Journal of Advanced Scientific Research

Available online through https://sciensage.info

ISSN
0976-9595
Research Article

Evaluation of Some Heavy Metals Loading During Summer and Winter in Free Fall Atmospheric Dust Nearby Coal-Fired Power Plant in an Industrial City Kota, Rajasthan

Bharat Singh Meena[1], Chetan Meena[1], Adhiraj Singh Shekhawat[2], Uttra Chandrawat[1], Manju Meena[1*]

[1]*Department of Chemistry, Government College, Kota, Rajasthan, India.*

[2]*Department of Computer Science and Engineering, Manipal University Jaipur, Jaipur, Rajasthan, India.*

*Corresponding author: meenamanju87@gmail.com

Received: 08-03-2025; Accepted: 13-04-2025; Published: 29-04-2025

https://doi.org/10.55218/JASR.2025160405

ABSTRACT

In this study, 376 free-fall atmospheric dust samples were collected at 47 sampling locations in the industrial city of Kota, India, to examine variation in average concentrations of heavy metals in the summer and winter months. For anthropogenic heavy metals (Cu, Cd, Zn, and Pb), average concentrations were higher in the winter and lower in the summer. The opposite pattern was seen for crustal metals (Fe and Ca). In both seasons, the average concentrations of heavy metals were in the order Zn > Pb > Cu > Cd. Variations in temperature, relative humidity, wind direction, wind strength, and human activity at sampling locations were the causes of seasonal variations in metal concentrations. Coal combustion at thermal power plants is the common source of anthropogenic metal species as indicated by the enrichment factor and positive correlation between Cu and Cd, Cu and Zn, Cu and Pb, Cd and Zn, Cd and Pb, in both seasons.

Keywords: Free fall atmospheric dust, Heavy metals, Correlation coefficients, Wind direction, Enrichment coefficients.

INTRODUCTION

Free fall atmospheric dust is a complex heterogeneous mixture of solid and liquid components such as those from power plants and industries, gas flaring, motor vehicles and natural source elements such as dust.[1-3] Dust can be defined as matter or particulate in the form of fine powder lying on the ground or on the surface of objects or blown about by the wind. Pollutants found in dust include heavy metals, biological material, and polycyclic aromatic compounds.[4]. They are kept suspended in air or transported from sources by wind and can travel long distances across regions and continents, transferring contaminants to ecosystems.[5]

Through a variety of human activities, these heavy metals enter the environment, impact the quality of the air, and then get incorporated with dust particles to deposit themselves on the earth's surface and in vegetation during rainfall.[6]

Consequently, due to the wind speed or the precipitation of the heavens, they will remain in the human being's life cycle.[7] Metals like Pb, Cd, Cu, and Zn are dangerous pollutants that can be gathered in the human body with a relatively long half-life, leading to skin diseases and types of cancer in different forms.[8-10]

The Kota thermal power plant (KTPP) in Kota City produces tons of fly ash, a uniform mixture of various metallic oxides. Considering the fact that the smallest particles of fly ash are enriched with heavy metals, making it a potential source of pollution for the atmosphere, the situation of heavy metal pollution in Kota city is alarming.[11-14] The concentration of heavy metals is further increased by several Kota stone manufacturers as well as other small and major businesses.

Therefore, the present study was conducted, with the main objectives being: (1) to determine the composition of free fall atmospheric dust in terms of crustal (Fe, Ca) and anthropogenic (Cu, Cd, Zn and Pb) metals at various sampling sites located in various sampling sites; (2) to identify possible sources of heavy metals associated with free fall atmospheric dust using enrichment factor and Pearson correlation coefficient; (3) to study the effect of climate on the concentration levels of heavy metals as a function of sampling sites, distance from KTPP, seasons and meteorological parameters such as temperature, relative humidity, wind speed and wind direction.

MATERIALS AND METHODS

Study Area

Located on the eastern bank of the Chambal River at 25°11 N and 75°51 E, Kota is a large industrial city in south Rajasthan with a temperature range of 4.4 to 46.6°C. Additionally, the Kota thermal power plant is one of the primary hubs for the production of electricity.

Since more than 200 stone units get mined, cut, and polished to produce the well-known Kota stone, the region also generates a generous amount of slurry, primarily made up of Ca, Mg, and Si oxides.[15]

Free Fall Atmospheric Dust Collection and Analysis

A total of 47 sampling locations were selected using the Global Positioning System in accordance with certain standards.[16] The locations of all the Kota City sampling sites selected for this investigation are displayed in Fig. 1.

Using the global positioning system, 47 sampling sites were chosen based on standard criteria. Fig. 1 shows the locations of sampling sites in Kota City chosen for this study. The 47 locations selected from Kota City were sampled in the summer (March, April, May, and October 2022) and winter (November 2022 to February 2023) months. A total of 376 free-fall atmospheric dust samples were collected (47 samples times 8 sampling months).

In all sampling sites, dust samples falling freely due to gravity were gathered on 1-m^2 plastic trays at a height of 6 meters above the ground. Since there was no rain during the sampling period, all of the free-fall atmospheric dust samples gathered here only represent dry fallout. Dry depositions were scraped off the trays following sampling, and the trays were then cleaned with milli-Q water to remove any remaining particles. The scraped samples were combined with the residue following gradual evaporation of water at 50°C.[17] Samples were then digested in preparation for analysis.

Total Heavy Metal Digestion

The samples were digested for subsequent procedures after passing through 300 BSS (< 53 μm) sieves. Since metal levels in dust vary according to the nature of their existence, the nitric acid digestive procedure was used to extract out only the HNO_3 soluble fraction was extracted.[17,18] The Shimadzu Atomic Absorption Spectrophotometer AA-6300 was then used to measure iron, zinc, copper, cadmium, and lead, and a flame photometer made by Systronics-128 was used to measure calcium. The use of internal standards monitored the precision and accuracy of the analysis, verified reference material, and quality control blanks.

Monitoring of Meteorological Parameters

The weather data shown in Table 1 and Fig. 2 were provided by the Automated Meteorological Centre (DCPAWS02) throughout the measurement period (summer and winter season). Hourly data was captured and averaged across the samplers' 24-hour operation period.

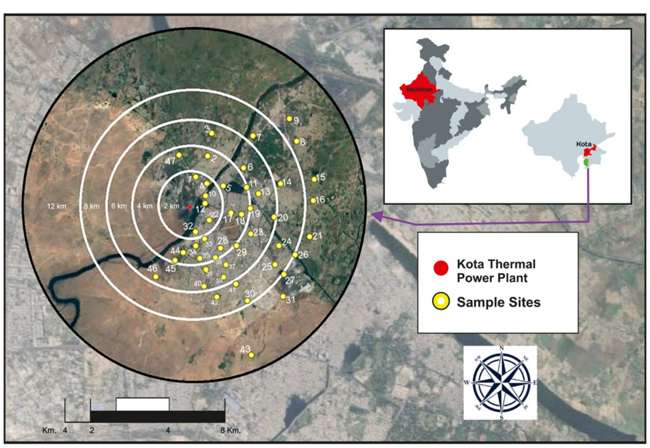


Fig. 1: Kota City sampling locations in the study area.

Statistical Analysis

MS-Excel 2021 was used to calculate the metal concentration statistics in free-fall atmospheric dust. Using SPSS 22.0, the data were subjected to principal component analysis with varimax rotation, enrichment factor analysis, and Pearson correlation analysis.

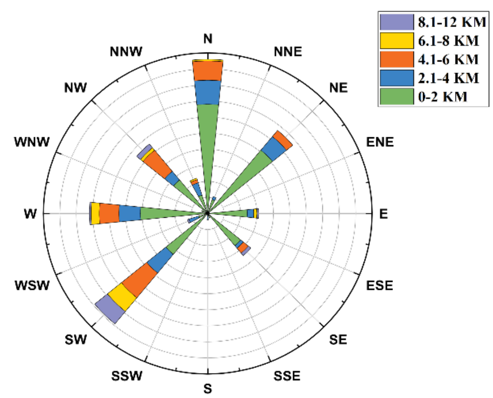
RESULT AND DISCUSSION

Heavy Metals Concentration During Summer and Winter Months

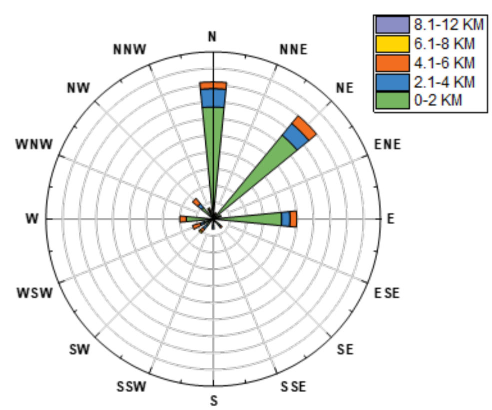
The average concentrations of all the analyzed metals (Cu, Pb, Cd, Zn, Ca and Fe)of environmental concern in free fall atmospheric dust collected at 47 sampling sites in the summer and winter months are given in Figs 3-6. We see changes in the elemental concentration as a function of wind velocity (speed and direction), sampling locations and their distance from emission sources.

Table 1: Meteorological conditions all through the study period

Meteorological conditions	*Summer*	*Winter*
Temperature (°C)	31.64 ± 12.85	19.4 ± 14.00
Relative humidity (RH) (%)	38.31 ± 15.26	59.28 ± 9.165
Wind speed (km/h)	1.7 ± 1.2	0.75 ± 0.36
Rainfall (mm)	1.61	0.258



(a)



(b)

Fig. 2: Wind rose in the study area all through the sample collection in (a) summer and (b) winter months

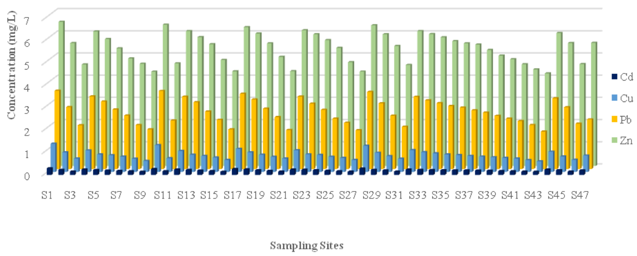


Fig. 3: The average concentrations of Cu, Pd, Cd and Zn in summer months

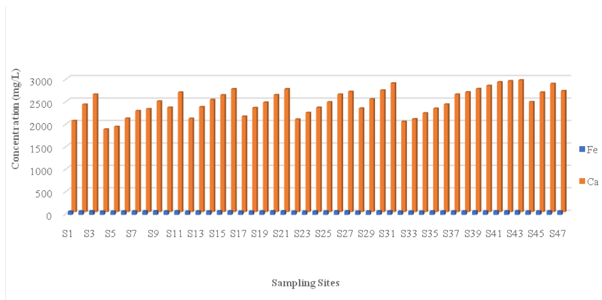


Fig. 4: The average concentrations of Ca and Fe in summer months

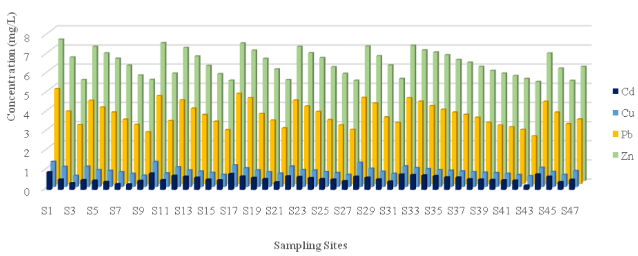


Fig. 5: The average concentrations of Cu, Pd, Cd and Zn in winter months

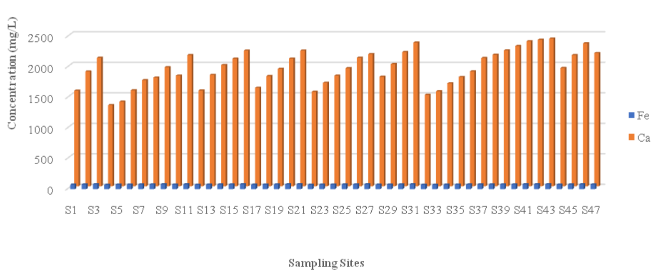


Fig. 6: The average concentrations of Ca and Fe in winter months

Due to the presence of a coal-based thermal power plant, S_1 had the highest average concentrations of anthropogenic metal species (Cu, Pb, Cd and Zn) among all sampling sites in both seasons, while S_{43}, having the fewest anthropogenic sources, had the lowest concentrations of all the metal species measured in both seasons.

North direction (21.20 and 26.97% in summer and winter seasons) of wind blow from KTPP encourages the worrying level of heavy metals in the study region present in fly ash. In all sampling sites, the relative abundances of these heavy metals in free-fall atmospheric dust samples are in the following order: Zn > Pb > Cu > Cd. Pb particles in roadway dust, accumulated from previous vehicle exhaust for a long time due to their high residence time in the environment may be the cause of their high concentration even when lead-free gasoline is used.[19] The average concentrations of all the analyzed metals showed seasonal fluctuation that varied by metal species but were generally constant across sites.

Concentrations of anthropogenic metal species Cu, Pb, Cd and Zn were greater in the winter and lower in the summer at all sampling sites, whereas those of crustal metals, such as Ca and Fe, were lower in the winter and higher in the summer. The two seasons, summer and winter, have different concentration levels, which can be attributed to variations in the weather.

Anthropogenic metal species were found in higher concentrations in ambient air in Kota city during the winter, when average temperatures were low (19.4°C) with high relative humidity (59.28%), and low wind speed (0.75 km/h). In contrast, high temperature (31.64°C), low relative humidity (38.31%), and high average wind speed (1.7 km/h) during summer resulted in lower concentrations of anthropogenic metal species (Table 1).[20]

Since coarse particles are affected by gravity, the high wind strength in the summer causes deflation or entrainment and the movement of crustal metals [21], while the wind strength, which may move these metals, decreases considerably in the winter. Additionally, winter's steady and cold weather prolongs the life of ambient particles in the atmosphere and raises the concentrations of heavy metals in free-falling atmospheric dust. The current study's findings are consistent with those of past research conducted in India[22, 23] and other nations.[24, 25]

Pearson Correlation Coefficient

To predict the possibility of a common source, the concentration of the element was used to calculate the Pearson correlation coefficient (r) in the summer and winter (Table 2). Calcium and iron were shown to have significant positive relationships, suggesting a common source, which may be natural soil. Likewise, a strong positive association between Cu and Zn, Cu and Pb, and Cu and Zn in both seasons indicates a common source or point source KTPP, primarily in addition to other industrial operations.

Enrichment Factor

Finding out if an element has an additional or man-made source in addition to its primary or natural source is made easier by calculating the enrichment factor (EF). Assuming that the contribution of its anthropogenic sources to the atmosphere is minimal, calcium (Ca) has been chosen as a reference element for an EF evaluation.[26] The EF calculation formula employed in this work is as follows:

$$EF = \frac{\left(\frac{X}{C}\right)_{\text{indoor dust}}}{\left(\frac{X}{C}\right)_{\text{earth crust}}} \quad \text{----------------} \quad (I)$$

Where x is the concentration of the ion of interest and c is the concentration of the reference ion. An EF > 5 suggests that a significant portion of the element can be ascribed to non-crustal or human sources, whereas an EF value close to unity shows that

Table 2: Correlation coefficients between concentrations values of analyzed metals in free fall atmospheric dust in Kota city (significant at 5% level)

		Summer	*winter*			
Metal	*Cu*	*Pb*	*Cd*	*Zn*	*Ca*	*Fe*
Cu	1.000	0.735	0.444	0.795	-0.452	-0.373
Pb	0.831	1.000	0.734	0.883	-0.357	-0.293
Cd	0.835	0.815	1.000	0.626	-0.251	-0.343
Zn	0.790	0.859	0.792	1.000	-0.454	-0.338
Ca	-0.418	-0.555	-0.530	-0.610	1.000	0.784
Fe	-0.535	-0.522	-0.718	-0.481	0.494	1.000

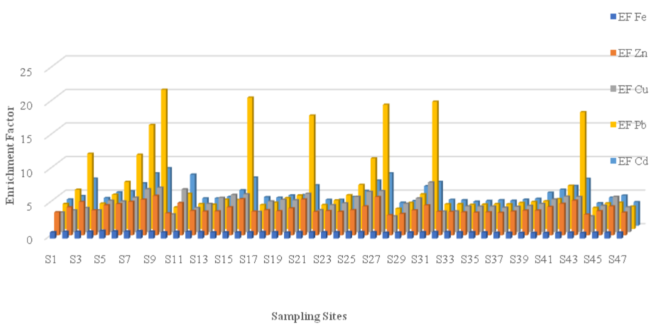


Fig. 7: Enrichment factor of Cu, Pd, Cd, Zn and Fe in summer months

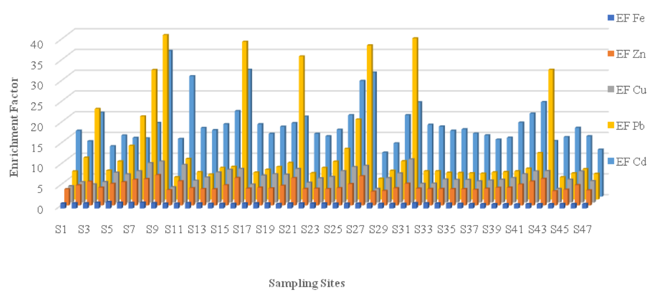


Fig. 8: Enrichment factor of Cu, Pd, Cd, Zn and Fe in winter months.

crustal sources predominate.[27] Based on the average seasonal metal concentration of heavy metals found in free fall atmospheric dust gathered from the 47 sampling sites, Figs 7 and 8 display the seasonal mean enrichment factors (EFs) during summer and winter, respectively.

Pb had the greatest EF values, followed by Cd, Cu and Zn, all of which had EFs significantly more than 5. This suggests that there was significant anthropogenic contamination in the collected dust samples. The transport of fly ash from coal combustion activity from point source KTPP and steady, cold weather conditions may be the cause of the higher EF values of metals (Cu, Cd, Zn, and Pb) in the winter as compared to summer.

CONCLUSION

It is concluded that the concentrations of all anthropogenic metal species (Cu, Cd, Zn and Pb)were highest in S_1, which is located within 2 Km radii from point source KTPP, while lowest in S_{43}, mainly a residential area, located far away from thermal power plant and having comparatively low traffic load in both summer and winter seasons. Concentrations of anthropogenic metal species are found higher in winter and lower in summer, while a reverse trend is observed for crustal metal species. The high enrichment coefficients and positive correlations showed that heavy metals viz. Cu, Cd, Zn and Pb have similar origin sources in the city and particularly can be related to point source coal-based thermal power plants besides other industrial activities and traffic load. In view of the warning level of heavy metals in the city environment, there is an urgent need to maintain the receptive capacity of the atmosphere by adopting proper abatement procedures by the industrial and mining sectors to maintain a healthy environment to breathe.

Anthropogenic metal species concentrations are higher in the winter and lower in the summer, while crustal metal species concentrations show the opposite trend. High enrichment coefficients and positive correlations demonstrated that heavy metals Cu, Cd, Pb and Zn have similar point sources, predominantly coal-based thermal power plants, besides other industrial activities and traffic loads. The industrial and mining sectors must immediately adopt appropriate abatement measures to maintain the atmosphere's receptive capacity in order to maintain a healthy breathing environment, given the alarming levels of heavy metals in the urban area.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SOURCE OF FUNDING

This work was supported by Council of Scientific & Industrial Research (CSIR ID number- 35100006).

REFERENCES

1. Yahi D, Ojo NA, Ngulde SI, Telta AD, Dibila HM, Sambo N, Sanni S, Sodipo OA, Madziga HA, Mbaya YP, Simon J. Economic implications of dust assaults on humans and animals exposed to environmental hazards due to air pollution in the dry belt zone of Nigeria. Journal of Environmental Issues and Agriculture in Developing Countries. 2014;6(1):2141-2731.
2. Song H, Li J, Li L, Dong J, Hou W, Yang R, Zhang S, Zu S, Ma P, Zhao W. Heavy metal pollution characteristics and source analysis in the dust fall on buildings of different heights. International Journal of Environmental Research and Public Health. 2022 Sep 9;19(18):11376. https://doi.org/10.3390/ijerph191811376.
3. Xu Z, Mi W, Mi N, Fan X, Tian Y, Zhou Y, Zhao YN. Heavy metal pollution characteristics and health risk assessment of dust fall related to industrial activities in desert steppes. PeerJ. 2021 Nov 3;9:e12430. https://doi.org/10.7717/peerj.12430.
4. Adekola FA, Dosumu OO. Heavy metal determination in household dusts from Ilorin City, Nigeria. J. Nigeria Society for Experimental Biology. 2001;3(1):217-21.
5. Adriaenssens E. Analysis of heavy metals in ambient air. Spectroscopy Focus. Vlaamse Milieumaatschappij. Antwerp, Belgium. Accessed in 4 October [Internet]. 2011
6. Wang SH, Zhang K, Chai FH, Zhong XC, Zhou GZ, Yang Q, Ke XS. Characteristics and sources of elements in atmospheric dust fall in Zhuzhou City, Central China. Huan Jing ke Xue= Huanjing Kexue. 2017 Aug 1;38(8):3130-8.
7. Zhao Z, Ball J, Hazelton P. Application of statistical inference for analysis of heavy metal variability in roadside soil. Water, Air, & Soil

Pollution. 2018 Jan;229:1-2.
8. Nwosu FO, Raheem AA, Shehu Z. Evaluation of some heavy metals loading in dust fall of three universities motor parks in Western Nigeria. Journal of Applied Sciences and Environmental Management. 2016 Jul 25;20(2):327-32.
9. Onder S, Dursun S. Air borne heavy metal pollution of Cedrus libani (A. Rich.) in the city centre of Konya (Turkey). Atmospheric Environment. 2006 Feb 1;40(6):1122-33.
10. Esfandiari M, Sodaiezadeh H, Hakimzadeh Ardakani MA, Mokhtari MH. Determination of heavy metal pollutions in the atmospheric falling dust by multivariate analysis. Caspian Journal of Environmental Sciences. 2019 Sep 1;17(3):199-211.
11. Fulekar MH, Dave JM. Disposal of fly ash—an environmental problem. International Journal of Environmental Studies. 1986 Mar 1;26(3):191-215. doi.org/10.1080/00207238608710257.
12. Jablonska M, Janeczek J, Rietmeijer FJ. Seasonal changes in the mineral compositions of tropospheric dust in the industrial region of Upper Silesia, Poland. Mineralogical Magazine. 2003 Dec 1;67(6):1231-41. doi.org/10.1180/0026461036760161.
13. Xu M, Yan R, Zheng C, Qiao Y, Han J, Sheng C. Status of trace element emission in a coal combustion process: a review. Fuel Processing Technology. 2004 Feb 15;85(2-3):215-37. doi.org/10.1016/S0378-3820(03)00174-7.
14. Smołka-Danielowska D. Heavy metals in fly ash from a coal-fired power station in Poland. Polish Journal of Environmental Studies. 2006 Nov 1;15(6).
15. Meena M, Meena M, Chandrawat U, Rani A. Seasonal variations and sources of heavy metals in free fall dust in an industrial city of Western India. Iranica Journal of Energy & Environment. 2014 Apr 1;5(2). doi:10.5829/idosi. ijee.2014.05.02.07.
16. Rajput JS, Trivedi MK. Determination and assessment of elemental concentration in the atmospheric particulate matter: a comprehensive review. Environmental Monitoring and Assessment. 2022 Apr;194(4):243. doi:10.1007/s10661-022-09833-9.
17. Meena BS, Meena M, Chandrawat U, Rani A. Dry deposition of heavy metals associats characterization in an industrial. Res J Recent. 2019;8(3):1-11.
18. Rashed MN. Total and extractable heavy metals in indoor, outdoor and street dust from Aswan City, Egypt. Clean–soil, air, water. 2008 Nov;36(10-11):850-7. doi:10.1002/ clen.200800062.
19. Sun G, Crissman K, Norwood J, Richards J, Slade R, Hatch GE. Oxidative interactions of synthetic lung epithelial lining fluid with metal-containing particulate matter. American Journal of Physiology-Lung Cellular and Molecular Physiology. 2001 Oct 1;281(4):L807-15. doi:10.1152/ ajplung.2001.281.4.L807.
20. Meena BS, Meena C, Hada PS, Chandrawat U, Meena M. Determination of Heavy Metals in Indoor Dust in the Vicinity of Kota Thermal Power Plant under Meteorological Influence at an Industrial City. Current World Environment. 2024;19(1):283. dx.doi.org/10.12944/CWE.19.1.24
21. Moja SJ, Mnisi JS. Seasonal variations in airborne heavy metals in Vanderbijl park, South Africa. J Environ Chem Ecotoxicol. 2013 Sep 30;5(9):227-33. doi:10.5897/JECE2013.0291.
22. Savant A, Pandey GS. Deposition of toxic metals on surface soil in the vicinity of a steel plant. INDIAN JOURNAL OF ENVIRONMENTAL PROTECTION. 1993;13:168.
23. Sandhu RS, Gehlan MS. Estimation of some metals in the ambient air of Amritsar. Indian Journal of Environmental Protection. 1992;12:733.
24. Lee BK, Hieu NT. Seasonal variation and sources of heavy metals in atmospheric aerosols in a residential area of Ulsan, Korea. Aerosol and Air Quality Resarch. 2011 Nov 1;11(6):679-88. doi.org/10.4209/aaqr.2010.10.0089
25. Krolak E. Heavy metals in falling dust in Eastern Mazowieckie province. Polish Journal of environmental studies. 2000 Jan 1;9(6):517-22.
26. Yaroshevsky AA. Abundances of chemical elements in the Earth's crust. Geochemistry International. 2006 Jan;44:48-55. doi:10.1134/S001670290601006X.
27. Wu Y-S, Fang G-C, Lee W-J, Lee J-F, Chang C-C, Lee C-Z. A review of atmospheric fine particulate matter and its associated trace metal pollutants in Asian countries during the period 1995–2005. Journal of Hazardous Materials 2007;143:511–5. https://doi.org/10.1016/j.jhazmat.2006.09.066.

HOW TO CITE THIS ARTICLE: Meena BS, Meena C, Shekhawat AS, Chandrawat U, Meena M. Evaluation of Some Heavy Metals Loading During Summer and Winter in Free Fall Atmospheric Dust Nearby Coal-Fired Power Plant in an Industrial City Kota, Rajasthan. *J Adv Sci Res*. 2025;16(04): 30-34 **DOI:** 10.55218/JASR.2025160405