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Traffic Related Air Pollution in Residential Environment, Damietta, Egypt

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Abstract: In recent years, people have started to recognize the importance of indoor environment. The traffic related air pollutants were assessed in homes located on streets with different traffic density in Damietta, Egypt. Paired indoor and outdoor concentrations of particulate matter (PM_{10}), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were determined at 22 homes during winter and summer Seasons 2010. Measurements were supplemented by a questionnaire on housing characteristics and possible indoor sources. The influence of the traffic on the indoor concentration was apparent in the high traffic areas. There was a general pattern of increasing summer I/O ratios. The most I/O ratios of PM_{10}, NO_2 and SO_2 were less than one indicating that the outdoor traffic-related sources contributed more to indoor air quality. The concentrations of all pollutants varied significantly ($P<0.05$) in both seasons. The PM_{10} had higher values in winter while both NO_2 and SO_2 were slightly higher in summer for the all traffic density areas. The correlations observed between outdoor and indoor concentrations in winter were relatively low than those observed in summer. Results showed poor correlation between indoor and outdoor PM_{10} and relatively strong correlation of NO_2 and SO_2 at both summer and winter.

Key words: Indoor air quality · Transportation · PM_{10} · NO_2 · SO_2 · I/O ratios

INTRODUCTION

Traffic is considered to be the major contributors to atmospheric pollution in urban areas [1-7]. Air quality in the vicinity of roadways can be seriously impacted by emissions from heavy traffic flows [8]. Despite the constant developments on environmentally friendlier fuels and the production of less pollutant vehicles, atmospheric pollution by road traffic is not diminishing in several metropolitan areas because of continuous traffic increasing [9].

Areas close to roadways may have their indoor air quality (IAQ) affected by traffic-related pollution sources. Several studies have indicated the associations between traffic-related air pollution and the IAQ [10-12]. Homes located very close to large volumes vehicle traffic demonstrate higher levels of exposure to air pollutants [4, 7].

Epidemiological studies consistently report increases in a broad array of adverse health effects associated with vehicle related air pollution. These include increased risk of reduced lung function [13-15], asthma [16-19], adverse respiratory symptoms [20-22], cardiovascular and cardiopulmonary events [23-25], adverse birth outcomes [26-27], cancer [28-29] and non traumatic mortality [30-33].

Transportation and energy production are the primary sources of the outdoor PM_{10} [34-38], while cooking, smoking and cleaning activities contribute primarily to the indoor PM_{10} levels [39-41]. Course particles are mainly a result of wear of road pavement, tyres and brakes [42-43]. Traffic is emitting a wide range of particle and reduces the air quality in urban areas due to both direct vehicle emissions and the resuspension of particles from the road surface [44]. The concentrations of traffic-related particulates have been reported by several authors [45-53]. Also, these particles arrive at the indoor environment due to ventilation and at closed windows, too [54-55].

The major outdoor sources of NO_2 are mobile and stationary combustion sources [56-59], whereas indoor sources include gas cookers, wood stoves, fireplaces and environmental tobacco smoke [60]. Diesel vehicles are the main sources for SO_2 emissions while gasoline engine is the major source of NO_2. D'Angiola *et al*. [61] stated that together, diesel light and heavy-duty vehicles were responsible for almost 80% of SO_2 emissions and 55% of NO_x emissions.

Damietta City, the capital of Damietta governorate, is located northeast of Cairo on the eastern branch of the Nile and is surrounded by The Mediterranean Sea to the

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north. To assess the contribution of traffic related air pollution to the indoor air quality in homes located on areas of different traffic density in Damietta, this study was undertaken with the following objectives: (1) to characterize the traffic related air pollutants in the residential environment through the measurements of indoor and outdoor PM_{10}, NO_2 and SO_2 during winter and summer of 2010 and (2) to investigate the relationships between traffic related pollutants in the Indoor and outdoor air through the estimate of indoor/outdoor ratios and correlations as well as seasonal variations.

MATERIALS AND METHODS

Study Area: To assess the impact of traffic related air pollution on the Damietta metropolitan area, Egypt, 22 homes on streets with different degree of traffic density were recruited for the study. The homes were classified into three groups according to the nearby traffic density, namely high, medium and low traffic density areas. The high traffic density area contained seven sampling sites designated H1- H7, the medium traffic density area contained six sites designated M1- M6 and low traffic density areas contained nine sites designated L1- L9. Fig. 1 shows the locations of the sampling sites in different traffic density areas.

Sampling Strategy: Paired indoor and outdoor concentrations of PM_{10}, NO_2 and SO_2 were determined in 22 homes during winter and summer seasons of 2010. Sampling was not restricted to days when the occupants were home the entire 24-h period, although since most households had young children, homes were typically occupied throughout the sampling period. Inlets for both the indoor and outdoor samplers were placed at breathing level for a typical adult. Measurements were supplemented by a questionnaire on household characteristics and possible indoor sources. Brief details of all of the homes studied appear in Table 1. Participants spent on average approximately 80% of their time indoors at home, with little difference by season. Only 5 homes reported indoor smoking during air monitoring.

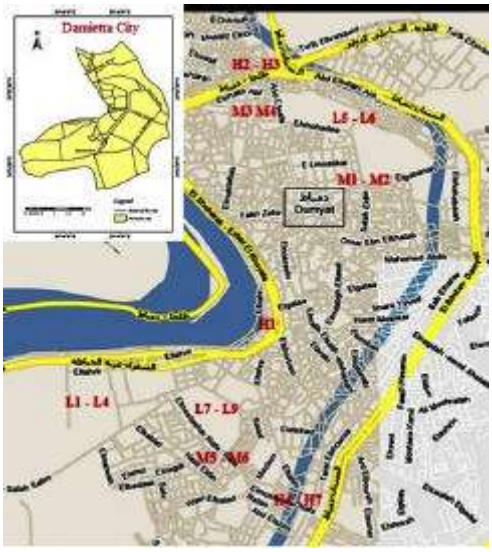

Fig. 1: The sampling sites in different traffic areas in Damietta City.

Table 1: Main characteristics of homes used in the study areas.

ID	Ventilation	Fuel	Smoking	Pollution Sources
H1	Natural, rare window opening	LPG	no	outdoor furniture workshop, cooking, cleaning
H2	Natural, frequent window opening	Gas	no	cooking, cleaning
H3	Natural, frequent window opening	Gas	no	cooking, cleaning, cosmetics
H4	Natural, frequent window opening	Gas	no	cooking, cleaning, pesticides,
H5	Natural, rare window opening	Gas	yes	cooking, cleaning, hair spray, cosmetics
H6	Natural, frequent window opening	Gas	no	cooking, cleaning
H7	Natural, no window opening	Gas	no	cooking, cleaning, cosmetics
M1	Natural, frequent window opening	LPG	no	cooking, cleaning
M2	Natural, frequent window opening	LPG	no	cooking, cleaning
M3	Natural, frequent window opening	Gas	no	cooking, cleaning
M4	Natural, no window opening	Gas	no	cooking, cleaning
M5	Natural, frequent window opening	LPG	no	outdoor furniture workshop, cooking, cleaning
M6	Natural, frequent window opening	Gas	yes	cooking, cleaning
L1	Natural, frequent window opening	LPG	yes	outdoor furniture workshop, cooking, cleaning
L2	Natural, frequent window opening	LPG	no	outdoor furniture workshop, cooking, cleaning
L3	Natural, frequent window opening	LPG	yes	outdoor furniture workshop, cooking, cleaning
L4	Natural, rare window opening	LPG	no	outdoor furniture workshop, cooking, cleaning
L5	Natural, no window opening	Gas	yes	outdoor furniture workshop, cooking, cleaning
L6	Natural, frequent window opening	Gas	no	outdoor furniture workshop, cooking, cleaning
L7	Natural, frequent window opening	Gas	no	outdoor furniture workshop, cooking, cleaning
L8	Natural, no window opening	Gas	no	cooking, cleaning, pesticides, cosmetics
L9	Natural, frequent window opening	Gas	no	cooking, cleaning, pesticides

Air conditioning in the living room was present infrequently. Gas was used for cooking in the majority of homes. Indoor pollution sources are mainly cooking, smoking and cleaning activities.

Sampling Methods: Identical sampling equipment was positioned inside and outside sampled homes. Indoor samplers were placed in a living room or dining room, but never directly in a kitchen. The sampling equipment was housed such that it was as compact as possible and positioned indoors to cause minimal intrusion to the occupants. Residences had to be at safe locations for the placement of the pumps outdoors during the measurements. Outdoor samplers were housed in a weather-proof cabinet at least 1 m from the homse, trees, etc.

PM_{10} concentrations were measured using the filtration method [62]. Particles were collected on Whatman 47 mm Teflon filters with 2μm pores size. Filters were weighed in temperature and relative humidity control. Weighing methods are detailed elsewhere [63]. NO_2 was measured by sodium arsenite method and then determined calorimetrically at λ= 540 nm [62]. West and Gaeke method (Pararosaniline Method) was applied for determination of SO_2 calorimetrically at λ= 548 nm [64].

Quality Control: Data quality assurance procedures were enforced to ensure minimal contamination in sample handling and field work. All air samples were collected in duplicate. Field blanks were used and analyzed simultaneously with the exposed samples for quality control during the study. Flows were measured at the beginning and end of each sampling period and used to calculate the sampled volumes.

Statistical Analysis: The descriptive statistics (i.e. arithmetic means, standard deviations, maxima, minima and median) were used to present the data. Indoor/outdoor ratios were computed to assess indoor/outdoor associations. Summer/winter ratios were computed to evaluate the seasonal variations. Linear regression was performed to determine the relationships between indoor and outdoor concentrations. All analyses were performed using SPSS for Windows, v. 12.0 (SPSS, Inc., Chicago, IL).

RESULTS AND DISCUSSION

Air Pollution in Areas with Different Traffic Densities: A summary statistics of the indoor and outdoor concentrations of PM_{10}, NO_2 and SO_2 concentrations obtained from different traffic density areas in both summer and winter are provided (Table 2). The PM_{10}, NO_2 and SO_2 concentrations measured in indoor and outdoor in the two seasons are presented in Fig. 2. The concentrations of traffic related pollutants in the different traffic density areas varied significantly ($P<0.05$). The concentrations of all pollutants were higher in areas with higher traffic density in the both seasons. High traffic density areas are often subject to higher congestion and hence higher traffic emissions.

The results showed significant ($P<0.05$) differences between indoor and outdoor concentrations in both summer and winter. In summer, the mean outdoor air PM_{10}, NO_2 and SO_2 concentrations were 953.7, 114.7 and 69.9 μg/m^3 in high traffic areas; 791.3, 99.8 and 57.7 μg/m^3 in medium traffic areas and 750, 83.4 and 51.6 μg/m^3 in low traffic areas, respectively. The mean indoor PM_{10}, NO_2 and SO_2 concentrations were 855.7, 98.8 and 57.6 μg/m^3 in high traffic areas; 766.5, 86.6 and 46.2 μg/m^3 in medium traffic areas and 688.3, 77.1 and 43.3 μg/m^3 in low traffic areas, respectively.

In winter, the mean outdoor air PM_{10}, NO_2 and SO_2 concentrations were 1088, 98.4 and 45 μg/m^3 in high traffic areas; 896.5, 89.8 and 36.8 μg/m^3 in medium traffic areas and 841.4, 74.7 and 34.6 μg/m^3 in low traffic areas, respectively. The mean indoor PM_{10}, NO_2 and SO_2 concentrations were 814.6, 71.3 and 42.1 μg/m^3 in high traffic areas; 654.2, 55.7 and 32 μg/m^3 in medium traffic areas and 625.8, 48.1 and 30 μg/m^3 in low traffic areas, respectively.

As shown in Fig. 2, the indoor concentrations of PM_{10}, NO_2 and SO_2 were slightly lower than outdoor concentrations in both seasons. The PM_{10} concentrations tended to have higher values in winter than in summer while the concentrations of both NO_2 and SO_2 were slightly higher in summer than in winter for the all traffic density areas. Among the gaseous pollutants concentrations measured in the three areas, NO_2 concentration was the highest, followed by SO_2.

Janssen *et al*. [7] reported that in both indoor and outdoor air, concentrations of PM_{10}, SO_2 and NO_2 significantly increased with increasing traffic density. Several studies have shown the significant difference of PM_{10} and NO_2 levels at the highest and the lowest traffic areas [65-69]. El-Henawy [65] studied the contribution of road traffic to PM_{10} emissions in Damietta City and found the mean annual concentration of PM_{10} was 963.79 μg/m^3 with a range of 1341.67 to 744.09 μg/m^3. Mao *et al*. [66] found that aerosols levels in high traffic areas were about two times those in low traffic areas.

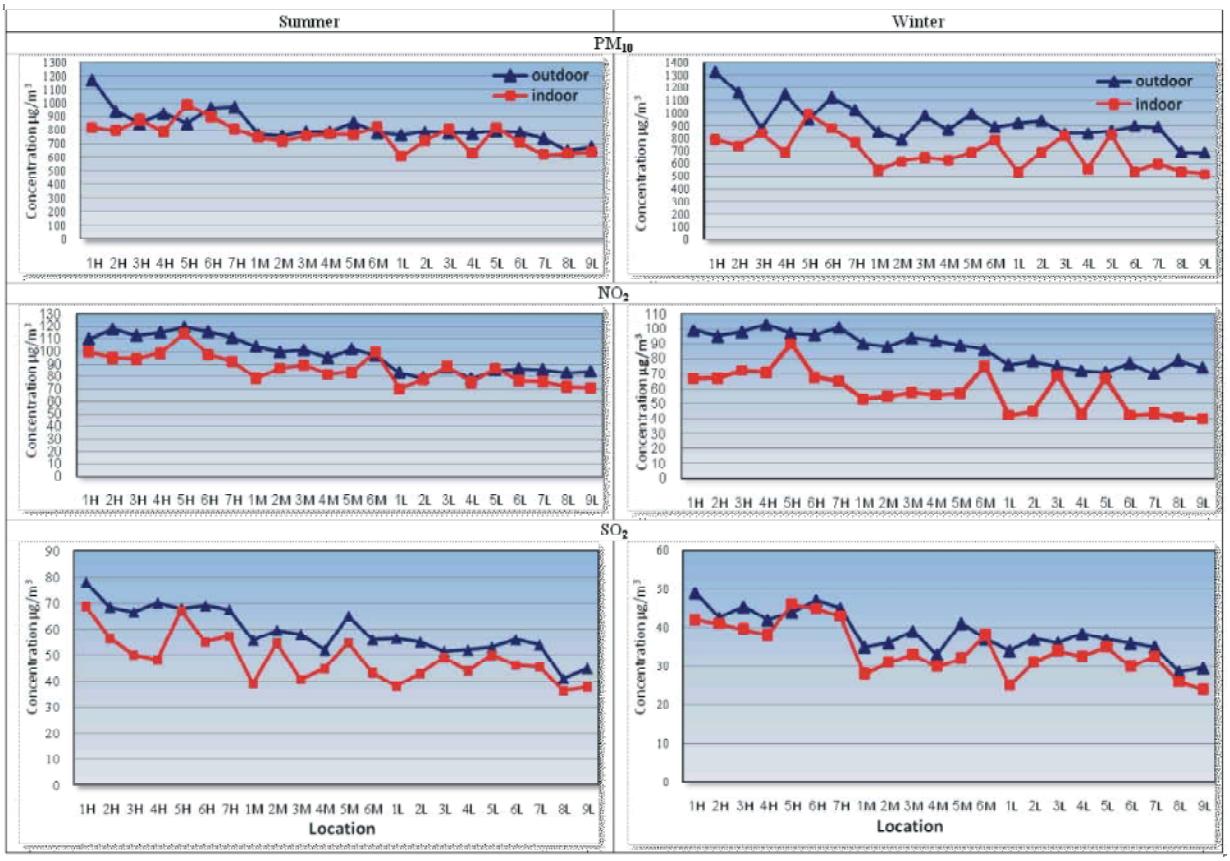

Fig. 2: The PM_{10}, NO_2 and SO_2 concentrations measured in indoor and outdoor in summer and winter seasons

Table 2: Descriptive statistics for indoor and outdoor traffic related pollutants at different traffic density areas in both summer and winters.

			Mean			SD			Max			Min			Median		
Pollutant	Season	category	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
PM µg/m^3	Summer	Indoor	855.7	766.5	688.3	72.3	34.3	82.1	990.0	824.0	820.0	790.0	720.0	610.0	820.0	765.0	640.0
		Outdoor	953.7	791.3	750.0	108.4	35.5	52.3	1172.0	860.0	793.0	850.0	760.0	650.0	940.0	784.0	776.0
	Winter	Indoor	814.6	654.2	625.8	100.1	78.8	123.9	992.0	785.0	829.0	690.0	550.0	520.0	790.0	640.0	560.0
		Outdoor	1088.0	896.5	841.4	148.7	79.5	92.0	1324.0	995.0	940.0	879.0	790.0	687.0	1124.0	880.0	860.0
NO_2 µg/m^3	Summer	Indoor	98.8	86.6	77.1	7.4	7.3	6.4	114.3	99.7	88.3	92.2	78.9	70.4	97.6	85.0	76.0
		Outdoor	114.7	99.8	83.4	3.6	3.3	3.1	119.5	104.0	87.0	110.0	95.0	78.0	115.6	100.3	84.0
	Winter	Indoor	71.3	55.7	48.1	8.6	8.0	11.4	89.9	75.0	69.0	65.0	53.0	40.0	67.5	56.0	43.0
		Outdoor	98.4	89.8	74.7	2.8	2.9	3.2	103.0	94.0	79.0	95.0	86.0	70.0	98.0	89.5	75.0
SO_2 µg/m^3	Summer	Indoor	57.6	46.2	43.3	7.8	6.9	4.9	68.8	54.8	50.0	48.2	39.0	36.4	56.6	44.1	44.0
		Outdoor	69.6	57.7	51.6	3.8	4.4	5.2	78.0	65.0	56.5	66.5	52.0	41.0	68.5	57.0	53.0
	Winter	Indoor	42.1	32.0	30.0	2.9	3.4	4.1	46.0	38.0	35.0	38.0	28.0	24.0	42.0	31.5	31.0
		Outdoor	45.0	36.8	34.6	2.5	2.9	3.4	49.0	41.0	38.4	42.0	33.0	28.5	45.0	36.5	35.9

El-Gammal *et al.* [67] concluded that the mean annual concentrations of NO_2 and SO_2 over Damietta City atmosphere were 55.73±24.14 and 44.03±30.24 µg/m^3, respectively. Rijnders *et al.* [69] have shown that indoor and outdoor NO_2 concentrations are significantly influenced by the traffic density followed by the distance to a nearby highway. Several studies have shown that outdoor levels of NO_2 could be higher due to increased primary NO_2 emissions from vehicles [70-73].

The relationship between traffic related pollutants in the indoor/outdoor air: The indoor/outdoor (I/O) ratios were calculated to investigate the relationship between traffic related pollutants in indoor and outdoor air. The I/O ratio is an indicator of whether indoor levels are the result of outdoor particle concentrations or if indoor levels are influenced by significant indoor sources of particulates. I/O mean ratios of PM_{10}, NO_2 and SO_2 at different traffic areas in both summer and winters were presented in Figure 3 and their summary statistics were presented in Table 3.

Table 3: A summary statistics of indoor/outdoor (I/O) ratios of traffic related pollutants at different traffic density areas in both summer and winters.

		PM_{10}		NO_2		SO_2	
		Summer	Winter	Summer	Winter	Summer	Winter
Mean	H	0.91	0.77	0.86	0.73	0.83	0.94
	M	0.97	0.73	0.87	0.66	0.80	0.87
	L	0.92	0.75	0.92	0.65	0.84	0.87
SD	H	0.15	0.18	0.05	0.09	0.09	0.06
	M	0.05	0.09	0.09	0.11	0.09	0.09
	L	0.09	0.14	0.07	0.17	0.08	0.07
Max	H	1.16	1.04	0.96	0.93	0.99	1.05
	M	1.06	0.88	1.03	0.87	0.92	1.03
	L	1.04	0.98	1.02	0.94	0.95	0.95
Min	H	0.70	0.60	0.81	0.64	0.69	0.86
	M	0.90	0.65	0.76	0.59	0.70	0.78
	L	0.80	0.58	0.85	0.52	0.68	0.74
Median	H	0.85	0.75	0.84	0.70	0.83	0.96
	M	0.97	0.71	0.87	0.62	0.81	0.85
	L	0.92	0.73	0.89	0.57	0.84	0.85

Table 4: A summary statistics of summer/winter (S/W) ratios of traffic related pollutants at different traffic density areas in both indoor and outdoor.

		PM_{10}		NO_2		SO_2	
		Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Mean	H	1.05	0.88	1.39	1.17	1.37	1.55
	M	1.18	0.89	1.48	1.11	1.46	1.57
	L	1.12	0.90	1.65	1.12	1.45	1.49
SD	H	0.05	0.06	0.08	0.06	0.14	0.08
	M	0.11	0.05	0.09	0.05	0.25	0.06
	L	0.11	0.06	0.21	0.07	0.08	0.09
Max	H	1.14	0.97	1.50	1.24	1.64	1.67
	M	1.36	0.96	1.57	1.16	1.76	1.65
	L	1.31	0.98	1.83	1.22	1.58	1.66
Min	H	1.00	0.80	1.27	1.10	1.22	1.46
	M	1.05	0.80	1.33	1.03	1.14	1.49
	L	0.99	0.83	1.28	1.01	1.35	1.35
Median	H	1.05	0.89	1.42	1.15	1.33	1.55
	M	1.17	0.89	1.48	1.13	1.44	1.58
	L	1.13	0.92	1.75	1.12	1.43	1.49

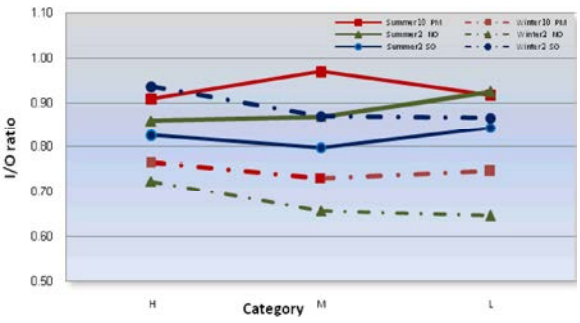

Fig. 3: I/O mean ratios of PM_{10}, NO_2 and SO_2 at different traffic areas in both summer and winters.

As shown in Table 3, the mean I/O ratios of PM_{10}, NO_2 and SO_2 in summer are higher than those measured in winter at all traffic areas. Gupta and Cheong [74] observed a relative increase in I/O ratio with increase in temperature due to the temperature gradient that is favoring the migration of the particles indoors. During summer, when ventilation is high, the variation between the pollutants concentrations is less than for winter due to the infiltration of outdoor air into indoors through open windows.

The summer PM_{10} I/O ratios ranged from 1.16 (H5) to 0.7 (H1); 1.06 (M6) to 0.9 (M5); and 1.04 (L3) to 0.8 (L1) in high, medium and low traffic areas, respectively. The winter PM_{10} I/O ratios ranged from 1.04 (H5) to 0.6 (H1); 0.88 (M6) to 0.65 (M1) and 0.98 (L3) to 0.58 in high, medium and low traffic areas, respectively. The summer NO_2 I/O ratios ranged from 0.96 (H5) to 0.81 (H2); 1.03 (M6) to 0.76 (M1) and 1.02 (L5) to 0.85 (L1, L9) in high, medium and low traffic areas, respectively. The winter NO_2 I/O ratios ranged from 0.93 (H5) to 0.64 (H7); 0.87 (M6) to 0.59 (M1) and 0.94 (L5) to 0.52 (L8) in high, medium and low traffic areas, respectively. The summer SO_2 I/O ratios ranged from 0.99 (H5) to 0.69 (H4), 0.92 (M2)

to 0.7 (M1, M3) and 0.95 (L3) to 0.68 (L1) high, medium and low traffic areas, respectively. The winter SO_2 I/O ratios ranged from 1.05 (H5) to 0.86 (H1); 1.03 (M6) to 0.78 (M5) and 0.95 (L5) to 0.74 (L1) in high, medium and low traffic areas, respectively.

As expected, the most I/O ratios of PM_{10}, NO_2 and SO_2 were less than one indicating that the outdoor traffic-related sources contributed more to indoor air quality. The averaged I/O ratios were higher than one in the homes with strong indoor activities as smoking, cooking and cleaning (Table 1). Abt *et al*. [75] found that indoor activities, such as vacuuming, dusting, washing and carpet cleaning, contributed from 50% to 80% of the indoor particles concentrations. The effect of cooking activities on the indoor air particulate levels was very important as it released significant amounts of oily fumes from kitchens. Results showed that indoor sources contribution to indoor NO_2 is important, especially for homes with gas cookers.

Results obtained in this study agreed with those found by other investigators who performed PM_{10} measurements in the roadside homes. Martuzevicius *et al.* [4] found that the PM_{10} I/O ratio ranged from 0.5 to 2.9 in spring and from 0.7 to 4.7 in fall while Jones *et al*. [52] reported the I/O of 1.6–1.7 for PM_{10}. Kornartit *et al.* [60] studied the personal exposure to nitrogen dioxide in indoor and outdoor microenvironments with NO_2 mean indoor to outdoor ratio of 0.93.

Seasonal Variation of Indoor and Outdoor Concentrations: Summer to winter ratios (S/W) were calculated to investigate the effect of seasonal variations on indoor and outdoor air quality. S/W ratios of PM_{10}, NO_2 and SO_2 at different traffic areas in both indoor and outdoor were presented in Figure 4 and their summary statistics were presented in Table 4.

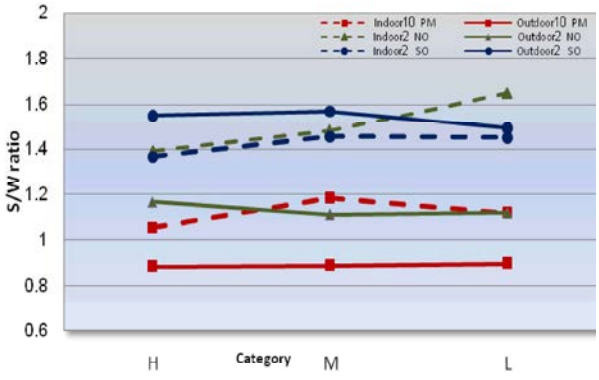

Fig. 4: S/W ratios of PM_{10}, NO_2 and SO_2 at different traffic areas in both Indoor and outdoor environment.

As shown in Table 4, the mean outdoor PM_{10} S/W ratios were 0.88, 0.89 and 0.90 in high, medium and low traffic areas, respectively while the mean indoor PM_{10} S/W ratios were 1.05, 1.18 and 1.12 in high, medium and low traffic areas, respectively. The outdoor mean S/W ratios of PM_{10} were less than one at all traffic areas indicating a general pattern of increasing PM_{10} levels from winter to summer. Slightly higher PM_{10} concentrations measured in the winter could be attributed to the ambient meteorological conditions. In winter, stable atmospheric conditions are common which restricts the dispersion of air, especially in cities [76]. During summer times in contrast, greater dispersion can lead to lower ambient levels of PM_{10}.

The mean outdoor NO_2 S/W ratios were 1.17, 1.11 and 1.12 in high, medium and low traffic areas, respectively while the mean indoor NO_2 S/W ratios were 1.39, 1.48 and 1.65 in high, medium and low traffic areas, respectively. The mean outdoor SO_2 S/W ratios were 1.55, 1.57 and 1.49 in high, medium and low traffic areas, respectively while the mean indoor SO_2 S/W ratios were 1.37, 1.46 and 1.45 in high, medium and low traffic areas, respectively.

It was apparent that the concentrations of both NO_2 and SO_2 in summer were higher than those measured in winter at all traffic areas as their outdoor mean S/W ratios were more than one. The atmospheric chemical reactions play a substantial role in the seasonal variation. The seasonal variation of NO_2 from the traffic sector may be influenced by the higher traffic density during summer and by secondary NO_2 formation via reaction of NO with O_3 [77-78]. Consequently, the direct oxidation of NO to NO_2 contributes significantly to the total NO_2 during the summer season when O_3 concentrations are high. The rate of oxidation processes of SO_2 by the OH radical increase with increasing temperature and relative humidity [79].

These findings are in agreement with other authors who observed a general increase of average summer NO_2 concentrations than those in winter [60, 80]. El-Gammal *et al*. [67] evaluated the traffic gaseous pollutants in Damietta City-Egypt and found average NO_2 levels varied from 19.90 to 126.16 $\mu g/m^3$ over the four seasons, with the highest concentrations recorded in summer (126.16±9.02 $\mu g/m^3$) and followed by spring (95.91±4.52 $\mu g/m^3$). Artíñano *et al*. [78] observed that in Madrid City-Spain, NO_2 exhibits a different seasonal behavior associated with its photochemical nature.

El-Gammal *et al.* [67] found average SO_2 levels in Damietta City varied from 16.99 to 122.86 $\mu g/m^3$ over the four seasons, with the highest concentrations recorded in summer. Shakour [81] recorded that

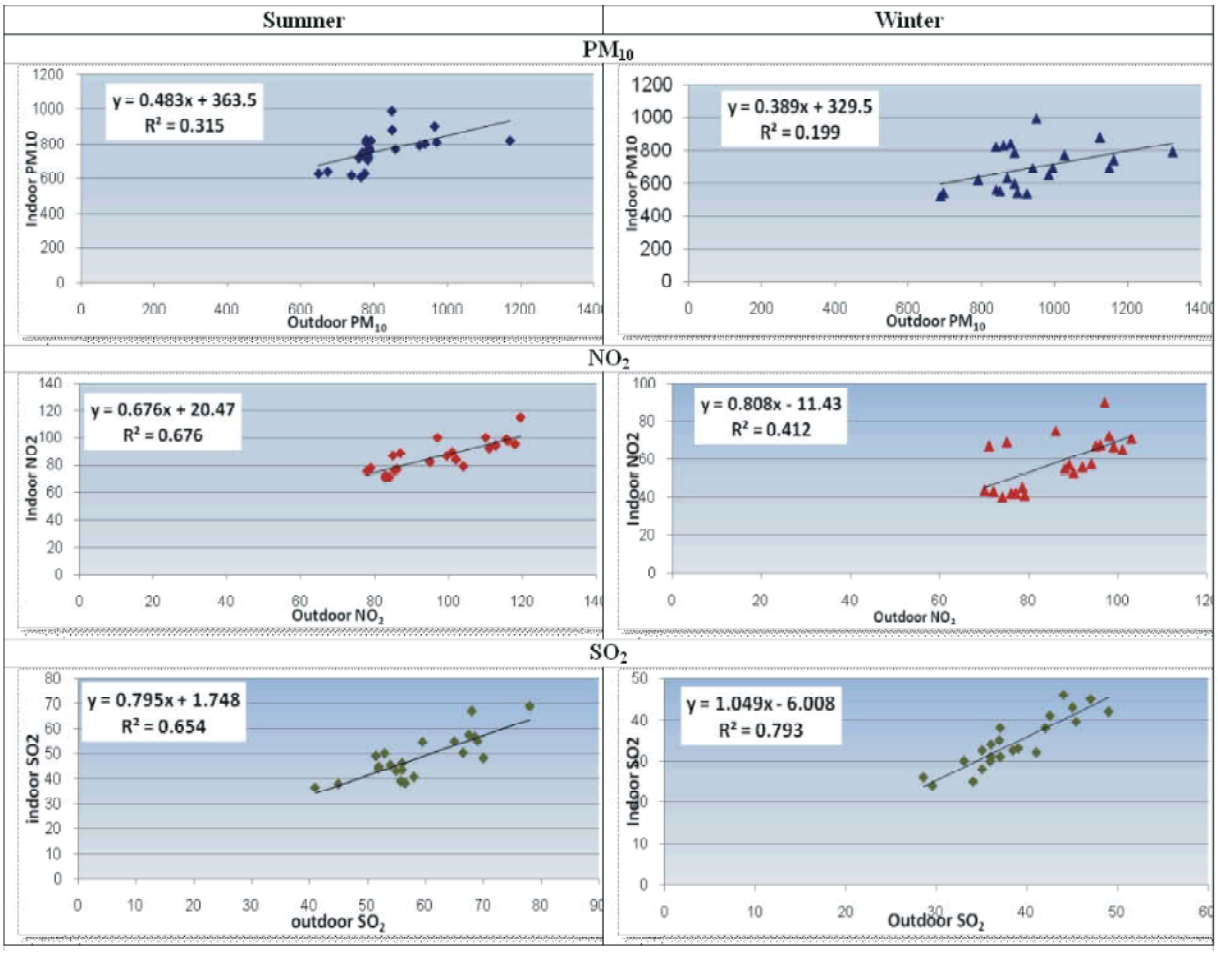

Fig. 5: The relationship between outdoor and indoor PM_{10}, NO_2 and SO_2 in summer and winter seasons.

Table 5: Summary of correlations of indoor and outdoor traffic related pollutants concentrations.

	Summer			Winter		
Indoor vs Outdoor	Intercept	Slope	R^2	Intercept	Slope	R^2
PM_{10}	363.5	0.483	0.315	329.5	0.389	0.199
NO_2	20.47	0.676	0.676	11.43	0.808	0.421
SO_2	1.748	0.795	0.654	-6.008	1.049	0.793

the average SO_2 levels at new residential areas in Cairo City vary from 13.28 to 19.10 µg/m^3 over the four seasons, with the highest concentrations recorded in summer and autumn. Ingle *et al*. [82] observed high concentration of oxides of sulfur during the summer season in India. On the other hand, many authors observed a general decrease of average summer NO_2 concentrations than those in winter [67, 83]. This may be due to the differences in the climatic conditions between the different study areas. Damietta City has the climate of Mediterranean Sea area which is characterized by high atmospheric temperature at summer and rainy winter.

Impact of Outdoor Traffic Related Air Pollution on IAQ: The indoor versus outdoor correlations serves as an indication of the impact of outdoor traffic related air pollution on indoor air quality. Higher correlation is expected for the pollutants of solely outdoor origin while indoor source-related pollutants should show lower or no correlation. A linear regression of indoor versus outdoor PM_{10}, NO_2 and SO_2 was performed in both summer and winter (Fig. 5). The values of the regression parameters slope, intercept and correlation coefficients (R^2) were shown in Table 6.

The correlations observed between outdoor and indoor concentrations in winter were relatively low than those observed in summer. This showed that the contribution of outdoor pollutants to indoor pollution is higher in summer than winter. In summer, the infiltration of outdoor air into indoors is high through open windows.

The relatively poor correlations of PM_{10} (R^2 of 0.315 and 0.199 in summer and winter, respectively) suggested that particles not only attributed to traffic exhaust, but also to other local outdoor sources. Nine houses are located adjacent to furniture workshops which emit considerable amounts of particles (Table 1) to the outdoor air.

Results showed a relatively strong correlation between indoor and outdoor NO_2 and SO_2 at both summer and winter, which implied that outdoor levels strongly influenced indoor levels. The indoor NO_2 and SO_2 might be the cause of inflow from the ambient outdoor air as the homes were all situated in close proximity to a heavy-traffic road whereas a lot of vehicles often caused traffic jams. The effects of traffic condition and motor vehicle exhaust outdoors on the indoor levels of NO_2 and SO_2 were very significant. The only exception was the correlation between the NO_2 concentrations in winter season (R^2 of 0.421) indicating the prevailing of their indoor sources in winter.

Previous studies demonstrated that outdoor particle concentrations are generally higher at residences located in the traffic sites or near busy streets [20, 55]. Outdoor NO_2 and PM_{10} sources may be generated simultaneously, as is known to occur from vehicle exhaust [11, 51]. Mao *et al*. [66] indicated that the traffic density was highly correlated with primary pollutants (NO_2, SO_2) and significantly correlated with aerosols pollutants in Taipei area. Janssen *et al*. [7] concluded that the traffic density was highly correlated with NO_2 and SO_2 and significantly correlated with PM_{10}.

CONCLUSION

The contribution of traffic related air pollution to the indoor air quality in homes located on areas of different traffic density in Damietta was apparent, especially in the high traffic ones. The concentrations of all pollutants in the different traffic density areas varied significantly in both seasons. There was a general pattern of increasing summer I/O ratios of PM_{10}, NO_2 and SO_2 at all traffic areas. The most I/O ratios were less than one indicating that the outdoor traffic-related sources contributed more to indoor air quality. The indoor NO_2 and SO_2 might be the cause of the penetration of traffic-related aerosols to indoor environment while PM_{10} not only attributed to traffic exhaust, but also to other local outdoor sources as the furniture workshops located adjacent to many houses.

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