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Efficacy of phytoremediation in improving indoor air quality in homes in Alexandria, Egypt

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ABSTRACT

Home can be a source of various air pollutants due to different activities such as cooking and smoking. The aim of the study was to assess the efficacy of phytoremediation in improving indoor air quality in homes in Alexandria, Egypt. This is an intervention study was conducted on 21 homes: 7 households from each zone (west, east and middle of Alexandria). Types of plants used during the course of the study included, *Nephrolepis exaltata*, *Dracaena marginata*, *Spathiphyllum wallisii*, *Dypsis lutescens*, *Latania Livistona*, *Epipremnum aureum*. The plants were obtained from Burj Al - Arab and Montazah palace nursery, in Alexandria. Plants were placed and maintained in the living rooms of the apartments under study as one plant for each 12 m^2. NPK fertilizer was used to keep the plants in a good healthy condition. The removal efficiency of *N. exaltata*, *D. marginata*, *S. wallisii* ranged between (45.4 - 51%) & (36.2 - 42.7%) for CO_2 and VOCs, respectively. While the removing efficiency of *D. lutescens* and *L. Livistona* ranged between (40.9 - 41.8%) & (46 - 47.8%) for CO_2 and VOCs respectively. Also, the removing efficiency of *E. aurums* has ranged between (35.6 - 38.6%) & (32 - 34.3%) for CO_2 and VOCs, respectively. The presence of elevated VOCs indicates strong contaminating source in the building. VEF of about 1 indicates that the bio effluent emissions prevail, while; VEF > 5 indicates the existence of strong abiotic VOCs sources, and finally; VEF < 0.3 indicates the existence of large combustion source of CO_2.

Key wards: Phytoremediation, Indoor air Quality, VOCs enrichment Factor, Alexandria.

1. Introduction

Scientific evidence has indicated that the air within homes and other public and office buildings can be more seriously polluted than the outdoor air (Oanh and Hung, 2005). Indoor air pollution has been ranked by the United States Environmental Protection Agency (EPA) Science Advisory Board and the Centers for Disease Control and Prevention (CDC) as a high environmental risk (Gibson et al., 2013). The primary factors that affect indoor air quality are the nature of indoor pollution's source, ventilation of the building, occupant behaviors, and climate (Koo et al., 1994). Most people spend about 90% of their time indoors (Pipal et al., 2012). Smoke exposure affects mainly women and young children who accompany their mothers during cooking and other household activities (Bruce et al., 2002). In particular the old-aged tenants and those suffering from chronic illnesses (Lucattini et al., 2018).

Common symptoms of exposure to indoor air pollutants include wheezing, coughing, sneezing, fatigue, dizziness, headache, difficulty in concentrating, lethargy, irritation of the eyes, nose, throat, skin and lungs, shortness of breath, and sinus congestion (Borchers et al., 2006). Increased levels of indoor air contaminants may lead to cardiopulmonary disease and cancer (Jafta et al., 2017). Home pollutant exposure may adversely affect the immune and nervous systems of the human body; besides, lower physical and mental health, well-being, and productivity with social, political, and economic consequences (Jones and Molina, 2017). Close to 4 million people die prematurely each year from illness attributable to household air pollution (Austin and Mejia, 2017).

The quality of the indoor environment has become a basic requirement for human health and well-being (Hänninen, 2011). Families can promote the quality of air in their homes, by following simple actions, which can have health return (Dales et al., 2008). The most effective ways to improve indoor air quality are to reduce or remove the sources of pollutants and to ventilate with clean outdoor air, and by installing equipment heating, ventilation, and air conditioning (Cociorva et al., 2017).

Global climatic and demographic changes and advancing machinery of daily life will go along with modern ways of living. Temperature extremes and increasing requirements for a comfortable life result in the implementation of sensor networks for creating reasonable and enhanced living conditions. Smart technologies are the efficient use of energy, the optimization of ventilation technology, and control of particles and gaseous pollutants indoors (Schieweck et al., 2018).

Phytoremediation is the process of using plants to detoxify and improve indoor air quality; an Attractive and cost-effective method (Liu et al., 2007). Phytoremediation is recommended and can be applied in our homes and workplaces (Gawronski et al., 2017). It can effectively complement engineering measures to reduce indoor air pollution, and hence improve human wellbeing and productivity (Pipal et al., 2012). The latest research evaluated the exposure to surrounding greenness and its effects on health (Franchini and Mannucci, 2018). Scientific studies review plants' ability to remove Volatile organic compounds (VOC_S) from indoor air, and many of these can affect human health. So, plants are a potential green solution for improving indoor air quality and thus can promote human health (Dela et al, 2014). This study aimed to assess the efficacy of phytoremediation in improving indoor air quality in homes in Alexandria, Egypt. This was achieved through analyzing indoor air quality and assessing the effectiveness of plant interventions in improving indoor air quality.

2. Material and Methods

The study took place over one year, and due to the availability of plants; multiple plants were selected. Available plants in the nurseries were used according to each season. A group of plants was selected, especially those are supposed to absorb VOCs and CO_2. Most indoor plant types were chosen based on the National Aeronautics and Space Administration (NASA) clean air study, indicating that plants can be used to reduce indoor pollutant levels (Wolverton et al., 1984 and Wolverton et al., 1989). Twenty-one households were selected randomly and distributed equally in the 3 geographic zones: east, middle, and west of Alexandria. In each zone, 7 households (33.3%) were selected. The zones were selected to represent the different natures of Alexandria city which are commercial (East zone), high traffic (Middle zone), and Industrial (West zone).

The choice did not affect the efficiency of plants in removing pollutants from the indoor air of the house, but other factors affect the conditions of the house such as (area - number of ventilation holes) and natural environmental factors such as (temperature - humidity - level of lighting). Plants were distributed within the selected homes as (1plant for each 12 m^2).

The plants were obtained from Burj Al - Arab and Montazah palace nursery, at Alexandria. They were placed and maintained in the living rooms of the apartments under study. NPK fertilizer was used to keep the plants in a good healthy condition. The physical factors affecting the ability of plants to remove VOCs and CO2 included temperature and relative humidity (Construction Safety Council , 2019) and the level of illumination (Vihma and Nurminen,1983) were measured. CO_2 and VOCs concentration levels was monitored seasonally (indoor and outdoor), during the four seasons. In each season, CO_2 was measured before using the plants and after using them for three successive months. CO_2 was measured using direct-reading instruments. Miran 1A variable filter Gas Analyzer was used (FoxboroiWilkins, 1978). VOCs samples were collected by sampling train in each home. The flow rate of pump is about 0.12 L/min, calibrated by occupational health and air pollution research center - WHO collaborating center, and the pump was running for 60 minutes. Air was pumped into Adsorption technique (pump with sorbent tube made of Teflon tube filled with activated charcoal), and brought back to laboratory for weighting (mg). VOCS Enrichment factor (Batterman and Peng ,1995). was calculated to indicate indoor air quality (IAQ):

$$\mathrm{VEF} = \frac{[\Delta C_{\mathrm{VOCs}} \;/\; \Delta C_{\mathrm{CO2}}]\, t}{0.000419}$$

3. Results

Table 1 summarizes the characteristics of the chosen plants including plant name, number of plants used, plant height (cm), number of leaves/plant, leaf area (cm^2) and plant age (year).

The physical factors affecting the ability of plants to remove VOCs and CO_2

Table 2(A) demonstrates the physical factors affecting the ability of plants to remove VOCs and CO_2 in the east of Alexandria during Summer (June – August). In June; the temperature ranged between 30.8 and 32.4 °C, and it is obvious that during this month the relative humidity was the highest level at all during the months of the experiment, as it ranged between 66% and 72% , while the duration of natural sunlight reached 14 hours / day, which is the longest, and it remained constant through summer season during the experiment, while the level of illumination ranged between 375 and 390 lux.

Table 1. Characteristics of the houseplants chosen for the experiments

Seasons	Zone	Plant name	Number of plants in the living room/ Apartment	Plant height (cm)	Number of leaves/plants	Leaf area (cm^2)	Plant age (year)
Summer	East of Alexandria	Boston Fern	1	50	100	7500	3
		Red-Edged Dracaena	1	150	120	5688	4
		Peace lily	2	30	10	1120	2
Autumn	West of Alexandria	*Dypsis lutescens*	1	130	15	1310	4
		Latania Livistona	1	90	6	792	3
Winter	Middle of Alexandria	Pothos	1	100	160	3092	2
Range			(1-2)	(50-150)	(6-160)	(792-7500)	(2-4)
Mean			1.17	91.67	68.50	3250.33	3
Median			1	85	57.5	2201	3

In July; where the temperature ranged between 31.1 and 33.7 °C, and the relative humidity ranged between 64 % and 70 %, and the level of illumination ranged between 374 and 391 lux. Otherwise in August; Where the temperature ranged between 32.1 and 34.7 °C, which is the highest ever rise in heat rates during the months of conducting the experiment, and the relative humidity ranged between 62% and 68%, as the level of illumination ranged between 377 and 393 lux.

Table 2(B) demonstrates the physical factors affecting the ability of plants to remove VOCs and CO_2 in the west of Alexandria, during October – December . In October; where the temperature ranged between 29.3 and 31.5 °C, and the relative humidity ranged between 52% and 62%, while the duration of natural sunlight decreased by 4 degrees, reaching 10 hours / day during this month, and the level of illumination ranged between 377 and 412 lux. In November as the temperature ranged between 28.3 and 30.6 °C, and the relative humidity ranged between 47% and 56%, while the duration of natural sunlight was 9.30 hours / day throughout this month, and the level of illumination ranged between 372 and 410 lux. Otherwise; in December, where the temperature ranged between 24.1and 26.5 °C, and the relative humidity ranged between 42% and 48%, while the duration of natural sunlight was 9 hours / day during this month, and the level of illumination ranged between 370 and 408 lux.

Tables 2(C) shows the physical factors affecting the ability of plants to remove VOCs and CO_2 in the middle of Alexandria during February – April; Where the temperatures dropped sharply in the winter season, ranged between 18.1and 20.3 °C, and the relative humidity ranged between 51% and 53%, It is noted that the duration of natural sunlight amounted to 8.30 hours / day throughout this month, and it is the shortest at all during the months of conducting the experiment. And the level of illumination ranged between 371 and 340 lux. In March; where the temperature ranged between 24.3 and 26.5 °C, and the relative humidity ranged between 54% and 58%, while the duration of natural sunlight was 9.30 hours / day throughout this month, and the level of illumination ranged between 346 and 373 lux. Otherwise in April; where the temperature ranged between 27.1and 29.4 °C, and the relative humidity ranged between 65 % and 67 %, while the duration of natural sunlight was 10 hours / day throughout this month, and the level of illumination ranged between 350 and 375 lux.

Characteristics of the houseplant

The number of leaves in plant ranged between 6 and 160 Leaves, and the leaf area of plants ranged from 792 to 7500 m^2 according to the plant species. The first building is in the east of Alexandria, where the study was carried out in summer monthes using *Nephrolepis exaltata* (N=1), *D. marginata* (N=1), *Spathiphyllum wallisii* (N=2). The second building is in the west of Alexandria where the study was carried out in autumn monthes using *D. lutescens* (N=1) and *L. Livistona* (N=1). The third buildingis in the middle of Alexandria where the study was carried out in winter monthes monthes using *E. aureum* (N=1), Figures (1:A-C).

Table 2A. The physical factors during summer season (June - August), in the east of Alexandria, building #1

Apart-ment	June				July				August			
	Temp. °C	RH%	D time (h)	LI (lux)	Temp. °C	RH%	D Time (h)	LI (lux)	Temp. °C	RH%	D Time (h)	LI (lux)
No.1	32.4	72	14	375	33.7	70	14	374	34.7	68	14	377
No.2	32.0	71	14	376	33.4	68	14	378	34.4	65	14	380
No.3	31.6	70	14	375	32.3	69	14	379	34.1	66	14	381
No.4	31.4	70	14	377	32.1	65	14	380	33.8	66	14	384
No.5	31.4	69	14	381	31.8	66	14	382	33.5	63	14	387
No.6	30.9	67	14	385	31.5	64	14	388	32.3	64	14	390
No.7	30.8	66	14	390	31.1	64	14	391	32.1	62	14	393
Range	(30.8-32.0)	(66-72)	--	(375-390)	(31.1-33.7)	(64-70)	--	(374-391)	(32.1-34.7)	(62-68)	--	(377-393)
Mean	31.50	69.29	14	379.86	32.27	66.57	14	381.71	33.58	64.86	14	384.57
Median	31.40	70.00	14	377.00	32.1	66.00	14	380.00	33.80	65.00	14	384.00

Temp; Temperature, RH%; Relative humidity, D; Duration of natural sunlight, LI; Level of illumination.

Table 2B. The physical factors during autumn (October- December), in the west of Alexandria, building #2

Apart-ment	June				July				August			
	Temp. °C	**RH%**	**D time (h)**	**LI (lux)**	**Temp. °C**	**RH%**	**D Time (h)**	**LI (lux)**	**Temp. °C**	**RH%**	**D Time (h)**	**LI (lux)**
No.1	31.5	53	10	377	30.6	48	9.30	372	26.5	45	9.00	370
No.2	31.3	58	10	378	29.3	52	9.30	373	26.3	44	9.00	375
No.3	31.3	56	10	386	29.5	50	9.30	380	25.7	45	9.00	379
No.4	30.1	55	10	390	28.9	53	9.30	388	25.6	46	9.00	385
No.5	29.7	58	10	397	28.8	52	9.30	395	25.2	46	9.00	390
No.6	29.4	62	10	387	28.7	56	9.30	385	24.4	48	9.00	383
No.7	29.3	52	10	412	28.3	47	9.30	410	24.1	42	9.00	408
Range	(29.3-31.5)	(52-62)	--	(377-412)	(28.3-30.6)	(47-56)	--	(372-410)	(24.1-26.5)	(42- 48)	--	(370- 408)
Mean	30.37	56.29	10.00	389.57	29.16	51.14	9.30	386.14	25.40	45.14	9.00	484.29
Median	30.10	56.00	10.00	387.00	28.90	52.00	9.30	385.00	25.60	45.00	9.00	383.00

Temp; Temperature, RH%; Relative humidity, D; Duration of natural sunlight, LI; Level of illumination

Table 2C. The physical factors during winter-spring seasons (February-April), in the middle of Alexandria, building #3

Apart-ment	June				July				August			
	Temp. °C	**RH%**	**D time (h)**	**LI (lux)**	**Temp. °C**	**RH%**	**D Time (h)**	**LI (lux)**	**Temp. °C**	**RH%**	**D Time (h)**	**LI (lux)**
No.1	20.3	53	8.30	340	26.5	57	9.30	346	29.4	67	10	350
No.2	20.2	53	8.30	349	26.3	58	9.30	351	29.1	66	10	353
No.3	20.1	52	8.30	352	26.0	58	9.30	356	28.9	66	10	358
No.4	19.8	51	8.30	355	25.9	56	9.30	359	28.8	67	10	361
No.5	19.4	52	8.30	361	25.8	55	9.30	360	28.5	67	10	364
No.6	18.3	51	8.30	366	24.4	55	9.30	369	27.3	65	10	370
No.7	18.1	51	8.30	371	24.3	54	9.30	373	27.1	65	10	375
Range	(18.120.3)	(51-53)	--	(340-371)	(24.3-26.5)	(54-58)	--	(346-373)	(27.1-29.4)	(65-67)	--	(350-375)
Mean	19.64	51.86	8.30	356.29	25.60	56.14	9.30	359.14	28.44	66.14	10	361.57
Median	19.80	52.00	8.30	355.00	25.0	56.00	9.30	359.00	28.8	66.00	10	361.00

Temp; Temperature, RH%; Relative humidity, D; Duration of natural sunlight, LI; Level of illumination

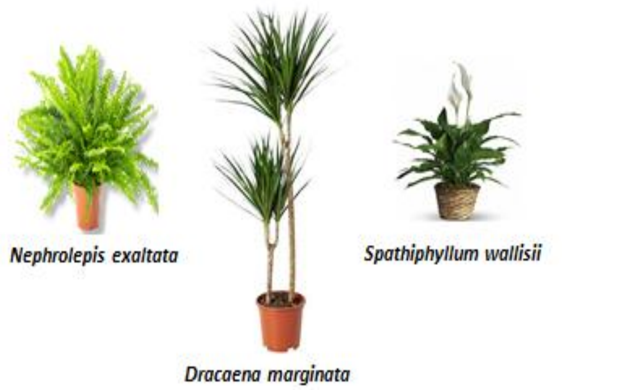

Fig. 1A. The houseplant chosen for experiments in the easts of Alexandaria, summer seasons, building #1

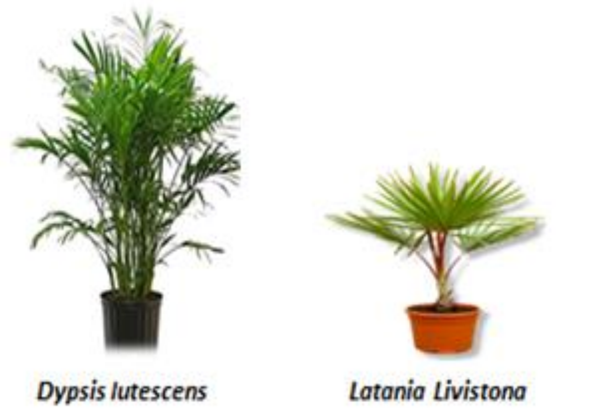

Fig. 1B. The houseplant chosen for experiments in the west of Alexandaria, automn season, building #2

Fig. 1C. The houseplant chosen for experiments in the middle of Alexandaria, winter and spring seasons, building #3

In the present study; the number of potted-plants was defined according to the living room area in each home. Plants were distributed within the selected homes as (1plant for each 12 m^2) and in agreement with a study was conducted in USA[26]. Otherwise; The present study disagree with another study was also condugted in the USA where the removal efficiency, expressed on a leaf area basis for each volatile organic compound (VOC), varied with plant species. The variation in removal efficiency among species indicates that for maximum improvement of indoor air quality, multiple species are needed. The number and type of plants should be tailored to the type of VOCs present and their rates of emanation at each specific indoor location (Yang et al., 2009). In the present study; the plants available in each season was used regardless the type of the VOCs as the IAQ has been assessed using VOCs – Enrichment factor for the purpose of declaring the most dominant source of indoor air pollution.

CO_2 and VOCs removal efficiency of the plants

CO_2 and VOCs removal efficiency of the plants was determined during the course of one year divided into three intervals: summer (June to August), winter (October to December), and spring (February to April). The first interval was conducted in the east of Alexandria, 1st building; the removing efficiency has ranged between (45.4 and 51.0 %), and (36.2 and 42.7%) with an arithmetic mean removal efficiency of 47.1 and 39.3% for CO_2 and VOCs respectively using *N. exaltata* (N=1), *D. marginata* (N=1), *S. wallisii* (N=2), during summer season 2019, Table 3A. The second interval was conducted in the west of Alexandria, 2nd building; the removing efficiency has ranged between (40.9 and 42.1%), and (34.4 and 39.5%) with an arithmetic mean removal efficiency of 41.6 and 36.6% for CO_2 and VOCs respectively using *D. lutescens* (N=1), *L. livistona* (N=1), during autumn season 2019, Table 3B. The third interval was conducted in the west of Alexandria, 3rd building, middle of Alexandria, the removing efficiency has ranged between (35.6 and 38.6%), and (32.0 and 34.3%) with an arithmetic mean removal efficiency of 36.8 and 33.0% for CO_2 and VOCs respectively using *E. aurums* (N=1), during winter, Table 3C.

VOCs Enrichment factor and exploring the sources of indoor pollutants

Figures 2(A-C) demonstrate VOCs Enrichment factor (VEF) during May-August, in the east of Alexandria, summer season, 1st building; where The VEF values declares that the most common source of indoor pollutants is bioeffluents (75%), while; the least sources are incomplete combussion sources of CO_2 (14%) and strong abiotic VOCs sources (11%). Considering the west of Alexandria , before and after setting plants, during September-December, autumn season, 2nd building; The most common source of indoor pollutants is the strong abiotic VOCs sources(50%), while; the lower sources are both the bioeffluents and incomplete combussion sources of CO_2 (25% for each).

Table 3A. CO2 and VOCs Removal efficiency (%) of the plants [*N. exaltata* (N=1), *D. marginata* (N=1), *S. wallisii* (N=2)] used in the building#1, east of Alexandria, summer season (June – August)

Apartment No	CO_2 Indoor concentration levels (ppm)		CO_2 Removal efficiency %	VOCs Indoor concentration levels mg/m^3		VOCs Removal efficiency %
	Before setting plants	After setting plants		Before setting plants	After setting plants	
No.1	655	352	46.3	0.894	0.512	42.7
No.2	646	348	46.1	0.865	0.534	38.3
No.3	643	351	45.4	0.873	0.557	36.2

No.4	637	345	45.8	0.884	0.533	39.7
No.5	632	337	46.7	0.862	0.539	37.5
No.6	625	325	48.0	0.877	0.522	40.5
No.7	621	304	51.0	0.856	0.510	40.4
Range	(621-655)	(304-352)	(45.4-51.0)	(0.856-0.894)	(0.510-0.557)	(36.2-42.7)
Mean	637.00	342.57	47.04	0.816	0.530	39.33
Median	637.00	345.00	46..30	0.873	0.533	39.70

Table 3B. CO2 and VOCs Removal efficiency (%) of the plants [*D. lutescens* (N=1), *L. Livistona* (N=1)] used in building #2, west of Alexandria, autumn season (October-December)

Apartment No	**CO_2 Indoor concentration levels (ppm)**		**CO_2 Removal efficiency %**	**VOCs Indoor concentration levels mg/m^3**		**VOCs Removal efficiency %**
	Before setting plants	**After setting plants**		**Before setting plants**	**After setting plants**	
No.1	738	433	41.3	0.777	0.500	35.6
No.2	731	425	41.9	0.788	0.495	37.2
No.3	726	429	40.9	0.772	0.500	35.2
No.4	722	421	41.7	0.765	0.463	39.5
No.5	714	417	41.6	0.759	0.498	34.4
No.6	711	412	42.1	0.754	0.481	36.2
No.7	705	410	41.8	0.746	0.460	38.3
Range	(795-738)	(410-433)	(40.9-42.1)	(0.746-0.788)	(0.460-0.500)	(34.4- 39.5)
Mean	721.00	421.00	41.61	0.766	0.485	36.6
Median	722.00	421.00	41.70	0.765	0.495	36.2

Table 3C. CO_2 and VOCs Removal efficiency (%) of the plants [*E. aurums* (N=1)] used in building3, middle of Alexandria, winter and spring seasons (February- April)

Apartment No	**CO_2 Indoor concentration levels (ppm)**		**CO_2 Removal efficiency %**	**VOCs Indoor concentration levels mg/m^3**		**VOCs Removal efficiency %**
	Before setting plants	**After setting plants**		**Before setting plants**	**After setting plants**	
No.1	638	411	35.6	0.799	0.525	34.3
No.2	635	405	36.2	0.791	0.527	33.4
No.3	620	398	35.8	0.787	0.525	33.3
No.4	618	391	36.7	0.771	0.522	32.3
No.5	612	382	37.6	0.774	0.517	33.2
No.6	607	373	38.6	0.768	0.516	32.8
No.7	592	371	37.3	0.754	0.513	32.0
Range	(592 - 638)	(371 - 411)	(35.6 - 38.6)	(0.754 - 0.788)	(0.513 - 0.527)	(32.0 - 34.4)
Mean	620.29	390.14	36.83	0.778	0.521	33.04
Median	618.00	391.00	36.70	0.774	0.522	33.20

As regards the middle of Alexandria, before and after setting plants, during (January-April), Winter and Spring seasons, 3rd building; the most common source of indoor pollutants is the strong abiotic VOCs sources(64%), the lower sorces are the bioeffluents (25%) and incomplete combussion sources of CO_2(11%). This results agree with the fact the east of Alexandria is mainly a commercial area, the middle is mainly highly traffic,while; the east is mainly industrial zone.

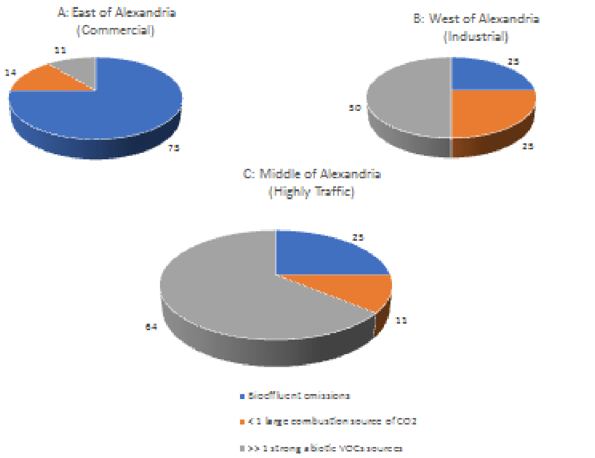

Figure 2A-C. The values of VOCs enrichment factors and the sources of indoor pollutants

4. Discussion

In 1989, NASA in collaboration with Associated Landscape Contractors of America (ALCA) carried out clean air study and published results which provide a definitive list of plants that are most effective at purifying indoor air. The study found that plants are effective at filtering of benzene, trichloroethylene, ammonia and formaldehyde etc. from the air, in addition to absorbing carbon dioxide and releasing oxygen through photosynthesis. Among the plants were tested during the study are *S. wallisii, D. marginata, D. lutescens, N. exaltata, E. aureum, R. excelsa, C. comosum, H. helix, C. elegans, C. morifolium* etc. NASA discovered that plants help reducing volatile organic chemicals/ compounds and can be an efficient way to filter the air in living compartments (Wolverton et al, 1989). Another study was conducted on 1993. These studies positively demonstrated that potted plants could remove substantial amounts of gaseous VOCs in sealed chambers, with reductions ranging from 10% to 90% in 24 hr (Wolverton et al, 1993). Plants absorb VOCs from the air through their leaves and then transport them into the root zone, where they are broken down by microbes, and microorganisms in the soil feed on a few amounts of those pollutants. Also, during the biological processes of plant some of the organic chemicals absorbed by plant from the air are destroyed. On the other hand, the plant roots absorb the aqueous solutions present in the soil, since the air can reaches the roots, the absorption of the root tissues is another way to air purification (Kobayashi et al 2007).

Many indoor ornamental plants such as *C. comosum* plant, snake plant, *E. aureum and G. daisy* etc. have been seen to mitigate the indoor pollution. Plants remove pollutants such as CO_2 through plant foliage during photosynthesis, degrade VOC through rhizosperic microbes and have the capacity to sequester particulate matter and oxygen is produced and then returned back by the plant as a by-product (Sharma et al., 2019 and Baosheng et al., 2009).

The influence of Spathiphyllum flowers on indoor air quality (IAQ) was studied, the results indicate a beneficial effect brought by the flowers' presence inside the bedroom, but only if the door is open both day and night. The measurements indicate nearly 4% reduction on CO_2 concentration inside the bedroom over one week, it is good to have flowers inside the house, but their place is in living room or in kitchen, and no one should sleep with the bedroom door closed because of the CO_2 accumulation inside (Năstase and Șerban, 2019). An experiment was carried out to find the formaldehyde absorption capacity of *S. wallisii*. The plant showed excellent absorption capacity by the range of absorption from 0.09-1.006 ppm. The laboratory results show that Spathiphyllum has a potential to alter indoor air in turn it will affect the health and well-being of the inhabitants (Ghate, 2020). In addition; *C. comosum* and *E. aureum* were both effective cultivars for CO_2 removal at light densities greater than 50 μmol m−2 s−1(Torpy et al.,2017)

A number of plants were tested to define the ability of plants to reduce the concentration of benzene in indoor air (*E. aureum, C. comosum, H. helix* and *E. tubiflora*). The results indicated that they could remove about 72% of the benzene within 72 h. The characteristics of each plant, lighting, concentrations of benzene affected the efficiency of benzene removal. It is noted that the higher rate of transpiration and concentration of chlorophyll in a plant, the increasing efficient of the plant to reduse benzene concentration in indoor air(Gong et al., 2022). Ornamental potted indoor plants provide environment friendly, self-regulating and cost-effective solutions to ameliorating indoor air pollution. A study conducted in India aimed to measure Air Pollution Tolerance Index (APTI) of 15 commonly used indoor ornamental plant species. Estimation of APTI for such plants provides a reliable method for selection of indoor plants, which can be used as a mitigator and bioindicator of indoor air pollutions. It was found that among all plant species, *D. deremensis* (APTI 13.03) and *F. benjamina* (APTI 12.19) appeared as tolerant; nine species (*S. wallisii, E. aureum, P. bipinnatifidum, D. seguine, S. trifasciata, H. helix, C. indicum, C. comosum and F. elastica*) were middle tolerant with APTI values ranging from 11.40 to 10.32, and four were sensitive (*Rhapis excels* APTI 8.58, *C. seifrizii* APTI 8.47, *D. lutescens* APTI 7.47, and *G. jamesonii* APTI 6.76) towards air pollution (Chauhan et al., 2022).

The findings of another study highlighted the impact of *D. lutescens* potted plants in reducing TVOCs, CO_2, and CO at a greater extent that is up to 95.70%. The study concluded that Dypsis lutescens are an effective, low-cost and sustainable solution to purified IAQ thus increase human well-being and productivity in indoor environments (Bhargava et al., 2021).

In another experiment, the findings showed that *C. elegans* effectively remove formaldehyde from polluted air by 65–100%. Therefore, phytoremediation of VOCs from indoor air by the ornamental potted plants is an effective method which can be economically applicable in homes and offices (Teiri et al., 2018). This study assessed the formaldehyde removal ability of the active green wall using dynamic experiments. Three levels of airflow rate (30, 50, and 65 $m^3 \cdot h^{-1}$) and inlet formaldehyde concentration (1.0, 2.0, and 3.5 $mg \cdot m^{-3}$) were used and three plant species were investigated. The removal of formaldehyde by active green walls was significantly ($P < 0.01$) affected by the airflow rate, formaldehyde concentration, and plant species. The single pass removal efficiency varying from 38.18 to 94.42% decreased as the airflow rate and formaldehyde concentration increased. The elimination capacity varied from 189 to 1154 $mg \cdot m^{-2} \cdot h^{-1}$ and increased with the inlet formaldehyde loading rate. Significant differences in formaldehyde removal effectiveness among the plant species were observed with *C. comosum* performing the best, followed by *S. octophylla*, with *C. elegans* being the worst (Permana et al., 2022). Indoor plants can efficiently purify formaldehyde and Promote IAQ. Plant parts (aerial parts / stems - ground parts / roots) have different capacities in their ability to remove formaldehyde. Astudy was conducted on *E. aureum* and *Rohdea japonica*. The results illustrate that the stems of plants could remove formaldehyde, the rate of purification was 40.0 and 61.6%, respectively (Zuo et al.,2022).

Twenty-eight ornamental species commonly used for interior plantscapes were screened for their ability to remove five volatile indoor pollutants; benzene. toluene, octane, trichloroethylene (TCE) and a-pinene. Of the 28 species tested, *H. alternata*, *H. helix*, *H. carnosa*, and *A. densifloru* had superior removal efficiencies for each of the fifth test compounds. Likewise, *T. pallida* had superior removal efficiencies for four of the compounds (i.e., benzene, toluene, TCE, and a-pinene). *H. alternata*, in particaular, had the highest removal efficiency for four of the compounds (benzene, toluene, octane, and TCE) (Yang et al, 2009).

It could be summerized that many researches were carried out internationally studing phytoremediation and its role in improving IAQ. They agreed with the present study mainly in the types of plants used; but, they more or less disagree with the efficacy of the plants in decreasing the level of pollutants. This may be mainly attributed to the nature of the outdoor air concerning the levels of air pollutants. As; this has a great effect on the IAQ.

Conclusion and recommendations

Phytoremediation is an important and valuable technique for improving IAQ and promoting morale and health; so, plants can be used to improve indoor air quality at home as houseplants are an effective and affordable way to promote health and performance, give a sense of calm and reduce the feeling of fatigue and stress leading to increased interests, mental skills and performance, develop the environment, increase the home aesthetics, and make living environment more attractive.

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