'34.01"E
20	Muttukaadu (Karikattukuppam)	CMK	12°48'36.74"N	80°16'40.72"E
21	Kovalam Beach	CKB	12°47'24.36"N	80°16'48.33"E
22	Vadanemmeli, (Puthiyakalpakkam)	CVM	12°44'59.05"N	80°16'39.20"E

gives the geographical information of sampling locations. A top sediment layer was scooped with an acid washed plastic spatula and 25 cm thick sub-surface samples from the sea bed were collected. The collected samples were immediately transferred to polythene bags and refrigerated at 4ºC until analysis. The samples were air-dried and larger stone fragments or shells were removed by hand picking. The samples were sub-sampled using the coning and quartering method [12].

The samples were oven dried at 105ºC for 2 hours to a constant weight and sieved using a 63µm sieve in order to identify the heavy metal concentration. The grain size of<63µm, presents several advantages:(1) heavy metals are mainly linked to silt and clay; (2) this grain size is like that of the suspended matter in water; and (3) it has been used in many studies on heavy metal contamination. The samples were then grinded to a fine powder using an agate mortar. All powder samples were stored in desiccators until they were analyzed. One gram of the fine grinded sample and 0.5 g of boric acid (H_3BO_3) were mixed. The mixture was thoroughly ground and pressed into a pellet of 25mm diameter using a hydraulic press (20 tons) [13].

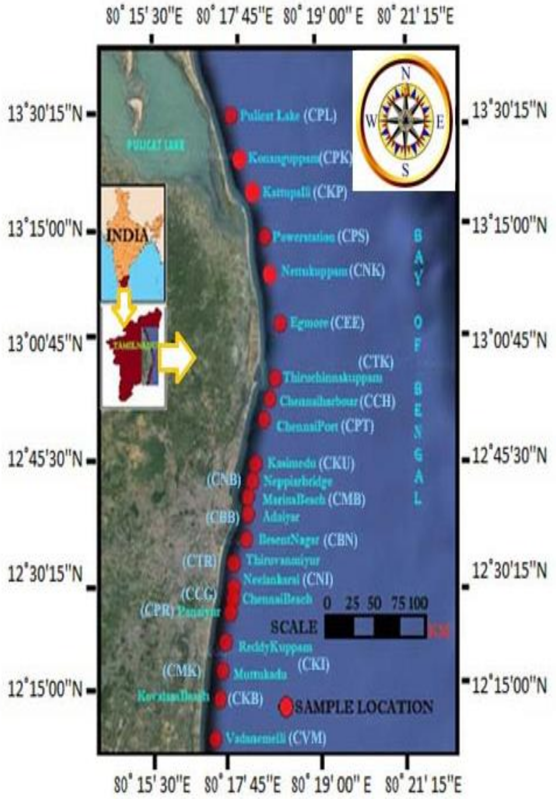

Fig. 1: Sampling locations of Pulicat Lake to Vadnemmelli coastal area Tamilnadu.

3.2 Heavy Metals by EDXRF Technique

The pellets were analyzed using the EDXRF spectrometer available at Environment and Safety Division, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, Tamilnadu. This spectrometer is fitted with a side window X-ray tube (370W) that has Rhodium as anode. The power specifications of the tube are 3-60kV and; 10-5833µA. Selection of filters, tube voltage, sample position and current are fully computer controlled and having an energy resolution of 136eV ± 5eV Mn customizable. The 25mm silicon drift detector (SDD) and 10-sample turret enables the instrument to position and analyze 10 samples concurrently. Quantitative analysis was conducted with the help of in-built nEXT software. National Institute of Standards and Technology has provided soil Standard Reference Materials certified for element content (NIST, 2010): SRM 2709a San Joaquin Soil (Baseline Trace Element Concentrations). This standard has been used worldwide for quality assurance by a variety of laboratories involved in the determination of major, minor, and trace element content of soils and similar materials. This standard was very useful in non-destructive multi-element techniques, instrumental neutron activation analysis (INAA) and X-ray fluorescence spectrometry (XRF), both of which are well suited for analysis of silicate matrix materials (soil, sediments and sands). This original SRM 2709a soil standard is certified and provides information values for approximately 50 elements (NIST, 2010). Fig 2 shows the typical EDXRF spectrum for sediment (CPL) sample. Hence, a standard sail [14] was used as reference material for standardizing the instrument and obtained results are a given in Table 2.

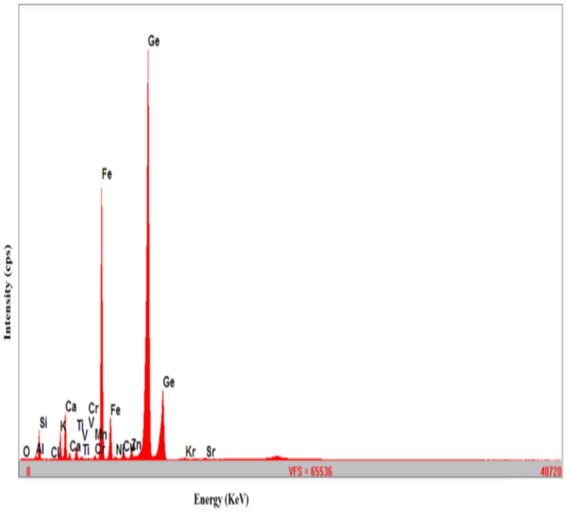

Fig.2: A typical EDXRF spectrum for sediment (CPL) sample.

Table 2: Results of soil standard - 2709a using EDXRF (in mg kg^{-1}).

Element	Certified Values	EDXRF Values
Mg	14600	14900
Al	72100	68400
K	20500	19100
Ca	19100	16500
Ti	3400	3100
Fe	33600	33900
V	110	98.8
Cr	130	112.1
Mn	529	568.2
Co	12.8	12.8
Ni	83	69.3
Zn	107	127.9

3.3 Magnetic Susceptibility (χ) Measurements

In the laboratory, the samples were air dried at room temperature to reduce mass contribution of water and to avoid any chemical reactions. They were then sieved using a 1 mm sieve mesh [15] to remove particles such as glass, plant debris, refuse and small stones. The sieved samples were stored in a plastic container for further laboratory measurements. The magnetic susceptibility measurements were then carried out on the sieved samples packaged in a 10 ml plastic container at laboratory temperature. Measurements of magnetic susceptibility were made at both low (0.465 kHz) and high (4.65 kHz) frequencies using MS2B dual frequency susceptibility meter linked to a computer operated using a Multisus2 software. All measurements were conducted at the 1.0 sensitivity setting. Each sample was measured five times in two different frequencies (low and high) and an average is calculated.

For natural samples which generally exhibit a continuous and nearly constant grain size distribution, can be used as a proxy for relative changes in concentration in pedogenic fined – grained magnetic particles [16]. Hence frequency dependent susceptibility (χfd) was calculated from the expression [17].

$$\chi_{fd}(\%) = \left[\frac{(\chi_{lf}-\chi_{hf})}{\chi_{lf}}\right] \times 100 \text{ --------------- } (1)$$

3.4 Multivariate Statistical Analysis

Statistical analyses (Cluster and Factor analysis) of the magnetic and chemical data were undertaken using SPSS (Statistical Package for Social Science) for Windows 16.0 software. Correlation coefficients and the associated level of significance (p) were employed to establish the relationship between heavy metal levels and magnetic parameters in the sediments.

4 Results and Discussions

4.1 Heavy Metal Concentration in Sediments

The concentration of heavy metals in sediments from Pulicat Lake to Vadanemmeli, along the East Coast of Tamilnadu, southeastern India is presented in Table 3. The concentration (mg kg^{-1}) varies from 100 to 4200 for Mg; 16400-33500 for Al; 7900-11400 for K; 2400-15700 for Ca; 500-8300 for Ti; 4100-20000 for Fe; 23.70-129 for V; 16.20-93 for Cr; 68.40-381.10 for Mn; 1.20-7.10 for Co; 15.60-23.60 for Ni and from 18.60-45.30 for Zn. Among the heavy metals detected, Aluminum (Al) is the most abundant metal in the sediments. The mean of metal concentrations decreased in the following order, Al > Ca > K > Fe > Ti > Mg > Mn > V > Cr > Zn > Ni > Co in the study area. The locations of Chennai Port (CPT), Vadanemmeli (CVM) are characterized by higher concentrations of Co, Cr, Ni, V and Zn when compared with other locations. This may be due to the high tourism activities and other anthropogenic activities like boating, shipping, harbor activities, industrial, urban waste discharges, dredging, etc.,. Present findings are in agreement with the results of similar workers [18-20].

Among the elements studied Ti, Fe, V, Cr, Mn, Co, Ni and Zn have high concentrations in Vadanemmeli (CVM), Kovalam Beach (CKB) locations and Mg, Al and K have high concentrations in Chennai Harbor (Nagooranthottam) (CCH), Panaiyur (CPR) locations. This may be due to recent increase in major industrial (in the coastal areas) and minor harbor activities that involves movement of naval vessels throughout the year. Furthermore, the presence of heavy metals in coastal sediments can also be attributed to other sources, such as municipal waste waters, irrigation discharge, and local rivers and creeks, along with erosion of rocks and parent soil materials [21-23]. Several studies have shown that accumulations of heavy metals in sediments might be due to point sources such as direct discharge of large amounts of industrial and domestic sewages into rivers and/or seas [24, 25]. There are many chemical and pharmaceutical factories located along the east coast of Tamilnadu whose discharge can heavily pollute the soils with heavy metals. Additionally, these enriched metals may also have originated from non-point sources such as agricultural runoff (e.g, fertilizers and livestock manure), atmospheric transport and other industrial activities [26]. Overall, our data indicate that the elevated heavy metal levels in the sediments resulted partially from the anthropogenic activities, such as waste waters, aquaculture activities and shipping.

4.2 Distribution of Magnetic Susceptibility (χ) in Sediments

Magnetic susceptibility is a measure of the presence of iron-bearing minerals within the sediments and is widely used as a proxy indicator for sources of heavy metals in sediment. Table 4 shows the results of the magnetic measurements (magnetic susceptibilities (χ_{lf} and χ_{hf}). The χ_{lf} values depend on the geology of the area, sedimentation and anthropogenic dope additive magnetic materials such as emission from fossil-fuel combustion process, vehicle emissions and waste products and dust from metallurgical industries three broad categories as follows: According to Gautam *et al.*, 2004, [27] Sediments are weakly magnetic if $\chi_{lf} < 10 \times 10^{-8}$ m^3 kg^{-1}, moderately magnetic if χ_{lf} 10 – 100 $\times 10^{-8}$ m^3 kg^{-1} and highly magnetic if $\chi_{lf} > 100 \times 10^{-8}$ m^3 kg^{-1}). χ_{lf} is a concentration dependent parameter and tells us about the total sum of magnetic minerals such as ferrimagnetic, antiferromagnetic, paramagnetic, diamagnetic present in the samples [28, 29].

In the present work, no weakly magnetic sediment samples found in the study area whereas samples CKP, CKU, CBB and CTR shows the significant concentration low frequency susceptibility in the samples. Hence, they are highly magnetic. Finally most of the samples such as CPT, CNB, CKB, CPK, CPS, CNK, CEE, CTK, CCH, CMB, CNI, CCG, CPR, CKI, CMK, CVM, and CPL shows that moderately magnetic. Previous studies showed those variations in magnetic susceptibility sediments due to geology (lithogenic/geogenic), sediment forming processes (pedogenesis), and the anthropogenic input of magnetic material [28, 30]. Fig. 3 shows the variation of χ_{lf} with location id.

Fig 4 shows the variation of high frequency susceptibility with sample id, as seen from fig 3, the, χ_{lf} have higher values than χ_{hf}. This is due to at high frequency; the relaxation time of super paramagnetic grains is shorter than the measurement time and their contribution do not count. At low frequency, the measurement time detects the susceptibility of all grains, including those that have a short relaxation time such as super paramagnetic, which are generally fine. Thus the volume of the grain size in sediment is the same, magnetic susceptibility at low frequency at higher than that high frequency [31].

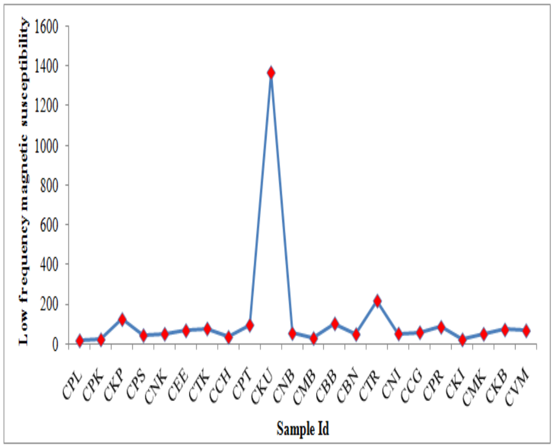

Fig. 3: Variation of low frequency magnetic susceptibility with sample Id

Table 4: Low frequency, High frequency and percent frequency dependent magnetic susceptibility of sediments

Sample ID	Low Frequency χLF	High Frequency χHF	χFD%
CPL	15.67	13.33	14.89
CPK	21	20	4.76
CKP	122.67	107.33	12.5
CPS	42	39.67	5.55
CNK	48.67	46.33	4.79
CEE	66.33	63.67	4.02
CTK	75.33	72.67	3.54
CCH	33.33	31.67	5
CPT	93.67	92.67	1.07
CKU	1364.67	1347	1.29
CNB	52.33	51.33	1.91
CMB	27.33	25	8.53
CBB	101.33	99	2.30
CBN	47.33	45	4.93
CTR	216	211.33	2.16
CNI	50.33	48.33	3.97
CCG	56.67	54.67	3.53
CPR	83.67	81	3.18
CKI	20.67	18.67	9.67
CMK	48.67	47.33	2.74
CKB	70.67	69.67	1.41
CVM	66.33	64.33	3.01
Average	**123.85**	**120.45**	**4.76**

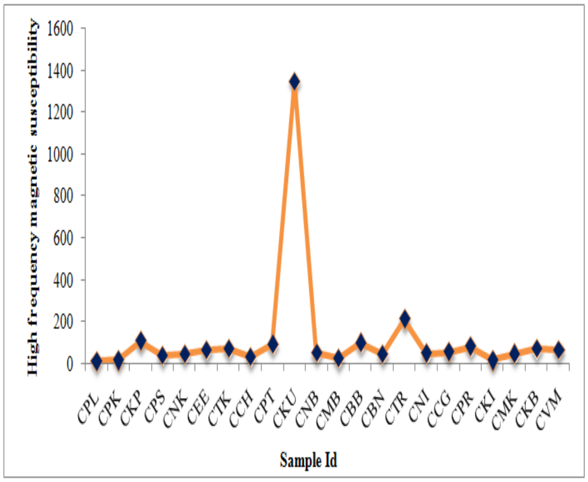

Fig. 4: Variation of High frequency magnetic susceptibility with sample Id

4.3 Percent Frequency Dependent Susceptibility (χFD%)

Percent frequency dependent susceptibility is an important magnetic parameter which is used to identify the total concentration of SP grains and coarse multi domain (MD) magnetic grains. Dearing (1999) [17] proposed a model for the interpretation of percent frequency dependence as follows. If χFD% < 2% indicates the virtually no SP, χFD% 2 – 10% indicates admixture of SP and coarser non-SP (MD), χFD% 10 – 14% indicates virtually all (> 75%) SP grains; χFD%>14% indicates rare values, erroneous measurement, anisotropy, weak samples or contamination. The Percent frequency-dependent susceptibility measurement results of sediment samples are listed in Table 4. In the present study, there are three type of magnetic groups can be identified in the samples. Only two samples, CKP and CPL show that χFD 10-14% are dominated by virtually all (> 75%) SP grains. The sediment samples, CPK, CPS, CNK, CEE, CTK, CCH, CMB, CBB, CBN, CTR, CNI, CCG, CPR, CKI, CMK and CVM with χFD between 2% and 10% belong to an intermediate group, corresponding to amixture of SP and SD grains. Also we found virtually no SP grain samples such as CPT, CKU, CNB and CKB with χFD>10%. Fig.5 shows that variations of Percent Frequency-dependent susceptibility with location id.

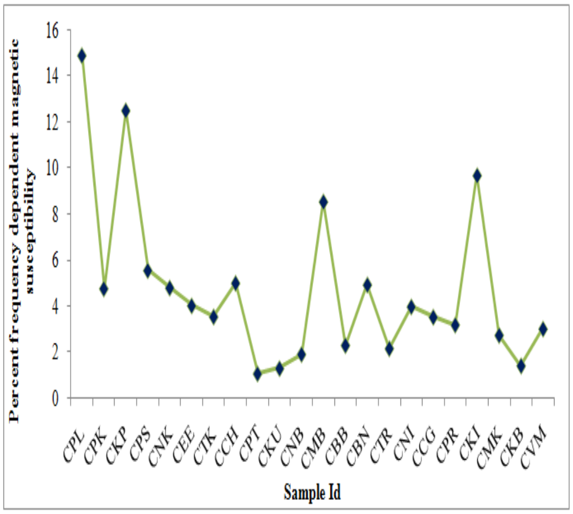

Fig.5: shows that variations of Percent Frequency-dependent susceptibility with location id

Table 5: Pearson correlation between concentration of heavy metal and magnetic variables.

Variables	**Mg**	**Al**	**K**	**Ca**	**Ti**	**Fe**	**V**	**Cr**	**Mn**	**Co**	**Ni**	**Zn**	**χLF**	**χHF**	**χFD**
Mg	1														
Al	0.409	1													
K	0.486	0.723	1												
Ca	0.365	0.707	0.553	1											
Ti	-0.025	0.463	-0.087	0.473	1										
Fe	0.057	0.572	0.000	0.509	0.967	1									
V	-0.017	0.437	-0.107	0.437	0.987	0.955	1								
Cr	-0.033	0.367	-0.146	0.385	0.938	0.945	0.940	1							
Mn	0.071	0.596	0.007	0.499	0.949	0.990	0.928	0.919	1						
Co	0.062	0.570	0.001	0.517	0.965	0.998	0.952	0.942	0.990	1					
Ni	0.294	0.618	0.291	0.555	0.722	0.787	0.717	0.792	0.788	0.798	1				
Zn	0.110	0.557	0.122	0.406	0.640	0.739	0.668	0.623	0.713	0.725	0.487	1			
χLF	**0.195**	**0.010**	0.049	**0.102**	**0.082**	**0.113**	**0.092**	**0.083**	**0.120**	**0.103**	**0.155**	**0.110**	1		
χHF	0.193	0.010	0.047	0.099	0.080	0.110	-0.090	0.080	0.117	0.100	0.153	0.109	1.000	1	
χFD	-0.057	-0.167	-0.056	-0.404	-0.264	-0.311	-0.198	-0.319	-0.349	-0.325	-0.318	-0.251	-0.259	-0.265	1

4.4 Pearson Correlation Analysis

Pearson Correlation refers to a technique used to measure the relationship between two or more variables. When two things are correlated, it means that they vary together. Positive correlation means that high scores on one are associated with high scores on the other, and that low scores on one are associated with low scores on the other.

Negative correlation, on the other hand, means that high scores on the first thing are associated with low scores on the second. Negative correlation also means that low scores on the first are associated with high scores on the second. Generally, sign of the correlation coefficient tell us strength of the variables. A positive correlation coefficient means that as variable 1 increases, variable 2 increases, and conversely, as variable 1 decreases, variable 2 decreases. In other words, the variables move in the same direction when there is a positive correlation. A negative correlation means that as variable 1 increase, variable 2 decreases and vice versa.

Hence, Pearson's correlation (r) analysis was performed between heavy metals and magnetic parameters with the level of significance ($p \leq 0.05$ and $p \leq 0.01$). In various studies, the relationship between magnetic susceptibility and heavy metal concentrations was usually analyzed by correlation analysis [32-35]. Pearson correlation coefficients between magnetic susceptibility and concentrations of heavy metals are listed in Table 5. The correlation coefficients were calculated for all points as a single group. According to correlation analysis, heavy metals Mg (r = 0.195), Al (r = 0.010), Ca (r = 0.102), Ti (r = 0.082), Fe (r = 0.113), V (r = 0.092), Cr (r = 0.083), Mn (r = 0.120), Co (r = 0.103), Ni (r = 0.155) and Zn (r = 0.110) shows very weak positive correlations with low frequency magnetic susceptibility (χlf) (Fig. 6). The positive correlations indicate that concentration of heavy metals and magnetic minerals may be either inherited from the parent rocks (lithogenic origin) [36, 37] or formed during pedogenesis in the study area.

4.5 Factor Analysis

Factor analysis is a statistical tool to measure the impact of variables called factors. It is a data reduction method. In the present study, factor analysis (FA) was applied to identify the source of heavy metals in the coastal sediments by applying Varimax rotation with Kaiser Normalization [38].

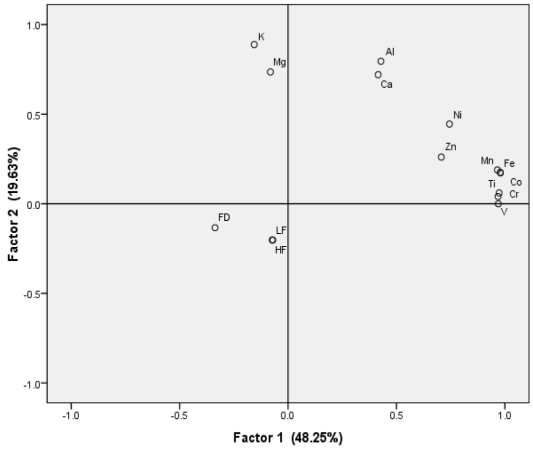

Fig. 6: Shows the rotated factor loadings of heavy metal and magnetic variables.

By extracting the eigenvalues and eigenvectors from the correlation matrix, the number of significant, non-significant factors and the percent of variance explained. The results show that there are two factors that explain 67.88% of the total variance in the sediments. As shown in Table 6.

The first factor explains 48.25% of the total variance and is dominated by Ti, Fe, V, Cr, Mn, Co, Ni, and Zn; Factor 2 accounts for 19.63% of the total variance and loads in Mg, Al, Ca and K with and very weak positive loadings of χlf, χhf, and χfd%; This weak positive loadings of magnetic parameters indicates there is weak mutual relationship with heavy metals in the sediments of study area. The relationships between the heavy metals and the magnetic parameters based on the two factors of the sediments are illustrated in Fig. 6 in two dimensional spaces.

Table 6: Rotated factor components of heavy metal and magnetic variables.

Variables	**Factor 1**	**Factor 2**
Mg	-0.081	**0.735**
Al	0.428	**0.795**
K	0.156	**0.888**
Ca	0.416	**0.720**
Ti	**0.974**	0.060
Fe	**0.979**	0.172
V	**0.968**	0.040
Cr	**0.970**	0.000
Mn	**0.965**	0.188
Co	**0.978**	0.175
Ni	**0.744**	0.445
Zn	**0.707**	0.260
χLF	0.073	0.202
χHF	0.070	0.202
χFD	-0.337	-0.134
% of Variance explained	**48.25**	**19.63**

4.6 Cluster Analysis

Cluster analysis (CA) is a multivariate method which aims to classify a sample of subjects (or objects) on the basis of a set of measured variables into a number of different groups such that similar subjects are placed in the same group. These groupings are frequently based on the correlation coefficients of variables. In order to evaluate further similarities in heavy metal and magnetic parameter sources, cluster analysis was performed by squared Euclidean distance method [39,40]. The CA results for magnetic parameters and heavy metals are shown in Fig 7. As a dendrogram Fig. 7 displays two clusters: Cluster I formed due to heavy metals such as Mg, Al, Ca Ti, Fe, V, Cr, Mn, Co, Ni, Zn and magnetic parameters χlf, χhf, and χfd%; Cluster II formed from only concentration of K. As shown in this figure 7, heavy metal and magnetic variables in clusters I join together at a relatively high level likely implying originated from same sources, The CA results are in agreement with the FA results listed in Table 5 and illustrated in Fig. 7.

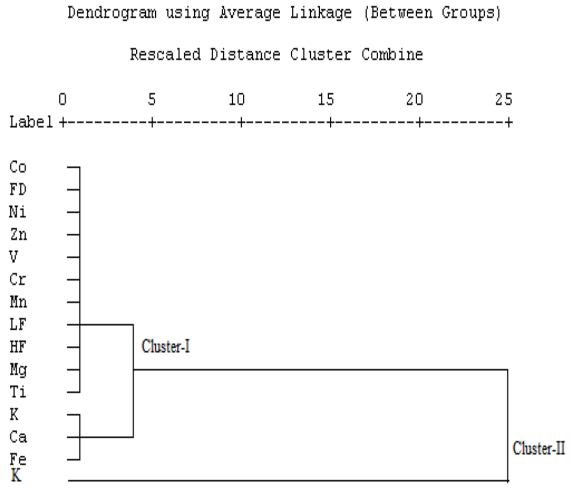

Fig 7: shows the clustering of heavy metal and magnetic variables

5 Conclusions

The relationship between magnetic susceptibility and concentration of heavy metals has been investigated by multivariate statistical analysis for sediment samples collected from Pulicat Lake to Vadanemmili coastal area, Tamilnadu, The samples CKP, CKU, CBB and CTR shows highly magnetic in nature. Among the determined metals Ti, Fe, V, Cr, Mn, Co, Ni and Zn have high concentrations in Vadanemmeli (CVM), Kovalam Beach (CKB) locations and Mg, Al and K have high concentrations in Chennai Harbor (Nagooranthottam) (CCH), Panaiyur (CPR) locations. This may be due to recent increase in major industrial) and harbor activities in the study area. Pearson correlation, Factor and cluster analysis of magnetic and heavy metal variables reveals the heavy metals are originated from parent rocks. Our study suggests that simple, rapid, and nondestructive magnetic measurements could provide useful information about some heavy metal pollution in sediments of study area.

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