



Baseline survey of trace metals in ambient PM₁₀ at Tummalapalle uranium mining site

Allabaksh Murad Basha¹, Nookala Yasovardhan¹, Suggala Venkata Satyanarayana¹,
Gopireddy Venkata Subba Reddy², Aerattukkara Vinod Kumar³

¹ Department of Chemical Engineering, JNTUA College of Engineering, Anantapur, 515 002, Andhra Pradesh, India

² Department of Chemistry, JNTUA College of Engineering, Pulivendula, 516 390, Andhra Pradesh, India

³ Radiation Safety Division, BARC, 400 085, Mumbai, India

ABSTRACT

Trace metals (Ag, Al, As, Cd, Co, Cr, Cs, Cu, Fe, Mn, Ni, Pb, Se, Sr, Tl, U, V and Zn) in PM₁₀ were measured at 10 different sites in the surrounding areas of Tummalapalle Uranium Mining (India). The PM₁₀ samples were collected on glass fiber/EPM 2000 filter using high volume air samplers in 10 different sampling sites during November–2010 to February–2012. Trace metals in PM₁₀ were analyzed using Inductively Coupled Plasma Mass Spectrometer (ICP–MS). The observed trace metal concentrations varied from 0.01 to 2 640 ng/m³. It was found that metals associated with crustal sources like Al and Fe were in higher concentrations. The elements Tl, U, Cs and Co were found to be in very low concentrations. Obtained trace metal data in PM₁₀ were subjected to statistical analyses using correlation matrices and factor analysis to examine the interrelationship between the investigated trace elements and possible source identification of the elements. Enrichment factors of trace metals were also determined to determine the anthropogenic contribution to ambient PM₁₀. The daily intake of analyzed trace metals by the adult population in the surrounding of Tummalapalle Uranium mining (30 km radial distance) was estimated and it was found to be in the range of 1 to 13 401 ng/day through the inhalation route.

Keywords: ICP–MS, statistical analysis, enrichment factor, daily intake



Corresponding Author:

Suggala Venkata Satyanarayana

☎ : +91-98495-09167

☎ : +91-8554-272098

✉ : svsatya7@gmail.com

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1. Introduction

In view of importance of uranium in the generation of electricity, there is a rapid growth of uranium mining and processing activity in developing countries like India. Uranium mining and activity may discharge particulates (PM₁₀, TSP) containing various trace metals into the atmosphere through machinery usage, burning of fuel, ore transportation, chemical usage, constructional works, etc. Particulate matter is the carrier of many harmful trace metals (such as Ag, Al, As, Cd, Co, Cr, Cs, Cu, Fe, Mn, Ni, Pb, Se, Sr, Tl, U, V, Zn), and can be deposited into the human respiratory system (Limbeck et al., 2009). Exposure to trace metals can be in a variety of routes, inhalation of particulates is one of the important routes (Abulude et al., 2003; Leili et al., 2008). Hence, a great deal of research has been focused on the metal composition of the atmospheric suspended particulate matter (PM₁₀) (Bhuyan et al., 2010).

Trace metal content in PM₁₀ have been widely reported in the literature in various parts of the world (Abulude et al., 2003; Banerjee, 2003; Lopez et al., 2005; Karar et al., 2006; Senlin et al., 2007; Leili et al., 2008; Feng et al., 2009; Limbeck et al., 2009; Bhuyan et al., 2010). However, the data on the trace metals in PM₁₀ at the surroundings of the mining industry and activity in India are very limited.

The present work gives information about content of trace metals (Ag, Al, As, Cd, Co, Cr, Cs, Cu, Fe, Mn, Ni, Pb, Se, Sr, Tl, U, V,

and Zn) in ambient PM₁₀, likely contributing sources of release and anthropogenic activities in and around the surroundings of the mining area. The study also calculates the daily intake of the analyzed trace metals by the surrounding population through inhalation route and its comparison with the standard acceptable exposure intake limits (Nordberg et al., 2005).

2. Materials and Methods

2.1. Study area

The study area, Tummalapalle, an uranium underground mining site is located in Tummalapalle Village, Vemula Mandal of YSR district of Andhra Pradesh, India. The excavation site is located in latitudes 14°18'36" N and 14°20'20" N and longitudes 78°15'16" E and 78°18'03.3" E according to Survey of India (Toposheet numbers 57 J/3 and 57 J/7).

The sampling was carried out at ten locations, which are located within 30 km radial distance from the Uranium mining site. The sampling locations were fixed on the basis of wind roses and locations were distributed according to the radial distances from the site. Five locations (L–1 to L–5) were within 5 km, considered as Core Zone; three locations (L–6 to L–8) were in between 5–10 km, considered as Buffer Zone–1 and two locations (L–9 to L–10) were between 10–30 km, considered as Buffer Zone–2.

The sampling locations and its longitude and latitudes were determined using a GPS locator (Make: Janak Positioning and Surveying System Pvt. Ltd., India and Model: GPS-72H) and the values are given in the Table 1. The geographical distribution of the sampling locations is shown in Figure 1. The wind rose from the mining site collected during the sampling period (November–2010 to February–2012) is shown in Figure 2.

2.2. Materials and methods

All reagents used for the analysis were of analytical grade and Milli-Q water is used for all dilutions. Supra pure grade reagent (Merck, Germany) of nitric acid is used for the microwave digestion

of PM₁₀ samples. All the glass wares were cleaned by soaking in dilute nitric acid and were rinsed with distilled water prior to use.

2.3. Sample collection and analysis

The PM₁₀ samples were collected twice a month at 10 sampling locations in and around the vicinity of the excavation site during November–2010 to February–2012, covering all the seasons (i.e., winter, summer and monsoon). High Volume air sampler Model APM 460 BL (Envirotech Instruments Pvt. Ltd.) was used to collect the samples by running the equipment for a period of 24 hours at an average flow rate of 1.3 Lpm. PM₁₀ samples were collected by passing air on pre-weighted glass fiber (EPM 2000) filters (20.3 cm x 25.4 cm).

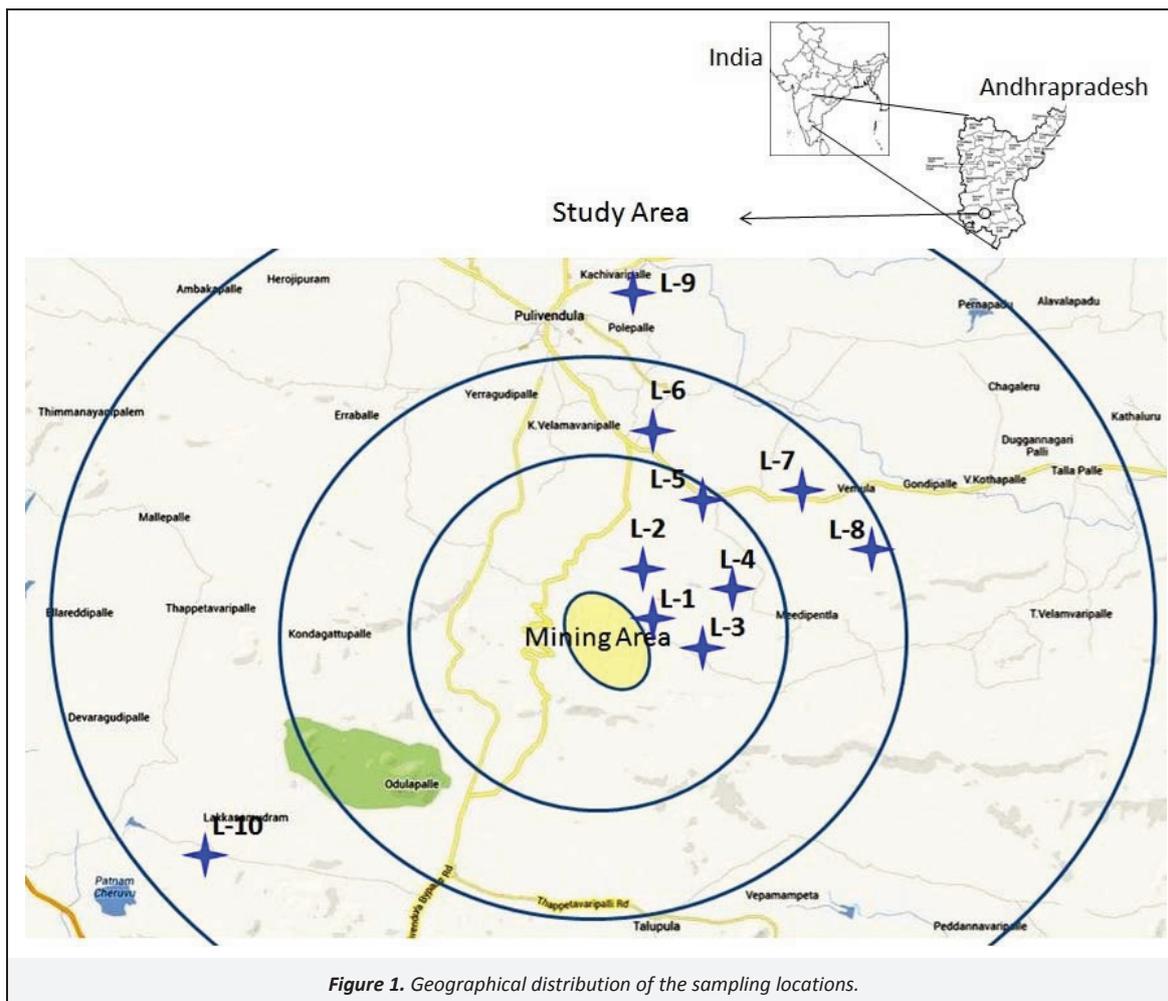
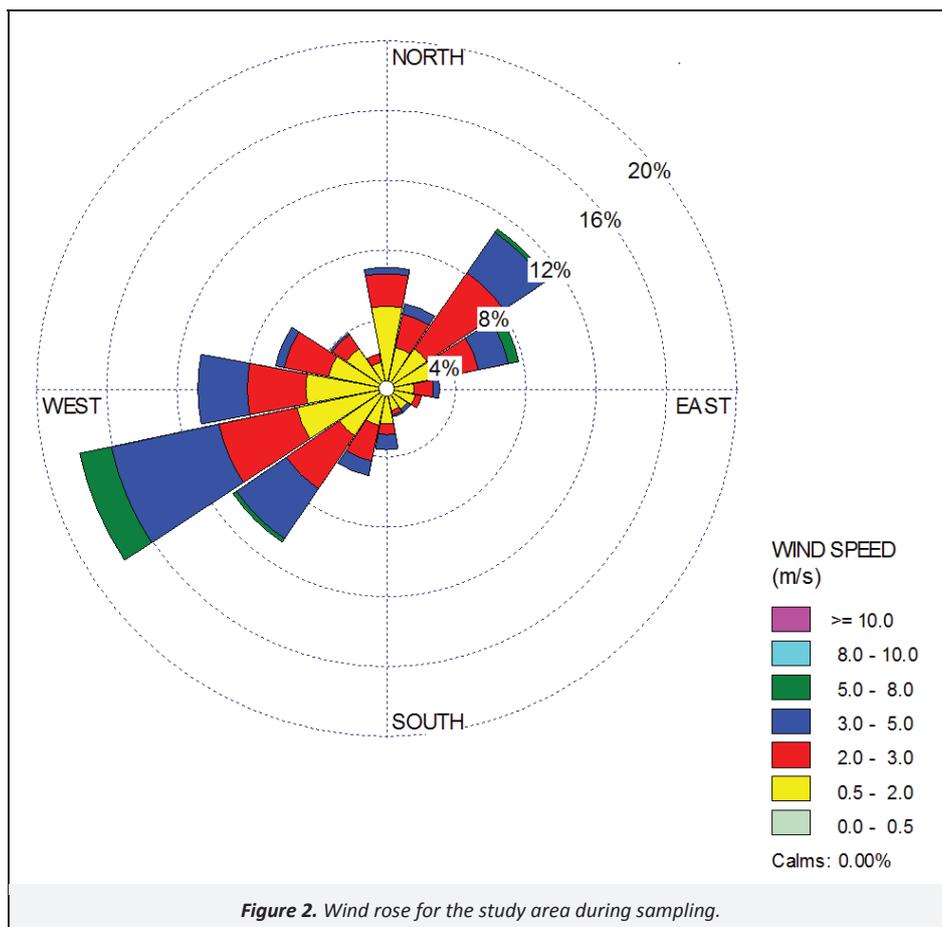


Figure 1. Geographical distribution of the sampling locations.

Table 1. Location names, latitudes/longitudes and distances from the mining site

S. No	Location	Zones	Distance from the Site (km)	Latitude/Longitude
1	L-1	Core Zone	0.53	14°19'09.25"N/78°16'08.22"E
2	L-2		1.17	14°19'37.61"N/78°15'20.28"E
3	L-3		3.74	14°18'24.12"N/78°17'46.38"E
4	L-4		3.93	14°19'50.64"N/78°18'05.94"E
5	L-5		4.55	14°21'52.14"N/78°16'11.76"E
6	L-6	Buffer Zone-1	6.64	14°22'56.58"N/78°15'11.94"E
7	L-7		7.85	14°22'14.46"N/78°19'13.26"E
8	L-8		9.90	14°22'10.44"N/78°21'29.46"E
9	L-9	Buffer Zone-2	14.28	14°26'55.74"N/78°14'04.50"E
10	L-10		17.70	14°10'49.68"N/78°11'30.06"E



The filter papers used for the collection of PM₁₀ were pre-conditioned (24 h in a desiccator under the conditions of temperature of 15–30 °C and humidity less than 40%). They were pre-weighed and after the particulates collected, the filter papers were reconditioned for another 24 h in the desiccator and weighed for particulate mass.

A closed vessel microwave digestion system (Anton Paar–Multiwave 3000) was used for the digestion of PM₁₀ collected filters. Prior to the use of Teflon sample vessels, they were sonicated for 15 min with 10% HNO₃ and finally rinsed with Milli-Q water. The PM₁₀ collected filters were digested with 10 ml of supra pure HNO₃ at the power range of 500 watts and 20 minutes hold time at a temperature of 120 °C. After digestion, the vessels were let for cooling and then the digested aliquot was transferred into 100 mL beaker. The digested aliquot was washed with 2 N supra pure HNO₃, filtered and made up to 50 mL in the standard flask. The trace metals in these processed PM₁₀ samples were estimated using Inductively Coupled Plasma Mass Spectrometer (ICP–MS, Agilent Technologies, Model No. 7700). The instrumental parameters for ICP–MS operation are given in Table 2.

Procedures for handling filter papers and Quality control were strictly followed to avoid any possible contamination. The quality assurance of the operation for the estimation of trace metals in PM₁₀ by ICP–MS has been assessed by calibrating the instrument using multi element calibration standard 2A (Lot No. 28–68 JB) obtained from Agilent Technologies. The robustness of the method was further ascertained by spike recovery and replicate analysis.

2.4. Statistics

The PM₁₀ associated trace metals data were statistically analyzed by XLSTAT add-in of the Microsoft Excel. Pearson

correlation coefficient and factor analysis were used to determine the interrelationship between investigated trace elements and possible source identification of the elements.

Table 2. Operating conditions for the analysis of trace metals by ICP–MS

Parameter	Value
RF Power (W)	1 500
RF Matching (V)	2.1
Sample depth (mm)	6.8
Carrier gas flow rate (L/min)	0.7
Make up gas flow rate (L/min)	0.57
Nebulizer pump rate (rps)	0.1
Data acquisition	Peak Hoping
Replicates	6

3. Results and Discussion

Descriptive statistics (minimum, mean and maximum) of PM₁₀ and associated trace elements for 10 different sampling locations (L–1 to L–10), comparison with standard regulatory bodies (WHO, 2000; ATSDR, 2002; NAAQS, 2006) and the literature reported values from various regions of India and from the world are given in Table 3. The analyzed PM₁₀ and trace metals are found in the range of 13–110 µg/m³ for PM₁₀; 9–2 640 ng/m³ for Al; <1–6 ng/m³ for V; <0.1–8 ng/m³ for Cr; <0.1–78 ng/m³ for Mn; 15–1 761 ng/m³ for Fe; <0.1–1.55 ng/m³ for Co; <1–17 ng/m³ for Ni; <0.1–32 ng/m³ for Cu; 6–340 ng/m³ for Zn; <0.1–5 ng/m³ for As; <1–3 ng/m³ for Se; <1–135 ng/m³ for Sr; <0.1–10 ng/m³ for Ag; <0.1–4 ng/m³ for Cd; <0.1–3 ng/m³ for Cs; <0.1–0.3 ng/m³ for Tl; <1–35 ng/m³ for Pb; and <0.1–0.6 ng/m³ for U.

It was observed that the concentrations of Al and Fe were much higher than that of other trace metals as these metals are associated with crustal sources (Lim et al., 2010) and they are likely to be contributed from the wind mineral dust from soil erosion. Whereas, the elements Tl, U, Co, and As had low concentrations since these are the least abundant elements in the earth's crust (Nordberg et al., 2005). As per simple comparison of metal concentrations by their scale and magnitude, the data can be grouped into four categories: (1) <math><10\text{ ng/m}^3</math>: V, Cr, Co, Cu, As, Se, Ag, Cd, Cs, Tl and U; (2) $10\text{--}100\text{ ng/m}^3$: Mn, Ni, Sr and Pb; (3) $100\text{--}1\,000\text{ ng/m}^3$: Zn; (4) >1 000 ng/m³: Al and Fe. The reported values of above categorized trace elements are comparable with values of standard regulatory agencies and values from various regions of India and the world reported in the literature. The highest concentration of Al (864 ng/m³), Fe (586 ng/m³), Co (0.4 ng/m³) and U (0.1 ng/m³) was observed at sampling location L-1. This location is very close to the mining area having activities like movement of vehicles, transportation of ore etc. The resuspension of dust on the soil may be the probable reason of observing high values of these elements at this location. The highest mean concentrations of Zn (170 ng/m³), Sr (32 ng/m³) and Ag (1 ng/m³) were observed at the sampling location L-2; Mn (18 ng/m³) and Se (0.6 ng/m³) at the sampling location L-4; V (2 ng/m³) and Cr (4 ng/m³) at the sampling location L-7; Ni (5 ng/m³), Cu (6 ng/m³), As (1 ng/m³), Cd (1 ng/m³), Cs (1 ng/m³), Tl (0.1 ng/m³) and Pb (17 ng/m³) at the sampling location L-8.

3.1. Seasonal pattern

Based on the trace metal results derived for individual samples, monthly concentration averages were calculated, which were used for the construction of the seasonal pattern of trace metals. The seasonal patterns of all investigated trace metals are shown in Figure 3. Interpreting the derived results, distinct differences were observed for the individual components. Interestingly

the trace elements Cd, Pb, Cs and Sr exhibit comparable results and showing higher concentrations in the monsoon season. The seasonal pattern of the elements Al, V, Fe, Mn, Cu and Ag showed high concentrations in winter and summer and low concentrations in monsoon. The elements Cr, Ni, Co, Se, and As, showed a seasonal pattern in the order of summer>winter>monsoon. It has been observed that the locations L-1, L-2, L-7 and L-8 showed elevated levels of Al, Fe and Zn during winter and summer. This is because of the location L-1 and L-2 are situated in the core zone and expecting the pollution load from the mining area having activities like movement of vehicles, transportation of ore, etc. The location L-7 and L-8 is situated in the buffer zone and beside the Kadapa–Pulivendula highway, catering to huge vehicular movement. In addition to the above, the existing stone crushing mills near the location adding extra pollution load. Further, the resuspension of dust on the soil may be the probable reason of getting high values of these elements at this location. It has been observed that the concentrations of the trace metals at the location L-10 are showing low levels in all the seasons. This may be mainly due to the fact that the location is situated far away from the mining site as well as road side activity, and it is situated at one side of a hill.

3.2. Correlation analysis

A linear regression correlation analysis was performed to investigate the correlation between all the trace metals in PM₁₀ under consideration and to identify the possible sources contributing to PM₁₀. The values of correlation coefficients (significant at *P*<0.1) pertaining to the PM₁₀ and trace elements are given in Table 4. Al, V, Cr, Mn, Fe, Co and Ni correlated well with each other as shown in the triangular matrix (Table 4). This correlation pattern indicates that the metals Al, V, Cr, Mn, Fe, Co and Ni are mostly derived from the same source. According to the Goldschmidt's classification (Nordberg et al., 2005; White, 2013), these metals are

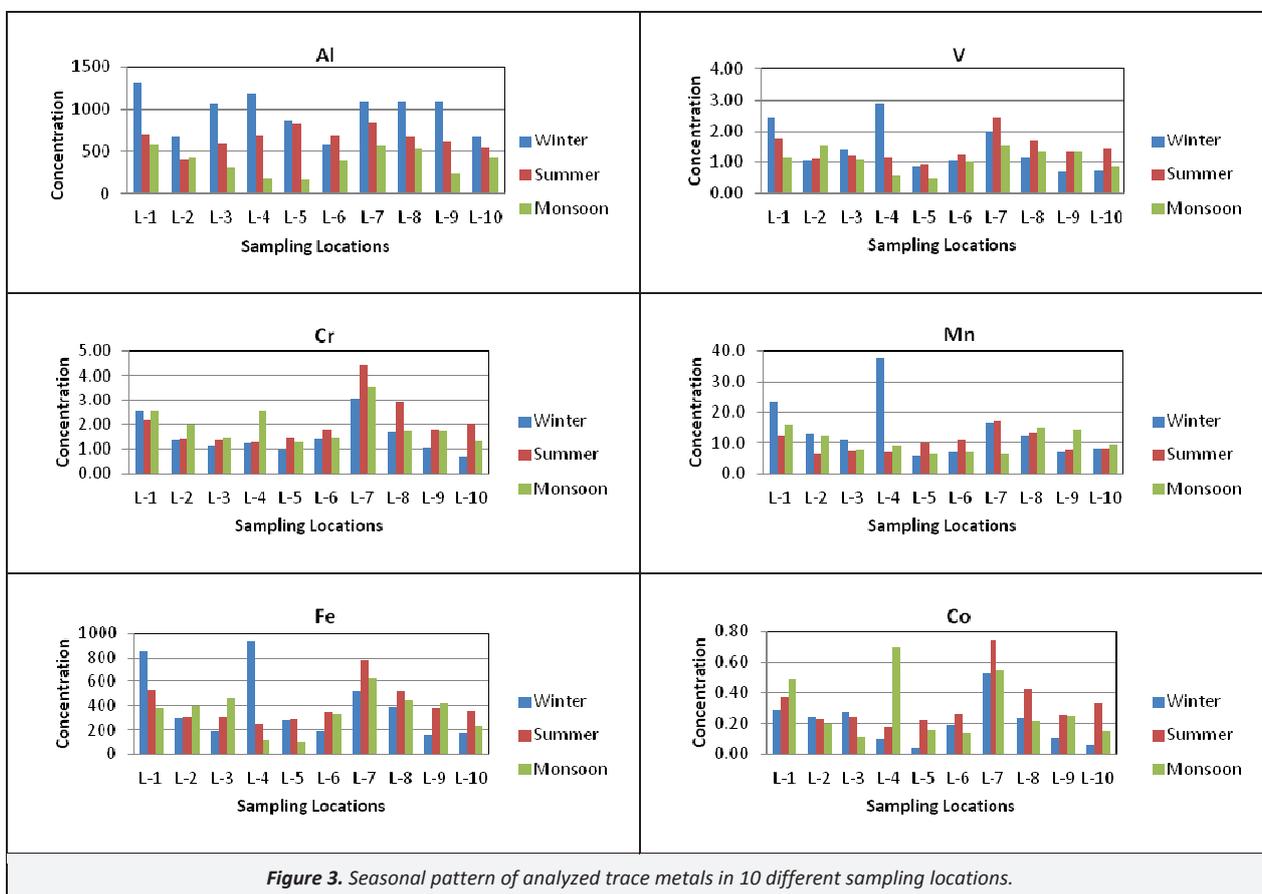


Figure 3. Seasonal pattern of analyzed trace metals in 10 different sampling locations.

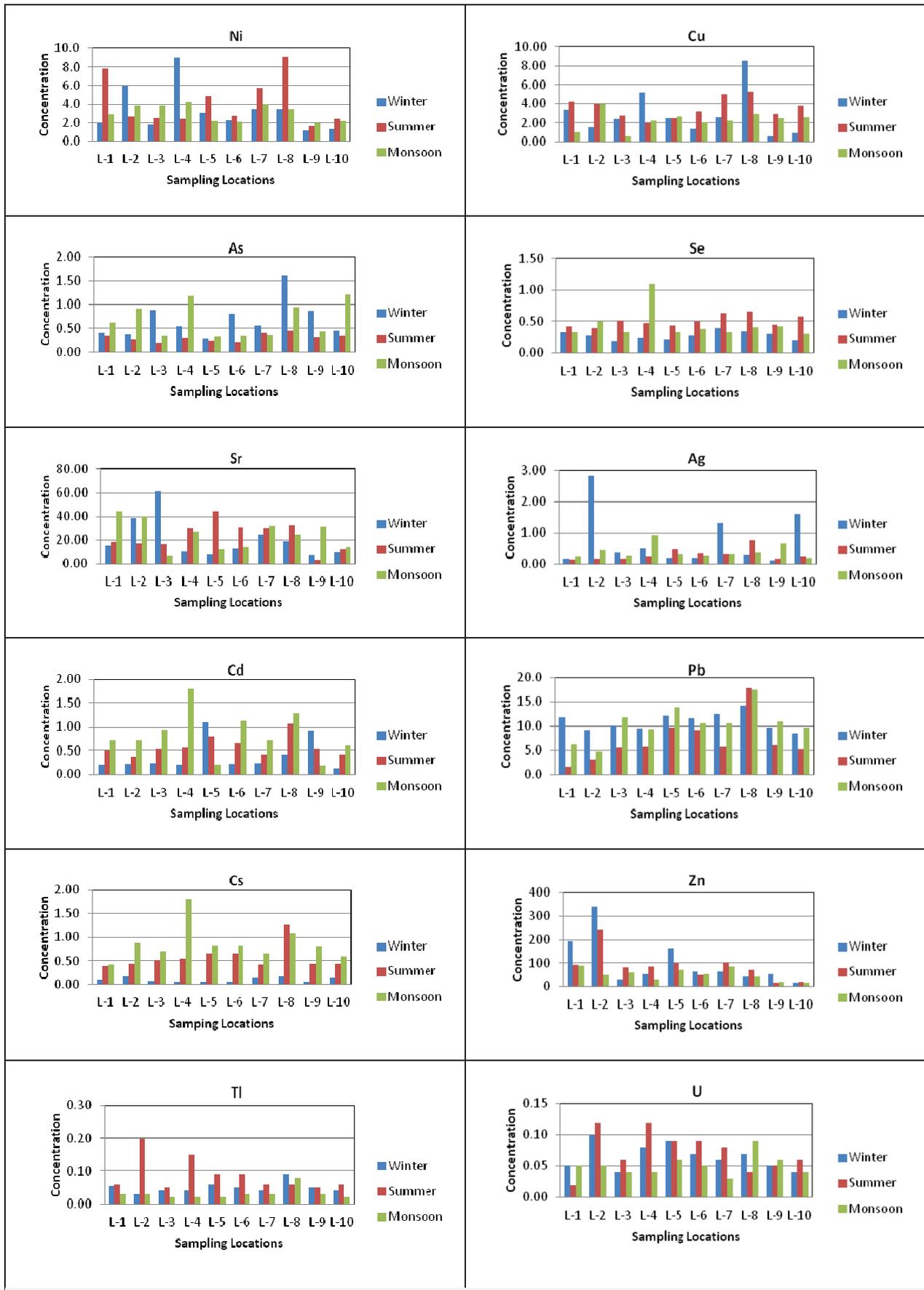


Figure 3. Continued.

classified as Lithophile, which are more concentrated in the crust and mantle of the earth and are the first series of the transition metals in the periodic table. Hence, these are likely to be contributed from windblown soil particulates. Also significant correlations were observed between Al–Se (0.5), Al–Sr (0.6), Al–Cd (0.6), Al–Cs (0.5), Al–U (0.5), V–Se (0.7), V–Sr (0.5), V–U (0.6), Cr–Zn (0.5), Cr–Se (0.5), Cr–Sr (0.5), Cr–U (0.5), Mn–Cd (0.5), Mn–Cs (0.5), Mn–U (0.5), Fe–Se (0.6), Fe–Sr (0.5), Fe–Cs (0.5), Fe–U (0.7), Co–Se (0.6), Co–Sr (0.5), Co–U (0.5), Ni–Cu (0.5), Ni–Zn (0.5), Ni–Se (0.5), Ni–Ag (0.5), Ni–Cs (0.5) and Ni–U (0.5). Significant correlations were also observed between Cu–As (0.6); Zn–Sr, Se, Cs (0.6, 0.5, 0.5); Se–Cd, Cs, Tl, U (0.7, 0.7, 0.6, 0.6); Sr–Ag, Cs, U (0.5, 0.5, 0.5); Cd–Cs, Tl, Pb, U (0.9, 0.7, 0.6, 0.7); Cs–Tl, Pb, U (0.7, 0.5, 0.7) and Tl–U (0.6). The metals Cu, Zn, Se, Sr, Cd, Cs, Tl and U are generally contributed by anthropogenic activities and may be due to vehicular emissions, metal corrosion, etc. According to Goldschmidt’s classification (Nordberg et al., 2005; White, 2013), these metals are classified as Chalcophile. These metals have an affinity towards sulfide liquids and these metals are mainly distributed into group 11, 12 and heavier group 13–16 in the periodic table. Among all the trace metals Ag, As, and Pb have not demonstrated any significant association with other metals. They indicate independent variations and this can be attributed to the multisource origin for the atmospheric PM₁₀.

3.3. Factor analysis

Analyzed trace metals data were subjected to factor analysis in order to get interrelation between trace metals and source apportionment of PM₁₀ and trace metals (Bruno et al., 2001; Guo et al., 2004; Shaheen et al., 2005; Karar et al., 2006; Senlin et al., 2007; Shah and Shaheen, 2007). Three factors obtained by factor analysis (significant at P≤0.1) are given in Table 5. The maximum variability (39.82%) was contributed by Factor 1, which has higher principal loadings for PM₁₀ (0.5), Al (0.7), V (0.9), Cr (0.7), Mn (0.9), Fe (0.9), Co (0.8), Ni (0.9), Cu (0.7), Se (0.6), Sr (0.6) and U (0.6). This demonstrates the evidence that Al, V, Cr, Mn, Fe, Co, Ni, Cu, Se, Sr and U in PM₁₀, they are likely to be contributed from one source, probably emitted by the wind–blown mineral dust from soil erosion (Zhang et al., 2003; Moreno et al., 2004; Shaheen et

al., 2005; Shah and Shaheen, 2007). The second factor (F2) showed 23.32% variability and higher loadings of As (0.6), Cd (0.8), Cs (0.9), Tl (0.6) and Pb (0.6). These metals are originated from automobile emissions and industrial emissions (Karar et al., 2006; Senlin et al., 2007). A third factor (F3) with 14.64% variability showed high loadings of Zn (0.8) and Ag (0.8). Particulate Zn in PM₁₀ is originated from automobile sources like wear and tear of vulcanized rubber tires, lubricating oil and corrosion of galvanized vehicular parts (Banerjee, 2003; Karar et al., 2006).

3.4. Enrichment factors

The enrichment factors (EF) estimate the contribution of anthropogenic emissions to ambient atmospheric elemental levels in PM₁₀ over and above the natural crustal contribution (Lopez et al., 2005; Feng et al., 2009; Lim et al., 2010; Rovira et al., 2011). The choice of the reference element for the estimation of EF is mostly Fe, Al and Si. In this study, Fe was taken as the reference element. The crustal trace elements and reference element values are taken from an upper continental crustal composition given by Taylor and McLennan (Taylor and McLennan, 1985).

$$Enrichment\ Factor\ (EF) = \frac{(X/R)_{Air}}{(X/R)_{Crust}} \tag{1}$$

where, X is the trace element concentration and R is the reference element concentration. If the EF is close to unity, the crust is the predominant source. The logarithmic plot of Enrichment factors (EF) at the study area is depicted in Figure 4. According to analysis of the data, the sequence of EF at the study area was: Pb>Ag>Cd>Se>Zn>As>Cu>Sr>Cs>Ni>Tl>U>Cr>Co>V>Mn>Al. Pb, Ag and Cd elements with a toxic character and representing the group called highly enriched elements showed the highest EFs, which is in the range of 10³–10⁴. This suggested that non–crustal sources predominate and a variety of pollutant emissions like fossil fuel combustion, vehicular exhaust, incineration, construction, stone mills, industrial processes, mining activities, etc., contribute to atmospheric PM₁₀.

Table 4. Linear Regression Correlation coefficients [®] between the trace metal concentrations in PM₁₀ (values in bold are significant at P<0.1)

	PM ₁₀	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Ag	Cd	Cs	Tl	Pb	U	
PM ₁₀	1.0																			
Al	0.5	1.0																		
V	0.4	0.6	1.0																	
Cr	0.4	0.6	0.8	1.0																
Mn	0.2	0.7	0.5	0.6	1.0															
Fe	0.5	0.7	0.9	0.8	0.6	1.0														
Co	0.3	0.6	0.9	0.9	0.5	0.9	1.0													
Ni	0.3	0.3	0.5	0.5	0.3	0.6	0.6	1.0												
Cu	0.3	0.3	0.4	0.4	0.3	0.4	0.5	0.5	1.0											
Zn	0.2	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.2	1.0										
As	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.3	0.6	0.2	1.0									
Se	0.3	0.5	0.7	0.6	0.4	0.6	0.6	0.5	0.3	0.5	0.3	1.0								
Sr	0.2	0.6	0.5	0.5	0.4	0.5	0.5	0.4	0.3	0.6	0.2	0.4	1.0							
Ag	0.2	0.2	0.3	0.4	0.2	0.3	0.3	0.5	0.2	0.4	0.2	0.2	0.5	1.0						
Cd	0.2	0.6	0.4	0.4	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.7	0.4	0.1	1.0					
Cs	0.1	0.5	0.4	0.4	0.5	0.5	0.4	0.5	0.3	0.5	0.2	0.7	0.5	0.1	0.9	1.0				
Tl	0.1	0.4	0.4	0.2	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.6	0.3	0.1	0.7	0.7	1.0			
Pb	0.1	0.4	0.2	0.4	0.3	0.3	0.3	0.3	0.1	0.3	0.2	0.4	0.4	0.2	0.6	0.5	0.3	1.0		
U	0.2	0.5	0.6	0.5	0.5	0.7	0.6	0.5	0.4	0.3	0.2	0.6	0.5	0.2	0.7	0.7	0.6	0.4	1.0	

Upper triangular matrix shows the Lithophile elements.

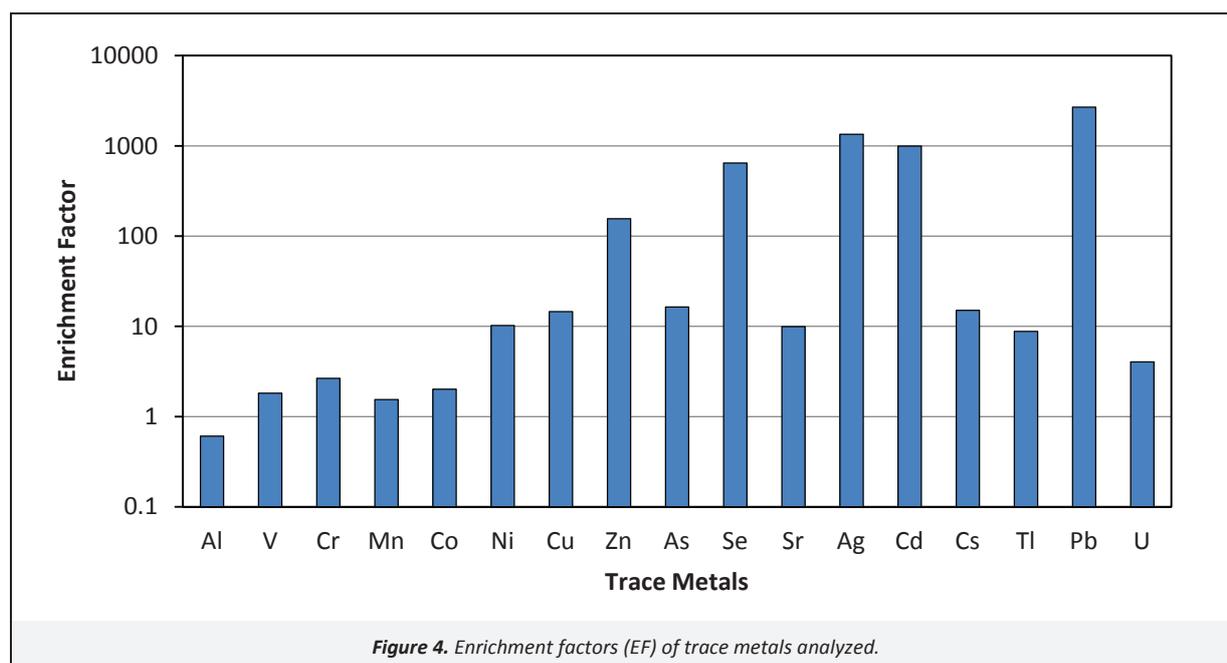


Figure 4. Enrichment factors (EF) of trace metals analyzed.

Table 5. Principal Component (significant at $P \leq 0.1$) analysis of trace metals

	Factor 1 (F1)	Factor 2 (F2)	Factor 3 (F3)
PM ₁₀	0.5	-0.5	0.4
Al	0.7	-0.3	-0.5
V	0.8	-0.5	-0.1
Cr	0.7	-0.5	-0.2
Mn	0.9	-0.1	-0.1
Fe	0.9	-0.4	-0.1
Co	0.8	-0.5	-0.2
Ni	0.9	0.3	0.1
Cu	0.7	0.5	-0.1
Zn	0.5	0.1	0.8
As	0.4	0.6	-0.2
Se	0.6	0.4	0.0
Sr	0.6	-0.2	0.4
Ag	0.2	0.1	0.8
Cd	0.3	0.8	-0.3
Cs	0.4	0.9	0.0
Tl	0.4	0.6	0.6
Pb	0.1	0.6	-0.5
U	0.6	0.2	0.00
Eigen values	7.6	4.4	2.8
Variability (%)	39.8	23.3	14.6
Cumulative (%)	39.8	63.1	77.8

Bold values shows the significant values

Ni, Cu, Zn, As, Se, Cs, Tl and Sr showed EF values in the range of 10^{-1} – 10^3 . These represent a group of moderately enriched elements. This group also suggests contribution from the non-crustal sources although to a lesser extent. The low enriched elements are Al, V, Cr, Mn, Co, Ni and U, which showed EFs in the range of 10^{-1} – 10^1 . This indicates that they have mainly originated from crustal sources like crustal soil, resuspended soil and mining ore.

3.5. Daily intake of trace metals

The daily intake of trace metals through inhalation is calculated based on the assumption of 20 m^3 of air intake per day by an adult (Tripathi et al., 1998; Tripathi et al., 2002). The daily intake of

trace metals with their permissible exposure intake limits and percentages of contribution are tabulated in Table 6. The daily intake values were $13.4 \mu\text{g/day}$ for Al; 26.3 ng/day for V; 37.0 ng/day for Cr; $0.23 \mu\text{g/day}$ for Mn; $7.7 \mu\text{g/day}$ for Fe; 5.5 ng/day for Co; 70.9 ng/day for Ni; 58.7 ng/day for Cu; $1.5 \mu\text{g/day}$ for Zn; 11.1 ng/day for As; 8.2 ng/day for Se; $0.5 \mu\text{g/day}$ for Sr; 9.8 ng/day for Ag; 12.3 ng/day for Cd; 10.2 ng/day for Cs; 1.1 ng/day for Tl; $0.2 \mu\text{g/day}$ for Pb and 1.6 ng/day for U. The percentage contribution through inhalation route on daily permissible exposure limit of intake (Nordberg et al., 2005) for the trace metals is in the range of 0.01–0.11%. Cr and U have been observed to contribute 0.11%, over the daily permissible exposure limit of intake. Mn, Co, Cu, As, Se and Pb has a lesser percentage of contribution, about 0.01%.

4. Conclusion

The present study investigated the baseline survey of eighteen trace metals associated with PM₁₀, carried at 10 different sampling locations in and around the vicinity of the Tummalapalle uranium mining site, India. Trace metal concentrations obtained in the present study in PM₁₀ samples were found to be acceptable and are within the permissible limits as compared with the standard regulatory bodies (WHO, 2000; ATSDR, 2002; NAAQS, 2006). It has been observed that the locations in core zone (L-1 and L-2), buffer zone (L-7 and L-8) showed high levels of PM₁₀ and its associated trace metals when compared to other sampling locations whereas, the location L-10 is showed low levels of PM₁₀ and its associated trace metals. The seasonal pattern of the trace metals at 10 different sampling locations (L-1 to L-10) is in the order of summer > winter > monsoon. Based on correlation and factor analysis, it was indicated that the trace metals Al, V, Cr, Mn, Fe, Co and Ni are likely to be contributed from windblown soil particulates. Also Cu, Zn, Se, Sr, Cd, Cs, Tl, and U are likely to be contributed by various automotive and industrial emissions, both due to anthropogenic activities. Pb, Ag, and Cd showed high enrichment values, suggesting that non-crustal sources predominate and a variety of emission sources like fossil fuel combustion, vehicular exhaust, incineration, construction, stone grinders, industrial processes and mining activities contribute to PM₁₀ variability. According to the daily intake estimations, the percentage of trace elements contribution through inhalation route is in the range of 0.01–0.11% of the daily permissible exposure intake limit.

Table 6. Daily intakes of trace metals through inhalation route and % contribution to permissible exposure limit

Trace Metal	Intake through inhalation of PM ₁₀	Permissible exposure limit of intake (Nordberg et al., 2005)	% Contribution from inhalation route
Al	13.4 µg/day	60 mg/day	0.02
V	26.3 ng/day	50 µg/day	0.05
Cr	37.0 ng/day	35 µg/day	0.11
Mn	0.2 µg/day	4.1 mg/day	0.01
Fe	7.7 µg/day	15 mg/day	0.05
Co	5.5 ng/day	50 µg/day	0.01
Ni	70.9 ng/day	0.1 mg/day	0.07
Cu	58.7 ng/day	2.5 mg/day	0.01
Zn	1.5 µg/day		
As	11.1 ng/day	0.37 mg/day	0.01
Se	8.2 ng/day	55 µg/day	0.01
Sr	0.5 µg/day		
Ag	9.8 ng/day	44 µg/day	0.02
Cd	12.3 ng/day	60 µg/day	0.02
Cs	10.2 ng/day		
Tl	1.1 ng/day	2.0 µg/day	0.06
Pb	0.2 µg/day	32 µg/day	0.01
U	1.6 ng/day	1.5 µg/day	0.11

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