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Statistical Analysis of Selected Heavy Metals in Indoor and Outdoor Dust in the Area around Kota Thermal Power Plant, Kota, Rajasthan

B. S. Meena[1], C. Meena[1], A. S. Shekhawat[2], U. Chandrawat[1], M. Meena[1*]

[1]Department of Chemistry, Government College, Kota, Rajasthan, India, 324001

[2]Department of Computer Science and Engineering, Manipal University Jaipur, Jaipur, Rajasthan, India, 3033007

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Abstract

This study was carried out to investigate the concentration of six heavy metals (Cu, Pb, Cd, Zn, Ca and Fe) under meteorological influence in indoor and outdoor dust samples collected during the winter months namely November 2022 to February 2023 in the vicinity of Kota, Rajasthan. The average values of Cu, Pb, Cd, Zn, Ca and Fe concentrations (mg/L) are found to be 1.0432, 3.8961, 0.6017, 5.9503, 2205.08 and 77.0935 in indoor and 0.8281, 3.5099, 0.5665, 6.0942, 2622.74 and 80.8036 in outdoor dust samples, respectively. The concentration of studied metals is influenced by the prevalent meteorological environment during the study period although alterations are observed in this trend possibly due to varying wind speed. Wind roses indicate that the sampling sites confronting primarily North wind blow (26.97%) from the point source Kota Thermal Power Plant (KTPP) are found to have the highest metal burden due to their location being closest to the source. Pearson's correlation, Enrichment factor and Principal component analysis indicate that the Cu, Pb, Cd and Zn are mainly originated from coal burning activities at KTPP besides other industrial activities in the study area.

Keywords: Enrichment factor; Heavy metals; Indoor dust; Outdoor dust; Pearson's correlation; Principal component analysis.

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1. Introduction

Indoor and outdoor dust contamination by heavy metals has become a burning global concern owing to its detrimental effects on plant life and human health. Persistent nature, bioaccumulation potential, profused existence, toxicity and non-degradability of heavy metals make them a major cause of environmental pollution [1-6]. These metals, which correspond to the airborne dust component, can enter the human body through food contamination and skin contact [7-9]. Heavy metal pollution of dust, both indoors and outdoors, is a serious environmental problem. Dust that falls both indoors and outside contributes significantly to urban pollution [10-12]. About 85 % of indoor dust is estimated

* *Corresponding author:* meenamanju87@gmail.com

to come from outdoor activities, such as crustal materials, road dusts, construction activities, fossil fuel burning, industrial emissions, atmospheric depositions and vehicular traffic. Besides, indoor emission sources, such as human activities or wall paints, smoking, cooking and heating also contribute to this pollution [13-18]. As nowadays people reside more in indoors like houses, working premises, academic institutes, the indoor atmosphere is significant from human health point of view due to the presence of pollutants posing threat to human life besides outdoor environment [19-22]. Additionally, indoor dust particles can vary greatly in size, causing variety of breathing malfunctioning in human. The poisonous minute particles are particularly dangerous because they can penetrate deeply into the alveoli [23]. Temperature changes, moisture content, and relative wind speed are climatic elements that must be regularly monitored because they determine the diffusion and distribution of metals, incorporated with dust, from the origin to the study area. These heavy metals are released into the food chain after accumulation in the atmosphere, impacting all plants and animals [24-28]. In Kota City, Kota Thermal Power Plant (KTPP) produces tons of fly ash, a uniform mixture of various metallic oxides. The smallest particles of fly ash enriched with heavy metals are potential source of pollution for the atmosphere and make the situation of heavy metal pollution in Kota city quite alarming [29-32]. The concentration of heavy metals is further increased by several Kota Stone manufacturers as well as other small and major industries. Studies on evaluation and exposure of heavy metals in indoor and outdoor dust are lacking which can be quite significant in assessing the heavy metal burden in Kota. It is essential to evaluate air quality in Kota City in terms of heavy metals by measuring their scourge in indoor and outdoor dust from various sampling sites characterised by different anthropogenic activities. Hence, the current study was carried out with the primary goals: (i) To assess the levels of selected heavy metals (Cu, Pb, Cd, Zn, Ca and Fe) in indoor and outdoor dust collected from various sampling sites; (ii) to identify possible sources of heavy metals using statistics namely enrichment factor, Pearson's correlation coefficient and principal component analysis; (iii) to investigate influence of temperature, relative humidity, wind direction, and other meteorological factors on heavy metal concentration besides distance of sampling sites from KTPP.

2. Materials and Methods

2.1. *Study area*

Kota, a large industrial city in South Rajasthan, is situated on the eastern bank of the Chambal River at 25°11 N and 75°51 E with temperature range 7.2 °C to 46.6 °C. Additionally, it is having Kota Thermal Power Plant for electricity generation making it one of the major power production hub.

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 [25].

2.2. *Indoor and outdoor dust collection and analysis*

The locations of all the 47 sampling sites selected for this investigation, using the Global Positioning System in accordance with certain standards [33], are displayed in Fig. 1. Sampling took place during the winter months of November 2022 to February 2023. A total of 188 (47 samples multiplied by four sampling months) samples from indoors were gathered by picking dust off bottom surfaces, dirty ledges, and interior parts of residential homes using vacuum machines while outdoor samples were collected by polyethylene brush and tray. Every dust sample was gathered and promptly put into a fresh, labelled, airtight polythene container for safe transportation and storage [34].

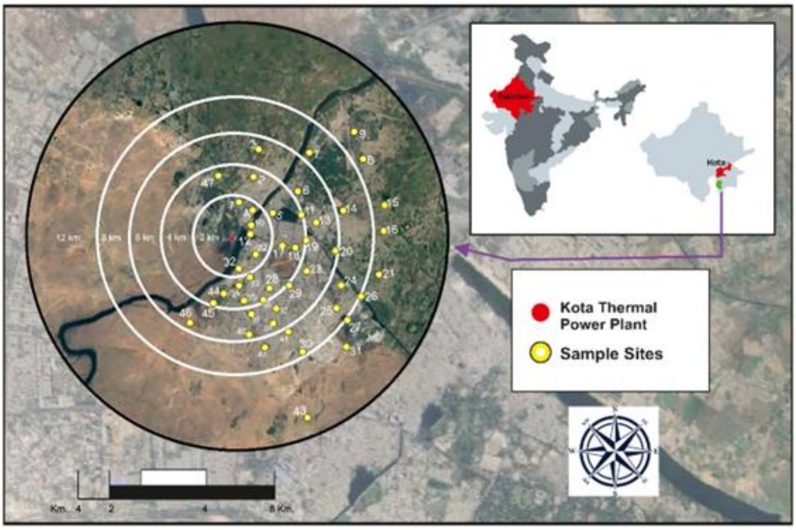

Fig. 1. Location of sampling sites of Kota city at the study area.

2.3. *Total heavy metal digestion*

After passing through 300 BSS (< 53 µm) sieves, the samples were digested for subsequent procedures. Since metals levels in dust varies according to nature of their existence, nitric acid digestive procedure was used to extract out only the HNO_3 soluble fraction [12,24]. Shimadzu Atomic Absorption Spectrophotometer AA-6300 was used to measure iron, zinc, copper, cadmium, and lead. Flame Photometer of Systronics-128 make was used to measure calcium. The precision and accuracy of the analysis were monitored using internal standards, verified reference material, and quality control blanks.

2.4. *Monitoring of meteorological parameters*

The weather data, throughout the measurement period [winter months (November, 2022 to February, 2023), is shown in Table 1 and Fig. 2. These data were provided by the Automated Meteorological Centre (DCPAWS02)]. Hourly data was captured and averaged across the samplers' 24 h operation period.

Table 1. Meteorological conditions during the study period.

Meteorological conditions	Measurements
Temperature (°C)	19.4 ± 14.00
Relative humidity (RH) (%)	59.28 ± 9.165
Wind speed (km/h)	0.75 ± 0.36
Rainfall (mm)	0.258

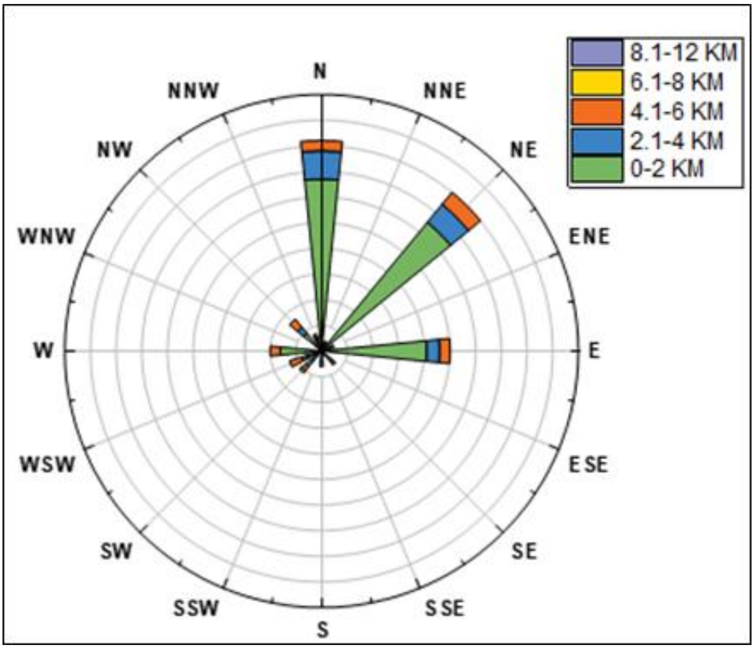

Fig. 2. Wind rose of study area during the sampling.

2.5. *Statistical analysis*

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

3. Result and Discussion

3.1. *Metal concentrations in indoor and outdoor dust samples*

Figs. 3 and 4 indicate that in indoor dust, the average concentration (mg/L) of analysed metals Cu, Pb, Cd, Zn, Ca and Fe were maximum at S_1 (1.531625), S_1(5.1759), S_{10}(0.862), S_{10}(7.0414), S_{43}(2670.68) and S_{43}(81.7739) respectively and lowest in S_{43}(0.7633),

S_{43}(2.7287), S_{43}(0.2539), S_{43}(4.9771), S_4(1652.08) and S_4(71.8125) respectively. Figs. 5. and 6 indicate that in outdoor dust, the average concentration (mg/L) of analysed metals Cu, Pb, Cd, Zn, Ca and Fe were highest in sampling sites S_1 (1.2931), S_1(4.5816), S_{10}(0.8435), S_{10}(6.9292), S_{43}(3104.12) and S_{43}(84.8494) respectively and lowest in S_{43}(0.5488), S_{43}(2.3589), S_{43}(0.2146), S_{43}(4.9084), S_4(2012.30) and S_4(75.6886) respectively.

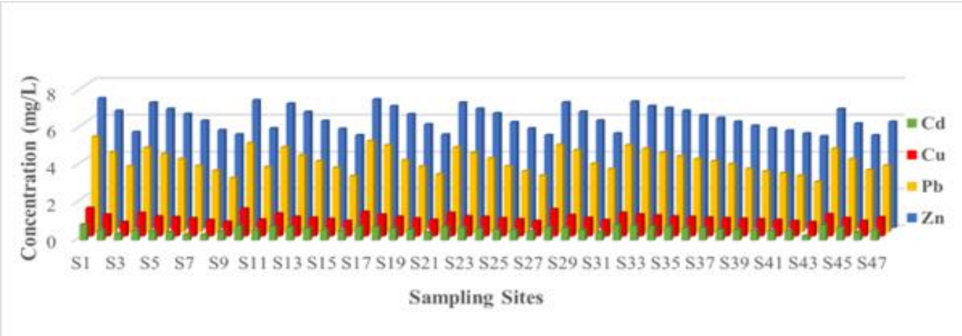

Fig. 3. The average concentrations of Cu, Pd, Cd and Zn in indoor dust.

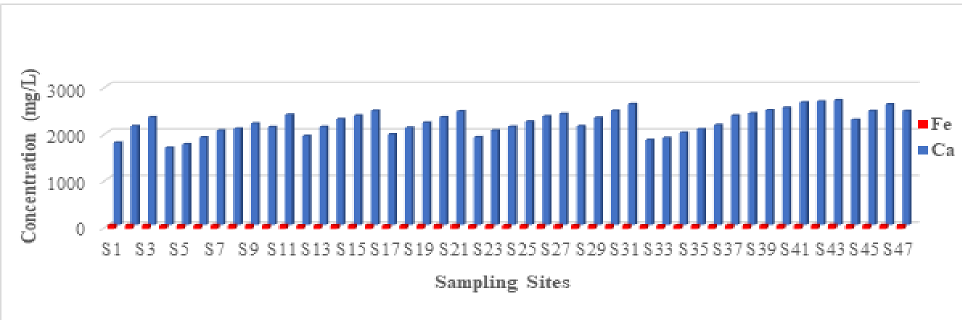

Fig. 4. The average concentrations of Ca and Fe in indoor dust.

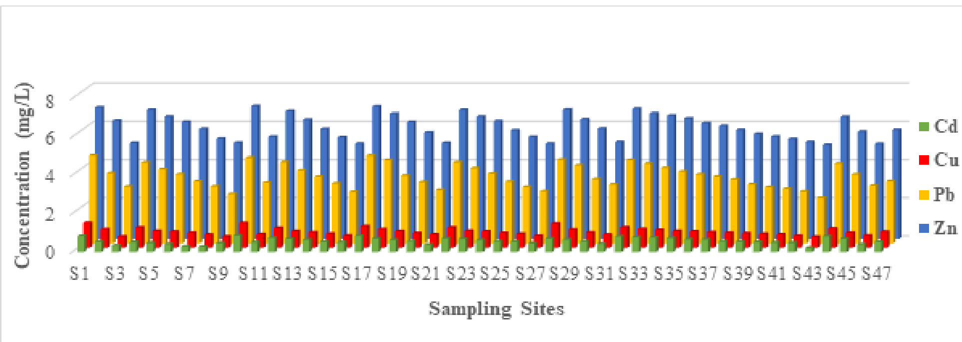

Fig. 5. The average concentrations of Cu, Pd, Cd and Zn in outdoor dust.

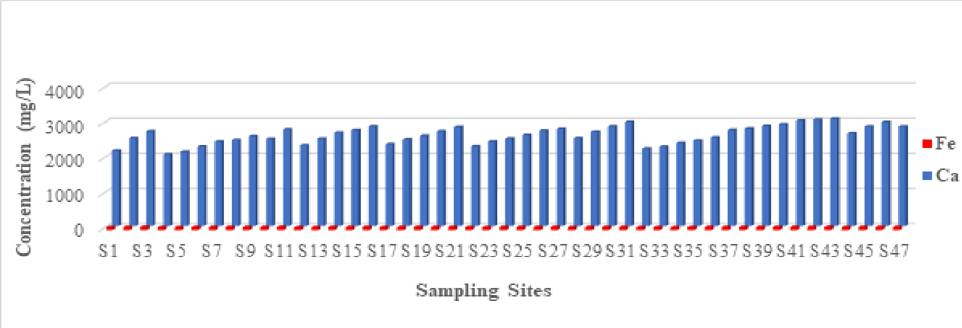

Fig. 6. The average concentrations of Ca and Fe in outdoor dust.

It is inferred from the results that the concentration of heavy metals varies depending on the sampling sites, distance from emission sources, wind speed and direction. Cu and Pb and Cd and Zn are found to be highest in S_1 and S_{10} respectively which were closest to the KTPP in both indoor and outdoor dust. Residential sampling sites, with less anthropogenic sources, are observed with the least levels of all the analysed metals.

Due to the steady and cold weather throughout the winter sample period, ambient particles in the atmosphere have a longer lifespan resulting in higher concentrations of Cu, Pb, Zn, Ca and Fe in both indoor and outdoor samples while Cd is observed in lower levels. The threatening amounts of heavy metals found in fly ash in the study area is further encouraged by the north (21.01 %) wind blow from KTPP. Average concentrations of Cu, Pb, Cd and Zn indoors are more in comparison to the outdoor dust samples. The reason for their worrying levels might be their generation from interior activities such as use of electrical devices, smoking tobacco, and cigarette in closed environment with inadequate ventilation, paint color besides contribution from the outdoor activities such as traffic, agriculture, and industries.

In the present study, Zn was found in highest concentration followed by Pb, Cu and Cd respectively which is in accordance with earlier studies [35-37]. Pb is a universal pollutant in urban environments due to its presence in earlier automobile emissions from gasoline containing Pb (owing to its higher residence time in the atmosphere) despite the use of unleaded fuel these days. This explains the reason of these Pb particles being accumulated in indoor and outdoor dust for a long time [38]. Additionally, leaded batteries, paints, and cement, all of which are utilized in a variety of home appliances, provide Pb in indoor samples.

Ca and Fe are prevalent in the atmosphere from earth crust, mining and polishing activities along with fly ash emission from KTPP. As heavy metals from industrial emissions infiltrate more readily owing to their smaller sizes than coarse desert dust particles containing Ca and Fe, the concentration of Ca and Fe in indoor dust samples are found to be in lower levels [39]. Another factor is that entire sampling was performed during fair weather, free of dust storms and strong winds, which reduced weathering and erosion and, consequently, reduced Ca and Fe levels.

3.2. *Pearson's correlation analysis*

Pearson correlation analysis is used to examine the correlations between the metals to predict common origin, if any. A significant positive correlation suggests that the metals have a common source which has been displayed in Table 2.

Table 2. Values of correlation coefficients(r) for the study (* noteworthy at 5%).

			Indoor Outdoor			
Metal	Cu	Pb	Cd	Zn	Ca	Fe
Cu	1.000	0.750*	0.436*	0.791*	-0.321	-0.369
Pb	0.751*	1.000	0.722*	0.885*	-0.301	-0.290
Cd	0.120*	0.491*	1.000	0.618*	-0.214	-0.328
Zn	0.703*	0.898*	0.568*	1.000	-0.362	-0.346
Ca	-0.326	-0.309	-0.195	-0.415	1.000	0.824*
Fe	-0.375	-0.282	-0.274	-0.393	0.825*	1.000

Pb-Cu (0.751), Cd-Cu (0.120), Zn-Cu (0.703), Cd-Pb (0.491), Zn-Pb (0.898), and Zn-Cd (0.568) all had positive correlations with one another in indoor dust. Pb-Cu (0.750), Cd-Cu (0.436), Zn-Cu (0.791), Cd-Pb (0.722), Zn-Pb (0.885), and Zn-Cd (0.618) all showed positive correlations in outdoor dust. This suggests that in both indoor and outdoor dust, these metals share the origin which is point source KTPP, in addition to other common industrial activities. It is to be noted that in both indoor and outdoor dust, a similar positive correlation between Ca-Fe (0.825 and 0.824 respectively) indicates that natural soil may be the common source of these metals [40,41].

3.3. *Enrichment factor*

Enrichment Factor Analysis (EF) facilitates the assessment of the degree of contamination resulting from heavy metal pollution and helps in identifying the anthropogenic origin of an element besides its principal natural origin. Ca is used as an element of reference for this purpose since its concentration is not anthropogenically changed [42-44]. To calculate EF, the following formula has been used:

$$EF= \frac{\left(\frac{X}{C}\right)\text{indoor dust}}{\left(\frac{X}{C}\right)\text{earth crust}} \quad (1)$$

Here, concentrations of the reference metal and the selected metal are denoted by x and c, respectively. When EF is less than 1, it is assumed that human activities have no effect on the heavy metal buildup. If $1 \leq EF < 2$, $2 \leq EF < 5$, $5 \leq EF < 20$, $20 \leq EF < 40$, or $EF > 40$, the pollution level is considered slight, moderate, heavy, severe, or excessive, indicating that human activities have an impact on the environment. As shown in Figs. 7 and 8, moderate results shown by Zn, heavy contamination by Cu while severe contamination by Cd and Pb which can be linked to the dispersion of fly ash from coal burning activities at KTPP [25].

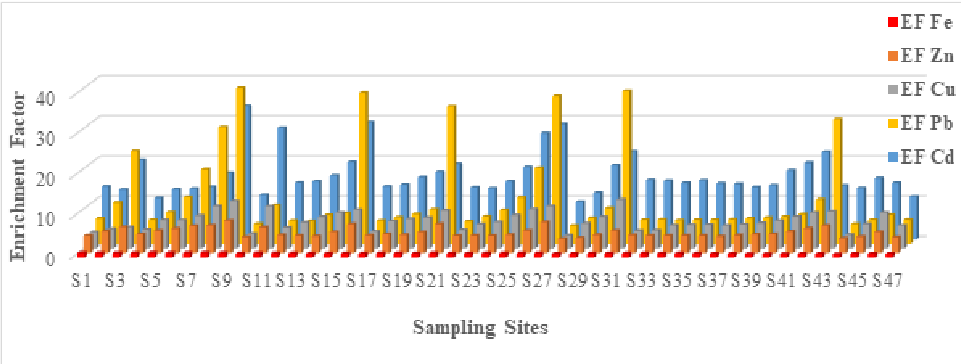

Fig. 7. Enrichment factor of Cu, Pd, Cd, Zn and Fe in indoor dust.

Fig. 8. Enrichment factor of Cu, Pd, Cd, Zn and Fe in outdoor dust.

3.4. *Principal component analysis*

It seeks to extract the key information as a collection of variables such as principal components, factors, eigenvectors, or loading and to find out the origins of pollution burden by metals. It identifies the minimal number of significant factors that account for the statistical variance [45-48]. The results from Table 3 showed that only two eigenvalues, accounting for almost 77.91 % and 82.55 % of the variance in indoor and outdoor dust respectively, were greater than 1. According to the rotational component matrix, all six metal species under analysis are accounted by two variables (varimax factors 1 and 2). The first factor (VF 1), which explained roughly 56.32 % and 59.64 % of the variance in indoor and outdoor dust respectively, showed the influence of anthropogenic activities, namely coal burning at KTPP, with notable loading of heavy metals as Cu, Pb, Cd, and Zn. The contribution of crustal aerosols was suggested by the excessive loading of Ca and Fe in VF 2, which accounted for 21.59 % and 22.90 % of the variance in indoor and outdoor dust respectively [48,49].

Table 3. Principal component analysis with six variable loading in both indoor and outdoor dust with 2 VF.

Indoor			Outdoor		
Variables	Component		Variables	Component	
	VF 1	VF 2		VF 1	VF 2
Cu	0.757	-0.240	Cu	0.816	-0.227
Pb	0.954	-0.116	Pb	0.951	-0.127
Cd	0.604	-0.104	Cd	0.770	-0.124
Zn	0.930	-0.240	Zn	0.918	-0.204
Ca	-0.185	0.936	Ca	-0.162	0.942
Fe	-0.201	0.934	Fe	-0.200	0.933
% of variance	56.32 %	21.59 %	% of variance	59.64 %	22.90 %
Cumulative (%)	56.32 %	77.91 %	Cumulative (%)	59.64 %	82.55 %

4. Conclusion

In the present work, contamination caused by metals in indoor and outdoor dust gathered from selected 47 sites in Kota City throughout the winter months namely November, 2022 to February, 2023 has been illustrated. In both indoor and outdoor dust, lower concentrations of Cu, Pb, Cd, and Zn are found at S_{43} because of its furthest distance from KTPP. It is to be noted that S_1 and S_{10} sampling sites are found to have elevated levels of Cu and Pb and Cd and Zn respectively, because of their closest proximity to the point origin KTPP and being confronted by the north (26.97 %) windblow from KTPP prevailing during the steady and cold winter sampling period. Higher Ca and Fe levels were found outdoors while Cu, Pb, Cd, and Zn pollution was conspicuously higher indoors caused by interior household activities such as the use of electrical devices, tobacco smoking, and cigarette use in poorly ventilated spaces, in addition to contributions from outdoor sources such as traffic, agriculture, and industrial activities. Cu, Cd, Zn, and Pb witnessed common origins in both indoor and outdoor dust samples, primarily coal-based KTPP, according to the Enrichment Factor, positive correlations, and Principal Component Analysis. The heavy metal scourge found indoors in this study suggests that polluted household dust could be a prime source of these hazardous metals for people who spend more time at home, particularly children. It is concluded that the identification of the major sources of certain metals inside home can be of great significance in reducing these sources through the implementation of appropriate administrative procedures and minimizing the risks associated with heavy metal exposure.

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