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Data analysis of indoor air pollutants in the laboratories of an Indian engineering institute

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ABSTRACT

Introduction: Indoor Air Pollution (IAP) is a serious problem, especially in enclosed environments where humans are present for a long period. Similar enclosed environments can be seen in educational Institutions, where employees and students spend much of their time. The objective of this research is to assess the Indoor Air Quality (IAQ) of engineering Institute's laboratories.

Materials and methods: The sample of Indoor Air Pollutants (IAPs) such as Particulate Matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), Total Volatile Organic Compounds (TVOC), Formaldehyde (HCHO), and Carbon dioxide (CO_2) were obtained by using a portable air quality meter from 12 different laboratories during July 2021 to September 2021 from 10:00 to 17:00. The statistical analysis was performed to interpret the outcomes.

Results: As a result, the higher concentration of $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TVOC, HCHO, and CO_2 was observed in ML 11, ML2, ML12, ML5 and ML4. The correlation analysis shows that all laboratories, with the exception of ML4, ML5, ML9, and ML11, show good positive correlation for Particulate Matter (PM) of all sizes (R^2>0.90). Additionally, ML6 and ML9 exhibited a strong positive association (R^2>0.78) for TVOC, ML4 and ML8 for HCHO (R^2>0.68), and ML3 and ML10 for CO_2 (R^2>0.66). In addition, cluster analysis was performed on the datasets to group them into similar source categories. As a result, 3, 2, 2, 4, 3, and 3 clusters for $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TVOC, HCHO, and CO_2 are extracted.

Conclusion: Overall, it appears that the presence of IAPs is caused by nearby outdoor activities, sweeping and dusting, wood furniture, paints, and poor ventilation in laboratories.

Introduction

Pollution through air is a global concern issue. It has especially, become a serious issue in developing countries where humans are directly exposed to Particulate Matter (PM) [1]. Typically, the government policies, local authorities and public are majorly focused on outdoor air pollution, may be due to its detrimental impact

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on human health, economic growth, and living habits [2]. Nevertheless, the impact of Indoor Air Pollution (IAP) can not be ignored as it is also adversely affecting the human health and living habits. Here, "indoor" termed as various environments that include homes, and workplaces etc. [3]. Previous studies show that Indoor Air Quality (IAQ) has been receiving huge recognition over last two decades. Still in India, there are no such guidelines or standards for IAQ, which represent the casual attitude towards IAP [4]. Consequently, continuous monitoring of the level of IAPs is required, as it has a negative impact on human health [5].

Typically, people consume most of the time in the indoor environment (i.e. inside and around buildings and structures) [6, 7], and undergoes with several activities such as sweeping, vacuuming, or presence of synthetic chemicals, improper ventilation, which can lead to contaminate the indoor environment through emitting particles and Volatile Organic Compounds (VOCs) in the air [8]. Correspondingly, it can surge the level of IAP by ten times that of outdoor air pollution [9]. Such conditions may further affect the health, comfort, and learning performance of students in educational institutions and schools [10, 11]. Therefore, it need to be emphasized in educational institutions [12].

IAQ refers to the quality of air in indoor environment [4, 8]. It is due to influence of IAPs such as varied sized particles, gases, and biological aerosols, etc. Furthermore, there are following factors that affects the IAQ: 1) Penetration of outdoor pollutant in indoor environments [13], 2) Building/Construction materials i.e. cement, resins, glues, wood preservative, cleaning agents etc., 3) Building features such as the air ventilation and air tightness [7, 14], 4) Living areas and their utilities, 5) Building equipment (e.g. photocopiers, printers, heaters), 6) Economic status of occupants [13], 7) Industrial finished products [15], 8) Cooking [16], heating and wood burning in fireplaces [17, 18], and tobacco smoking [17, 19]. These IAPs concentrations may vary with time and location within the school building, or even within a single classroom [20].

A lot of studies have been observed that characterize the quality of air in various indoor microenvironments, such as dwellings, offices, and schools. In this context, it was revealed about the IAQ of 25 family houses in Macedonia in which 64% and 32 % of houses breach the standard level of PM_{10}, and TVOC concentrations [21]. Further, in a study observations revealed that the student's physical activities become a primary source of particle re-suspension in the micro-environment [22]. Therefore, PM and VOCs are found higher in concentration in educational institutes as governed by several studies represent a state of knowledge regarding particle concentration in the classrooms of elementary school throughout the world [23, 24]. Further, in the other study it was showed about the relationship between different sized PMs through coefficient of correlation [25]. Findings reveal about the negative factors that affect the IAQ within the schools [26]. Researchers used statistical analysis to evaluate IAPs in a school [27].

This study is intended to quantify IAPs concentration within each laboratory in an engineering institute and evaluate through statistical and cluster analysis. To accomplish this task, monitoring of IAPs was undertaken in the respective laboratories. Furthermore, data acquired from the monitoring were adequately prepared and processed for statistical analysis and cluster analysis. The long exposure of IAPs may degrade the air quality in indoor environment and affect the performance of students learning. Therefore, regular monitoring of IAPs are required to develop healthy condition in the closed environment of any specific building [28].

Materials and methods

Study area

Gwalior city has a historical background and

situated in the North region of Central India. Gwalior is surrounded by high rock hills from all sides and has an elevation of 197 m from the mean sea level. It is densely populated with an average population of over one million. Gwalior city covers geographical area of 4560 Km^2 in which 1193 Km^2 is covered with forest area. This study was carried out in various laboratories of prominent engineering college at MITS, Gwalior (26.2314° N, 78.2053° E). These laboratories are situated in different engineering departments of the institution (see Fig. 1), and are chosen on the basis of following factors: 1) Comprehensive time spent by institute professionals and staff, 2) To elaborate the spatial variability of IAPs, 3) Functioning of the laboratories (see Table 1).

Fig. 1. Arial picture of the technical institute of MITS, Gwalior, M.P

Table 1. Different laboratories chosen for study in the MITS, Gwalior, M.P

Monitoring laboratory	Name Of laboratory	Duration	Total sample
ML 1	Waste Water Lab.	19-23, Jul 2021 (04 days)	60
ML 2	Chemical Engineering Lab.	20-22, Sep 2021(03 days)	45
ML 3	GIS and Remote Sensing Lab.	16-18, Aug 2021 (03 days)	45
ML 4	Computational Lab.	9-13, Sep 2021 (03 days)	45
ML 5	Programming Lab. III	14-16, Sep 2021 (03 days)	45
ML 6	Microprocessor and Digital Electronics Lab.	23-25, Aug 2021 (03 days)	45
ML 7	Control Lab.	26-31, Aug 2021 (03 days)	45
ML 8	I C Engine Lab.	9-13, Aug 2021 (03 days)	45
ML 9	Central Workshop	6-8, Sep 2021 (03 days)	45
ML 10	Material Diagnostic Lab.	2-6, Aug 2021 (05 days)	75
ML 11	Surveying Lab.	1-3, Sep 2021 (03 days)	45
ML 12	Highway Lab.	26-30, Jul 2021 (04 days)	60

Sampling of IAPs

The sampling of IAPs (i.e. $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TVOC, HCHO, and CO_2) was undertaken in 12 laboratories during the period of July 2021 to September 2021 with a portable air quality monitor. Portable air quality monitor is a sensor-based equipment widely utilized for to monitor abovementioned indoor air pollutants. The sampling time was taken from 10:00 AM to 05:00 PM, which match the institute official time. During sampling, the sensor based monitor was placed at a certain height (i.e. 1.2 m) from ground level, representing breathing level of a person in seating position (2), and at some distance from surrounding walls to ensure unavailability of any obstruction in their vicinity. The time resolution was maintained to 30 min intervals. In such a manner, total 600 samples were obtained from 12 laboratories at the rate of at least 45 sample from each laboratory.

Data preparation

Data collected from the portable air quality

monitor were noted down carefully in a daily observation book. Besides, data inventory is prepared in MS-Excel that included the Lab. name, sampling date and time, or pollutant name. Subsequently, the data was transferred to an MS-Excel for further analysis. Further, IBM-SPSS version 23 was utilized for statistical analysis, and python libraries i.e. sklearn, seaborn, matplotlib, numpy, and pandas, etc. were used for advanced data analysis and data visualization.

Research methodology

Coefficient of correlation (R^2)

The coefficient of correlation (R^2) signifies the measure of the relationship among the features. Its value ranges from -1 to 0 and 0 to 1. Here, the negative value represents the inverse relationship and the positive value showed the existence of a linear relationship among the features in the datasets. In this study, the correlation analysis was performed between the pollutants within the specific laboratories, and between the laboratories for each specific IAPs. Also, the correlation value (R^2) equal to more than 0.5 is considered a significant value to show a significant relationship between the laboratories or IAPs.

Cluster analysis

Cluster analysis is an unsupervised learning algorithm of Machine learning. It is used to group the data of similar identities in the form of a cluster. An umbrella of cluster algorithms is composed of several types of algorithms such as K-means, DBSCAN, Affinity Propagation, hierarchical clustering, etc. Each of these algorithms has its own merits and demerits. Nevertheless, the use of the K-means algorithm has been popular among researchers due to its fast implementation. However, it required several clusters to be formed which is a tedious task to perform. The Elbow method has been widely utilized to determine the number of clusters. Also, the silhouette score can be utilized for the same purpose (see Eq. 1). However, the combination of the Elbow method and Silhouette score can provide more confident outcomes.

$$\text{Silhouette Coefficient} = \frac{(x-y)}{\max(x,y)} \quad (1)$$

Where,

x = Mean distance to the points of the next nearby cluster.

y = Mean distance from one point to other point in the same cluster.

Additionally, a cardinality v/s magnitude graph has been incorporated to judge the anomalies of the clusters. Finally, the outcomes are obtained in the form of a deviation of the mean per cluster to the overall mean of the feature (in percentage).

Results and discussions

Concentration of IAPs

The concentration of ultra-fine and fine PM is found maximum in ML11 (i.e., 38.62±6.37 and 60.41±11.13 (in µg/m³)) and ML2 has a higher concentration of coarse ranged particles (i.e., 82.38±15.20 (in µg/m³)) (see Table 2).

Also, minimum concentration of all sized range PM has seen in ML3 Lab. (i.e., $PM_{1.0}$ 20.39±25.12, $PM_{2.5}$ 34.23±30.20, and PM_{10} 43.32±31.66 (in µg/m³)). Furthermore, ML2, ML11, ML5, ML6, ML7, and ML8 have shown a huge contribution of coarser particles as compared to finer particles (see Fig. 2).

Table 2. Mean±SD of indoor air pollutant concentration in all laboratories

Monitoring Lab	N	PM_1 µg/m³	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	TVOC mg/m³	HCHO mg/m³	CO_2 ppm
ML1	60	29.17 ± 31.68	47.88 ± 42.22	61.94 ± 51.79	0.14 ± 0.14	0.02 ± 0.03	4412.77 ± 516.64
ML2	42	37.66 ± 7.60	57.45 ± 12.91	**82.38 ± 15.20**	0.17 ± 0.27	0.02 ± 0.02	4681.88 ± 38.36
ML3	42	20.39 ± 25.12	34.23 ± 30.20	43.32 ± 31.66	0.44 ± 0.41	0.07 ± 0.07	4412.81 ± 484.37
ML4	42	26.73 ± 3.19	41.83 ± 5.91	56.42 ± 9.95	0.25 ± 0.49	0.07 ± 0.10	**4823.43 ± 687.33**
ML5	42	36.89 ± 3.83	57.33 ± 7.72	76.93 ± 7.28	0.47 ± 0.30	**0.15 ± 0.19**	4582.40 ± 50.82
ML6	42	30.47 ± 11.83	52.31 ± 12.18	69.69 ± 12.55	0.17 ± 0.45	0.02 ± 0.06	4213.64 ± 64.68
ML7	42	30.20 ± 7.69	51.30 ± 16.73	72.12 ± 23.32	0.54 ± 0.70	0.10 ± 0.16	4156.10 ± 217.56
ML8	42	25.68 ± 19.35	46.73 ± 25.42	65.00 ± 30.46	0.46 ± 0.50	0.06 ± 0.07	4131.19 ± 416.44
ML9	42	23.66 ± 5.60	35.74 ± 6.70	50.13 ± 9.64	0.09 ± 0.02	0.01 ± 0.01	4468.38 ± 47.29
ML10	70	20.46 ± 20.15	35.31 ± 25.61	47.88 ± 28.43	0.32 ± 0.26	0.05 ± 0.04	4425.46 ± 661.70
ML11	42	**38.62 ± 6.37**	**60.41 ± 11.13**	79.85 ± 14.10	0.46 ± 0.57	0.08 ± 0.12	4520.07 ± 66.03
ML12	60	21.81 ± 25.74	34.55 ± 30.50	45.44 ± 39.61	**0.70 ± 0.63**	0.10 ± 0.09	4025.43 ± 482.52

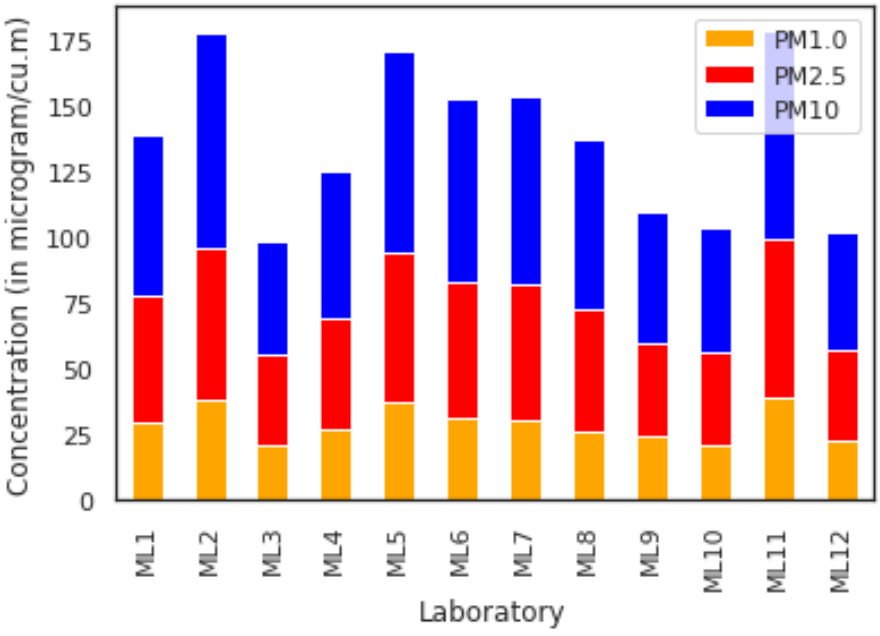


Fig. 2. Composition of different size ranged particulate matter in each lab

However, the remaining laboratories have shown a nearly equal distribution of coarse and fine size range (fine + ultrafine) particle. With these above facts, it has been seen that ML2, ML11, ML5, ML6, ML7, and ML8 laboratories can be majorly influenced by re-suspension of particulates and outdoor dust particles whereas, ML1, ML3, ML4, ML9, ML10, and ML12 may be affected by mixed activities that emitted PM. Many previous studies in the Asia and the rest of the world have quotes resuspension of dust particles as a major factor that influence the concentration of indoor PM, [29] is one such study whose result are in line with the present study.

The maximum concentration of the TVOC and HCHO are 0.70±0.63 (in mg/m^3) and 0.15±0.19 (in mg/m^3) have been found in ML12 and ML5 (see Table 2). Also, the minimum concentration of these IAPs lies in ML9 (i.e. TVOC 0.09±0.02 mg/m^3, HCHO 0.01±0.01 mg/m^3). Additionally, the max. and min. concentrations of CO_2 have observed in the ML4 (4823.43 ± 687.33 (in ppm)) and ML12 (4025.43 ± 482.52 (in ppm)).

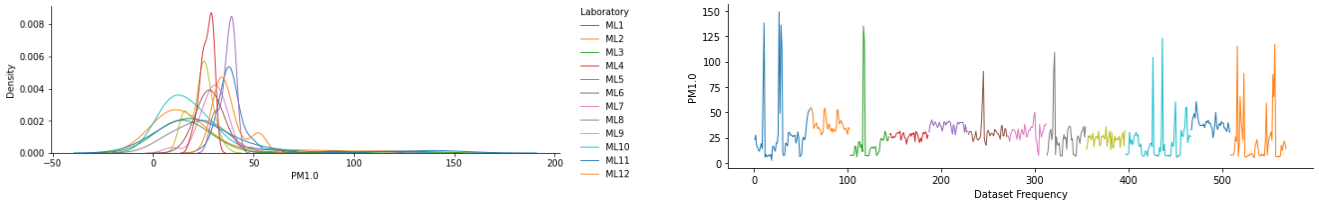
Spatial distribution and probability density function

The concentration of the PM of varied size ranges such as coarse, fine, and ultra-fine are showing a similar type of distribution related to each Lab. (see Fig. 3 a-c). It reveals that the source of particulate emission is the same in each individual Lab. However, some laboratories such as ML1, ML3, ML7, ML8, ML10, and ML12 have been seen affected by outlier concentration and widely spread in concentration range. It may be the reason for the presence of any specific event or activities within or nearby of these laboratories such as wind-blown or road dust from outside [30], open windows, inside dust due to sweeping [30], resuspension of particulates [31], etc. Furthermore, the PM concentration of remaining laboratories such as ML2, ML4, ML5, ML6, ML9, and ML11 are consistent in nature and possess higher peaks with lesser spread. It represents the closed environment of the laboratories which may be due to the presence of trees, dust-free open space nearby the Lab., and the installation of the fixed window.

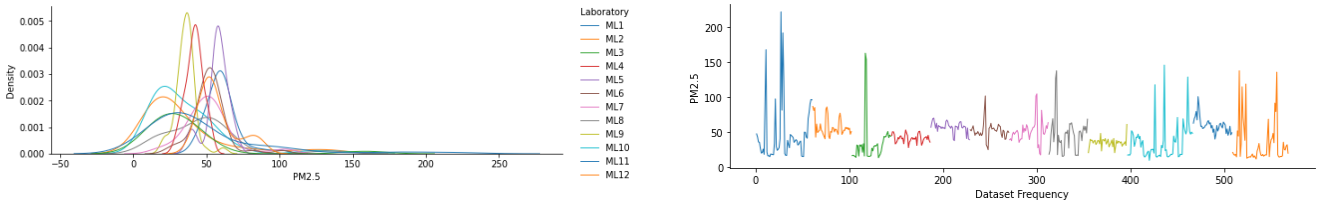
The concentration of the TVOC has been found highly variable in all laboratories (see Fig. 3-d). However, their concentration is seen as consistent with a higher peak in the minimal concentration range in ML9. A similar trend has also been found in the case of HCHO concentration (see Fig. 3-e). It is observed that linear trends and data distribution patterns of TVOC and HCHO are similar with distinct concentration levels. Therefore, it can be assumed that the source of emission of TVOC and HCHO are the same. The presence of wooden furniture, Oil used for machinery, and paints may rise the concentration level of the TVOC and HCHO. Correspondingly, researchers revels about the same fact that the building supplies, aerosol [8] , and wood preservatives are the major source of TVOC emissions [31]. Laboratories with furniture and desks made of pressed wood may have higher levels of formaldehyde and TVOCs.

Additionally, the concentration of CO_2 has been found consistent and showed unimodal distribution in ML2, ML5, ML6, ML9, and ML11 (see Fig. 3-f). These facts showed that the laboratories have a closed environment with fixed windows installation. In such a situation, the air exchange rate gets reduced and severe conditions may be raised in the absence of an air conditioning system. However, the remaining laboratories have variable nature with well-dispersed data distribution in concentration range. These laboratories can be attributed to having an open space in its nearby and having a movable windows system so that air can be exchanged. It is well known fact that human release CO_2 during respiration which surge the level of CO_2 concentration in the closed environment [32]. Therefore, there should be

availability of an appropriate space based on no. of person so that proper air exchange rate can be achieved naturally. Otherwise, an artificial system such as A.C., Air duct etc. should be installed in the laboratories which improve the freshness in the closed environment.



a)



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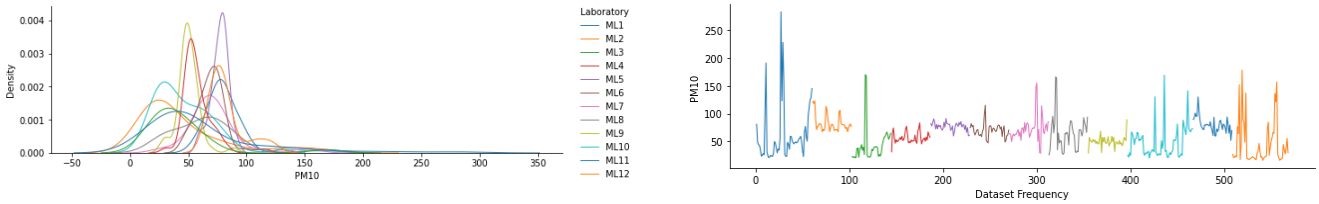

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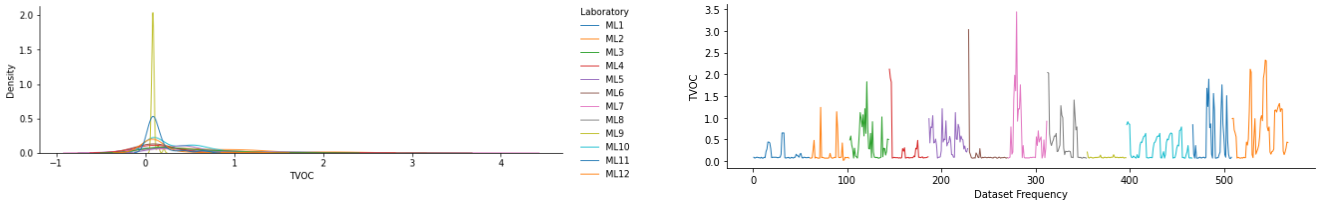
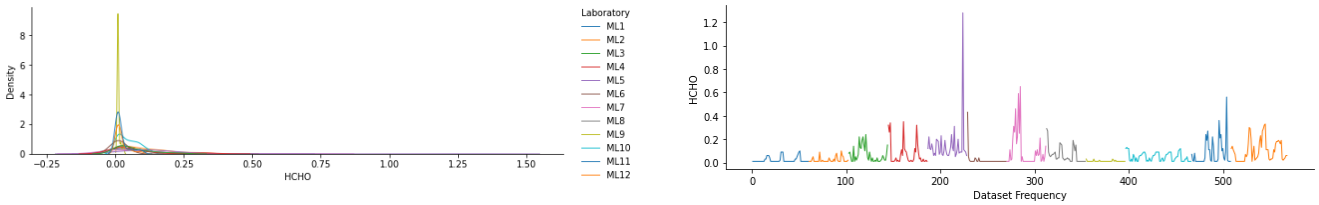
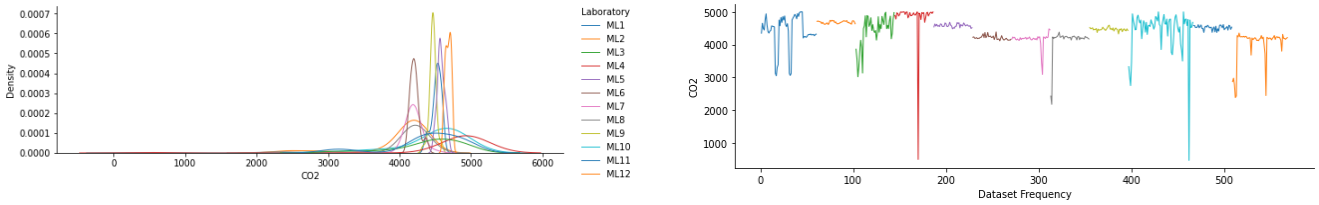


d)



e)



f)

Fig. 3. Spatial distribution and Probability density function of the indoor air pollutant's concentration: a) $PM_{1.0}$, b) $PM_{2.5}$, c) PM_{10}, d) TVOC, e) HCHO, and f) CO_2

Correlation analysis

The correlation coefficient between the concentration of PM of all sized ranges in each Lab. has shown a significant positive correlation (i.e., R^2>0.90) (see Supplementary data). This reveals the same source of emission of PM in each specific Lab.. However, insignificant and lesser positive correlation have found between $PM_{1.0}$ and PM_{10} in ML4 (R^2=0.24), ML5 (R^2=0.43), ML9 (R^2=0.60), and ML11 (R^2=0.67). This evidence shows that sources of ultrafine and coarse PM are distinct in these laboratories. Also, contradictory correlation values have been found between all sized ranged PMs, especially in ML4. Therefore, it seems to have the presence of multiple sources of particulate emissions in ML4. Additionally, the correlation coefficient between the laboratories in the ultrafine, fine, and coarse-sized PM is not significant enough to explain. However, ML2 showed significant negative correlation with ML9 (i.e., R^2=-0.52) (see Supplementary data) in ultrafine particulate concentration. Furthermore, ML2 also showed significant positively correlation with ML4 (i.e., R^2=0.66) and ML6 (i.e., R^2=0.50) in fine PM concentration. These aforementioned facts reveal that the source of fine PM concentration in ML2 with ML4 and ML6 is the same. However, ML2 has a distinct source of emission from ML9 in the case of ultrafine PM concentration. The correlation results coincide with the results found in previous study [12] where PM matter of various sizes have shown significant correlation with each other.

Furthermore, many laboratories showed significantly positive correlation for TVOC such as ML1 with ML11 (R^2=0.66), ML4 with ML6 (R^2=0.64) ML8 (R^2=0.72) ML10 (R^2=0.60), ML5 with ML9 (R^2= 0.50) ML10 (R^2=0.51), ML6 with ML8 (R^2=0.52) ML9 (R^2=0.78), and ML8 with ML9 (R^2=0.63) (see Table 3-d). The maximum correlation was found between ML6 with ML9 and ML4 with ML8. These shreds of evidence show that TVOC is emitted from the same source in these laboratories. Also, the correlation for HCHO is found positively

significant in laboratories ML4 with ML8 (R^2 = 0.68) ML10 (R^2= 0.54), ML6 with ML8 (R^2= 0.55) ML9 (R^2= 0.52), and ML8 with ML9 (R^2= 0.62) (see Table 3-e). The Lab. ML4 has shown maximum correlation with ML8 in terms of HCHO. Further, the correlation of TVOC and HCHO with the PM have found insignificant for each specific Lab. Similar results have been mentioned in research where it has been stated that both TVOCs and PM concentration exhibits different diurnal patterns in the study area but laid emphasis that both TVOC and PM concentration are strongly effected by human activities [30]. However, TVOC & HCHO have been found significant and strongly positively correlated (see Supplementary Material). Both TVOC and HCHO also showed a negative correlation with CO_2 in ML1, ML8, ML10, and ML12 and an insignificant correlation in the remaining laboratories. These aforementioned facts reveal their source of emission. Therefore, it can be assured that the TVOC and HCHO are emitted from the same source, but their source is different from PM emission. Also, they have shown inverse relations with CO_2 which signify about their emission source are entirely distinct in nature.

Additionally, ML3 with ML10 (R^2= 0.66) ML12 (R^2= 0.54), ML8 with ML10 (R^2= 0.61), and ML10 with ML12 (R^2= 0.50) are found significantly positive correlated to CO_2 (see Table 3-e). However, a negative correlation has been found between ML1 and ML2 (R^2= 0.50). Here, the positive correlation represents the similar ventilation facilities and the negative correlation shows the distinct nature of ventilation facilities in between the laboratories. With this, the CO_2 correlation with individual IAPs is insignificant in each Lab. However, it shows a significant positive correlation with $PM_{1.0}$ in ML7 and ML2 (see Supplementary Material). It signifies that the presence of ultrafine particles may result in poor ventilation conditions in the laboratories. The previous studies, have found positive correlation among CO_2 and PM of all sizes opposed to the finding of this study [19, 33]. In another study, the correlation between PM_{10} and CO_2 was relatively high that reveals about the robustness between coarse particles with indoor activities and occupancy level [23].

Table 3. The correlation value of indoor air pollutants between the laboratories

(a) Ultra-fine Particulate matter ($PM_{1.0}$)												
	ML1	ML2	ML3	ML4	ML5	ML6	ML7	ML8	ML9	ML10	ML11	ML12
ML1	1	0.089	-0.115	0.401**	-0.341*	-0.106	0.352*	-0.135	-0.338*	0.254	-0.031	0.100
ML2		1	0.332*	0.102	-0.280	0.393**	0.024	-0.380*	-0.516**	-0.061	0.052	-0.062
ML3			1	0.220	-0.275	0.346*	-0.007	-0.193	-0.227	-0.005	-0.153	0.314*
ML4				1	-0.318*	0.168	0.227	0.080	-0.296	0.304	-0.240	0.284
ML5					1	0.014	-0.429**	0.116	0.195	-0.151	0.361*	-0.197
ML6						1	0.011	-0.217	-0.131	0.043	-0.049	-0.119
ML7							1	0.056	-0.142	0.408**	-0.088	0.068
ML8								1	0.109	0.012	0.076	0.260
ML9									1	0.037	0.041	0.072
ML10										1	0.029	-0.060
ML11											1	-0.001
ML12												1
(b) Fine Particulate matter ($PM_{2.5}$)												
ML1	1	0.058	-0.147	0.200	-0.034	-0.066	0.398**	-0.155	-0.294	0.121	-0.144	0.050
ML2		1	0.351*	0.654**	0.115	0.497**	0.167	-0.345*	-0.374*	0.092	0.137	-0.044
ML3			1	0.172	-0.219	0.255	0.048	-0.195	-0.113	0.033	-0.098	0.279

ML4				1	0.165	0.458**	0.133	-0.344*	-0.329*	0.172	0.013	0.001
ML5					1	0.080	-0.237	-0.178	-0.133	-0.112	0.408**	-0.215
ML6						1	-0.065	-0.277	0.010	0.027	0.069	-0.164
ML7							1	-0.049	-0.210	0.314*	-0.078	-0.036
ML8								1	0.217	-0.027	-0.046	0.154
ML9									1	0.007	0.020	-0.040
ML10										1	0.151	-0.039
ML11											1	0.096
ML12												1
(c) Coarse Particulate matter (PM_{10})												
ML1	1	0.043	-0.119	0.002	0.051	-0.070	0.439**	-0.188	-0.186	0.100	-0.112	0.089
ML2		1	0.194	0.360*	0.293	0.462**	0.151	-0.414**	-0.278	0.030	0.326*	-0.077
ML3			1	0.143	-0.131	0.149	-0.035	-0.163	-0.045	0.121	-0.139	0.247
ML4				1	0.109	0.391*	0.258	-0.336*	0.151	0.296	0.021	-0.087
ML5					1	0.222	-0.018	-0.199	-0.438**	-0.060	0.339*	-0.133
ML6						1	-0.046	-0.293	-0.011	-0.014	0.075	-0.275
ML7							1	-0.205	-0.120	0.292	-0.108	-0.064
ML8								1	0.183	-0.015	0.025	0.169
ML9									1	0.051	-0.150	-0.071
ML10										1	0.186	0.023
ML11											1	0.082
ML12												1
(d) Total Volatile Organic Compound (TVOC)												
ML1	1	-0.124	0.072	-0.045	0.312*	-0.083	-0.065	0.171	-0.047	0.169	0.629**	0.043
ML2		1	0.038	-0.058	0.181	-0.069	-0.018	0.169	0.246	-0.024	-0.208	-0.131
ML3			1	0.030	0.037	0.030	-0.004	0.044	0.045	0.125	0.091	-0.006
ML4				1	0.305*	0.635**	-0.201	0.716**	0.471**	0.599**	-0.006	0.074
ML5					1	0.251	-0.239	0.468**	0.507**	0.511**	0.254	0.178
ML6						1	-0.079	0.519**	0.782**	0.313*	0.088	0.052
ML7							1	-.004	-0.083	-0.274	-0.311*	-0.358*
ML8								1	0.634**	0.454**	0.110	-0.135
ML9									1	0.247	-0.002	-0.029
ML10										1	0.221	0.352**
ML11											1	0.237
ML12												1
(e) Formaldehyde (HCHO)												
ML1	1	-0.183	0.161	0.458**	-0.078	-0.097	-0.037	0.209	0.017	0.064	0.417**	0.231
ML2		1	-0.071	-0.158	-0.059	-0.110	-0.046	-0.038	0.121	0.070	-0.009	0.234
ML3			1	0.148	-0.031	0.035	0.247	0.174	-0.102	-0.040	0.042	-0.242
ML4				1	-0.045	0.414**	-0.159	0.678**	0.288	0.542**	0.201	0.114
ML5					1	-0.024	-0.048	-0.038	0.012	-0.141	0.537**	-0.049
ML6						1	-0.044	0.548**	0.520**	0.327*	-0.047	0.004
ML7							1	0.060	0.094	-0.162	-0.272	-0.350*
ML8								1	0.615**	0.419**	0.123	-0.129
ML9									1	0.212	0.041	-0.109
ML10										1	0.031	0.283*
ML11											1	0.127

ML12												1
(f) Carbon Di Oxide (CO2)												
ML1	1	-0.504**	-0.199	-0.100	-0.229	-0.331*	0.196	-0.047	0.215	-0.037	-0.271	-0.162
ML2		1	-0.060	-0.014	0.068	-0.014	-0.072	-0.224	0.096	-0.205	0.250	-0.147
ML3			1	0.009	-0.034	0.066	-0.064	0.327*	-0.254	0.658**	-0.025	0.543**
ML4				1	-0.293	-0.418**	0.053	-0.014	-0.167	-0.041	0.336*	-0.047
ML5					1	0.141	-0.334*	0.003	-0.293	-0.009	0.063	0.001
ML6						1	0.040	-0.038	0.051	0.042	-0.126	0.077
ML7							1	-0.040	0.083	-0.125	0.004	-0.091
ML8								1	-0.156	0.613**	-0.216	0.432**
ML9									1	-0.253	-0.203	-0.153
ML10										1	-0.053	0.491**
ML11											1	-0.104
ML12												1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Cluster analysis

A cluster of laboratories has been formed for each specific IAPs to investigate the IAQ inside these laboratories. In this process, several clusters were obtained based on a combined outcome of the Agglomerative hierarchical method, Elbow method, and Silhouette score such as $PM_{1.0}$ (03), $PM_{2.5}$ (02), PM_{10} (02), TVOC (04), HCHO (03), and CO_2 (03) (see Supplementary Material). The ultrafine particles formed cluster between the laboratories such as cluster-1 (ML5, ML2, and ML11), cluster-2 (ML1, ML3, ML4, ML6, ML7, and ML8), and cluster-3 (ML9, ML10, and ML12) (see Fig. 4-a). In these clusters, cluster 1 has possess a higher level of ultrafine particle concentration followed by cluster 2 and cluster 3. The possible cause of the higher concentration of ultrafine particles in cluster-1 is sweeping or wind-blown dust as these laboratories are covered with trees. Further, cluster-3 laboratories are located in the proximity of ongoing construction activities and roads. Therefore, these laboratories can be attributed to roadside dust and dust from construction activities including renovation activities [30]. Furthermore, cluster-2 laboratories have been found affected by mixed activities as some laboratories are covered with vegetation and some are open to the roadside.

The fine particles formed cluster-1 (ML2, ML5, ML6, and ML11) and the remaining laboratories are included in cluster-2 (see Fig. 4-b). The cluster-1 laboratories show a higher concentration of fine PM as compared to cluster-2. Actually, cluster-1 laboratories are highly affected by construction activities and these laboratories are situated adjacent to each other in the proximity of construction activities. However, ML2 is situated within the campus far away from construction activities, so outdoor sweeping may increase the level of fine particulate in these laboratories. Further, the rest of the laboratories are attributed to mixed activities of particle emission.

The coarse particles formed cluster-1 (ML1, ML3, ML8, ML10, and ML12) and cluster 2 (ML2, ML4, ML5, ML6, ML7, ML9, and ML11) (see Fig. 4-c). It has been observed that cluster-2 included laboratories having a higher concentration of coarse particles. These laboratories are also attributed to particles emitted from construction activities. It also has been seen that ML2, ML5, and ML11 come under higher PM concentration clusters in all size ranges. With these facts, it can be assumed that ML2, ML5, and ML11 are highly affected by particle pollution emitted through

various activities such as roadside dust, material dust, construction activities, etc. However, other laboratories are also affected by particle pollution due to mixed activities and especially sweeping.

The varied source of TVOC has been observed in the laboratories. A total of 4 clusters are obtained in TVOC concentration such as Cluster-1 (ML2, ML4), cluster-2 (ML7 and ML8), cluster-3 (ML1, ML5, ML6, ML9, and ML11), and cluster-4 (ML3, ML10, and ML12) (see Fig. 4-d). The maximum concentration of TVOC is found in Cluster-4 and it is attributable to the presence of wood furniture, and book shelves in the laboratories. However, ML12 also contains heavy machinery which can also be attributed to the presence of oil in the Lab. Further, cluster-1 is highly attributed to the presence of wood furniture and paint. Also, cluster-2 shows the presence of oil in machinery and electronics equipment in the laboratories which surges the level of TVOC. The HCHO concentration formed cluster-1 (ML1, ML3, and ML7), cluster-2 (ML2, ML5, and ML8) and cluster-3 (ML4, ML10, and ML12) (see Fig. 4-e). The CO_2 concentration formed cluster-1 (ML4, ML6, ML7, and ML9), cluster-2 (ML1, ML2, ML10, ML11, and ML12), and cluster-3 (ML3, ML5, and ML8) (see Fig. 4-f).

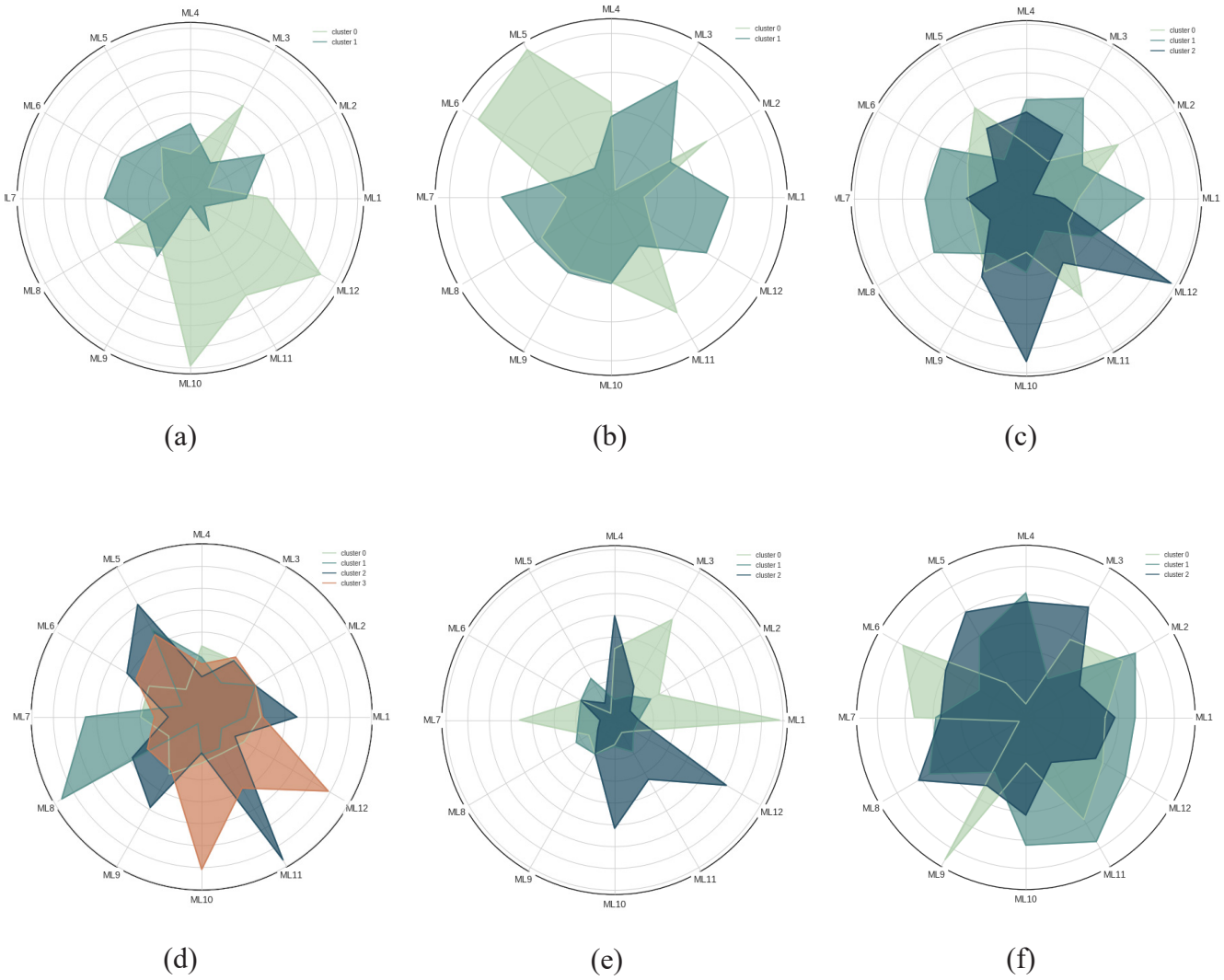


Fig. 4. Cluster of laboratories for each specific IAP's (a) PM_{10}, (b) $PM_{2.5}$, (c) $PM_{1.0}$, (d) TVOC, (e) HCHO, and (f) CO_2

Conclusion

This study comprises of statistical and clustering analysis of IAPs to investigate their levels and source of emission in the laboratories. The samples were obtained from specific laboratories during sampling duration with the portable indoor air sampler. The outlier concentrations were observed specially in the PM concentration. These observations represent presence of surprise activity in the vicinity of the laboratories such as renovation work, construction activities, and meteorological factor. However, the CO_2 concentration also gets affected with outlier, which may be due huge variation in air exchange. Furthermore, the maximum mean concentration of $PM_{2.5}$ and $PM_{1.0}$ are found in ML11, whereas PM_{10} in ML2. Majority of the concentration of IAPs were found consistent in nature that represent laboratories indoor environment are affect with their own existing source. Additionally, the correlation between PM of all sized was significantly positive. However, the correlation between $PM_{1.0}$ and PM_{10} were found less significant in some laboratories such as ML4, ML5, ML9, and ML11 that indicate about distinct source of emissions. Also, concentration of TVOC and HCHO were highly correlated which shows their same source of emission. Further, CO_2 was observed negatively correlated with TVOC and HCHO and shows their different source of emissions. However, it is relatively correlated with PM (Especially $PM_{1.0}$) in some laboratories such as ML2 and ML7 that shows particle load may also affect the ventilation within laboratories. At last, cluster analysis was performed for grouping the laboratories under individual IAP category. In which, 3, 2, 2, 4, 3, and 3 clusters was observed for PM_{10}, $PM_{2.5}$, $PM_{1.0}$, TVOC, HCHO, and CO_2 which shows about their possible source of emission of PM in the laboratories. Overall, the internal environmental condition of the laboratories are found poor that may be due to presence of Oils, Paints, Furniture, Printers, Computers, and old/non-working machines etc. With this other factor also found to suppress the indoor air quality such as influence of outdoor activities, laboratories location, and Construction activities etc. In addition, limited no. of air conditioning appliances are being installed/use to freshen up the air that may surge the poor ventilation condition in the laboratories.

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Author's contributions

All the authors contributed to study conception and design. The initial sampling and data collection was done by Aditya Singh Tomar and Aditya Kumar Agarwal, data preparation and analysis was performed by Aditya Singh Tomar and Jay Singh Rajput. The first draft of manuscript was written by Aditya Kumar Agarwal and Aditya Singh Tomar and then further modified by Manoj Kumar Trivedi and Jay Singh Rajput. All the authors have read and approved the final manuscript.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

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