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Characterization of indoor/outdoor PM_{10}, $PM_{2.5}$, PM_1 and radon concentrations in Imam Khomeini hospital

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In this study the concentrations of PM10, PM2.5, PM1 and [222] Rn and meteorological variables (atmospheric pressure, air temperature, and relative humidity) were measured simultaneously to find association of particulate matters and Radon gas emissions using multivariate statistical methods. The data (from 1512 samples for PM and 196 samples for Radon measurement) have been collected in six medical treatment floors of Imam Khomeini Hospital in Tehran (Iran) from June 2014 to June 2015, seven days per each season. In this study, we conducted a time-series analysis to evaluate the effects of indoor or outdoor PM10, PM2.5, PM1and Radon on hospital sections. During our study period, the PM10 and PM2.5, PM1 average concentration were 27.75, 20.05, 15.50 and varied between 7-49 µg/m3, 6-37 µg/m3 and 5-33 µg/m3, respectively. The records showed that the average of Radon emissions in six floors of building were 2.8 Bq m^{-3} , 1.8 Bq m^{-3} , 2.8 Bq m^{-3} 3.2 Bq m^{-3} , 1.2 Bq m^{-3} , 0.83 Bq m^{-3} and 0.53 Bq m^{-3}respectively.Multivariate Manova analysis for four variables (season, day, floor no., location) and through Pillai's Trace ،Wilks' Lambda ،Hotelling's Trace و ،Roy's Largest Root methods are used for providing table of Tests of Between-Subjects Effects for PM1, PM2.5, PM10 arrays. The results summarized meaningful deference between PM1, PM2.5 and PM10 for some effects.For evaluating of effects of air condition (Temperature, Pressure, and Relative Humidity) on PM concentrations we applied Stepwise Linear Regression (LR) and found that increasing of pressure and decreasing of temperature cause all PM increase but the temperature is sensitive more to PM1 and PM2.5 and pressure is sensitive just for PM10.

We found that in the first and second half of year the Radon emissions at Nursery location had same effect but in Outdoor location and in cold seasons it has been increased. Finally, based on stepwise regression model, we can report that the concentration of [222]Rn and PM2.5 and ambient pressure showed reverse and direct correlation respectively. Linear model has more than 50 percent reliability in correlations but study should be continued by others to find more correlations between Radon and parameters.

To our knowledge, this is the first study in Iran, or even in Asian developing countries, to report the effect of PM10, , PM2.5, PM1, and [222]Rn emission simultaneously on morbidity. Our findings also suggest that Radon could serve as a valuable air quality indicator that reflects the health risks of airborne particles.

Keywords: Particulate Matter, Hospital, Radon, Characterization, IAQ.

INTRODUCTION

Nowadays, people have paid more attention to indoor air quality (IAQ) in workplace and residential environments. People spend >90% of their time indoors (Jenkins et al., 1992); therefore, the quality of indoor air is crucial to us. Many factors can cause the deterioration of indoor air quality, such as building materials [1], architectural coatings applied to building materials [2-3], heating, ventilation, and air conditioning systems [4], consumer products [5], and various indoor activities [6]. Moreover, air pollutants generated from outdoor sources can affect indoor air quality, as well as our health. Several research studies have reported significant health risks associated with exposure to particulate matter (PM) [7]. Most studies on PM exposure consider particle mass, particularly particles smaller than 10, 2.5 and 1µm (PM10, PM2.5 and PM1 respectively).Hospitals have complex indoor environment influenced by many factors such as number and age of occupants, their activities, building design, and sources of pollution inside the building, outdoor pollutant concentrations, and ventilation conditions [8-9-10]. Respirable particulates (RP) with aerodynamic diameter smaller than 10 µm (PM10) has received considerable attention in recent years as it is easily inhaled and deposited within the respiratory system [11-12-13]. RP is divided into a coarse fraction (>2.5 µm in diameter) and a fine fraction (<2.5 µm in diameter) [14]. The coarse fraction is found to consist mainly of organic material, silicates and larger soot aggregates [15]. The fine fraction typically contains a mixture of particles resulting

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from different kinds of combustion processes (e.g., exhaust particles) and secondary particulates generated by chemical reactions in the atmosphere (acid condensates, sulfates and Studies show that RP plays a role in the incidence and severity of respiratory disease [16] and have significant associations with decline in lung function, respiratory and cardio-vascular diseases deaths.

Especially, public attention has been focused on fine particulates among the RP in aerosol highlighted for adverse health effect [17-18-19]. PM2.5, the fine fraction in RP is significantly correlated with deaths from cardiopulmonary disease and lung cancer [20]. These finer particles are also the potential allergen carriers, which are probably liable to affect respiratory health, as they are able to penetrate deep into the respiratory tree [21]. Therefore, these fine particles seem to be more harmful to humans than the coarse ones. USEPA revised the primary (health-based) particulate matter standards by adding new annual and 24-h PM2.5 standards at 15 and 65 μg/m3 for outdoor air, respectively, to more effectively control the aerosol problem [22]. Thus, assessment of PM10 and PM2.5 levels assumes significance from an environmental health perspective.

In the last few decades, a general social concern about the health risk associated with radon has grown worldwide. Historically, the detrimental effect on health attributed to radon came to light in connection with frequent lung disease (lung cancer) incidence among underground miners. Nowadays attention is paid to radon both at workplaces and homes. Although one usually spends less time at work than at home (the ratio is about 1:2.5), the radiation exposure from radon in the workplace can be significant in cases when the radon concentration is relatively high in work environments. The International Commission on Radiological Protection (ICRP) provides guidance to regulatory authorities on the radon action levels in its publication of ICRP-65. ICRP-65 suggests that workers who are not regarded as being occupationally exposed to radiation should be treated in the same way as the general public.

In this study, hospitals are selected for investigation. Their indoor PM10/PM2.5/PM1 and associated Radon emissions were focused on. This is based on three considerations. Firstly, hospital is regarded as a special and important type of public place in Iran. The number of people is much higher in hospital every day than in other medical centers. Therefore, effect of hospital IAQ to people is more significant than other public places. Secondly, epidemiological studies showed hospital-acquired respiratory system infection (HARSI, refer to diseases infected from hospital) is well affinity with hospital indoor aerosol that is the carrier for virus and Radon emission diffusion by adhering to aerosol particles. Thus, assessment of PM10, PM2.5, PM1 and Radon levels assumes significance from epidemiology. Finally, there are few studies that focused on the indoor air quality of hospitals in world based on both particulate matters and Radon simultaneously. Our study aims to (1) characterize the indoor/outdoor RP concentrations and associated Radon emissions in Imam Khomeini hospital, (2) investigate the potential indoor and outdoor sources and their correlations based on statistical analysis. This is the first comprehensive report on quantifying RP and associated Radon emissions at the same time in an old hospital environment in Tehran, Iran.

METHODOLOGY

This study was performed in an old urban hospital that located in Tehran, Iran during the four season period from June 2014 to June 2015. The building age covers about 50 years. All six floors of the building are occupied by patients, visitors and staff all day. This hospital is located in the densely populated commercial area in urban districts and adjacent to heavy traffic road nearby (see Fig.1). Owing to the hot summer periods of sampling, this surveyed hospital is cooled by air-water coolers or air conditioners and in cold season is heated by heating radiators. Particulate matters analyzer (Dust Trak 8520), Radon meter (RADSTAR RS800), ambient air condition analyzer (Lutron MHB 38SD) were used in the medical center for sampling, monitoring and recording data (see Fig.2).

The sampling campaign took place between June 2014 to June 2015 at the 3 locations (Nursery, Treating Rooms, and Outdoor) of 6 floors of monitoring hospital to cover summer, fall, winter, and spring seasons. Totally 504 PM samples and 196 Radon samples are analyzed in this study.

From Saturday to Friday, during the hospital 24h and 3 shifts working hours in the all seasons sampling was performed in 3 locations of hospital. Sampling was performed inside and outside of the 3 selected locations of each floors. Following the WHO guideline the sampling equipment's were placed in the best position to avoid direct contamination of the conditioning systems and

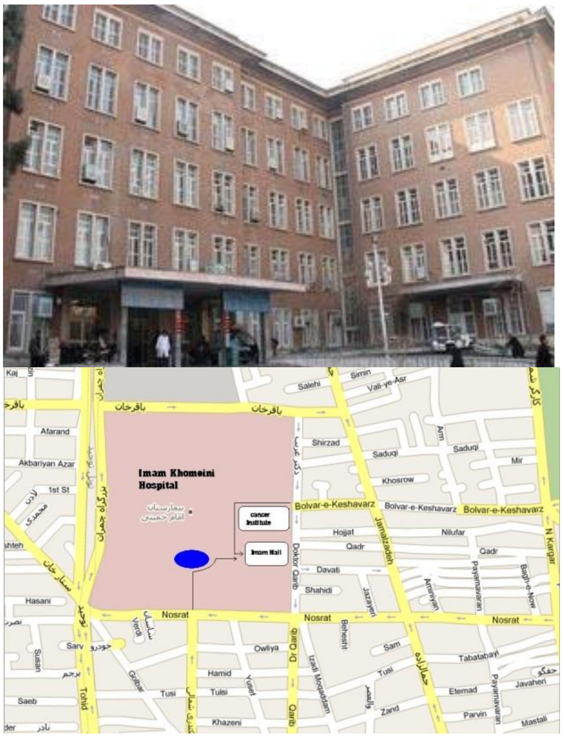

Fig. 1. Imam Khomeini hospital and its location.

Fig. 2. PM and radon analyzers.

people traffic. The sampling instruments were positioned at a distance of around 1 m from the bottom wall and at a height of about 1.5 m above floor [23-24]. For outdoor sampling, the samplers were placed at the front side of the building. Due to the lack of multiple samplers, indoor and outdoor measurements were taken alternately after each 15 min [25]. [26] reported that a variation between 4% and 12%was observed in the mass concentration of PM between alternately and continuously sampled in indoor and outdoor measurement for one successive week. Therefore, the individual 1512 (1008 indoor and 504 outdoor) measurements at hospital were obtained through all seasons in order to cover meteorological conditions and pollutant concentrations. The ambient temperature, air pressure and relative humidity in each location were simultaneously measured at the same time with particulate matter and Radon measurement. The particle counter and Radon meter were factory calibrated, prior to the sampling campaign and the calibration was repeated every season. A Lutron MHB 38SDwas used for temperature, relative humidity, and pressure measurements.

All data were normalized before application of MLR procedure. The analysis of the data was carried out using the statistical software, SPSS (Statistical Package for Social Science, version 20). Bivariate correlation analysis is used to assess the measure of pair wise association among the various variables. Pearson's coefficient(r) is used for measuring linear association, the strength and direction of the relationship between two variables. Stepwise multiple regressions were carried for PM10, PM2.5 and PM1and the results were checked for multicollinearity by examining the variance inflation factors (VIF) of the predictor variables.

RESULTS AND DISCUSSION

The Radon emission measured data reported in Table 1.The PM10 and PM2.5, PM1 average concentration were 27.75, 20.05, 15.50 and varied between 7-49 µg/m3, 6-37 µg/m3 and 5-33 µg/m3, respectively. The records showed that the average of Radon emissions in floors of building were 2.8 Bq m^{-3}, 1.8 Bq m^{-3}, 2.8 Bq m^{-3}, 3.2 Bq m^{-3} , 1.2 Bq m^{-3} , 0.83 Bq m^{-3} and 0.53 Bq m^{-3}respectively.

The statistical Pearson analysis approved strong positive correlation between PM10 and PM2.5, PM1 (Table 2).

Table 1. Statistics for Radon concentrations at nursery location in hospital (Bq m^{-3}).

	Spring	Summer	Fall	Winter
min	0.1	0.1	0.9	0.9
mean	0.89	0.87	2.2	2.15
max	3.1	2.8	4.5	4.42

Multivariate Manova analysis for four variables (season, day, floor no., location) and throughPillai's Trace ،Wilks' Lambda ،Hotelling's Trace و ،Roy's Largest Root methods are used for providing table of Tests of Between-Subjects Effects for PM1, PM2.5, PM10 arrays with following results:

- There is no meaningful difference between season-day for any PM's
- There is no meaningful difference between season-location for PM2.5
- There is no meaningful difference between location-day for any PM2.5 and PM10
- There are meaningful deference between PM1, PM2.5 and PM10 for other effects.

Table 2. Correlation analysis for PM.

	Spring	PM1	PM2.5	PM10
PM1	Pearson Correlation	1	.834**	.702**
	Sig. (2-tailed)		.000	.000
	N	504	504	504
PM2.5	Pearson Correlation	.834**	1	.810**
	Sig. (2-tailed)	.000		.000
	N	504	504	504
PM10	Pearson Correlation	.702**	.810**	1
	Sig. (2-tailed)	.000	.000	
	N	504	504	504

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

For evaluating of effects of air condition (Temperature, Pressure, and Relative Humidity) on PM concentrations we applied Stepwise Linear Regression (LR) and found that increasing of pressure and decreasing of temperature cause all PM increase but the temperature is sensitive more to PM1 and PM2.5 and pressure is sensitive just for PM10.

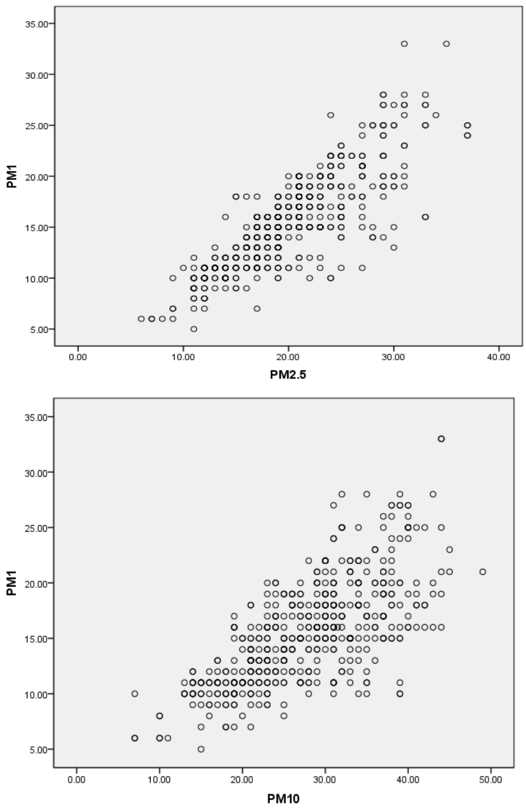

Fig. 3. Linear relation diagram of PM1, PM2.5and PM10.

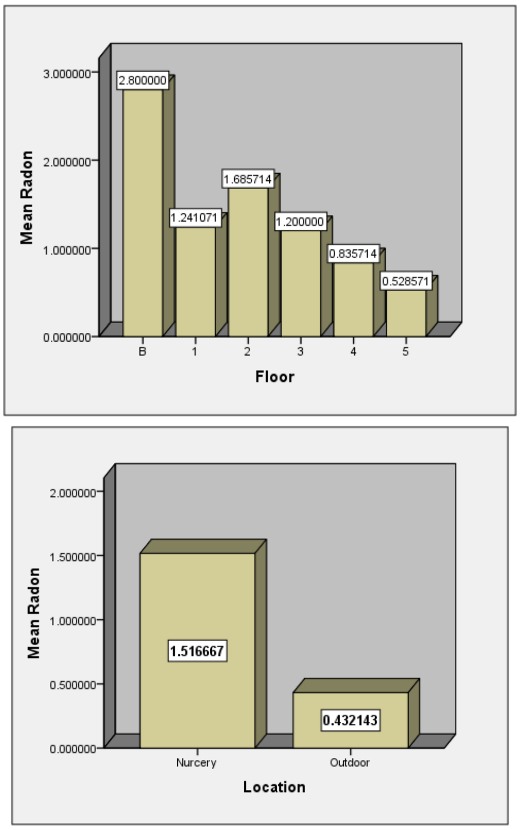

Fig 4. The radon measurements graphs.

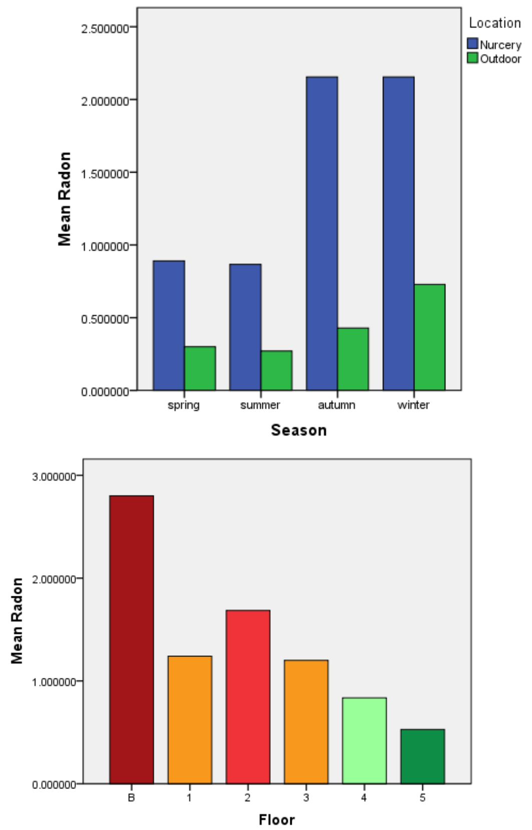

Fig. 5. The variance analysis results for season-location sources.

The Radon emission data analysis showed that the Nursery with 1.51Bq m^{-3}has the maximum emission and the hospital outdoor with 0.43Bq m^{-3}has the lowest emissions (Fig. 2).

The Variance analysis for Radon data, showed a large amount of F (44.871) for the season-location and it means that there is a strong meaningful correlation between two sources.

We found that in first and second half of year the radon emissions at Nursery location were the same but in outdoor location and in cold seasons it has been increased.

Finally, based on stepwise regression model, we can report that the concentration of [222]Rn and PM2.5 and ambient pressure showed reverse and direct correlation respectively. Linear model has more than 50 percent reliability in correlations but study should be continued by others to find more correlations between Radon and parameters. We understood that in regression model:

- The temperature had no any meaningful correlation
- The cold seasons had meaningful correlation specially in outdoor location

The parameters of temperature, pressure and humidity had very strong correlation with each other and the pressure as their representative was very good response variable to Radon mathematically.

CONCLUSION

To our knowledge, this is the first study in Iran, or even in Asian developing countries, to report the effect of PM10, PM2.5, PM1, and [222]Rn emission simultaneously on morbidity. Our findings also suggest that Radon could serve as a valuable air quality indicator that reflects the health risks of airborne particles. The study could be continued to explain more about particulate matters and Radon correlations.

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