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Appraisal of Heavy Metals in Soil/Sediments with Relation to their Physico-chemical Properties from Ankaleshwar Industrial Area, South Gujarat

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Abstract

Extensive industrialization in the southern part of Gujarat is characterized by regional pollution of soil and water resources. In view of this, the present study has been undertaken in Ankaleshwar, one of the biggest industrial townships of India. About, 25 surface sediment /soil samples were collected from top 10 cm representing entire study area and were analyzed for heavy metals by using X-ray fluorescence spectrometer (XRF). The heavy metals concentrations were compared with the standard shale to find out pollution index (PI), results shows the significant enrichment for arsenic, moderate enrichment for Pb and minimal enrichment for metals in descending order as Fe>Mn>Cr>Ni>Co>Zn>Cu>Mo. Physico-chemical properties such as texture, cation exchange capacity, total carbonate and organic matter, as well as the percentages of the sand, silt, and clay fractions have been examined. It is observed that heavy metals like Ni, Cu, Zn, and Mo show a positive correlation with the silt size fraction. Similarly, Mn, Cr, As, and Pb show positive correlation with clay size fraction. Chemical properties like EC, CEC and organic matter have control over majority of heavy metals. High correlation with these properties suggests that higher ionic conductivity soils have high heavy metal content. The effect of these properties can be arranged in descending order as follows: EC >OM > Clay % >Silt % > CEC.

1   INTRODUCTION

Large-scale industrialization in the southern part of Gujarat is characterized by regional pollution of soil and water resources. In view of this, the present study has been undertaken in Ankaleshwar, one of the biggest industrial townships of India. The Ankaleshwar Industrial Estate (AIE) is characterized by industrial and urban distends reclaiming a large extent of fertile alluvial flood plains of Narmada River in Gujarat state of India. AIE is essentially a chemical domain, which is a part of the industrial 'Golden Corridor' housing 171 industrial estates created by the Gujarat Industrial Development Corporation (GIDC). AIE includes an array of chemical, fertilizer, paint, dyes, glass, pharmaceutical and other allied industries, which have impacted the local environment to a great extent.

Discovery of hydrocarbons in the area has further hastened the pace of urbanization and industrialization with concomitant increase in environmental problems. Although there is some information generated by the local NGO's about levels of heavy metals in industrial effluents, there is no scientific data available on the dispersion of metals in the soils.

Soil samples are an excellent media to monitor heavy metal pollution because anthropogenic heavy metals are deposited generally on top soils. Generally the distribution of the heavy metals depends on the parent material, climate and very much on the soil properties i.e. texture and classification. The chemical composition of soil, particularly its metal content is environmentally important, because toxic metal can

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reduce soil fertility, and can increase input to food chain, which accumulate in food stuff and ultimately influence the human health (Krishna *et al.*, 2007). Therefore, depending on environmental conditions, soils can be a sink or a source for metals. A common approach to estimate the anthropogenic impact on sediments is to calculate a normalized enrichment factor also called as pollution index for metal concentrations above uncontaminated background levels. While the use of average earth or crustal values are the norm as reference concentrations, local baseline or background levels are more recent choice, carrying the advantage of reducing the effect of natural geochemical variability (Abrahim and Parker, 2008) so the tertiary shale from the study area was used as background value.

The examination of particle size distribution is an important approach for understanding the environment and hydraulic conductivity of soil and the process of heavy metal fortification. In an attempt to understand of the distribution the pollutant elements in the sediments and to know the relation of the measured elements with some physic-chemical properties such as texture, cation exchange capacity, total carbonate and organic matter content, as well as the percentages of the sand, silt, and clay fractions have been examined. The distribution of the metals in different size fractions reflect the differences in mineral compositions, surface chemical properties, specific surface area, and surface free energy of sediment, which are significantly important to understand the mechanisms of metal adsorption, desorption, and transportation in nature (Chen *et al.*, 2000; Thuy *et al.*, 1999). The primary objective of the present study was to assess the degree of pollution i.e

Pollution Index by calculating enrichment of metals above the standard. In an effort to obtain better understanding of distribution of the pollutant elements in this soils the relation of the measured elements with some physico-chemical properties of the soil such as CEC, total carbonate, and organic matter content, as well as the percentage of sand, silt, and clay fractions have been examined.

2   STUDY AREA

The study area, Ankaleshwar industrial Estate (AIE) is located in Bharuch district of south Gujarat in Western India (latitudes $21^{\circ} 30'$ N and $21^{\circ} 42'$ N and longitudes $72^{\circ} 49'$ E and $73^{\circ} 05'$ E). It is drained by a small third-order stream, Amla Khadi with watershed area of approximately 240 km^2. Amla Khadi is one of the tributaries of Narmada River that originates in the lower reaches of alluvial flood plain of Narmada (Figure 1). The area receives an average annual rainfall 860 mm recorded at Bharuch. It is also known for rich agriculture endowed with crops of cotton, horticulture and vegetables due to fertile alluvial soils and perennial availability of water. The Amla Khadi stream along its length is divisible into three distinct zones viz. (1) source region with dry stretch, (2) middle ponding segment and (3) lower dry reach. Ankaleshwar Industrial Estate (AIE) is located in upper and middle reaches. The stream segment in the lower reaches runs foamy red with a pungent foul smell as it carries only industrial effluents with toxic heavy metal concentrations several thousand times the permissible limits. During monsoon the stream overflows submerging the surrounding lands under polluted waters
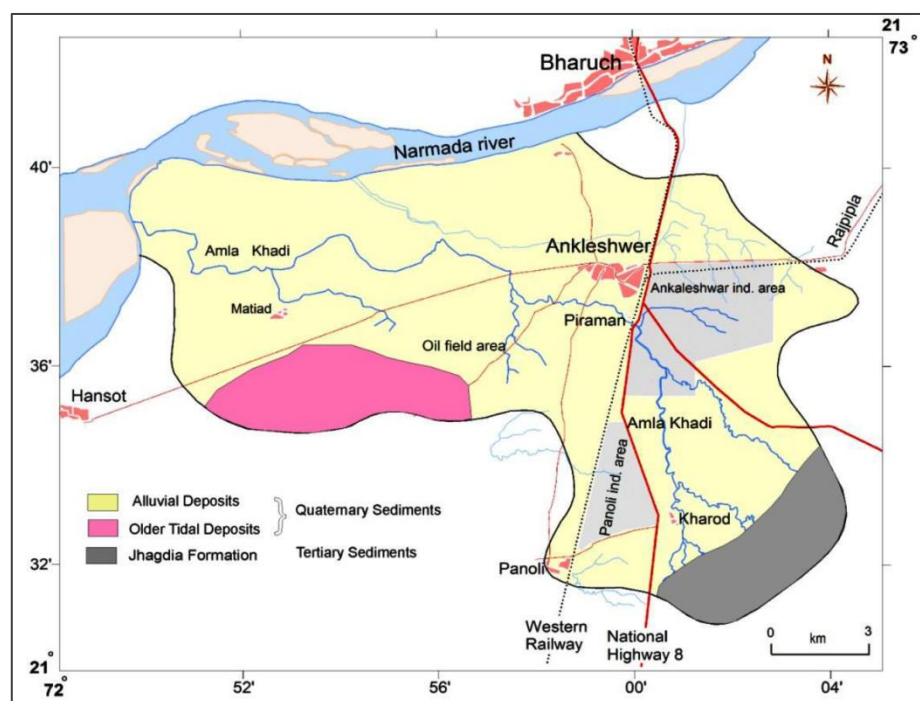

Figure 1. Study area: Ankaleshwar Industrial Estate (with Geology)

(Santillo *et al.*, 1996). The AIE incorporates two industrial zones: (1) Ankleshwar industrial area (AIA) and (2) Panoli industrial area (PIA). Both these sectors together comprise over 3,000 industrial units; over half of which are chemicals, manufacturing dyes, paints, fertilizers, pharmaceuticals, industrial chemicals, pulp and paper and pesticides (Bruno, 1995; CPCB, 1996). Aligned parallel to National Highway No. 8 (Mumbai – New Delhi) and Western Railways, Ankleshwar is one of the biggest industrial townships in India. The members of the AIE generate between 250 and 270 million liters/day of liquid waste and ~50,000 tonnes of solid waste annually (Bruno, 1995). Of this, 58% arises from the manufacture of dyes and dye intermediates, 19% from drugs and pharmaceuticals, and 5% from inorganic chemicals (CPCB, 1996). This set up in the basin provides an ideal site to monitor the interplay between the sources of heavy metals and the response of aqueous system to them.

3   GEOLOGY

The geology of the area is characterized by Quaternary alluvium. Alluvial sediments have been differentiated on the basis of their depositional environment by GSI (2002). They comprise older tidal flat and tidal marsh deposits of Rann Clay Formation and younger tidal flat deposits (spit/bar and shoal) of Mahuva Formation, representing marine environment. The flood plain deposits of Katpur Formation represent fluvial environment of deposition GSI (2002). The AIE belongs to Katpur Formation wherein low-lying flood plain south of Narmada exhibits poorly developed natural drainage and very low relief (Figure 1). It forms a part of regional alluvial deposits of Late Pleistocene to Holocene in age (Bhandari *et al.*, 2001; Chamyal *et al.*, 2002) through which the stream Amla Khadi drains. The

saline wastelands and swampy areas of broad estuarine mouth bar of river Narmada (Alia bet) and older Tidal flat/marsh deposits mark the western boundary of this plain. Towards the South and East, the plain is bounded by uplands comprising rocks of Tertiary Sequence (Lower Eocene to Pliocene) and Deccan Volcanics (Chamyal *et al.*, 2002).

4   MATERIALS AND METHODS

Since the purpose of the present study was to delineate spatial variations in the toxic metals and to identify their possible sources (industrial/urban, etc.) impacting the surface environment, the sampling plan was designed accordingly. Random sampling technique was adopted for the selection of surface soil/sediment samples and due consideration was given to represent industrial, urban and oil field areas besides highways and polluted stream stretches. However, overall 25 surface samples could be collected from the industrial and oilfield areas due to constraints in the field (Figure 2).

Undisturbed surface soil/sediments from 0 to 15 cm depth were collected in March 2006, to study the anthropogenic sources of pollutants which normally contaminate the upper layer of soil/sediment. In case of natural abundance of the metals the concentration at all its depths is equivalent. Only grabs that showed no evidence of leakage or surface disturbance were retained; the top 3 cm were removed so to avoid the surface contamination. The soils/sediment were collected in polythene self-locking bags and stored, use of metal tools were avoided and plastic spatula was used for sample collection, (Figure 2) shows the soil/sediment sample location map and its distribution in study area. Due care was taken to avoid contamination of samples during handling.
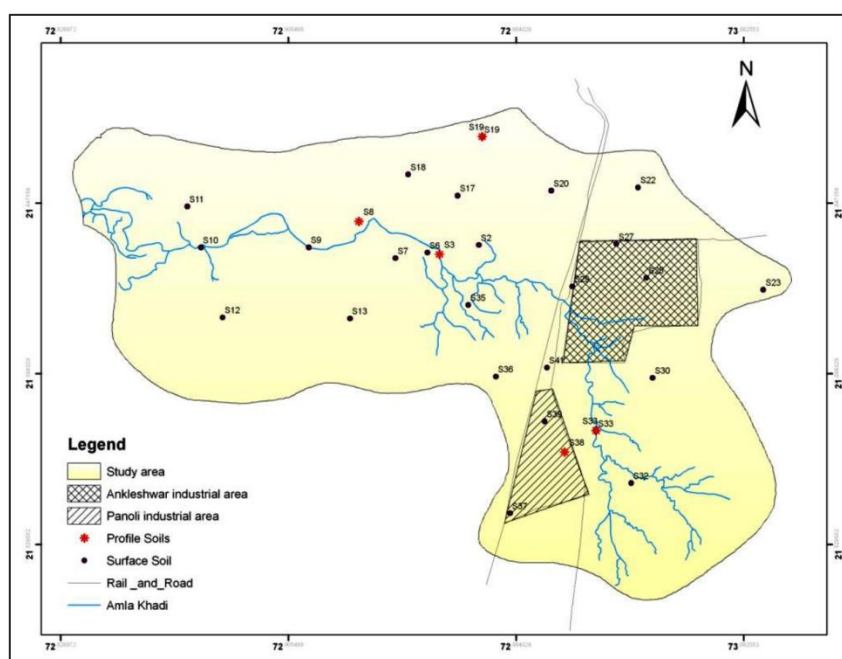

Figure 2. Soil/sediment sample locations

5   ANALYTICAL METHODS

In the laboratory the samples were kept in darkness at 4°C until processing and analysis. The samples were dried at normal room temperature. Particle size analysis was performed on sedigraph. Samples were sieved at (< 0.002mm) fine size fraction. Analysis of this fraction is normally carried out in sediment studies because clay and silt particles generally contain the highest concentrations of pollutants and are most readily transported in suspension in natural waters (Fytianos and Lourantou, 2004). The fine soil samples were used for the analysis by X-ray fluorescence the powder method was used to determine the elemental concentrations. The result obtained from the analysis performed on the sedigraph was plotted in the ternary diagram of soil by USGS in Rock ware software to get the textural classification. The collected samples have been analyzed for, total organic matter (% TOM), cation exchange capacity (CEC) and total carbonate content (% CO_3) based on the standard published methods (Hesse, 1972; Cotteni *et al.*, 1982; Loring and Rantala, 1992). Cation exchange capacity was determined by using sodium acetate and ammonium acetate solutions (Hesse, 1972). The total carbonate content was determined by chemical titration method (Cotteni *et al.*, 1982); and the organic matter content was determined by oxidation with potassium dichromate (Loring and Rantala, 1992).

To quantify the magnitude of pollution by different metals, pollution index was calculated for soil/sediments in study area. The ratio of heavy metals to its original background values may directly reveal the environmental quality and should be used as an index of evaluating the geochemical imbalance, thus elevating trace metal concentrations, which normally are attributed to the anthropogenic activities (Birch and Taylor, 1999). The pollution index is calculated as:

$$PI = C_i \backslash S_i$$

Where, PI is heavy metal contamination index, C_i is measure content of metal and S_i is the background value. Pollution Index according to Sutherland (2000), five contamination categories are generally classified on the basis of their enrichment factor (Table 1).

6   RESULTS

6.1   Enrichment of Heavy Metals

The values of pollution index were obtained and for the better understanding the dispersion of the heavy metals in surface soils of the study area by categorizing them into 8 distinct classes. Upper dry stretch, Middle pounding stretch, Lower stretch of Amla Khadi, The Ankaleshwar Industrial area (AIA), Panoli Industrial area (PIA), Oil Field area, Narmada bank sediment and Stream sediments of lower stretch.

The samples collected representing sample nos. S9 and S10 from lower stretch of the Amla Khadi is very highly polluted (mud sample), pollution index values for Mo vary from 20 to 40 EF, which is very highly enriched class followed by EF values of 5 to 20 for Cu, As, and Pb with significant enrichment and moderate enrichment values are seen for metal, Zn.

Table 1. Pollution Index according to Sutherland (2000), five contamination categories are generally classified on the basis of their enrichment factor.

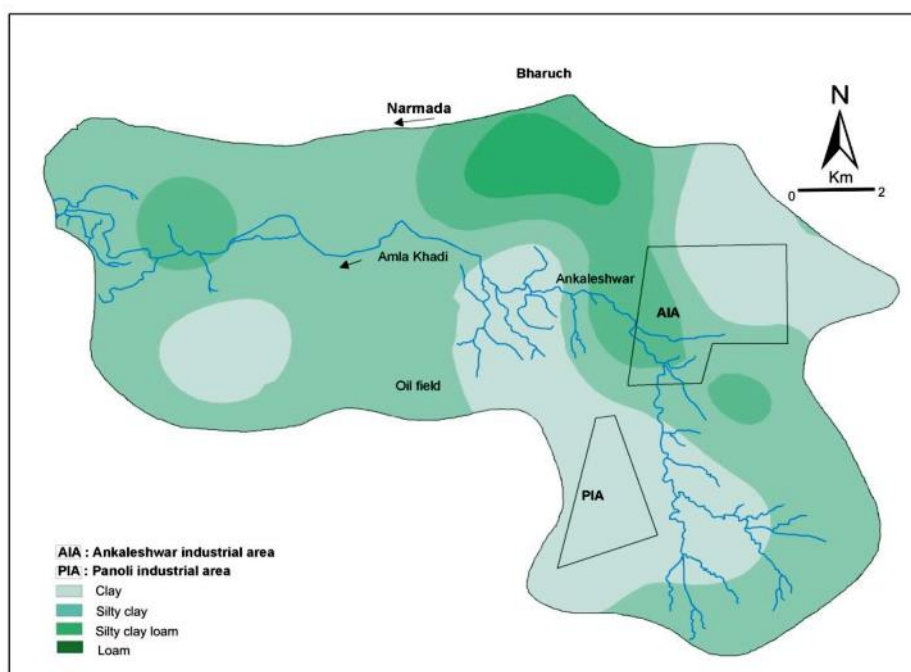| Classes (EF)	Descriptions
< 2	Depletion to minimal enrichment, suggestive of no or minimal pollution.
2 to5	Moderate enrichment
5 to 20	Significant enrichment
20 to 40	Very high enrichment
> 40	Extremely high enrichment

Figure 3. Surface soil texture: spatial distribution

In upper dry stretch (samples: S30, S32, S33) the dispersion of the metals shows highest arsenic values followed by Pb>Mn>Mo (Figure 4). The pollution index shows moderately enriched values for Mn and significant enrichment for As and Pb. In the middle pounding stretch (samples: S2, S6, S7) depicts the same pattern (Figure 4) of increase in metal content As>Pb>Mn>Fe and instead of Mo, Fe is present here. The pollution index values reveal significant enrichment for As and moderate for Pb. Lower stretch of Amla Khadi displays (samples: S11 and S12) the same trend of enrichment of heavy metals with values in descending order as As > Mn > Fe > Pb (Figure 4) with moderate enrichment for the As. The soil samples from Ankaleshwar and Panoli industrial area show increase in content of metals (Figure 4) As > Pb > Mn > Zn in both Ankaleshwar and Panoli industrial areas. This pattern of increase in the heavy metals can therefore be considered as characteristic of industrial zone. In oil field area, the increase in metal content is As > Mn > Fe > Pb (Figure 4) revealing very high concentration of the metals that are 2 to 10 times the actual concentration in the standard shales. The pollution index in this case shows moderate enrichment for As. The heavy metals in hierarchial order as As > Pb > Mn > Fe are seen (samples: S17, S18, S19 and S20) from the Narmada bank with very high concentrations as compared to the standard, background

values in shale (Figure 4) Besides pollution index moderate enrichment for metals Pb and As is noticed.

6.2   Controlling Parameters of Soils:

The size fraction in the present study area comprises of alluvial Quaternary deposits and belongs to a class of clay to clayey loam and silty clay. The soil samples were grouped into eight groups specifying the area which they represent (Table 2).

The sediment samples from industrial area are mostly clay and silt and show transition to clayey loam, soils from oil field are silt and clay, Narmada bank sediments are transition of clayey and silty clay loam, the upper stretch of Amla Khadi are in the group of clay, clayey loam and silty clay loam, middle pounding stretch show silt and silty clay, lower stretch shows clay and silty loam, the stream sediments of lower stretch are silty loam, loam, silty loam (Figure 3).

The chemical properties of soil/sediments have been determined by the colloidal portion of soils i.e. clays and humus. The chemical environment of soil not only influences the plant growth but also it decisively determines the physical environment of soil (Orlov, 1992). Therefore, in order to characterize the soils from the area, the chemical properties like pH, EC, CEC, Carbonate content and Organic matter were estimated (Table 3).

Table 2. Surface soil/sediment grain size data

Area	Soil samples	Sand	Silt	Clay	Soil texture
Urban and	S2	17	41	42	clay
lower stretch	S6	11	46	43	silty clay
	S7	14	51	35	silty clay/silty clay loam
	S9	10	54	37	silty clay
	S10	9	65	26	silty clay loam
	S11	16	60	24	silty clay loam
	S12	6	33	61	clay
	S13	10	49	40	silty clay
Narmada bank	S17	28	45	28	clay loam
	S18	8	65	27	silty clay loam
	S19	30	53	18	loam
	S20	30	41	29	clay loam
	S22	35	26	39	clay
AIA	S23	12	37	52	clay
	S25	10	37	53	clay
	S27	20	41	39	clay
	S29	25	41	34	clay loam
Upper stretch	S30	9	34	57	clay
	S32	26	40	33	clay loam
	S33	14	54	32	silty clay loam
	S35	6	33	60	clay
PIA	S36	14	33	52	clay
	S37	12	33	55	clay
	S39	7	31	61	clay
	S41	11	37	41	clay

In general, pH range of 6.5 to 7.5 of the saturation extract is considered as standard range in which most of the soil nutrients are available to plants. In the present study area, all surface samples except no. 9 and 10 the pH is above 7, and it ranges from 7.2 to 8.6 reflecting alkaline nature of majority soil/sediments while sample no. S9 and S10 show pH 5.4 and 5.7 that is acidic possibly showing effect of industrial effluents.

The EC values range from 0.082 to 24.3 dS/m in the study area. The highest values of EC have been observed for sample no S9 and S10 representing surface soil/sediments belonging to the polluted stream bank sediments of Amla Khadi. The highest values of EC 24.3 and 10.2 dS/m of this locations show that it is heavily loaded with the heavy metals. The remaining samples from unpolluted area have EC values of (0.082 dS/m) are on lower side. The areas showing moderate to high EC are from industrial, urban, environment and polluted stretch of Amla Khadi.

CEC values range from 34.5 to 89 meq/100g, considering this the soil in this area is classified as silty clay and inference that is also supported by textural analysis. The samples, S12 belonging to lower polluted stretch, S22 from Narmada bank sediment, S23 from Ankaleshwar industrial area and S35 from upper stretch of Amla Khadi and S 39, 41 from Panoli industrial area show highest values for CEC (Table 3).

Carbonate values vary from 1.04 to 49.2% (possibly nodules) the higher values of carbonates were seen the samples: 6,7,9,10,11,12,13,17,18,19,20 that are from the middle pounding and lower stretch of Amla Khadi as well as from Narmada bank sediments. The samples from industrial area in the upper dry stretch (samplers: .22, 23, 25, 27, 29, 30, 32, 33, 35, 36, 37, 39, and 41) show the lower values of carbonate.

Organic carbon and organic matter varies in surface soil/sediment samples from 0.18 to 1.98 and 0.31 to 3.4 %. The values are seen higher in the samples belonging to polluted stream bank sediments i.e. S9 and S10, and also in the industrial areas (sample: 41, 36, 32, 29). The higher values of organic carbon and organic matter in these areas can be attributed to the anthropogenic activities as many of the industrial sites are situated throughout the area, and samples, S9 and S10 are having higher values as they are from the polluted stream bank sediments receiving the highly loaded effluents from industries. Remaining samples in the area show moderate to lower values of organic carbon and organic matter as from (Table.3).

The correlation between heavy metals and phsyco-chemical properties of surface soil/sediments was performed in order to assess control of these properties on heavy metal dispersion. Correlation analyses of the soil phsyco-chemical properties with the

heavy metal content gives an judgment of how this properties has helped in determining the dispersion of heavy metals in soil and leading to the environmental impact.

Cobalt is positively correlated with the pH value with (r=0.72). Good positive correlation of EC with the heavy metal like Cu, Zn, Mo, Ni is seen and moderate to poor correlation of EC with the soil properties like percentage of Carbon and Organic matter is also seen. CEC shows moderate to poor correlation with metals like Ni, Zn, Pb and Cu. Carbonate content show moderate correlation with Cu Mo. Organic matter content show the positive correlation of the heavy metal content with Ni, Cu, Zn Pb and Mo.

Table 3. Chemical properties of surface soil/sediments

Area name	Sample Nos.	pH	EC	CEC	CaCO$_3$ (%)	Organic carbon (%)	Organic matter (%)
Urban and	S2	7.42	0.48	78.40	1.04	0.42	0.72
lower stretch	S6	8.3	0.21	60.50	49.2	0.76	1.31
	S7	7.52	0.37	57.60	40.4	1.35	3.12
	S9*	5.46	24.30	56.80	34	1.98	3.40
	S10*	5.76	10.12	55.90	33.8	1.98	3.40
	S11	8.03	0.29	46.90	34.6	0.56	0.97
	S12	7.87	0.14	89.20	34.2	0.21	0.37
	S13	8.03	0.22	71.50	35.7	0.56	0.97
Narmada bank	S17	8.05	0.36	34.50	38.4	0.35	0.61
	S18	8.04	0.25	36.80	34.4	0.76	1.31
	S19	7.7	0.44	47.50	33	1.52	2.40
	S20	8.12	0.48	46.30	34.2	1.00	1.72
	S22	7.96	0.56	68.10	1.91	0.85	1.47
AIA	S23	7.79	0.08	77.80	1.04	0.36	0.62
	S25	7.69	0.44	70.30	2.82	0.68	1.17
	S27	7.9	0.21	57.80	3	0.42	0.72
	S29	7.7	0.36	56.50	2.1	1.07	1.84
Upper stretch	S30	8.62	0.16	69.50	3.17	0.18	0.31
	S32	7.9	0.92	53.40	1.45	1.01	1.74
	S33	7.76	0.98	52.50	1.97	0.34	0.59
	S35	7.45	0.43	83.50	1.29	0.51	0.88
PIA	S36	7.86	0.28	67.20	1.76	1.08	1.86
	S37	7.89	0.12	68.60	1.15	0.39	0.68
	S39	8.3	0.38	78.20	2.2	0.83	1.43
	S41	7.7	0.91	73.50	2.65	1.93	3.33

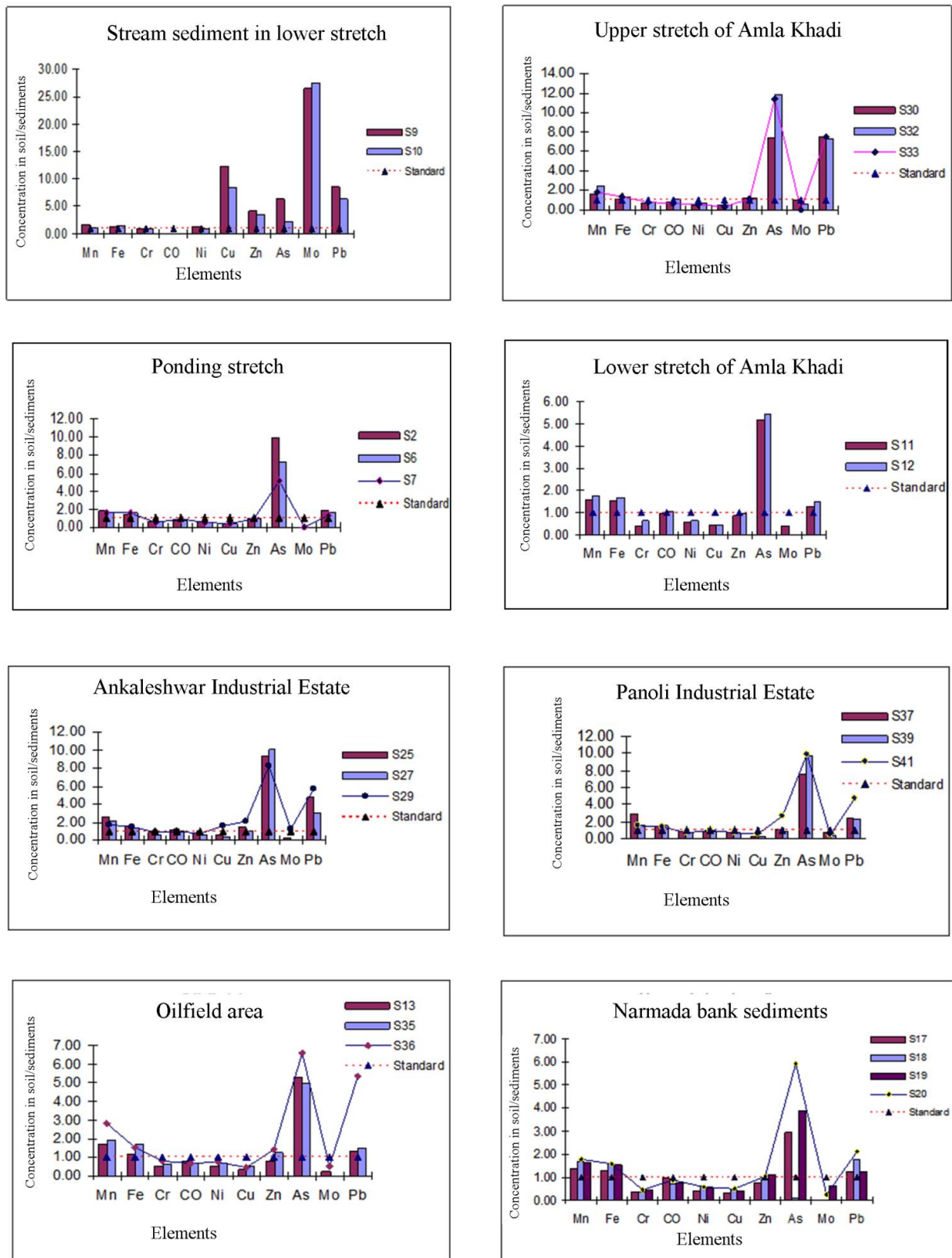* Mud samples from lower stretch.

Figure 4. Comparison of heavy metals with tertiary shale values

Table 4. Correlation of heavy metals and physical properties of surface soil /sediments

	Sand %	Silt %	Slay %	Mn	Fe	Cr	Co	Ni	Cu	Zn	As	Mo	Pb
Sand %	1												
Silt %	-0.09	1											
Clay %	-0.56	-0.75	1										
Mn	-0.16	-0.40	0.46	1									
Fe	0.03	0.09	-0.08	0.22	1								
Cr	-0.43	-0.23	0.48	0.43	-0.19	1							
Co	0.21	-0.48	0.24	0.43	0.35	-0.28	1						
Ni	-0.30	0.15	0.07	0.09	0.00	0.70	-0.55	1					
Cu	-0.20	0.42	-0.21	-0.25	-0.29	0.52	-0.79	0.84	1				
Zn	-0.20	0.28	-0.16	-0.19	-0.25	0.61	-0.66	0.80	0.89	1			
As	-0.15	-0.52	0.50	0.52	0.01	0.52	0.47	0.11	-0.18	-0.04	1		
Mo	-0.21	0.44	-0.22	-0.28	-0.28	0.51	-0.82	0.78	0.97	0.86	-0.23	1	
Pb	-0.11	-0.17	0.20	0.14	-0.41	0.73	-0.34	0.52	0.53	0.66	0.36	0.50	1

Table 5. Correlation of heavy metals with chemical properties of soil/sediments

	pH	EC	CEC	CaCO3	C (%)	OM	Mn	Fe	Cr	Co	Ni	Cu	Zn	As	Mo	Pb
pH	1															
EC	-0.87	1														
CEC	-0.21	0.32	1													
Caco3	-0.17	0.25	-0.13	1												
C (%)	-0.66	0.59	0.60	0.24	1											
OM	-0.64	0.57	0.54	0.26	0.99	1										
Mn	0.11	-0.19	-0.15	-0.52	-0.40	-0.40	1									
Fe	0.14	-0.31	-0.15	0.02	-0.13	-0.11	0.22	1								
Cr	-0.55	0.48	0.17	-0.46	0.21	0.19	0.43	-0.19	1							
Co	0.72	-0.75	-0.13	-0.31	-0.54	-0.51	0.43	0.35	-0.28	1						
Ni	-0.81	0.84	0.37	-0.08	0.51	0.48	0.09	0.00	0.70	-0.55	1					
Cu	-0.91	0.97	0.26	0.26	0.63	0.60	-0.25	-0.29	0.52	-0.79	0.84	1				
Zn	-0.85	0.84	0.38	0.04	0.75	0.71	-0.19	-0.25	0.61	-0.66	0.80	0.89	1			
As	0.14	-0.15	0.18	-0.59	-0.13	-0.14	0.52	0.01	0.52	0.47	0.11	-0.18	-0.04	1		
Mo	-0.91	0.91	0.22	0.26	0.63	0.60	-0.28	-0.28	0.51	-0.82	0.78	0.97	0.86	-0.23	1	
Pb	-0.41	0.51	0.30	-0.39	0.38	0.34	0.14	-0.41	0.73	-0.34	0.52	0.53	0.66	0.36	0.5	1

7   DISCUSSION

The groupings of metals into 8 different classes based on land use have made it easier to locate their possible sources and also the degree of the enrichment or pollution they have reached. Metals occurring at all sites are well correlated positively as discussed earlier, including As, Pb, Mn, Fe and Mo, indicating that they have a common source, which could be an anthropogenic or lithogenic. The samples show very high values of the metals like As followed by Pb >Zn and Mo. The concentration of Mo and Cu is found to be highest in the samples of the lower polluted stretch (mud) as it is directly in contact with the highly toxic and polluted industrial effluent from this area. The pollution index shows the significant enrichment in metals like As, moderate enrichment in case of Pb and minimal enrichment in Fe > Mn > Cr > Ni > Co > Zn > Cu > Mo. The data reveals that the surface soils/sediments in the area are appreciably contaminated, showing high levels of toxic elements than standard values of Shales.

Generally the distribution of the heavy metals is very high in the finer fraction then the coarser fraction (Li *et al.*, 2006) as this finer fraction mainly clay and silt have high surface area for adsorption and form complexes with different compounds.

High correlation with chemical properties suggests that higher ionic conductivity soils have high capacity for heavy metal storage. Also the affirmative relation between the Mo and $CaCO_3$ as well as organic matter content suggests possible presence of calcium humates in the soil/sediments. Co is the only metal which shows the positive correlation with the pH and all other heavy metals are negatively correlated. This concludes that the mobility of Co is strongly influenced by pH. Generally, the metals in soils are strongly bonded by soil organic matter. The higher CEC of the soil also means the greater adsorption capacity for heavy metals (Liu *et al.*, 2007). The measured total concentration of heavy metal was positively correlated with measured physico-chemical properties. The effect

of these properties can be arranged as fallow: EC > % C > Organic matter > Clay content > Silt content.

8   CONCLUSION

The present study shows significance to minimum enrichment of heavy metals in soil/sediment of study area. High concentration of heavy metals then the standard values has led to contamination of soil/sediment quality in the study area. This significant enrichment of heavy metals like As and Pb, was seen in the area which are influenced anthropologically including industrial, urban and lower stretch which is drained by industrial effluent.

The heavy metals like Arsenic and Pb have high values then the standard values which are really unsafe. Contribute firmly by the anthropogenic activities like industries and traffic, wastes from urban area, etc.

The measured total concentration of the heavy metal shows control of their physico-chemical properties. The effect of these properties can be arranged in descending order as follows: EC > OM > Clay % > Silt % > CEC. Thus, study clearly highlights the control of physico-chemical properties on heavy metal content and prerequisite measure for exceptionally severe metal pollution in the Ankaleshwar area.

CONFLICT OF INTEREST

Authors proclaimed no conflict of interest.

ACKNOWLEDGEMENTS

ABBREVIATIONS

AIE: Ankaleshwar Industrial Estate; **CEC**: Cation Exchange Capacity; **CPCB**: Central Pollution Control Board; **GIDC**: Gujarat Industrial Development Corporation; **GSI**: Geological Survey of India; **NGO**: Non-Governmental Organization; **OC**: Organic carbon; **OM**: Organic matter; **PI**: Pollution Index; **PIA**: Panoli Industrial Area; **XRF**: X-ray fluorescence spectrometer.

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