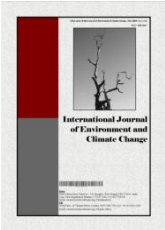

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Modeling to Reduce the Indoor Air Pollution in Dhaka: An Evidence from Randomized Experiment of NASA Recommended Plants

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Spider plant (*Chlorophytum elatum*), Snake plant (*Dracaena trifasciata*), Dracaena (*Dracaena marginata*) and Aloe vera (*Aloe vera*) are selected to conduct the experiment because which is the National Aeronautics Space Administration NASA recommended plants that are available in Bangladesh. In this study Indoor Air Quality Index (IAQI) is estimated by using seven parameters such that $PM_{2.5}$, PM_{10}, CO_2/PPM, Formaldehyde, Volatile organic compounds, Temperature and Humidity. Dracaena has significantly impact to reduce $PM_{2.5}$ after one month later 36.00 to 28.33. Also Dracaena and Aloe vera have significantly impact to reduce PM_{10} after one month later (46.00 to 36.33) and (21.33 to 44.33 to 32.67) respectively. Results showed that the more decreasing rate of CO2/PPM is recorded from Spider plant about 622 to 620 then 615. Another finding is that the highest rate of change of formaldehyde is planting Aloe vera (24%). The results of VOC obtained from Spider plant (0.290 to 0.204 to 0.178) gave positive results compared to other plants. Effects of different types of plants showed significant differences on room temperature. The highest rate of change of temperature (6%) is recorded from Snake plants and Aloe vera. The highest increasing rate of change of humidity (7.3%) is recorded from Snake plants. One month later after plantation, the sub indices of major four pollutants such that $PM_{2.5}$, PM_{10}, CO_2/PPM and Formaldehyde are similar without CO_2/PPM. Sub indices of $PM_{2.5}$ are less than 50 and one is near to fifty. The lowest score of sub indices of HCHO (less than 40) is recorded from

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Spider plants (25) whereas the statistically followed is obtained from PM_{10}. Aggregation of sub indices to get the overall IAQI by maximum operator method IAQI = Max (Isi1, Isi2, Isi3, Isi4) because a health based index cannot be combined or weighted. Finally results shows that IAQI of this study one month later after plantation for each type of plants are satisfactory but not good.

Keywords: Indoor air pollution; particulate matter; $PM_{2.5\ and}$ PM_{10}; Carbon dioxides (CO_2); Volatile Organic Compounds (VOCs); temperature; humidity.

1. INTRODUCTION

The Environmental Protection Agency (EPA) defines indoor air quality (IAQ) as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" [1]. Indoor air contaminants can cause acute or chronic health problems [2-4]. Previous research has associated acute health problems such as headache, nausea and respiratory infection to the quality of the indoor air [5]. Chronic health effects of poor IAQ may include systemic problems such as anemia, heart problems, decreased 2 lung elasticity, and even cancer [6]. The most important environment that relates to human health is the indoor environment because people spend as much at 90 percent of their time indoors [7]. The government has tried to inform people about the presence of different types of environmental pollution [8] such as arsenic in drinking water sources through a binary color coding system. For this, Spider plant (*Chlorophytum elatum*), Snake plant (*Dracaena trifasciata*), Dracaena (*Dracaena marginata*) and Aloe vera (Aloe vera) are selected to conduct the experiment because which are the National Aeronautics Space Administration NASA recommended plants that's available in Bangladesh. Bangladesh is significantly overpopulated country [9]. Dhaka is the capital and the largest city of Bangladesh that has developed with uncontrolled growth and few regulatory restraints. It is considered as one of the densely populated megacities in the world, with about 12 million population in 2011 with 3.48% growth rate means 17 million inhabitants within a 300-Square km area in 2020. Along with those, industrial growth was also rose to 7.9 % in the Fiscal Year 2018 (Bangladesh Bank 2019). Therefore, emission of different hazardous substances like particulate matter ($PM_{2.5}$, PM_{10}), some gases such as Carbon dioxides (CO_2), Volatile Organic Compounds (*VOCs*), temperature and humidity at elevated level deteriorate the air quality of Dhaka city. At present, the air quality of Dhaka has been ranked as a 2nd most polluted City in the world (WHO, 2019). Migration from rural to urban is increasing [10] which is increasing the density of population and air pollution in the Dhaka City. Also, Unparalleled level of migration flow from Bangladesh to other region of the world have been promoted [11] one of the reason of migration is living environment like air quality. Man himself should be considered another source of indoor air pollution, especially when living in a closed, poorly ventilated area. The quality of the indoor environment has become a major health consideration. One world health organization recently estimated that approximately 30 percent of all new or remodeled buildings have varying degrees of indoor air pollution. Two major problems with indoor air pollution are the identification of the trace chemicals and their correlation with disease like symptoms. Now that most environmental scientists and government agencies agree that indoor air pollution is a realistic threat to human health. The first and most obvious step in reducing indoor air pollution is to reduce off-gassing from building materials and furnishings before they are allowed to be installed. The National Aeronautics Space Administration (NASA) identified indoor air pollution problems associated with sealed space habitats. Bill Wolverton is a retired NASA scientist who studied the applications of plants in air and water purification, and he made an interesting discovery: plants become much better air filters when air circulation to their roots is improved. As previously stated, the bacteria living in the soil around plant roots are generally harmless for humans and can contribute to air purification. The NASA Clean Air Study was a project led by the National Aeronautics and Space Administration (NASA) in association with the Associated Landscape Contractors of America (ALCA) to research ways to clean the air in space stations. Its results suggested that, in addition to absorbing carbon dioxide and releasing oxygen through photosynthesis, certain common indoor plants may also provide a natural way of removing volatile organic

pollutants (benzene, formaldehyde, and trichloroethylene were tested). Now we consider four available plants in Bangladesh such as spider plant, snake plant, Dracaena and aloe vera well as we estimate the following parameters PM 2.5/PM10, CO2, VOC, temperature, humidity to measure the environmental impact. Dhaka is highly densely populated and highly polluted megacity. Research indicates 96 percent of homes have at least one type of indoor air quality issue. The overall goal of the study is to reduce the environmental pollution through beautification by using NASA recommended plants in the Dhaka city. The specific objectives are: Investigating the indoor air quality parameters of Dhaka city and estimating the impact of different NASA recommended plants in the indoor air quality.

2. METHODOLOGY

2.1 Study Locations

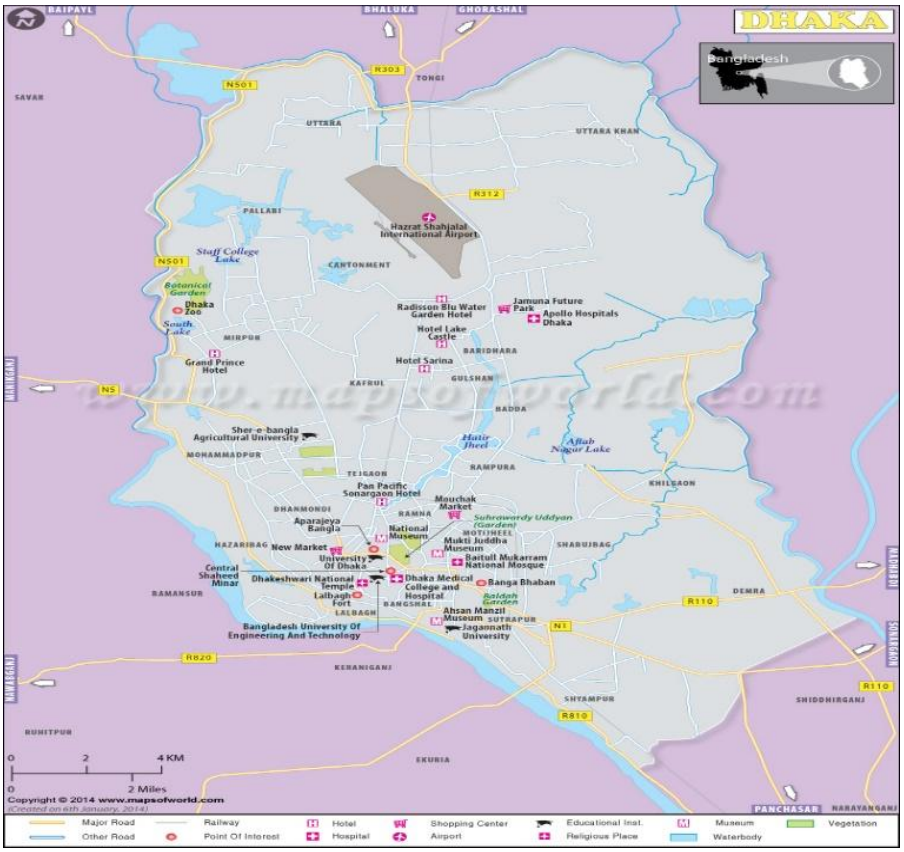
The study will be conducted in Dhaka metro area which is the most polluted area in Bangladesh. Specifically Sher-e-Bangla Agricultural University campus is selected to conduct the study as a less polluted area.

2.2 Experimental Materials

i) The following four types of plants are used for this study: Spider plant, Snake plant, Dracaena, Aloe vera
ii) Pots/tubs with soil
iii) Indoor Air Quality (IAQ) monitoring device: This device helped to stay on top of that by reporting on the levels of common pollutants and other air conditions inside the home in real time. The culprit could be anything from excessive dust to high humidity to emissions from household cleaners or building materials.

2.3 Parameters

The following five parameters are measured and mentioned to reduce the air pollution: Particulate matter, $PM_{2.5,}$ $PM_{10,}$ Carbon dioxides (CO_2), Volatile Organic Compounds (VOCs)**,** Temperature, Humidity.



Map. 1. Map Courtesy: mapsofworld.com

2.4 Indoor Air Quality Index (IAQI)

Establish the sub indices for each pollutant (I_{si})

$$I_{si} = (\frac{(C_{obs} - C_{min})(I_{max} - I_{\min})}{(C_{max} - C_{\min})} + I_{min}$$

Where
I_{si} = Sub index value of observed pollutant
C_{obs} = Observed pollutant concentration
C_{min} = Minimum concentration of AQI category that contains ≤ C_{obs}
C_{max} = Maximum concentration of AQI category that contains C_{obs}
I_{max} = Maximum AQI value corresponding to ≤ C_{max}
I_{min} = Minimum AQI value corresponding to C_{min}
T
he overall AQI: Aggregation can be by simple or weighted average method or summation or multiplication operation or simply a maximum or minimum operator.
In IAQI it is by maximum operator method IAQI = Max(I_{si1}, I_{si2}, I_{si3}, ...)
Because it is free for ambiguity. Hence a health based index cannot be combined or weighted.

3. RESULTS AND DISCUSSION

3.1 Beautification

Spider Plant: A room where sunlight is not available or insufficient in this condition Spider Plant is perfect for growing and beautification. However, they prefer bright indirect light where they are flourished. Water is provided on Spider Plant when the top 50% of the soil is dry. The striplings on the leaves are more prominent with indirect lighting. Avoid direct sunlight as it is scorch the leaves.

Snake Plants: Snake plants are desert plants that are accustomed to hot and humid conditions. That being stated, it is generally not recommended to mist the leaves of a snake plant. Misting the snake plant's leaves can cause them to become overwatered, leading to several other health issues.

Dracaena plants: Dracaena plants also benefit from a light misting of the leaves several times a week. This is especially important during periods of low humidity, such as that which occurs throughout the winter. Without sufficient moisture, growers may notice that leaf tips begin to yellow or turn brown.

Aloe vera: Aloe vera is the one miracle plant that every house needs. It's not only use in beautification but also use in health or skin treatment as well as indoor environmental purification purpose.

3.2 Indoor Air Quality Index (IAQI)

3.2.1 Particulate matter ($PM_{2.5}$)

It refers to particles that have diameter less than 2.5 micro meters and remain suspended for longer. These particles are formed as a result of burning fuel and chemical reactions that take place in the atmosphere.

Among the plants, Dracaena has significantly impact to reduce particle 38.00 to 27.33 (Table 1). Although the Aloe vera, Spider and Snake plant are also reduce the $PM_{2.5}$.

3.2.2 Particulate matter (PM_{10})

It describes inhalable particles, with diameters that are generally 10 micrometers and smaller. PM_{10} particles can be found in dust and smoke.


Fig. 1. Spider Plant


Fig. 2. Snake Plant


Fig. 3. Dracaena


Fig. 4. Aloe Vera

Dracaena and Aloe vera have significantly impact to reduce particle after plantation (96.26 to 85.33) and (91.43 to 82.67) respectively (Table 2). The Spider and Snake plant are also reducing the PM_{10} gradually, it may be occur these two types of plants is reduced particle significantly after a long period.

3.2.3 Carbon dioxide by parts per million (CO_2/PPM)

The global average atmospheric carbon dioxide in 2019 was 409.8 ppm, with a range of uncertainty of plus or minus 0.1 ppm. Carbon dioxide levels today are higher than at any point in at least the past 800,000 years.

Significant variation was found with different types of plants (Fig. 5). Results showed that the more decreasing rate of CO2/PPM is recorded from Spider plant about 622 to 620 then 615 which is similar decreasing rate for Snake plant and Dracaena that means air quality goes tends to good after plantation. Opposite scenario is visible for Aloe vera as it is not showed the effect within short duration.

3.2.4 Formaldehyde (HCHO)

Formaldehyde is a naturally occurring organic compound with the formula CH_2O. The pure compound is a pungent-smelling colorless gas that polymerizes spontaneously into par formaldehyde. Formaldehyde is found significant influence with different types of pants after plantation without Dracaena. Table 3 indicated that the highest rate of change of formaldehyde is Aloe vera (24%) then Spider plant (22%) follow by Snake plant (7%). An opposite findings is increasing rate for Dracaena, it may occur for unknown error.

Table 1. Mean particulate matter ($PM_{2.5}$) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	Mid term	End of the project
Spider plant	85.67	82.33	79.73
Snake plant	84.33	82.67	80.00
Dracaena	88.00	82.00	77.34
Aloe vera	86.67	83.67	78.00

Table 2. Mean particulate matter (PM_{10}) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	Mid term	End of the project
Spider plant	91.67	90.28	88.42
Snake plant	87.53	86.38	84.33
Dracaena	96.26	94.62	85.33
Aloe vera	91.43	89.34	82.67

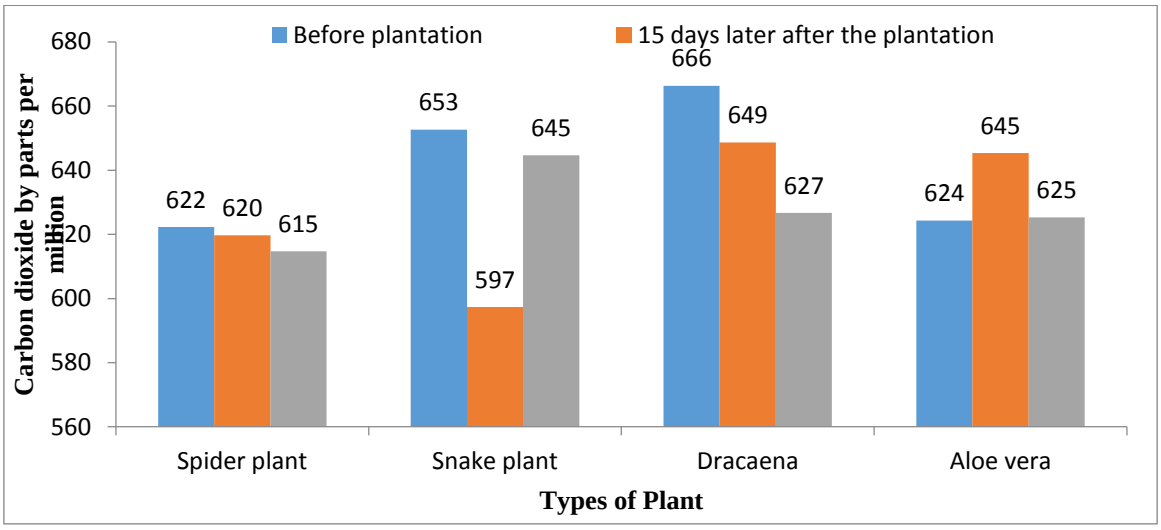


Fig. 5. Carbon dioxide by parts per million (CO_2/PPM) of three different times

3.2.5 Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Common examples of VOCs that may be present in our daily lives are: benzene, ethylene glycol, formaldehyde, methylene chloride, tetrachloroethylene, toluene, xylene, and 1, 3-butadiene. Less than 0.6 safety ranges, achieve 0.601 or more: Exceeding the standard can cause respiratory system Abnormal, inflamed, cancerous, etc. The results obtained from Spider plant (0.790 to 0.720 to 0.618) gave positive results compared to other plants (Table 4).

3.2.6 Temperature (Celsius)

Effects of different types of plants showed significant differences on room temperature (Fig. 6). The highest rate of change of temperature (6%) is recorded from Snake plants and Aloe vera (Table 5) whereas the statistically same followed (3%) is obtained from Spider plant where the lowest rate of change of temperature (2%) is recorded from Dracaena.

Table 3. Mean Formaldehyde (HCHO) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	End of the project	Change in Percentage
Spider plant	0.332	0.0325	-22
Snake plant	0.321	0.338	-7
Dracaena	0.327	0.328	4
Aloe vera	0.334	0.326	-24

Table 4. Mean volatile organic compounds (VOCs) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	Mid-term	End of the project
Spider plant	0.790	0.720	0.618
Snake plant	0.714	0.712	0.633
Dracaena	0.735	0.730	0.623
Aloe vera	0.763	0.733	0.612

Table 5. Mean temperature (Celsius) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	After plantation	Rate of change (%)
Spider plant	28.67	27.67	-3
Snake plant	28.67	27.00	-6
Dracaena	29.33	28.67	-2
Aloe vera	29.33	27.67	-6

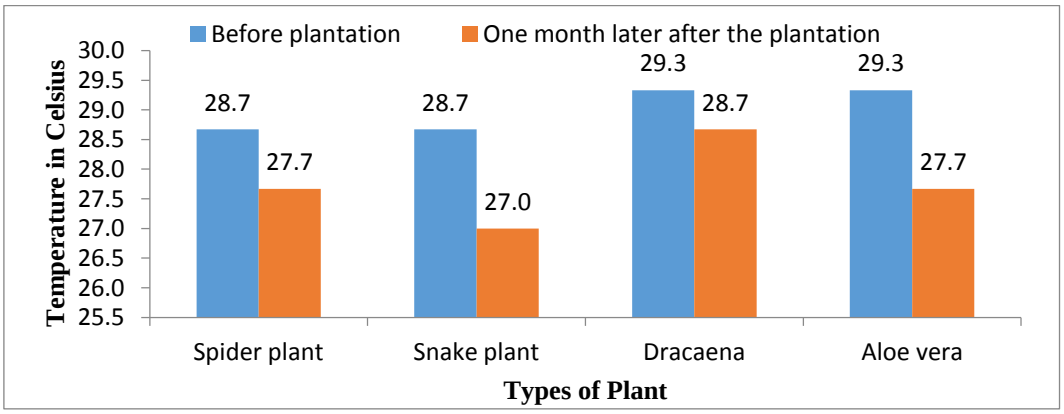


Fig. 6. Mean temperature (Celsius) of three different times in indoor area

3.2.7 Humidity (Percentage)

Plants increase humidity in the air through a process called evapo-transpiration. Water from the soil makes its way up through the roots of the plant, through the stems, and up to the leaves (transpiration), where it's evaporated into the air through pores on the leaves, called stomata. Most indoor plants increase humidity, but sometimes the change is not noticeable. It is because plants have different growing habits and patterns. Some transpire more water, others not as much. Effects of different types of plants showed significant differences on room humidity (Table 6). The highest increasing rate of change of humidity (7.3%) is recorded from Snake plants (Figure7) whereas the statistically followed (5.6%) is obtained from Aloe vera where the lowest increasing rate of change of humidity (0.5%) is recorded from Dracaena.

3.2.8 The Indoor Air Quality Index (IAQI)

After plantation the results shows that the sub indices of four pollutants are similar without CO_2/PPM (Fig. 8). Sub indices of $PM_{2.5}$ are less than 50 and one is near to fifty (53). The lowest score of sub indices of HCHO (less than 40) is recorded from Spider plants (25) whereas the statistically followed is obtained from PM_{10}. Aggregation of sub indices to get the overall AQI (Table 7) by maximum operator method IAQI = Max (Isi1, Isi2, Isi3, Isi4) because a health based index cannot be combined or weighted. Finally Table 7 shows that IAQI of this study after plantation for each type of plants are satisfactory but not good (Table 8).

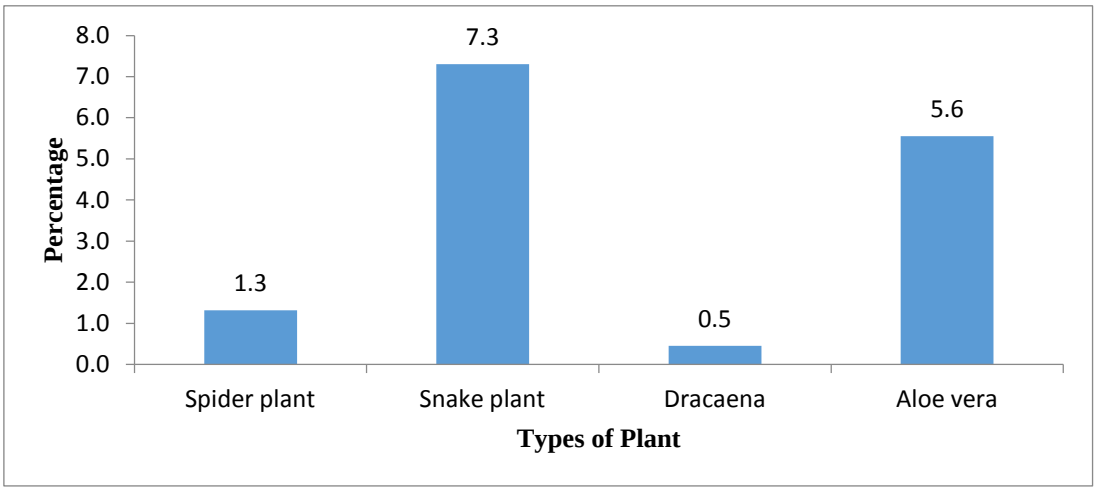


Fig. 7. Changing rate of humidity of three different times in indoor area

Table 6. Mean humidity (Percentage) of three different times in indoor area according to four types of plant

Type of Plant	Before plantation	Mid term	End of project
Spider plant	76.00	73.00	77.00
Snake plant	73.00	74.00	78.33
Dracaena	73.00	75.00	73.33
Aloe vera	72.00	74.00	76.00

Table 7. Sub indices of four pollutant and corresponding IAQI Label of four types of plant

Type of Plant	Sub Index of $PM_{2.5}$	Sub Index of PM_{10}	Sub Index of Co_2/PPM	Sub Index of HCHO	Max(Sub Indices)	IAQI label
Spider plant	42.22	32.00	76.83	25.00	76.83	Satisfactory
Snake plant	53.33	41.33	80.58	38.00	80.58	Satisfactory
Dracaena	47.22	36.33	78.33	28.00	78.33	Satisfactory
Aloe vera	41.67	32.67	78.17	26.00	78.17	Satisfactory

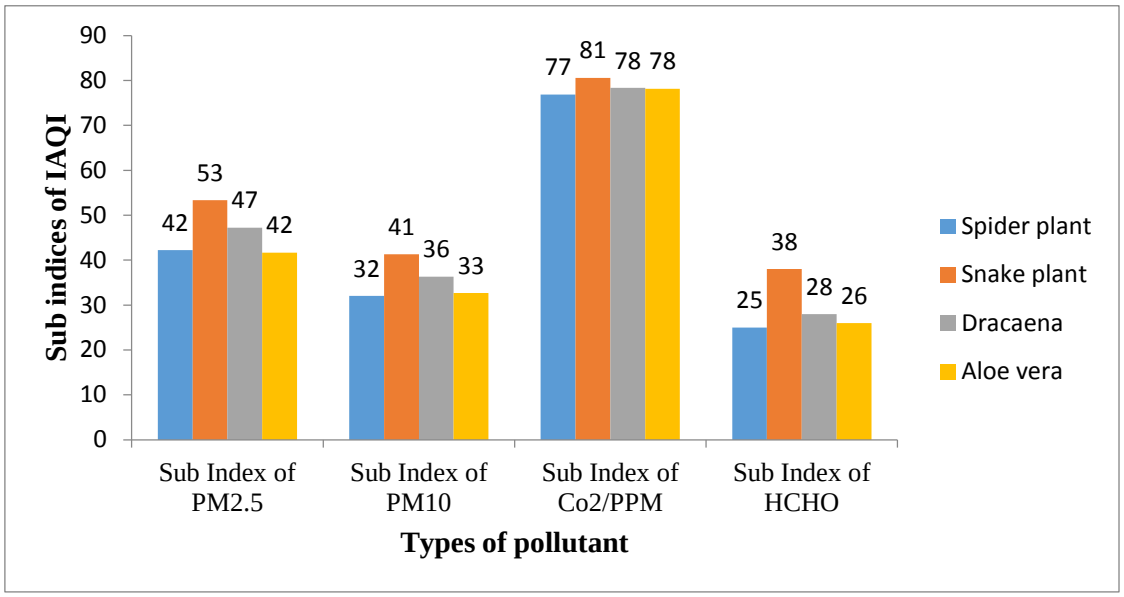


Fig. 8. Sub indices of four pollutant in indoor area according to four types of plant

Table 8. Indices categories and the corresponding concentration break points for each of the pollutant

AQI Category	Range	PM2.5	PM10	CO2/PPM	HCHO
NAAQ Standard	0-500	60	100	410	0.080
Good	0-50	0-30	0-50	0-400	0-0.050
Satisfactory	51-100	31-60	51-100	401-800	0.0501-0.100
Moderately polluted	101-200	61-90	101-250	801-1000	0.101-0.200
Poor	201-300	91-120	251-350	1001-1200	0.201-0.250
Very poor	301-400	121-250	351-430	1201-2500	0.251-0.300
Severe	401-500	250+	430+	2501-5000	0.301+

4. CONCLUSIONS

Spider plant (*Chlorophytum elatum*), Snake plant (*Dracaena trifasciata*), Dracaena (*Dracaena marginata*) and Aloe vera (*Aloe vera*) are selected to conduct the experiment. In this study Indoor Air Quality Index (IAQI) is estimated by using seven parameters such that PM2.5, PM10, CO2/PPM, Formaldehyde, Volatile organic compounds, Temperature and Humidity. Above the plants, Dracaena has significantly impact to reduce $PM_{2.5}$ after plantation 88.00 to 77.34. Also Dracaena and Aloe vera have significantly impact to reduce PM_{10} after plantation (96.26 to 85.33) and (91.43 to 82.67) respectively. Results showed that the more decreasing rate of CO2/PPM is recorded from Spider plant about 622 to 620 then 615. Another finding is that the highest rate of change of formaldehyde is planting Aloe vera (24%). The results of VOC obtained from Spider plant (0.790 to 0.618) gave positive results compared to other plants. Effects of different types of plants showed significant differences on room temperature. The highest rate of change of temperature (6%) is recorded from Snake plants and Aloe vera. The highest increasing rate of change of humidity (7.3%) is recorded from Snake plants. After plantation, the sub indices of major four pollutants such that $PM_{2.5}$, PM_{10}, CO_2/PPM and Formaldehyde are similar without CO_2/PPM. Sub indices of $PM_{2.5}$ are less than 50 and one is near to fifty. The lowest score of sub indices of HCHO (less than 40) is recorded from Spider plants (25) whereas the statistically followed is obtained from PM_{10}. Finally results shows that IAQI of this study after plantation for each type of plants are satisfactory but not good. We are repeating the study in different places with replication.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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