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Assessment of Indoor Water-Soluble Particulates in Medical and Residential Sites

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ABSTRACT

Indoor air quality is a significant concern due to the potential health risks and comfort issues associated with air pollutants. This study aimed to assess the concentrations of nitrate, ammonium, and sulfate in indoor water-soluble particulates in the air of both medical and residential sites in Damietta, Egypt. Thirty-five samples of particulate matter were collected from 15 medical sites and 20 residential sites from May to August 2021 located in Damietta City (urban) and El- Basarta village (suburban). The results indicated that indoor air is influenced by high concentrations of NO_3^-, NH_4^+, and SO_4^{2-}. The outdoor NO_3^-, NH_4^+, and SO_4^{2-} concentrations were higher than indoor ones. It was observed that the concentrations of the determined parameters (NO_3^-, NH_4^+, and SO_4^{2-}) were higher in the medical sites than the residential ones and also higher in the urban sites than the suburban ones. Additionally, the I/O ratios of NO_3^-, $NH_4^{+,}$ and SO_4^{2-} in almost sites were below 1.0 indicating the relatively high influence of the outdoor sources on the indoor air. Therefore, it was recommended to use more natural cleaning materials to improve indoor air quality, and clean indoor spaces often by vacuuming or mopping to remove hazardous pollutants.

Keywords: Air pollution; Ammonium; Indoor air quality; I/O ratio; Natural cleaning materials; Nitrate; Sulfate.

INTRODUCTION

People spend 80–90% of their time inside; therefore indoor air quality (IAQ) has a substantial impact on their health and well-being (El-Batrawy, 2013; Mata *et al*., 2022). IAQ has grown to be one of the primary factors affecting health since the World Health Organization (WHO) has consistently emphasized its significance and the possible risk of pollutants produced from indoor sources (Settimo *et al*., 2020). Cleaning chemicals, perfumes, construction activities, water-damaged building materials, cigarette smoke, and external pollutants can all contribute to indoor air pollution (Saad *et al*., 2017).

IAQ is also defined by the illustration of air pollutant concentrations and thermal conditions that may be detrimental and affect a building's occupants' health, comfort, and ability to function (Satsangi *et al*., 2014). Temperature and humidity have an impact on indoor air quality (Vijaykrishna and Balaji, 2023). Human wellbeing depends on thermal comfort, which is the right combination of temperature and relative humidity (Jing *et al*., 2013). Medical clinics have different temperature needs depending on the building or type of room. While surgical and inpatient rooms should be kept at a temperature range of 20°C to 23°C, clinics and care clinics should maintain a temperature range of 21°C to 24°C to keep patients safe and stop the spread of bacteria (Vijaykrishna and Balaji, 2023).

Healthcare facilities, as places of healing, should prioritize the well-being of all their occupants; however, paradoxically, they can sometimes transform into unhealthy environments with an increased risk of infections (Capolongo *et al*., 2015). Medical facilities, which cater to patients with diverse health conditions, cultures, and backgrounds, are among the buildings with the highest number of risk factors and indoor air pollutants (Capolongo, 2015). In healthcare settings, where maintaining a controlled microclimate is crucial for sterilization purposes, the introduction of air conditioning systems is necessary. Yet, if these systems are inadequately designed, operated, or maintained, they can inadvertently become sources of indoor air contamination (Cabo Verde et al., 2015). Homes are not designed for intense use and, sometimes, lack appropriate ventilation strategies and indoor air renewal (Hormigos-Jimenez *et al*., 2018). Since household users are exposed to several contaminants, such as chemicals for cleaning, animal fur, and tobacco smoke, natural ventilation is an effective means to reduce those contaminant agents (Vardoulakis *et al*., 2015). Most indoor air pollution inside homes comes from sources including building materials (varnishes and paints), human activities (combustion and smoking) and consumer products (fingernail polish, cleaning agents, adhesives and lacquers) whereas in outdoor air, traffic is known as a major source (Alves *et al*., 2019).

Water-soluble particulates containing nitrate (NO_3^-), ammonium (NH_4^+), and sulfate (SO_4^{2-}) have hygroscopic nature and can change composition, lifetime of aerosols size, and number-density (Salam *et al*., 2015). They are either directly emitted from primary sources, such as bio-mass burning, automobiles, and various industrial combustion processes, or indirectly through gas-to-particle conversion from gaseous nitric oxides, ammonia, and sulfur dioxide in the presence of oxidants through photochemical

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reactions (Wang *et al*., 2011). Secondary aerosols like NO_3^-, NH_4^+, and SO_4^{2-} were probably formed from the gaseous pollutants; the oxides of nitrogen were found particularly elevated indoors as they had indoor sources: Gas stoves and/or cooking through the process of gas-to-gas particle conversion (Zhang *et al*., 2020).

The ultrafine particles as nitrate in an urban as nitrate in an urban atmosphere come mainly from the emissions of motor vehicles (Li *et al*., 2023). The major identified sources of nitrate include biomass burning, human populations, industrial processes, fossil fuels, synthetic fertilizers, crops, and soils (Zhang *et al*., 2014). The nitrogen dioxide gas (NO_2) and hence nitrate, which is produced by cars, factories, and railroads, is largely poisonous (Moustafa and Mansour, 2022). Furthermore, local nitrate sources include highway gasoline vehicles, diesel engines, natural gas, and coal combustion (Zhang *et al*., 2014). So, these pollutants were easily infiltrated indoors of the clinic through the opened windows and doors.

Anthropogenic ammonium emissions originate mainly from agricultural activities including soils, fertilizers, and domesticated animals although industrial and traffic emissions are also important ammonia sources in urban areas (Vonk *et al*., 2016). Food wastes in the garbage is a major source of indoor ammonia gas and hence ammonium ions (De la Rubia *et al*., 2010). Using ammonium fertilizers on the soil surface led to NH_3 emission to the air by volatilization (Sutton *et al*., 2011). Lower temperature and higher humidity conditions favored the conversion of gaseous ammonia to particulate ammonium (Wang *et al*., 2015).

Urban sulfate concentrations were higher than neighboring rural sites; however, urban and rural sites were influenced by similar regional sources (Resitoğlu *et al*., 2015). Most of the sulfate ions come from the combustion processes (Saldarriaga-Noreña *et al*., 2014). As a result, it can get into the indoor environment through the opened windows and doors. The NO_2 and SO_2 and hence nitrate and sulfate ions in the indoor environment might be originated from the penetration of traffic-related aerosols to the indoor environment (El- Batrawy, 2011).

Studies available on the water-soluble aerosol in indoor environments in medical sites are very limited (Qiao *et al*., (2014); Yang *et al*., (2021); Varrica and Alaimo, (2023) as well as in residential sites (Shen *et al*., (2009), Švédová *et al*., (2019), Zhang *et al*., (2020). Such a study aims to assess the concentrations of nitrate, ammonium, and sulfate in indoor water-soluble particulates in both medical and residential sites in Damietta, Egypt, and to evaluate the effect of temperature and relative humidity (RH).

MATERIALS AND METHODS

Study Area

Damietta governorate is located in the northern region of the Nile Delta, adjacent to the Mediterranean sea, specifically at the confluence of the River Nile's Damietta branch. The geographic coordinates of the governorate is situated between latitude 31.26° N and longitude 31.48° E and longitudes 31.48° E. It is located approximately 15 km from the Mediterranean coastline. The governorate is divided by the Damietta branch of the River Nile, which separates it into two distinct areas, bordered by the Mediterranean Sea to the north, Lake Al-Manzala to the east, and agricultural lands of the Delta to the south and west (Abuzaid, 2017). Damietta Governorate covers an area of 1029 km^2 (Elnaggar *et al.*, 2017). The study was carried out in Damietta City as an urban site and in El-Basarta village as a suburban site (Figure 1). Damietta City is the capital of Damietta Governorate and is located north of the Governorate. El-Basarta is one of the villages of the Damietta center of the Damietta governorate and is located about 4.4 km south of Damietta City.

Sampling Strategy

Thirty-five air samples were systematically collected from both urban (Damietta city) and suburban (El-Basarta village) locations, comprising 15 medical sites and 20 residential apartments, over a four-month period from May to August 2021. Among the medical sites, seven were situated in urban settings within Damietta city and were denoted as M1 to M7, while the remaining eight medical sites were located in suburban El-Basarta and labeled as M8 to M15. Similarly, nine of the residential sites were positioned in urban Damietta city and designated as R1 to R9, whereas the other eleven residential apartments were sited in suburban El-Basarta and referred to as R10 to R20 (Table 1).

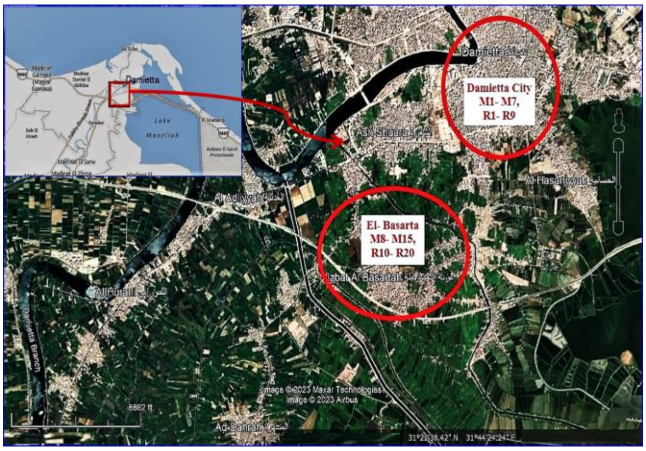

Figure (1): Location map of the selected medical and residential sites in Damietta City and El-Basarta village.

Most medical clinics had natural ventilation while others had an air conditioner (AC) either in the treatment, laboratory or radiology room or in the reception room. Most of the residential apartments had natural ventilation while others had an AC either in the living room or in the bedroom. Three indoor and one outdoor location were selected. The activities in Damietta City include charcoal cams, textile and sweet plants, cafes and restaurants, and fishing industry. In El-Basarta there are many activities as rice mills, carpentry workshops, paint fumes in the carpentry workshops, usage of pesticides in the agricultural lands, cafes and restaurants as well as burning of wood, crop residues and dung. These activities mainly affect the outdoor air and hence indirectly affect the indoor air through the infiltration into the indoor environments.

For NO_3^-, NH_4^+ and SO_4^{2-} determination, sampling apparatus consisted of Whatman 47 mm Membrane filters with 2µm pores size, a holder and a pump to drew the required air volume. Sampling was carried out for 2 hours with a mean flow rate of 2 l/min. In medical sites, the indoor samples (I) were collected from the reception room (R) while in residential sites, the indoor samples were collected from living room (L). The outdoor samples (O) were taken simultaneously with indoor ones. PM_{10} concentrations were measured using the filtration method (Harrison and Perry, 1986). Filters were weighed in temperature and relative humidity control. Weighing methods are detailed elsewhere (El-Batrawy, 2010).

All samples were collected in duplicate. To eliminate contamination effects, field blanks were used and analyzed simultaneously with the exposed samples for quality control during the study. The sampling equipment were positioned at a height of 1.0–1.5 m above the ground, at least 2 m away from doors, windows, and potential indoor sources; more than 20 cm away from a wall for 2 hours in each site in order to avoid the potential interferences from resuspension of particles due to indoor activities and also to sample aerosol concentrations in the breathing zone of a seated person. The outdoor equipment was housed in a cabinet which was weather-proof and it was placed right outside the home, usually in the garden, front yard, or on a balcony. The measurements were repeated twice a month for four months (May, June, July and August) for each indoor and outdoor sample and then the mean concentrations were calculated for each sample.

Analytical Methods

Temperature and relative humidity (RH%) were regularly measured using a digital LCD thermometer and hygrometer (model number: 2724445305121, manufactured in China). Water-soluble particulates such as nitrate (NO_3^-), ammonium (NH_4^+), and sulfate (SO_4^{2-}) were leached from filter paper and subsequently analyzed in all air samples. Nitrates were measured using the colorimetric method (Harrison and Perry, 1986), NH_4^+ ions were determined via the catalyzed indophenol-blue method (Harrison and Perry, 1986), and sulfates were measured turbidimetrically (Harrison and Perry, 1986).

Statistical Analysis

Indoor/outdoor ratios were calculated to assess the concentrations measured at the selected sites, aiming to determine the impact of indoor particulate sources and/or outdoor particulate concentrations on indoor levels. Linear regression was conducted to analyze the relationships between indoor and outdoor concentrations, as well as between medical and residential sites, and between urban and suburban locations. Additionally, an ANOVA test was performed. For all statistical analyses of the data, IBM SPSS Statistics 25.0 program and Excel 2013 were utilized.

RESULTS

Temperature and relative humidity in medical and residential Sites

The table (2) presents the indoor and outdoor temperature and relative humidity mean values recorded at the medical and residential sites. Temperature measureements taken at all medical sites within urban areas ranged from 22.5±0.57 °C (M3) to 38±0.57 °C (M2) indoors, and from 28±0.53 °C (M3) to 39±0.49 °C (M2) outdoors. In contrast, medical sites situated in suburban regions exhibited indoor temperature values between 22±0.65 °C (M10) and 39±0.60 °C (M15), and outdoor temperature readings from 27±1.03 °C (M10) to 40±0.68 °C (M15). Relative humidity (RH%) levels at urban medical sites varied from 49±0.42% (M2) to 72±0.42% (M6) indoors, and from 51±0.46% (M2) to 72±0.53% (M3) outdoors. On the other hand, medical sites located in suburban areas displayed indoor RH% values ranging from 43±0.46% (M9) to 73±0.53% (M12), and outdoor RH% values from 42±0.52% (M9) to 74±0.82% (M12).

Temperature values at residential sites within urban areas ranged from 25 ±0.73°C (R7) to 35±1.00 °C (R9) indoors, and from 28 ±0.46 °C (R3) to 35±0.60 °C (R1) and from 28±0.96°C (R7) to 35±0.87°C (R8) outdoors. Conversely, residential sites in suburban locations exhibited indoor temperature readings between 23.5-±0.62°C (R11) and 32 ±0.78°C (R14), and 32±0.60°C (R18), while outdoor temperatures ranged from 26±0.75°C (R16) to 34 ±0.64°C (R20). In terms of relative humidity (RH%) levels, urban residential sites displayed values ranging from 35 ±1.27% (R2) to 54±0.38% (R9) indoors, and from 37 ±0.60% (R6) to 53±0.32% (R8) outdoors. Suburban residential areas had RH% values varying from 35 ±0.53% (R17) to 56±0.48% (R10) indoors, and from 38 ±0.48% (R17) to 56±0.50% (R10) outdoors.

Water-soluble particulates in medical and residential sites

The mean concentration values (± SE) of water-soluble particles, including NO_3^-, NH_4^+, and SO_4^{2-}, measured in indoor and outdoor air at medical and residential sites in urban and suburban areas, were represented in Figure (2). Nitrate (NO_3^-) concentrations in urban medical sites for indoor sites ranged from 103.84±0.94 µg/m^3 (M7) to 128.45±1.02 µg/m^3 (M6) and from 107.13±1.25 µg/m^3 (M7) to 131.04±1.33 µg/m^3 (M6) for outdoors. Similarly, medical sites situated in suburban areas exhibited NO^{3-} values varying from 85.49±1.03 µg/m^3 (M14) to 120.11±1.86 µg/m^3 (M8) for indoor sites and from 87.16±1.41 to 124.01±1.01 µg/m^3 (M14-M8) for outdoors. In contrast, NO_3^- concentrations in urban residential sites ranged from 90.64±0.36 to 127.71±1.88 µg/m^3 (R2-R8) for indoor sites, and from 93.26±0.60 to 143.69±0.98 µg/m^3 (R2-R8) for outdoors. Suburban residential areas displayed NO_3^- concentrations, for indoor sites, ranging

Table (1): Distribution of studied sites based on location and their description, ventilation source, and pollution sources in urban and suburban Healthcare Facilities in Damietta City and El-Basarta.

Studied sites	Code[††]	Description	Ventilation source	Pollution Sources
Urban area (Damietta City)	M1	Medical lab, 2nd floor, on a side road	AC1, frequent window opening[†]	Cleaning, chemicals, Café
	M2	Radiology center, 1st floor, on a main road	AC2, frequent window opening	Carpentry workshop, cleaning, bakery
	M3	Medical lab, 1st floor, on a main road	AC1, rare window opening	Pesticides, chemicals, garden
	M4	Heart clinic, 2nd floor, on a main road	AC3, frequent window opening	Carpentry workshop, cleaning
	M5	Internal medicine clinic, 1st floor, on a main road	AC3, rare window opening	Carpentry workshop, pesticides, garden
	M6	Children clinic, 2nd floor, main road	AC2, frequent window opening	Pesticides, near café, restaurant
	M7	Internal medicine clinic, 1st floor, main road	AC2, frequent window opening	Cleaning, near restaurant, pesticides, metalworking shop
Suburban area (El-Basarta)	M8	Medical lab, 2nd floor, main road	AC1, rare window opening	Carpentry workshop, cleaning, agricultural land, fertilizers, pesticides
	M9	Dental clinic,1st floor, side road	AC2, frequent window opening	Carpentry workshop, pesticides, café
	M10	Internal medicine clinic, 2nd floor, main road	AC1, frequent window opening	Carpentry workshop, pesticides, café
	M11	Obstetrics and Gynecology clinic, 1st floor, side road	Natural ventilation, rare window opening	Agricultural land, pesticides, fertilizers
	M12	Orthopedic clinic, 2nd floor, main road	Frequent window opening	Near agricultural land, pesticides
	M13	Children clinic, 2nd floor, side road	Frequent window opening	Carpentry workshop, pesticides,
	M14	Dental clinic, 2nd floor, side road	Frequent window opening	Carpentry workshop, cleaning, café
	M15	Internal medicine clinic, 1st floor, road	Rare window opening	Agricultural land, fertilizers, pesticides, bakery
Urban area (Damietta City)	R1	3rd floor, side road	AC4, rare window opening	Carpentry workshop, cooking
	R2	4th floor, side road	AC4, rare window opening	Cooking, cleaning
	R3	1st floor, main road	Frequent window opening	Cooking, cleaning
	R4	2nd floor, main road	Rare window opening	Near café, cooking, cleaning, pesticides
	R5	3rd floor, side road	Frequent window opening	Cooking, cleaning
	R6	1st floor, side road	Frequent window opening	Carpentry workshop, café, cooking, cleaning
	R7	2nd floor, main road	Rare window opening	Cooking, cleaning
	R8	2nd floor, side road	Frequent window opening	Cooking, cleaning, cosmetics
	R9	3rd floor, main road	Frequent window opening	Carpentry workshop, cooking
Suburban area (El-Basarta)	R10	3rd floor, side road	AC4, rare window opening	Agricultural land cooking, cleaning
	R11	2nd floor, side road	AC1, rare window opening	Carpentry workshop, cooking, cleaning
	R12	1st floor, main road	Frequent window opening	Agricultural land, cooking, cleaning, pesticides
	R13	1st floor, side road	Frequent window opening	Cafe, cooking, cleaning
	R14	2nd floor, main road	Frequent window opening	Cooking, cleaning, pesticides
	R15	1st floor, side road	Frequent window opening	Cooking, cleaning
	R16	3rd floor, side road	Frequent window opening	Carpentry workshop, cooking, cleaning
	R17	1st floor, side road	Frequent window opening	Agricultural land, cooking, cleaning
	R18	1st floor, side road	Rare window opening	Agricultural land, cooking, cleaning,
	R19	2nd floor, main road	Frequent window opening	Café, cooking, cleaning, cosmetics
	R20	1st floor, side road	Frequent window opening	Cooking, cleaning

Code [††], M, Medical sites and R, for residential sites; [†]AC1, air condition in reception room; AC2, air condition in radiology room; AC3, air condition in doctor room; AC4, air condition in bed room,

Table (2): Comparative analysis of indoor and outdoor temperature (°C) and relative humidity (%) across urban and suburban study locations. Data are presented as mean ± SE (n=8).

Studied sites	Code	Physical Characterization			
		Temp. ± SE (°C)		RH ± SE (%)	
		InD[†]	OutD[††]	InD	OutD
Urban area (Damietta City)	M1	31.0± 0.76	35.0± 0.58	55.0± 0.46	56.0± 0.50
	M2	38.0± 0.57	39.0± 0.49	49.0± 0.42	51.0± 0.46
	M3	22.5± 0.57	28.0± 0.53	50.5± 0.49	72.0± 0.53
	M4	31.0± 0.52	32.0± 0.46	58.0± 0.42	60.0± 0.37
	M5	28.0± 0.60	31.0± 0.91	66.0± 0.57	68.0± 0.57
	M6	30.0± 0.32	33.0± 0.65	72.0± 0.42	71.0± 0.37
	M7	26.0± 0.60	28.0± 0.90	53.0± 0.52	55.0± 0.46
Suburban area (El-Basarta)	M8	26.0± 0.61	33.0± 0.91	48.0± 0.46	57.0± 0.32
	M9	29.0± 0.48	29.0± 0.60	43.0± 0.46	42.0± 0.52
	M10	22.0± 0.65	27.0± 1.03	56.5± 0.34	64.0± 0.68
	M11	33.0± 0.50	32.0± 0.53	51.0± 0.46	51.0± 0.46
	M12	28.0± 1.03	29.0± 0.32	73.0± 0.53	74.0± 0.82
	M13	27.0± 0.89	31.0± 0.60	49.0± 0.42	51.0± 0.46
	M14	30.0± 0.46	32.0±0.82	61.0± 0.30	62.0± 0.38
	M15	39.0± 0.60	40.0± 0.68	52.0± 0.63	55.0± 0.37
Urban area (Damietta City)	R1	34± 1.05	35± 0.60	45± 1.39	48± 0.84
	R2	29± 0.58	31± 0.58	35± 1.27	39± 0.65
	R3	26± 1.07	28± 0.46	37± 0.42	40± 0.68
	R4	30± 0.49	30± 0.60	42± 0.44	44± 0.50
	R5	27± 0.89	29± 0.87	52± 0.42	52± 0.56
	R6	31± 0.33	32± 0.42	39± 0.37	37± 0.60
	R7	25± 0.73	28± 0.96	47± 0.50	51± 0.46
	R8	34± 0.73	35± 0.87	49± 0.42	53± 0.32
	R9	35± 1.00	33± 0.61	54± 0.38	49± 0.53
Suburban area (El-Basarta)	R10	27± 0.65	27± 0.92	56± 0.48	56± 0.50
	R11	23.5± 0.62	28± 0.50	42.5± 0.68	46± 0.38
	R12	30± 0.72	31± 0.52	50± 0.59	53± 0.53
	R13	29± 0.75	29± 0.60	49± 0.71	52± 0.45
	R14	32± 0.78	32± 0.62	43± 0.53	45± 1.39
	R15	31± 0.42	33± 0.65	39± 0.53	42± 0.44
	R16	25± 0.87	26± 0.75	46± 0.78	49± 0.42
	R17	28± 0.73	28± 0.78	35± 0.53	38± 0.72
	R18	32± 0.60	34± 0.97	38± 0.77	42± 0.52
	R19	27± 0.83	29± 0.89	49± 0.38	53± 0.42
	R20	30± 0.94	34± 0.64	50± 0.53	51± 0.46

[†]InD, Indoor; OutD, Outdoor.

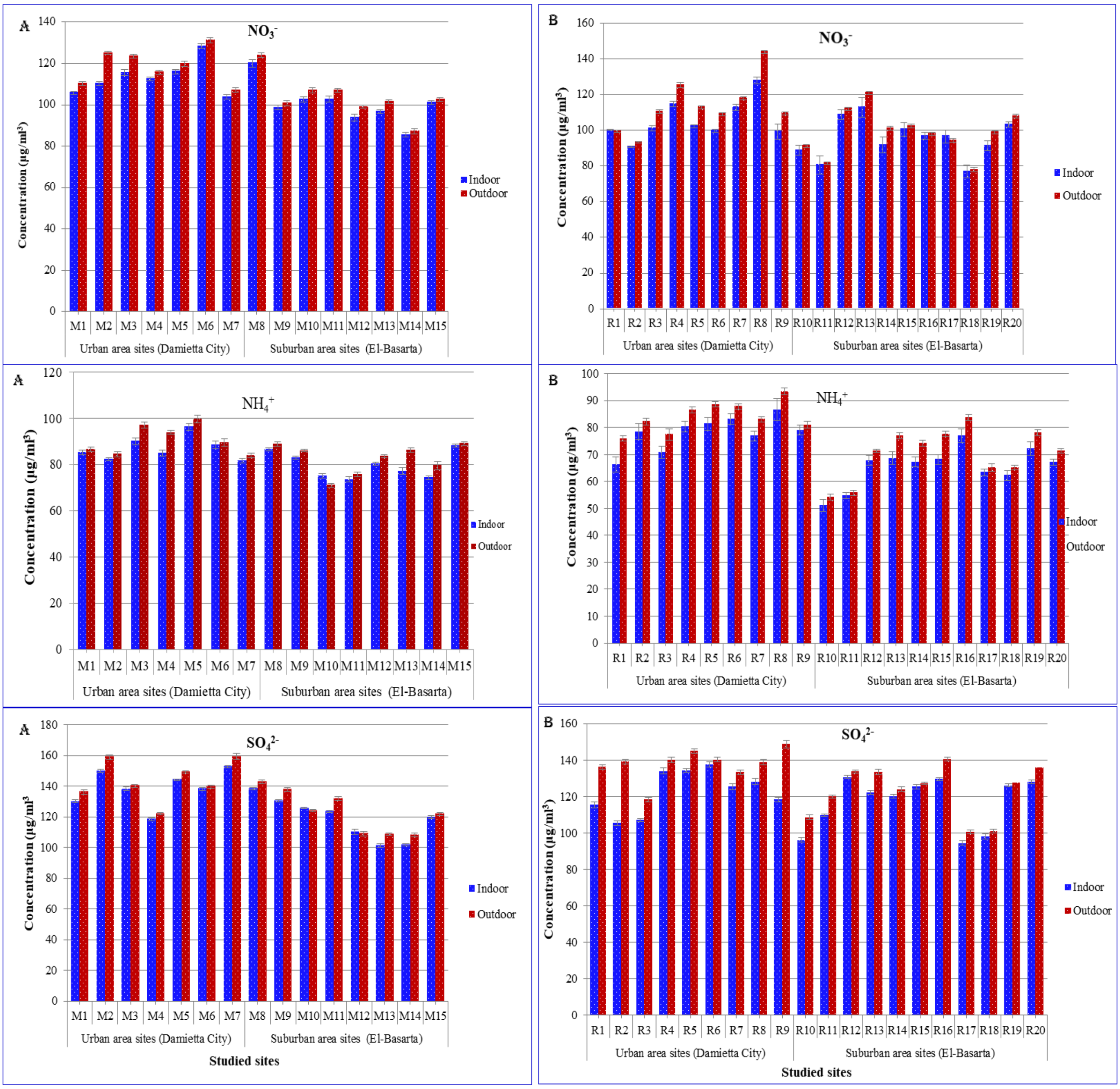

Figure (2): Comparative analysis of nitrate (NO_3^-), ammonium (NH_4^-), and sulfate (SO_4^{2-}) concentrations in urban, suburban, and residential medical sites.

from 76.92±3.71 to 112.82±5.59 µg/m^3 (R18-R13) verses to 77.81±1.25 to 120.92±0.79 µg/m^3 (R18-R13) for outdoors, respectively. Meanwhile, NH_4^+ concentrations in the urban medical sites ranged from 81.63±0.89 to 96.25±1.54 µg/m3 ((M7-M5) for indoor sites compared to 83.94±0.92 to 99.53±1.63 µg/m^3 (M7-M5) outdoor one. Meanwhile, suburban medical sites recorded less average values for NH_4^+ concentrations, no significant value recorded, which ranged from 73.52±1.01 to 88.15±0.79 µg/m3 (M11-M15) for indoor sites, and from 71.03±0.86 to 89.02±0.76 µg/m^3 (M18-M15) for outdoors. On the other hand, NH_4^+ concentrations in the urban residential sites ranged from 66.2±2.81 (R1) to 86.55±4.11 µg/m^3 (R8) for indoors, and from 75.9±0.94 (R1) to 93.33±1.24 µg/m^3 (R8) for outdoors.

Meanwhile, suburban residential sites had less NH_4^+ concentrations which ranged from 51.12±2.24 (R10) to 76.95±2.47 (R16) for indoor sites and from 54.24±1.13 (R10) to 83.7±1.02 (R16) µg/m^3 for studied outdoor sites.

Sulfate ion (SO_4^{2-}) concentrations showed different pattern in urban medical sites which is ranged from 118.58 ± 0.94 µg/m³ (M4) to 152.68 ± 0.68 µg/m³ (M7) for indoor sites, in comparable to outdoor sites a range from 122.12 ± 0.76 µg/m³ (M4) to 159.44 ± 1.93 µg/m³ (M7) were recorded. In contrast, less detected SO_4^{2-} was recorded in suburban medical sites and the concentrations were ranging from 101.54 ± 1.13 µg/m³ (M13) to 138.47 ± 0.97 µg/m³ (M8) for indoor sites. However, outdoor sites recorde higher concentrations which ranged from 108.31 ± 1.27 µg/m³ (M14) to 142.86 ± 1.24 µg/m³ (M8) outdoors.

Alternatively, in urban residential sites, the SO_4^{2-} concentrations ranged from 105.4±1.31 µg/m³ (R2) to 137.66±1.53 µg/m³ (R6) indoor sites and from

118.39±1.29 µg/m³ (R3) to 148.64±2.07 µg/m³ (R9) outdoors. Similarly, suburban residential sites exhibited SO_4^{2-} concentrations ranging from 94.38±1.31 µg/m³ (R17) to 130.61±0.78 µg/m³ (R12) indoor sites and from 100.55±1.10 µg/m³ (R17) to 140.53±0.95 µg/m³ (R16) outdoors. In urban medical sites, the SO_4^{2-} concentrations varied from 118.58±0.94 µg/m³ (M4) to 152.68±0.68 µg/m³ (M7) indoor sites and from 122.12±0.76 µg/m³ (M4) to 159.44±1.93 µg/m³ (M7) outdoors. Suburban medical sites had SO_4^{2-} concentrations ranging from 101.54±1.13 µg/m³ (M13) to 138.47±0.97 µg/m³ (M8) for indoor sites, and from 108.31±1.27 µg/m³ (M14) to 142.86±1.24 µg/m³ (M8) for outdoor sites. The data obtained indicate that SO_4^{2-} concentrations are generally higher in outdoor environments compared to indoor environments across both urban and suburban residential sites, as well as medical sites. Additionally, urban areas tend to have higher SO_4^{2-} concentrations than suburban areas, sugg-esting that urban environments might contribute to elevated SO_4^{2-} levels, potentially due to higher pollution sources.

Indoor/Outdoor (I/O) Ratio

The calculated Indoor/Outdoor (I/O) ratio is a critical metric for understanding the distribution and sources of pollutants, particularly in air quality assessments. The Indoor/Outdoor (I/O) ratios of NO_3^-, NH_4^+, and SO_4^{2-} at both medical and residential sites are presented in Figure 3.In urban medical sites, the I/O ratios for NO_3^-, NH_4^+, and SO_4^{2-} ranged from 0.88 (M2) to 0.98 (M6), from 0.91 (M4) to 0.99 (M1 and M6), and from 0.94 (M2) to 0.99 (M3 and M6), respectively. However, in suburban medical sites, the ratios recorded almost the same pattern with some minor variations between the sites and recorded a range from 0.95 (M11 and M12) to 0.99 (M15) for NO_3^-, from 0.89 (M13) to 1.06 (M10) for NH_4^+, and from 0.98 (M15) to 1.01 (M10 and M12) for SO_4^{2-}.

In general, the concentrations of NO_3^- NH_4^+, and SO_4^{2-} appear to be within a similar range, indicating a potential relation-ship or common source of these ions in the environ-ment. For urban residential sites, the I/O ratios ranged from 0.89 (R8) to 1.01 (R1) for NO_3^-, from 0.87 (R1) to 0.97 (R9) for NH_4^+, and from 0.76 (R2) to 0.98 (R6) for SO_4^{2-}. In suburban residential sites, the ratios ranged from 0.91 (R11 and R14) to 1.02 (R17) for NO_3^-, from 0.88 (R15) to 0.98 (R11) for NH_4^+, and from 0.89 (R12) to 0.99 (R15 and R19) for SO_4^{2-}.

Correlation of water-soluble particulates in both studied sites

The measured concentrations of inorganic ions (NO_3^-, NH_4^+, and SO_4^{2-}) in both indoor and outdoor environments across medical and residential sites, along with their respective correlation coefficients (R^2) are represented in Table (3).

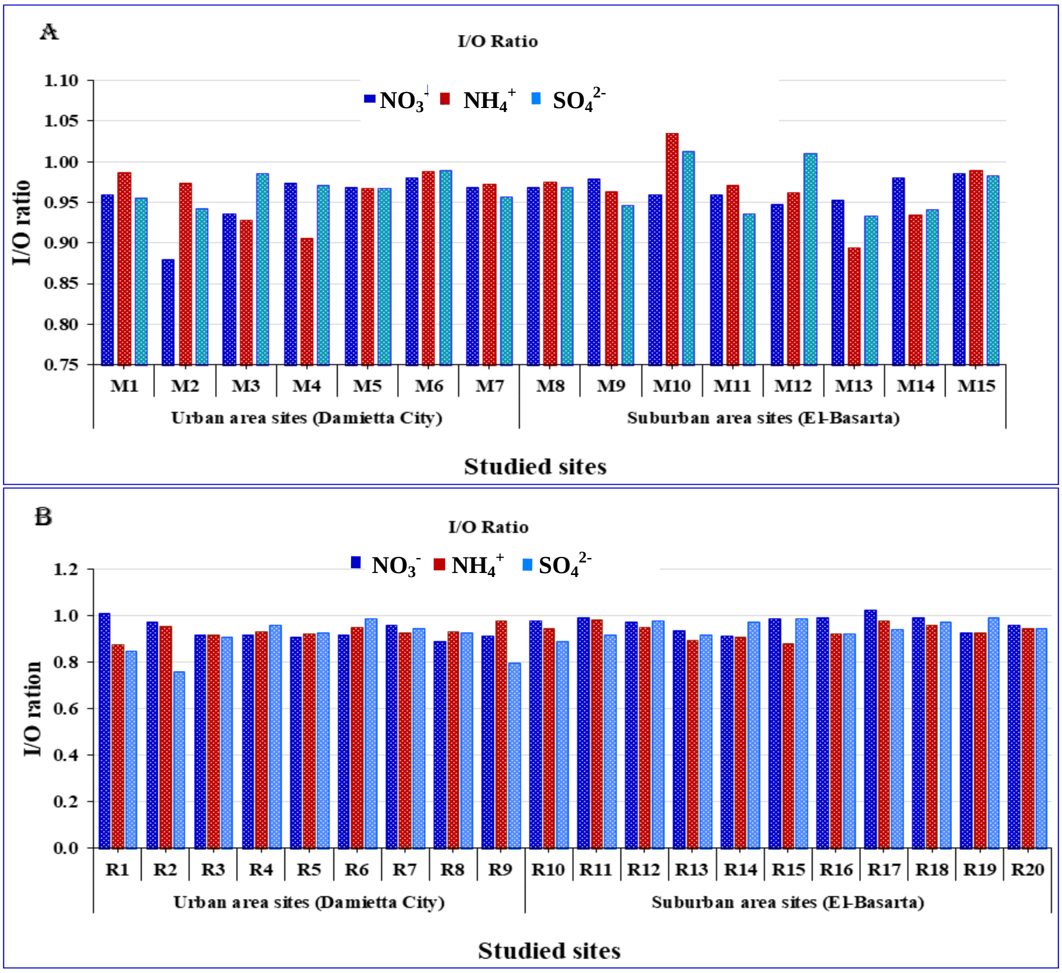

Figure (3): The I/O ratio of NO_3^-, NH_4^+, and SO_4^{2-} - in both studied sites. A, Urban and suburban medical sites; B, residential sites.

High Correlation for NO_3^- and NH_4^+

The correlation coefficients for both NO_3^- (R^2 = 0.928 for medical sites and 0.932 for residential sites) and NH_4^+ (R^2 = 0.834 for medical sites and 0.934 for residential sites) indicate a strong positive correlation between indoor and outdoor concentrations. This suggests that the levels of these ions are relatively consistent across different environments, potentially reflecting similar sources or atmospheric conditions.

SO_4^{2-} Correlation Discrepancy

The correlation for SO_4^{2-} is markedly lower in residential sites (R^2 = 0.624), indicating a weaker relationship between indoor and outdoor concentrations compared to NO_3^- and NH_4^+. This could suggest that SO_4^{2-} levels may be influenced by more variable factors such as local emissions or specific indoor activities that do not affect the other ions to the same extent. Additionally, in both medical and residential sites, the concentrations of all three ions are higher indoors than outdoors, which may indicate the influence of indoor sources or accumulation due to limited ventilation. This tendency is particularly pronounced for NH_4^+, suggesting that indoor activities may significantly contribute to its levels.

Correlation of water-soluble particulates and environmental factor measured

The correlation between urban and suburban NO_3^-, NH_4^+, and SO_4^{2-} concentrations of both medical and residential sites and measured environmental factors were investigated (Figure 4). The correlation of NO_3^-, NH_4^+, and SO_4^{2-} concentrations with temperature recorded very low correlations (R^2= 0.0018, 0.0029, and 0.0698, respectively). In parallel, the correlation with relative humidity (RH%) also recorded low correlation values (R^2= 0.0384, 0.0397, and 0.1310, respectively) in all medical and residential sites.

Table (3): Correlation between indoor and outdoor concentrations of NO_3^-, NH_4^+, and SO_4^{2-} measured in both urban and suburban medical and residential sites.

Measured inorganic ions	Indoor Vs Outdoor					
	Medical sites			Residential sites		
	Indoor	Outdoor	R^2	Indoor	Outdoor	R^2
NO_3^-	106.3	110.7	0.928**	99.8	105.34	0.932**
NH_4^+	83.1	86.3	0.834**	71.1	76.4	0.934**
SO_4^{2-}	128.3	132.8	0.962**	119.3	129.6	0.624*

**, highly correlated; *, moderate correlation

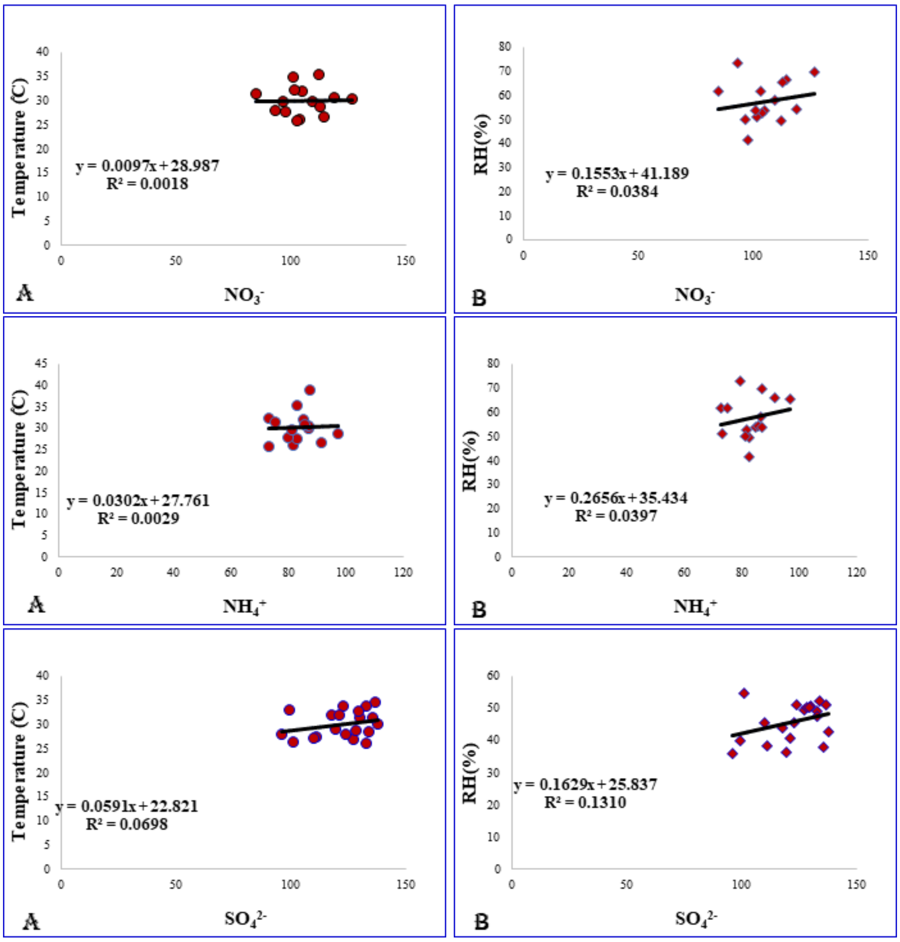

Figure (4): Correlation of NO_3^-, NH_4^+, and SO_4^{2-} with temperature and RH% in both urban and suburban medical sites (A) and residential sites (B).

According to ANOVA test comparison between medical and residential sites for the water-soluble particulates' concentrations showed significant difference particularly, for NH_4^+ at *p*-level of 0.001 and 0.05.

DISCUSSION

Temperature (T) and Relative Humidity (RH) in Medical Sites

The relatively high temperatures in medical sites may be due to the influence of the outdoor temperature as the samples were collected during summer periods and most clinics were naturally ventilated through the opened windows and door. It is obvious that the temperature values in the suburban medical sites were slightly lower than those found in the urban medical sites due to the presence of plants represented in the agricultural lands located in the suburban area. Plants can provide natural thermal comfort conditions that air conditioning or ventilation systems are not able to provide (Gunawardena and Steemers, 2019). The low variability in indoor temperature is due to controlled mechanical ventilation and the absence of natural ventilation (Montgomery *et al*., 2015).

In medical sites, the lowest indoor temperature in the urban and suburban areas was in site M3 (medical lab) (22.5±0.57^{o}C) and site M10 (internal medicine clinic) (22±0.65 ^{o}C), respectively, because of the action of the air conditioner (AC). The low variability in indoor temperature is due to controlled mechanical ventilation and the absence of natural ventilation (Lim *et al*., 2015). The highest indoor temperature in urban and suburban medical sites was reported in site M2 (Radiology center) (38±0.57℃) and M15 (internal medicine clinic) (39±0.60℃), respectively as a result of the influence of the outdoor temperate as it is naturally ventilated and high number of patients waiting in the reception room. As the population density rises in an area, the temperature typically increases (Atwoli *et al*., 2022). The urban and suburban medical sites experienced the highest outdoor temperatures at site M2 (39±0.49℃) and M15 (40±0.68℃), respectively, due to their proximity to a bakery with a chimney releasing continuous streams of hot air. It is widely recognized that baking activities result in significant heat emissions (Datta, 2007).

In medical sites, the lowest indoor RH value in the urban and suburban areas was noticed in site M2 (49±0.42 %) and M9 (dental clinic) (43±0.46 %), respectively due to operating the dry mode in the air conditioner. Most air conditioners can reduce the relative humidity as they reduce the temperature and consequently the evaporation rate (Sekartaji *et al*., 2023). The highest indoor RH in the urban and suburban areas were observed in sites M6 (children's clinic) (72±0.42%) and M12 (Orthopedic clinic) (73±0.53 %), respectively as they were affected by the outdoor humidity because of the natural ventilation. The high variability in RH was expected due to the natural ventilation (AlRayess *et al*, 2022), furthermore, because of the use of a steam inhaler in the children's clinic and the high density of patients whose breath causes high humidity (Mansour *et al*., 2019). The highest outdoor RH in the urban and suburban areas was in site M3 (72±0.53 %) and M12 (74±0.82 %), respectively. M3 was located near a water body that can be responsible for high RH. The presence of water bodies around buildings has a noticeable effect on the average temperature and relative humidity where the air temperature can be degraded by 2 ºC and relative humidity enhanced by 5% (Jin *et al*., 2017). M12 is located next to agricultural land. Plant transpiration can increase air humidity (Nederhoff, 2009).

The thermal comfort and hygiene of patients in medical clinics are affected by RH% levels as the air humidity has the potential to affect healthcare germs and viruses therefore relative humidity in a hospital should be ranged between 40% and 60%, depending on the procedures and facility (Vijaykrishna and Balaji, 2023). Most study samples in the medical sites were within the previous recommended RH% range (40-60%) except in sites M5 and M6 in urban area; M12 and M14 in suburban area.

Temperature (T) and Relative Humidity (%RH) in Residential Sites

In residential sites, the lowest indoor temperature in the urban and suburban areas was in site R7 (25±0.73 °C) and R11 (23.5±0.62 °C), respectively as it was ventilated by an air conditioner (AC). The highest indoor temperature value in the urban and suburban areas was reported in site R9 (35±1.00 °C) and sites R14 and R18 (32±0.78 and 32±0.60℃), respectively as in these sites there were cooking processes. Thermal sources inside homes include baking, roasting, and other cooking processes (Pan *et al*., 2014; Alugwu and Alugwu, 2022). Also, these sites were naturally ventilated through the opened windows and hence may be affected by the outdoor temperature. The highest outdoor temperature values in the urban and suburban areas were in sites R1, R8 (35±0.60 and 35±0.87 °C, respectively) and R20 (34±0.64°C) as R1 and R8 were located next to restaurants where cooking processes emitted large amounts of heat, while R20 was located in a high-density residential area, on the 1st floor and the temperature increases by decreasing the altitude (Montgomery, 2006).

In residential sites, the lowest indoor relative humidity in the urban and suburban areas was in site R2 (35±1.27 %) and R17 (35±0.53%), respectively as they were ventilated by an AC which was expected to reduce the relative humidity (Setyawan and Badarudin, 2020). The highest indoor relative humidity value in the urban and suburban areas was found in site R9 (54±0.38 %) and R10 (56±0.48 %), respectively as R9 was naturally ventilated and affected by the outdoor humidity, while R10 was located near agricultural land and has a nearby water bond. The highest outdoor RH value in the urban and suburban areas was recorded in sites R8 (53±0.32 %) and R10 (56±0.50 %) as R8 was located near a restaurant where large amounts of vapors were emitted during the cooking processes and hence resulting in an increase in relative humidity (TenWolde and Pilon, 2007), while R10 was located near a canal and water bodies can cause an increase in the RH (Wong *et al*., 2012).

Water Soluble Particulates (NO_3^-, NH_4^+, and SO_4^{2-}) in Medical Sites

In medical sites, the lowest indoor NO_3^- value in the urban and suburban areas was observed in sites M7 (103.84±0.94 μg/m^3) and M14 (85.49±1.03 μg/m^3), respectively as they were visited by a low number of patients and cleaned regularly. The highest indoor NO_3^- value in the urban and suburban areas was observed in sites M6 (128.45±1.02 μg/m^3) and M8 (medical lab) (120.11±1.86 μg/m^3), respectively as they were located on a main road and naturally ventilated through frequent window openings. The ultrafine particles (such as NO_3^-) in urban air come mainly from motor vehicle emissions (Palmgren *et al*., 2003). NO_3^- aerosol moves from a cooler outdoor to a warmer indoor environment (Lunden *et al*., 2003). The highest outdoor NO_3^- value in the urban and suburban areas was observed in sites M6 (131.04±1.33 μg/m^3) and M8 (124.01±1.01 μg/m^3), respectively. M6 is a children's clinic located near a restaurant while M8 is a medical lab located near agricultural land where pesticides and fertilizers were used regularly. Synthetic fertilizers, crops, and soils are major sources of NO_3^- ions (Bouwman *et al*., 1997).

The lowest indoor NH_4^+ concentration in the urban and suburban areas was reported in sites M7 (81.63±0.89 μg/m^3) and M11 (obstetrics and gynecology clinic) (73.52±1.01 μg/m^3), respectively. The highest indoor NH_4^+ concentration in the urban and suburban areas was reported in sites M5 (internal medicine clinic) (96.25±1.54 μg/m^3) and M15 (88.15±0.79 μg/m^3), respectively as site M5 was visited by a large number of patients, the garbage on this site contained food wastes which weren't discarded regularly and accumulated for long period representing an indoor source of NH_4^+ ions (De la Rubia *et al*., 2010). NH_4^+ in sites M5 and M15 originated mainly from outdoor sources which was the nearby agricultural land where pesticides and fertilizers were used regularly and hence may infiltrate through the opened windows. The highest outdoor NH_4^+ concentration in the urban and suburban areas was recorded in sites M5 (99.53±1.63 μg/m^3) and M15 (89.02±0.76 μg/m^3), respectively as these sites were located adjacent to gardens where pesticides and fertilizers were used which was considered as a major source of NH_4^+ (Vonk *et al*., 2016)

The lowest indoor SO_4^{2-} concentration in the urban and suburban areas was recorded in sites M4 (heart clinic) (118.58±0.94 μg/m^3) and M13 (children clinic) (101.54±1.13 μg/m^3), respectively as they were opened only two days a week. The highest indoor SO_4^{2-} concentration in the urban and suburban areas was recorded in sites M7 (152.68±0.68 μg/m^3) and M8 (138.47±0.97 μg/m^3), respectively. Most indoor sulfate in these sites might be originated from outdoor sources as these clinics (M7 and M8) had the highest outdoor SO_4^{2-} concentration in the urban and suburban areas 159.44±1.93 μg/m^3 and 142.86±1.24 μg/m^3, respect-tively. M7 was located next to a restaurant in which large amounts of oil were combusted and also on a main road with high traffic density. Automobiles are considered as a main source of sulfate particularly those resulting from diesel oil (Resitoğlu *et al*., 2015). Vehicle exhaust can infiltrate the indoor environment (Lin *et al*., 2019). M8 was located on a main road with heavy traffic density near outdoor carpentry workshop where large amounts of wood were combusted.

Water Soluble Particulates (NO_3^-, NH_4^+, and SO_4^{2-}) in Residential Sites

In residential sites, the lowest indoor NO_3^- value in the urban and suburban areas was recorded in sites R2 (90.64±0.36 μg/m^3) and R18 (76.92±3.71 μg/m^3), respectively as they were ventilated by an AC and cleaned regularly. The highest indoor NO_3^- value in the urban and suburban areas was recorded in sites R8 (127.71±1.88 μg/m^3) and R13 (112.82±5.59 μg/m^3), respectively as they were naturally ventilated through frequent window openings, fueled by gas, and many activities were recorded such as cigarette smoking, cooking, cleaning, and usage of cosmetics. The indoor levels of NO_3^- were formed from the gaseous oxides of nitrogen released from cooking and gas stoves (Adams *et al*., 2002).

The temperature in site R13 was 29±0.75°C while the RH was 49±0.71 %. The resuspension rate of NO_3^- showed a decrease by increasing the relative humidity (Zheng *et al*., 2019). The highest outdoor NO_3^- value in the urban and suburban areas was recorded in sites R8 (143.69±0.98 μg/m^3) and R13 (120.92±0.79 μg/m^3). R8 had a nearby restaurant, while R13 was next to a café. Particulate NO_3^- is formed through the photooxidation of nitrogen dioxide emitted from combustion processes (Ho *et al*., 2003).

The lowest indoor NH_4^+ concentration in the urban and suburban residential sites was reported in sites R1 (66.2±2.81 μg/m^3) and R10 (51.12±2.24 μg/m^3), respectively. The highest indoor NH_4^+ value in the urban and suburban areas was in sites R8 (86.55±4.11 μg/m^3) and R16 (76.95±2.47 μg/m^3), respectively as there were many activities inside these sites such as cooking on fueled cooker, cleaning, usage of cosmetics and cigarette smoking. Ammonium ions may be originated due to the impact of burning processes, especially biomass burning (Zhou *et al.*, 2021). It was noticed that the garbage in site R13 containing food waste wasn't discarded but remained there for many days. Food wastes are a significant source of ammonium ions (Wang and Zeng, 2018). The highest outdoor NH_4^+ value in the urban and suburban areas was in sites R8 (93.33±1.24 μg/m^3) and R16 (83.7±1.02 μg/m^3), respectively as there were many activities surrounding this site such as restaurants, and agricultural land. The agricultural activities are an important source of ammonia and hence ammonium (Chen *et al*., 2014).

The lowest indoor SO_4^{2-} concentration in the urban and suburban residential sites was reported in sites R2 (105.4±1.31 μg/m^3) and R17 (94.38±1.31 μg/m^3), respectively as they were located in a low-traffic density area. The highest indoor SO_4^{2-} concentration in the urban and suburban areas was recorded in sites R6 (137.66±1.53 μg/m^3) and R12 (130.61±0.78 μg/m^3) because of the activities practiced in these sites such as cooking, cleaning, and usage of pesticides. The highest outdoor SO_4^{2-} concentration in the urban and suburban areas was recorded in sites R9 (148.64±2.07 μg/m^3) and R16 (140.53±0.95 μg/m^3), respectively. Site R9 was located near the carpentry workshop where large amounts of wood were combusted. The burning of wood is a significant source of airborne SO_4^{2-} ion (Shen *et al*., 2009). Sites R9 and R16 were located on a main road with heavy traffic density. Vehicle exhaust can cause an increase in the concentration of SO_4^{2-} in the air (Awang and Jamaluddin, 2014).

Indoor/Outdoor (I/O) Ratio

The indoor/outdoor ratio (I/O) is considered an indicator of indoor sources' strength (Kulshreshtha and Khare, 2011). Since the I/O ratio was below 1.0 in most sites, this indicates the effect of outdoor sources on indoor air. It can be clearly concluded that there were few significant sources in these indoor environments. The sites with an I/O ratio higher than one means that these sites had strong indoor activities. In the medical site, the I/O ratio was slightly higher than 1 for NH_4^+ in sites M10 (1.06) and for SO_4^{2-} in sites M10 and M12 (1.01) as these clinics visited daily by a large number of patients and located in the suburban area where lower sources of water-soluble particulates were found. In the residential sites, the I/O ratio was slightly higher than 1 for NO_3^- in sites R1 (1.01) and R17 (1.02) as there were cooking processes inside these sites which are considered major indoor sources of nitrate ions.

Association between Medical and Residential Sites

The correlation between indoor and outdoor NO_3^-, NH_4^+, and SO_4^{2-} in both medical and residential sites acts as an indication of the impact of outdoor pollutants on indoor air quality (Table 3). Pollutant of only outdoor origin was expected to have a higher correlation while pollutants from indoor sources tend to have a lower or no correlation. There was a very strong correlation between indoor and outdoor NO_3^-, NH_4^+, and SO_4^{2-}, in both medical sites (R^2= 0.9276, 0.8336, and 0.9619, respectively) and residential sites (R^2= 0.9317, 0.9336 and 0.624, respectively) which indicated that outdoor levels strongly influenced indoor ones. This may be attributed to the outdoor sources of these pollutants that include combustion, vehicle exhausts, standby generators, construction, process plant discharge, demolition, ventilation discharges and nuisance sources such as cooking smells from kitchen extracts (Lawrence *et al*., 2004). The correlations between outdoor and indoor concentrations in medical sites were slightly lower than those in residential sites. The correlation between urban and suburban NO_3^-, NH_4^+, and SO_4^{2-} concentrations of both medical and residential sites were investigated (Figure 4). There was a weak correlation between the urban and suburban concentrations of nitrate, ammonium, and sulfate ions in medical sites (R^2= 0.1621, 0.0803, and 0.0901, respectively) and residential sites (R^2= 0.2058, 0.2102, and 0.0987, respectively). In urban areas, high populations and high traffic density affect the concentration of indoor pollutants (Agrawal *et al*., 2003; Massey *et al*., 2012).

The correlation of the water-soluble particulates with temperature and RH% in both medical and residential sites is shown in Figure (4). That explained the NO_3^-, NH_4^+, and SO_4^{2-} concentrations had a weak correlation with temperature (R^2= 0.0018, 0.0029, and 0.0698, respectively) and RH% (R^2= 0.0384, 0.0397, and 0.1310, respectively) in all medical and residential sites which indicate that these pollutants were not largely affected by temperature and RH% in study sites.

ANOVA was performed to compare the concentrations of water-soluble particulates between medical and residential sites. The significant value for NH_4^+ indicating a significant difference in ammonium concentrations between the medical and residential sites. In contrast, the significant values for NO_3^- and SO_4^{2-} were 0.120 and 0.301, respectively ($p > 0.05$), suggesting that there was no significant difference in nitrate and sulfate concentrations between the medical and residential sites.

CONCLUSION

This study highlights the significant impact of outdoor pollution on indoor air quality, particularly in urban and medical sites in Damietta, Egypt. The higher concentrations of nitrate, ammonium, and sulfate in these locations underscore the need for effective measures to reduce indoor exposure to harmful pollutants. The study demonstrated that medical sites had higher levels of these pollutants compared to residential sites, with urban areas showing higher concentrations than suburban areas. The results also indicated that outdoor sources significantly influenced indoor air quality. The findings suggest that adopting natural cleaning materials and maintaining regular cleaning practices can help mitigate indoor pollution levels. These strategies are crucial for improving indoor air quality and protecting public health, especially in environments where pollutant concentrations are notably high. To improve indoor air quality, the study recommended the use of natural cleaning materials and regular cleaning practices to reduce exposure to hazardous pollutants. Generally, addressing indoor air quality issues is essential for protecting the health and comfort of individuals in both medical and residential settings.

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تقييم الجسيمات القابلة للذوبان في الماء في الهواء الداخلى في المواقع الطبية والسكنية

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تعد جودة الهواء الداخلي مصدر قلق كبير لأن ملوثات الهواء قد تشكل مخاطر صحية ومشاكل تتعلق بالراحة. تهدف هذه الدراسة إلى تقييم تركيزات الجسيمات القابلة للذوبان في الماء مثل النترات والأمونيوم والكبريتات فى الهواء الداخلي في كل من المواقع الطبية والسكنية في دمياط، مصر. تم جمع 35 عينة من الجسيمات الدقيقة من 15 موقعًا طبيًا و20 موقعًا سكنيًا في الفترة من مايو إلى أغسطس 2021 في مدينة دمياط (حضري) وقرية البصارطة (تحت حضرى). أشارت النتائج إلى أن الهواء الداخلي يتأثر بتركيزات متباينة من النترات والأمونيوم والكبريتات. كانت تركيزات النترات والأمونيوم والكبريتات في الهواء الخارجى أعلى من التركيزات الداخلية. لوحظ أن تركيزات كل من النترات والأمونيوم والكبريتات كانت أعلى في المواقع الطبية منها في المواقع السكنية وأيضًا أعلى في المواقع الحضرية منها في المواقع تحت الحضرية. اثبتت الدراسة التأثير الأعلى للمصادر الخارجية على جودة الهواء الداخلي. لذلك، يوصى باستخدام المزيد من مواد التنظيف الطبيعية لتحسين جودة الهواء الداخلي، وتنظيف المساحات الداخلية غالبًا عن طريق الكنس أو المسح لإزالة الملوثات الخطرة.