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Original

Application of Cluster Analysis for Classification of Inhalation Exposure to Airborne Particles in a Tile and Ceramic Factory

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Abstract

Background: Particulate matter air pollution is one of the most important risk factors for cardiovascular and respiratory diseases. By increasing the number of mineral industries in the two past decades, workers in these industries are exposed to pathogenic respirable particulate matter pollutants. Cluster analysis is a multivariate statistical analysis method. Clustering creates groups or classes that the difference between the sub-groups samples is less than the difference between the groups. Therefore, this study assigns the cluster analysis to air sampling data collected from the various units of a tile factory. **Methods:** In this observational study, sampling from the respiratory zone of 93 workers in a tile and ceramic factory for both respirable and inhalable particles were performed. Sampling of inhalable particle based on NIOSH_0500 protocol and respirable particles based on NIOSH_0600 was conducted. Data were analyzed by both R 3.2.2 software and hierarchical cluster analysis with Ward link. **Results:** 92.47% of Workers were exposed to respirable particles less than TLV and 39.8% of them were exposed to inhalable particles more than TLV. The maximum average exposure for respirable particles 13.04 mg/m3 and inhalable particles 84.88 mg/m3 is respectively reported for crusher unit. The lowest average exposures to respirable (0.41 mg/m3) and inhalable (min=1.74 mg/m3) particles were observed in the glaze line division. **Conclusion:** Since the workers are exposed to concentrations more than the threshold limit value of respirable particles, and especially inhalable particles in some units, appropriate control measures must be considered to prevent possible consequences.

Keywords: Air sampling; Particulate matter; Cluster analysis; Tile and ceramic industry

Introduction

Human exposure to air pollution is ubiquitous. Air pollution is responsible for more than three million lives lost yearly. Approximately, 90% of the victims live in industrial countries. Exposure to air pollutants occurs in residential and occupational environments.[1] Epidemiological studies have shown the relationship between exposure to particulate matters exposure and

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the outbreak of acute and chronic respiratory complications and cardiovascular diseases.[2] The health effects of particulate matter extensively depend on their size. A significant relationship has been observed between exposure to PM2.5 and mortality.[3-8] Exposure to high concentrations of particulate matters is very common in occupation environments and especially mineral industries.[9-11] Several studies showed the relationship between the exposure to airborne particles and the decrease of lung function and aggravate respiratory obstructive pulmonary disease in workers.[10] Over the past two decades, the ceramic and tile industry has substantially grown in Iran and obviously, a lot of people are working in these industries that due to inhalation of the dust and particles, they are prone to the respiratory diseases.[12, 13] Several studies have reported the prevalence of respiratory symptoms caused by airborne pollutants among the ceramic and tile industries' workers.[10, 13, 14] The main ceramic and tile production process consist of crushing, spraying, continuous ball mills, pressing, ovens, glaze line, packaging, and administrative units.[10, 12, 13] Since the largest number of tile and ceramic companies are active in Yazd[10], this study was aimed to assess the exposure to particulate matter among the workers exposed to inhalable and respirable dust in a production unit in a ceramic and tile factory in Yazd province. We compared the results with occupational exposure limits.

Methods

This is an observational study conducted on 93 employees of a tile and ceramic factory in Yazd province in 2016. In this study, air sampling was conducted in the breathing zone of workers (hypothetical hemisphere with a diameter of about 30 cm around the mouth and nose of a worker).[15] Results of air sampling by inhalable and respirable sampling heads were considered as worker exposure to the inhalable and respirable dust. Each personal sample was taken for at least 4 hours. A sampling of the inhalable particles was based on NIOSH0500 method.[16] PVC filter with 37 mm diameter and 5 micrometers pore size (SKC Company) placed in IOM filter holder (SKC Company) and attached to the personal sampling pump at 2 liters per minute flow rate (calibrated against a primary standard). Respirable dusts sampling was performed based on NIOSH0600 method[17] by PVC membrane filter with 25 mm in diameter (SKC Company) and SKC Aluminum cyclone at 1.7 liters per minute flow rate. The filters were placed for 24 hours in the desiccator containing silica gel to remove the moisture. All filters were pre-weighted (digital scale AND, Model GR-200) and placed in the holders. After completion of the sampling, the filters were weighed again and the net changes in the filter weight were considered as loaded dust. All samplings were done in a period of 4 hours which represents all activities of an individual worker. To remove the sampling and analysis errors, for each sample set, 5 blanks were considered. At the end of the sampling time, the filters were placed inside a desiccator for 24 hours and then the filters weighted three times and the average weight was considered for further analysis. Finally, the concentration of dust collected on each filter was calculated according to the NIOSH0500 and NIOSH0600.

Statistical methods

After completing the sampling and data collection, firstly the data entered into a spreadsheet. The mean, standard deviation, the minimum and maximum concentration of pollutants in the units were determined by using descriptive statistics. Because of the existence of outliers, a large number of work units and the failure to fulfill the basic assumptions for analysis of variance, we used the hierarchical cluster analysis with the Ward link considering the Euclidean distance to determine the level of exposure. The Ward link cluster algorithm is not sensitive to the presence of the outlier data. To minimize the sum of squared error between the clusters (ESS), there was an attempt to create the clusters with the same size and examine the shape of the variables. To do this the package of

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NbClust was used. This package takes into account 30 clustering criteria and finally the cluster with the highest frequency among the 30 clustering criteria, considered as the optimal number of clusters. All analyses were conducted in R 3.2 software.

Results

In this study, 93 simultaneous side-by-side air samples were collected in 10 different units and operations of a selected tile and ceramic factory units including ball mill, crushing, glazing line, packing, maintenance, ferrite, supervisor stations, electricity, press and lift truck drivers. Mean of respirable dust concentration in crushing (84.87 mg/m^3), press (32.14 mg/m^3) and ball mill (29.2 mg/m^3) were respectively higher than other operation units Table 1 and Figure 1. Analyses of samples in individual level also showed that the highest exposures intensity with respirable and inhalable dust belongs to workers working in the crushing unit. A similar pattern was observed for inhalable particulate matters Table 2. The average concentration of respirable dust in ball mill unit was 2.43, electricity 0.98, packaging 0.58, press1.40, glazing line 0.41, lift truck drivers 0.98, supervisors 0.49, Ferrite1.62 and maintenance 1.75 mg/m^3. Exposure to respirable dust in the crusher unit was 13.04 mg/m^3, which was higher than the recommended exposure level. For inhalable particulate matters, the exposure intensity in ball mill unit, Ferrite, press, maintenance, and crushing was higher than the permissible exposure level.

Table 1. Descriptive statistics of the concentration of respirable dusts according to different occupational units

Occupational unit	Respirable concentration (mg/m^3)				
	N	Mean	SD	Min	Max
Ball mill	13	2.43	3.80	0.49	14.95
Electricity	3	0.98	0.25	0.74	1.23
Packing	30	0.58	0.31	0.05	1.23
Press	7	1.40	0.52	0.98	2.45
Glaze line	3	0.41	0.28	0.25	0.74
Lift truck driver	4	0.98	0.53	0.49	1.72
Supervisor	6	0.49	0.22	0.25	0.74
Crusher	9	13.04	26.34	1.23	82.84
Ferrite	8	1.62	0.67	0.98	2.94
Maintenance	10	1.69	1.56	0.74	5.88

Table 2. Descriptive statistics of the concentration of inhalable dust for the separated occupational units

Occupational unit	Inhalable concentration (mg/m^3)				
	N	Mean	SD	Min	Max
Ball mill	13	29.02	32.55	4.17	110.42*
Electricity	3	4.65	1.54	2.92	5.83
packing	30	7.86	13.90	0.63	70.42
Press	7	32.14	40.95	3.54	120.00*
Glaze line	3	1.74	0.84	1.25	2.71
Lift truck driver	4	2.29	0.45	1.67	2.71
Supervisor	6	7.19	8.71	0.42	21:04
Crusher	9	84.88	129.31	3.33	383.13*
Ferrite	8	25.86	46.73	2.50	138.54*
Maintenance	10	10:44	9.02	1.67	26.04

* Filter was overloaded

Table 1. Clustering of occupational units based on inhalable ($C_{inhalable}$), respirable ($C_{respirable}$) and interaction of both size definition ($C_{respirable}$ & $C_{inhalable}$)

Occupational Unit	$C_{Inhalable}$	$C_{Respirable}$	$C_{Respirable}$& $C_{Inhalable}$
Crushing	2	2	2
Glaze line	3	1	3
Electricity	1	1	3
Lift Truck Driver	3	1	1
Packing	1	1	1
Maintenance	1	3	1
Supervisor	3	1	3
Ball Mill	3	3	1
Ferrite	3	3	1
Press	3	3	1

To categorize the workers based on homogenous exposure group, a classification based on cluster analysis was performed. The ideal number of clusters for the data was explored based on average exposure to respirable and inhalable dust. Based on fitting criteria, finally, three clusters were selected Table 3. The hierarchical method in cluster analysis is an exploratory procedure to finalize conclusions about units in each cluster. Therefore, K-means cluster analysis based on two indices of $C_{Inhalable}$ and $C_{Respirable}$ used either separately or simultaneously. The Silhouette information index that is a criterion to determine the suitability of clustering in the allocation of occupational units was equal to 0.66 (acceptable value for this index should be between 0.5 to 1).

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The units located in the same cluster were homogenous in terms of an index or examined variable. According to figure 2, the dendrogram horizontal axis is the Euclidean distance of occupational units to the center of the cluster. Hierarchical clustering uses the agglomerative technique for each occupational units in a way that first all of 10 units are in a cluster (the top part of dendrogram charts in Euclidean distance 7) and gradually goes so far as to apply that each unit is considered as a cluster (the bottom part of dendrogram charts in the Euclidean distance of 0). Since in the hierarchal analysis by default, three clusters are considered the cut-off line is selected in the graph that the three broad categories of units are formed.

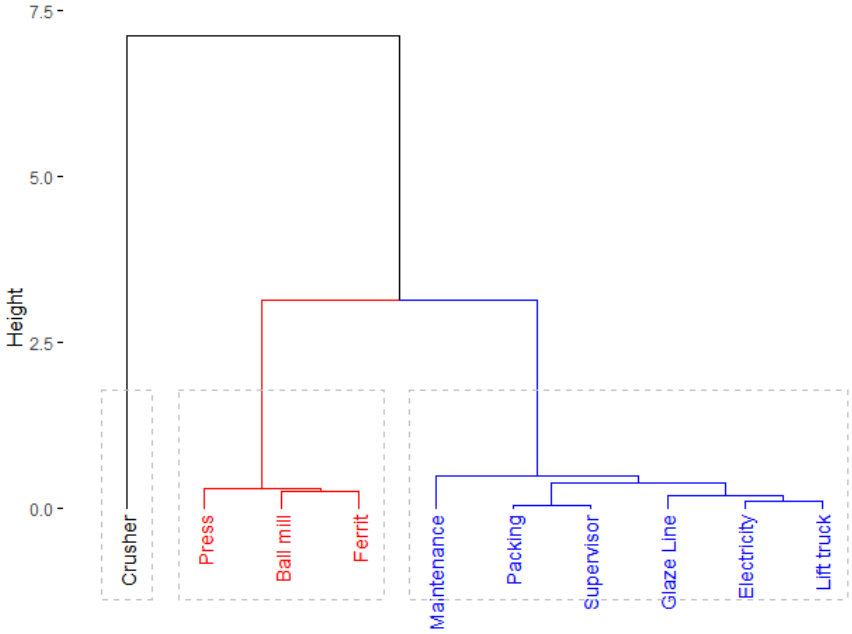

Figure 1. Clustering dendrogram based on $C_{inhalable}$ & $C_{respirable}$ by using Ward's linkage

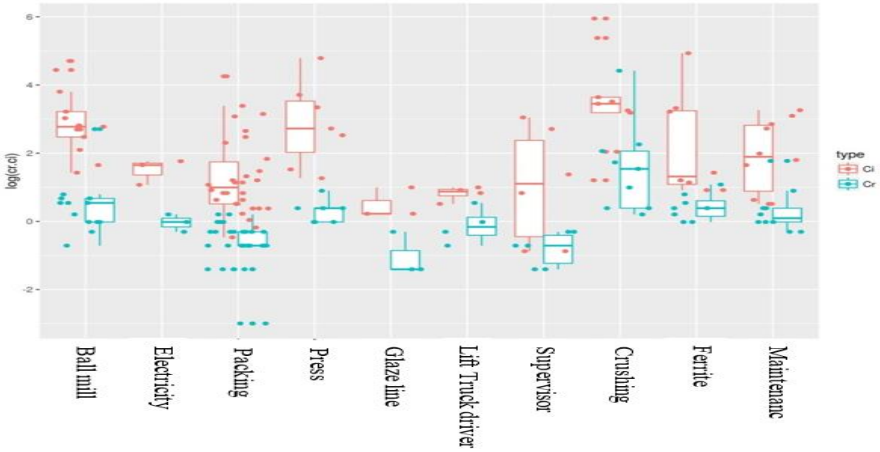

Figure 2. Box plot of inhalable and respirable particulate concentration distribution in different unit

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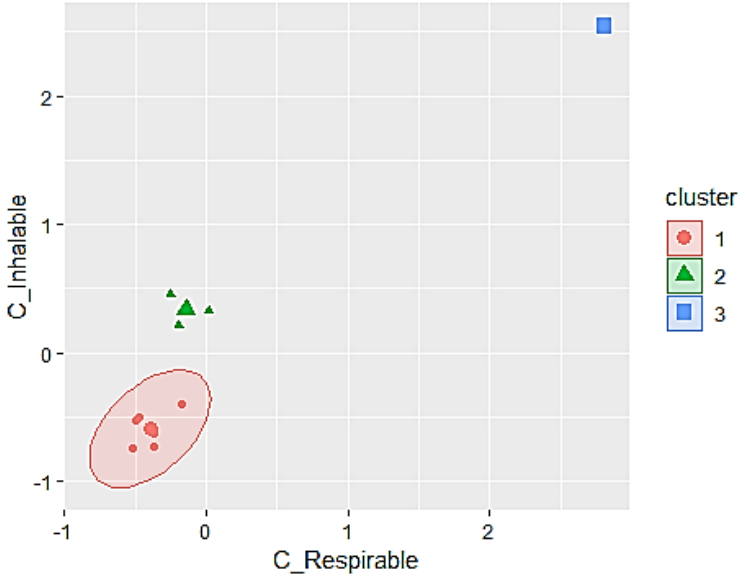

Figure 3. cluster plot for k-means

After checking the clustering accuracy, we described the features of work stations within each cluster. According to figure 3, we can describe clusters in terms of two indices of $C_{Inhalable}$ and $C_{Respirable}$. Workstations that are in a cluster 1(circles) (maintenance, electricity, Packaging, glazing line personnel, and lift truck drivers) have values lower $C_{Inhalable}$ and $C_{Respirable}$ values. Workstations of cluster 3 (press, ball mill, and Ferrite unit) in terms of both indices have average values. Cluster 2 (crusher unit) in terms of both indicators of $C_{Inhalable}$ and $C_{Respirable}$ has the highest value.

Discussion

Tile and ceramic industries are one of the main industries in Iran, especially in Yazd province.[10] Therefore, a huge number of workers who are working in this industry are at risk of inhalation of particulate matters and subsequent occupational diseases.[12,13] Due to the high risk of irreversible health effects of working in this industry, scientific studies are required to assess the extent and effects of exposure to particulate matter in this industry. Since the largest number of tile and ceramic factories is working in Yazd province[10], this study was aimed to evaluate the inhalation exposure of workers to airborne pollutants, including inhalable and respirable dust. We found that 90 percent of the units were exposed to the levels lower than the permissible exposure levels of respirable dust. Also, exposure in half of the units was higher than the permissible concentrations recommended by authorities. We observed the highest level of exposure to respirable dust in crushing unit workers and the lowest exposure to respirable dust among glaze line workers. Similarly, the highest level of exposure to inhalable dust was observed for the crusher workers and the lowest exposure among glaze line workers. The highest exposure to respirable and inhalable dust could be due to the open face crushers' activities, lack of ventilation, open conveyors, transportation and unloading equipment and dust accumulation and lack of housekeeping. Mehrparvar et al. in a study observed the highest exposure for the crushers, mixers, ball mill and spray drying .[10] The results of Dehghan et al. in the ceramic and tile industry showed that the concentration of dust in all

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departments was higher than the permissible exposure levels. The highest concentration of respirable dust in the press unit was 35.75 mg/m^3 and the maximum concentration of inhalable dust in the mixer was 54.01 mg/m^3. The average concentration of dust particles was lowest in administrative units. The workers exposed to respirable and inhalable dust at this industry in most of the units are higher than the recommended exposure limits by the international organizations and committee of technical protection and work health of Iran. Application of engineering controls is essential and should be considered by the authorities of the industry to reduce exposure and prevent possible disorders. Control measures such as local exhaust ventilation and covering the conveyor in ball mill units, press and crusher can reduce particulate matters in the air to the acceptable levels. Therefore, chronic complications caused by inhalation of particulate matters are probably in the workers. Based on the clustering approach, occupational groups were finally clustered into three clusters that were different in terms of clustering indices to the respirable and inhalable dust. In the clustering method, the clusters that are placed in the same group, have no difference in terms of clustering indices.

Conflicts of interest

The authors certify that they have no conflicts of interest.

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