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Dust capturing potential of some existing roadside tree species: Implications for urban dust aerosol monitoring and mitigation around Wazirpur Industrial Area, Delhi, India

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Abstract
Anthropogenic dust is major contributor of urban dust aerosols in highly urbanized areas anthropogenic ally derived dust accounts for about ≈ 30 to 70% of total dust concentrations. High concentrations of urban dust aerosols have led to detrimental health effects leading to high respiratory mortality and morbidity. Urban plantations have proved to be low cost sensors and monitors in monitoring of urban dust aerosols in many studies worldwide. Leaves of plants act as filter to polluted air and can thus be used for both monitoring and mitigation of urban dust aerosols. In this study some existing tree species in Wazirpur industrial area were investigated for their dust monitoring and mitigation potential. The average foliar dust deposition of tree species was higher in post- monsoon season and found to be 3.08 mg/cm^2 as compared to pre-monsoon season value of 2.21 mg/cm^2 In the pre-monsoon season dust capturing potential varied from maximum of 3.586 mg/cm^2 in *Terminalia arjuna* to 0.559 mg/cm^2 in *Polyalthia longifolia*. In the post-monsoon season dust capturing potential varied from maximum of 4.089 mg/cm^2 in *Terminalia arjuna* to 1.09 mg/cm^2 in *Polyalthia longifolia*. Average seasonal dust capturing potential sequence of tree species followed the sequence: *Terminalia arjuna* > *Ficus benghalensis* > *Bauhinia variegata* > *Ficus religiosa* > *Plumeria alba* > *Cassia fistula* > *Anthocephalus cadamba* > *Morus alba* > *Ficus virens* > *Mangifera indica* > *Polyalthia longifolia*. Percentage foliar dust deposition of different species was calculated to determine the efficiency of dust deposition. Highest percentage foliar dust was found in *Terminalia arjuna* (72.54%) and lowest in *Polyalthia longifolia* (15.58%).

Keywords: urban dust aerosols, dust capturing potential, foliar dust, mitigation, monitoring

Introduction

In the recent years rapid urbanization and industrialization has resulted in decrease in the urban vegetation cover leading to problem of urban dust aerosols especially in big metropolitan cities of the world. In pollution science urban dust aerosols have gained great attention owing to their complex morphological, physiochemical characteristics, potential toxicity and impact on global climate and regional air pollution episodes (Yang *et al*., 2021) [46]. Dust aerosols from natural sources in the form of dust storms, haze and suspended dust particles are known to cause substantial impact on local meteorological conditions through trans boundary transport causing detrimental effect on the air quality of neighboring areas (Sarkar *et al*., 2019) [36]. While anthropogenic dust aerosols are resultant of various human activities like construction, excavation and demolition waste, industrial activities, friction of tyres during brake application, on road movement of vehicles on the road (Chen *et al*., 2018) [2]. Anthropogenic dust are often laden with highly toxic heavy metals and are known to cause long lasting deleterious effects on human health. Some of these effects includes chronic pulmonary obstructive diseases, lung cancers, lower respiratory tract infections, cardiovascular and cerebrovascular diseases (Soltani *et al*., 2015) [39]. In fact in urbanized areas anthropogenic ally derived dust accounts for about ≈ 30 to 70% of total dust concentrations (Huang *et al*., 2015) [14]. The estimated global total premature mortality due to Anthropogenic urban dust aerosols is 0.8 million deaths per year and is more severe in densely populated regions of the world (Xia *et al*., 2022) [45]. In Indian context Anthropogenic dust has emerged as a top contributor of particulate pollution accounting for about ≈ 99, 900 of total PM 2.5 related deaths in India (GBD Report, 2017) [9].

Studies attribute a significant proportion of about 40% of the total air pollution to presence of dust in air (Kaler *et al*., 2016) [17]. In fact aerosol concentration over India have been reported to be three times higher than global mean value due to higher dust loadings (Dey *et al*., 2010) [6]. In a recent study Xia *et al* developed Anthropogenic Dust emission inventory constrained by satellite retrievals and implemented it in a global climate model which estimated that at the national level, China and India together bear more than 50% of premature deaths worldwide, resulting from elevated total PM 2.5 concentrations in which India directly suffers from approximately half of the health risks from Anthropogenic dust pollutants worldwide.

Urban vegetation provides great ecosystem service value by provisioning storm water reduction conserving energy and air quality improvement (Rossi *et al*., 2022) [33]. Many studies indicate potential of urban trees in mitigation of urban dust aerosols (Javanmard *et al*., 2020; Roy *et al*., 2020; Singh *et al*., 2021; Molnar *et al*., 2020) [34, 38, 28]. Trees provide large deposition surface for urban dust aerosols. They filter the polluted air and thereby removing toxic particles from traffic and industrial emissions. However the pollution abatement potential of trees along polluted environments depends on various factors such as leaf surface, leaf size, shape and phyllotaxy, petiole size and cuticular features, canopy structure, height of plant and meteorological conditions (Leonard *et al*., 2016; Meravi *et al*., 2021; Singh *et al*., 2021; Wang *et al*., 2021) [20, 26, 38, 43]. Deposition and subsequent removal of deposited particles on leaf surface differ significantly among different species. Some species are more efficient and some are less even being present in same polluted environment (Li *et al*., 2019) [21]. Morphological features of leaf are important in determining the dust capturing potential of the leaves. Foliar features such as leaf roughness, stickiness, presence of grooves and trichomes facilitate more dust retention then smooth non sticky leaves without grooves and trichomes (Kardel *et al*., 2012; Ram *et al*., 2014; Sæbø *et al*., 2012) [32,35]. Leaf characteristics such as leaf orientation, sessile/non-sessile nature are also important in affecting dust deposition on plant leaves. Monitoring of dust aerosols is done routinely by air pollution monitoring stations using conventional filter based techniques. Worldwide there is a great emphasis on application of low cost sensors and greener technologies with high spatial and temporal resolution to monitor and mitigate the problem of urban dust aerosols, since conventional monitoring through chemical filters is expensive and time consuming methodology (Wang *et al*., 2019) [42]. Moreover there is limited understanding of anthropogenic urban dust aerosol emissions because of the difficulty of identifying and measuring them, which derives from strong heterogeneities in the sources (Mahowald *et al*., 2002) [25]. Monitoring of through plant leaves filters not only provides greater spatial and temporal resolution but also essentially is a low cost technique (Weerakkody *et al*., 2018) [44].

Delhi being the capital metropolitan city of India is facing high load of about 52 Gg of dust load every year which is very high as compared to its global counterparts (Kumar *et al*., 2015) [19]. Source apportionment studies conducted in recent years indicate that dust is the main contributor of air pollution in Delhi. Dust from roads and construction sites constitute about 17% of respirable, 25% of coarser PM_{10} (Sharma *et al*., 2018) [37]. Lots of measures are being adopted in Delhi for curbing menace of urban dust aerosols like implementation of Graded Response Action Programme, Installation of 23 anti- smog guns at key traffic intersections of Delhi (Gulia *et al*., 2022) [10], implementation of 14 anti-dust pollution guidelines, sprinkling of water along roadside areas, proposed application of dust suppressants and plantations along roadside areas (Gulia *et al*., 2019) [11].These short term management plans are not sufficient in tackling urban dust aerosols in Delhi therefore for the long term comprehensive management of dust pollution mitigation plans focussing on application of urban tress is much needed (Ganguly *et al*., 2020) [8]. A study by Jain *et al*., 2021[15] concluded that increase in greenness index of highly polluted areas having high commercial and industrial built up can help in alleviating high concentration of pollutant levels and improve air quality of Delhi. In this scenario it is very important to update and gather important information about existing roadside trees, their dust capturing potential and role in mitigation of urban dust aerosols. Therefore this study aims to explore the dust capturing potential of existing roadside tree species to mitigate urban dust aerosol in Wazirpur Industrial area which is second most polluted industrial cluster of India.

2. Materials and Methods

2.1. Study area

The study was conducted in metropolitan city of Delhi, India (Fig 1). Delhi which has a population of nearly 29 million inhabitants and is divided into 11 districts. With a population of 16.7 million having annual growth rate of 1.92% (Census. 2011) [1] and population density 11, 297 Km^2 with 93% population living in urban areas compared to national average of 31.16% (SAD, 2014), it is second most populous metropolis in India. The city has been recognized as one of the main centre for industrial and economic growth with 22,000 industrial units. In the present study Wazirpur industrial area a heavily industrialized region containing 2, 294 industries comprising of a large number of steel pickling units, hazardous electroplating industries, metal casting units was selected as a study area. The area is surrounded by high commercial and residential activities and marked by extreme cold winter and dry hot summer climatic conditions. The temperature shows wide variations ranging from minimum of 7.3˚in winter to 47˚in summer with a mean annual rainfall of 611.8 mm. The region is also one of the known air pollution hotspot and sink for atmospheric aerosols from neighboring states. Fig.1 represents study area with sampling points.

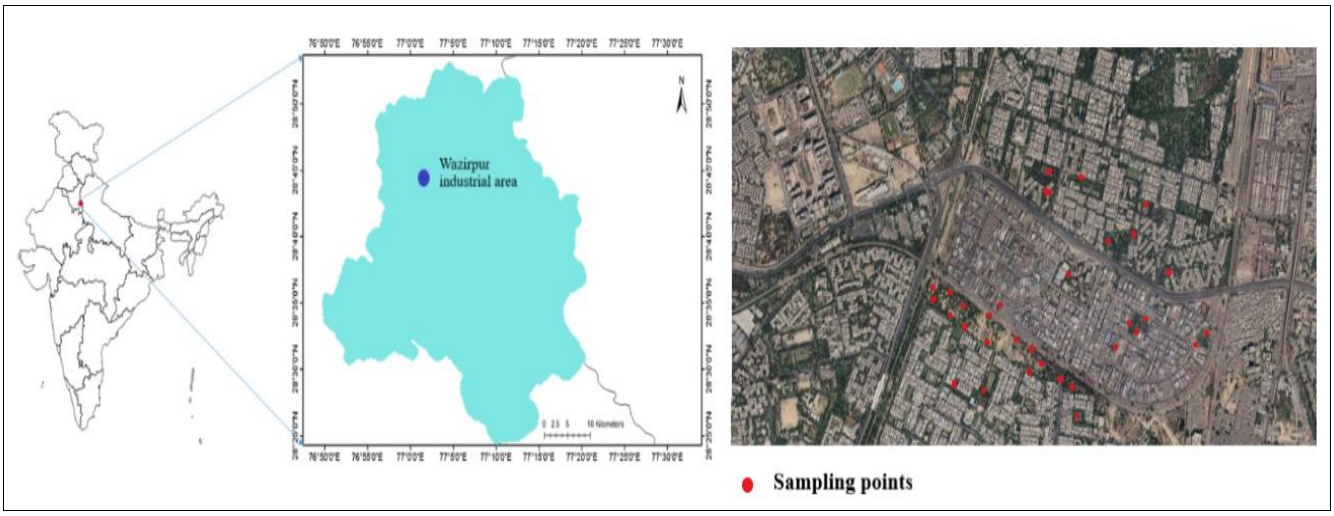

Fig 1: Map of Wazirpur industrial area showing sampling locations

2.2 Species selection and sampling

Prior to sampling a physical survey was done and the selection of tree species was done on the basis of local availability. Fully mature leaf samples of each selected species were collected during early morning hours (7 am to 9 am) in triplicates from a height of about 1.5 m from the ground. The leaves were detached from the trees using scissors and placed in zip lock bags and were brought in the lab for further analysis. Table 1 provides a detailed description of tree species used in this study. The sampling frequency was once a week and the samples were collected on a seasonal basis for both Pre-monsoon and Post monsoon.

2.3 Foliar dust deposition of tree species

Six leaves from each of the selected species were taken for the measurement of leaf surface area and foliar dust deposition. To screen species with high foliar dust deposition, dust capturing potential of each tree species was calculated gravimetrically. The leaves with dust particles were weighed with the help of digital balance (Sartorius) with accuracy of 0.1 mg and marked as W_1 for each species. In the next step dust adhering on the leaf surface was carefully washed from the leaf using brush and distilled water and the leaves were blotted dry and reweighed and marked as W_2. Measurement of leaf area was done using graphical method and marked as A (Das *et al*., 2012). Finally, dust capturing potential (mg/ cm^2) for each species was calculated using formula $W = (W_1 – W_2) / A$ Where, W = Foliar dust deposition (mg/ cm^2); W_1 = initial weight of leaf with dust; W_2 = final weight of leaf without dust; A = leaf surface area (cm^2).

2.4 Calculation of percentage (%) foliar dust deposition

Percentage foliar dust deposition for each tree species was calculated using following formula

Foliar dust capture (%) = Dust deposition on the leaf area of particular plant species / Sum of average dust deposits of all plant species under different sampling sites ×100

Further The tree species were categorized into three frequency classes based on percentage (%) dust capturing potential as follows (CPCB., 2007; Das *et al*., 2012), Low: < 10% dust capture; Medium: 11-20% dust capture; High: > 21% dust capture.

Table 1: Morphological features of selected Tree species in Wazirpur industrial area

S. No.	Tree species	Tree type	Canopy Shape	Phyllotaxy	Leaf shape	Leaf Margin	Surface
1	*Terminalia arjuna*	Deciduous	Spreading	Opposite	Oblong Lanceolate	Entire	Smooth leathery hairy
2	*Ficus virens*	Deciduous	Spreading	Opposite	Oval Lanceolate	Entire wavy	Smooth leathery hairy
3	*Mangifera indica*	Evergreen	Spreading	Alternate	Lanceolate	Entire	Fibrous
4	*Ficus benghalensis*	Deciduous	Round Spreading	Alternate	Elliptical	Entire	Leathery
5	*Cassia fistula*	Deciduous	Round	Alternate	Oval	Entire	Hairy
6	*Polyalthia longifolia*	Evergreen	Conical	Alternate	Linear Lanceolate	Wavy	Glossy smooth
7	*Ficus religiosa*	Deciduous	Spreading	Alternate	Cordate	Entire Wavy	Smooth
8	*Plumeria alba*	Deciduous	Round	Alternate	Elliptical	Entire	Smooth Leathery
9	*Bauhinia variegata*	Deciduous	Round	Alternate	Simple lobed	Entire	Smooth glabrous
10	*Morus alba*	Deciduous	Oval	Alternate	Simple lobed	Toothed	Rough
11	*Anthosephalus cadamba*	Deciduous	Round	Opposite	Elliptical	Entire	Smooth shiny

Table 2: Summation of average foliar dust deposition (mg/cm^2) of different sampling sites in different seasons in Wazirpur industrial area

Pre-monsoon season	Post-monsoon season	Average
2.21	3.08	5.29

Table 3: Percentage foliar dust deposition and allocated frequency classes for selected tree species in Wazirpur industrial area

S. No.	Tree species	Common Name	Family	(%) Percentage foliar dust deposition	Frequency class
1	*Terminalia arjuna*	Arjun	Combretaceae	72.54	High
2	*Ficus virens*	Pilkhan	Moraceae	58.68	High
3	*Mangifera indica*	Mango	Anacardiaceae	19.94	Medium
4	*Ficus benghalensis*	Banyan	Moraceae	60.05	High
5	*Cassia fistula*	Amaltas	Caesalpinaceae	37.70	High
6	*Polyalthia longifolia*	Ashoka	Annonaceae	15.58	Medium
7	*Ficus religiosa*	Peepal	Moraceae	46.32	High
8	*Plumeria alba*	Frangipani	Apocynaceae	30.16	High
9	*Bauhinia variegata*	Kachnar	Fabaceae	47.31	High
10	*Morus alba*	Mulberry	Moraceae	43.67	High
11	*Anthocephalus kadamba*	Kadam	Rubiaceae	29.47	High

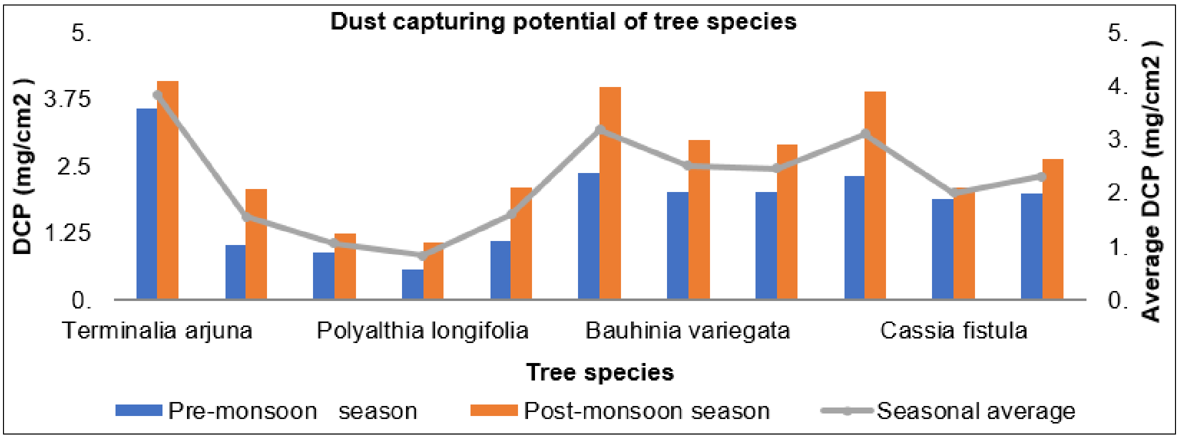

Fig 2: Dust capturing potential of tree species

3. Results and Discussion

3.1 Dust capturing potential

Urban dust aerosols have become significant problem in urbanized areas especially industrial areas. Wazirpur industrial area is a recognized air pollution hotspot having high concentration of particulate matter therefore dust capturing potential for different tree species exposed to vehicular traffic sources and industrial emissions was calculated to mitigate urban dust aerosol in and around Wazirpur industrial area. Fig 2 shows dust capturing potential of different tree species and their seasonal variations in the study site. Species under study responded differently to the prevalent urban dust aerosols in the area.

In the pre-monsoon season dust capturing potential varied from maximum of 3.586 mg/cm^2 in *Terminalia arjuna* to 0.559 mg/cm^2 in *Polyalthia longifolia.* Overall the trend of dust capturing potential in the species under study followed the sequence*: Terminalia arjuna> Ficus benghalensis > Ficus virens > Bauhinia variegata > Ficus religiosa > Morus alba > Cassia fistula > Plumeria alba > Anthocephalus cadamba > Mangifera indica > Polyalthia longifolia.* In post- monsoon season also *Terminalia Arjuna* showed maximum dust capturing potential of 4.089 mg/cm^2 and *Polyalthia longifolia* showed minimum dust capturing potential of 1.09 mg/cm^2. Overall the trend for dust capturing potential followed the same sequence as that of Pre- monsoon season: *Terminalia arjuna> Ficus benghalensis > Ficus virens > Bauhinia variegata > Ficus religiosa > Morus alba > Cassia fistula > Plumeria alba > Anthocephalus cadamba > Mangifera indica > Polyalthia longifolia.* Average seasonal dust capturing potential sequence of tree species followed the sequence: *Terminalia arjuna > Ficus benghalensis > Bauhinia variegata > Ficus religiosa > Plumeria alba > Cassia fistula > Anthocephalus cadamba > Morus alba > Ficus virens > Mangifera indica > Polyalthia longifolia.* Summation of average foliar dust deposition of different sampling sites in different seasons in the study area was done and results indicated that foliar dust deposition of tree species was higher in post- monsoon season and found to be 3.08 mg/cm^2 as compared to pre - monsoon season value of 2.21 mg/cm^2. Industrial operations, traffic movement unpaved roads, poor road conditions, trans boundary transport of emissions from crop residue burning in nearby states, local meteorological conditions, lower temperature, calm conditions and lower mixing of atmospheric particulates results in higher dust conditions in the post-monsoon season in the study area consequently average foliar dust deposition on the leaves was found to be higher in post- monsoon season then pre-monsoon. Lower temperature, foggy and dew conditions allowed more adherence of particles on the leaf surface in post – monsoon, while in the Pre-monsoon windy condition resulted in the lower deposition of the dust on leaf surface (Hrotkó *et al*., 2021; Meravi *et al*., 2021) [13, 26]. Deciduous/ Evergreen nature of trees has profound effect on dust deposition on the leaves in pre-monsoon season deciduous trees shed their leaves while in the evergreen species there is emergence of newer smooth and shiny leaves (Przybysz *et al*., 2019) [31]. These factors contribute little or less dust particle adherence and deposition on the leaf surface. These results of the present study confirm the findings of other studies confirming that dust retention capability of shows variations among different species (Li *et al*., 2019; Liu *et al*., 2017 Singh *et al*., 2021; Zhang *et al*., 2016) [21, 24, 38, 47]. The area is highly industrialised region with steel and electroplating industries, where there is high prevalence of particulate matter as a result the trees present in this area have to bear the stress of high pollution load and consequently the amount of foliar dust deposition of species present in this area is high (Liu *et al*., 2012; Prusty *et al*., 2005) [22, 30]. Dust deposition and accumulation is determined by variety of factors such as leaf size, shape, orientation, texture, presence and absence of trichomes, length of petioles (Leonard *et al*., 2016) [20]. Leaves having hairy, waxy coatings, rough surface with slightly folded leaf margins are known to accumulate more dust than smooth leaves (Corada *et al*., 2021) [3]. Among all the studied species *Terminalia arjuna* showed both highest dust capturing potential in both pre- monsoon and post-monsoon season ranking first among all studied species, which can be contributed to distinct morphological features of this tree which makes it to intercept more particles and facilitate higher dust capturing potential. Dense canopy structure, shorter petiole length, semi erect leaf orientation and crenate leaf margin increases the effective surface area of the leaf available to trap dust particles. Presence of hairs on adaxial and abaxial surfaces, longer leaf hairs, presence of hairs on leaf petiole, stem and leaf margin, prominent leaf venation all these features make interception of dust particles more efficiently and consequently more foliar dust deposition (Pallawalla *et al*., 2013) [29]. *Ficus benghalensis* was ranked second in dust capturing potential this species possesses large horizontally oriented hairy leathery leaves with waxy coatings, slightly folded margins and sunken stomata which facilitate condensation of water vapour during transpiration increasing moisture content on the leaf surface and thereby causing more dust capturing potential (Tanushree *et al*., 2011). *Ficus virens* wrinkled form of cuticle with deep grooves which easily retain dust (Liu *et al*., 2012) [22] makes it to accumulate more dust since deep grooves intercept more particles making release of particles less likely (Mo *et al*., 2015) [27], ranking it third among studied species. *Bauhinia variegata* ranked fourth among the eleven studied species, micromorphology of both adaxial and abaxial surface of leaf is very rough with scales in this plant, which makes ultrafine particles to get trapped on the leaf surface. Also round headed crown, dense leaves plays special role in its ability for particulate capturing (Sultan *et al*., 2022) [41]. *Ficus religiosa* ranked fifth among all studied species, leaves of this tree has smooth adaxial texture without trichomes with slightly rough abaxial surface and presence of micromorphological features like cuticular arches which favours dust deposition through Brownian diffusion (Jamil *et al*., 2009) [16]. *Morus alba* has pubescent leaf with large surface area, coarse and rough texture and serrate margins. It has both glandular and non-glandular type of trichomes on both surfaces of the leaf (Singh *et al*., 2021) [38], which seem to increase the dust capturing capacity of the leaves ranking it sixth among studied species. In *Cassia fistula* glabrous leaf surface resulted in low dust deposition as compared to *Morus alba* but foliar dust deposition was higher than *Plumeria alba* which may be attributed to due to tree height, dense canopy and compound leaf structure, thus making species to rank seventh among studied species (Wang *et al*., 2021) [43]. Presence of micromorphological features like deep ridges, furrows on leaf epidermis, cuticular arches, stomata, and vein projections in *Plumeria alba* assist in foliar dust deposition by the species (El-Khatib *et al*., 2011) [7].The species ranked eighth among studied species. *Anthocephalus cadamba* ranked ninth in dust capturing potential the species possess rough leaf surface, micro-ridges, cuticular ridges encircling stomata (Jamil *et al*., 2009) [16] which facilitate dust deposition, *Mangifera indica* with sunken stomata and cuticular arches ranked tenth, *Polyalthia longifolia* ranked last in dust capturing potential due to its leaf characteristics which do not favour dust deposition it has glossy green, long green narrow leaves with wavy edges causing lower surface deposition of dust particles as glossy foliar surface leads to bouncing off of the particles instead of particle retainment (Gupta *et al*., 2016) [12].

Percentage foliar dust deposition of different species was calculated to determine the efficiency of dust deposition Table 3.The percentage foliar dust deposition showed variations ranging from 15.58% in *Polyalthia longifolia* to 72.53% in *Terminalia arjuna*. The tree species were arranged in different frequency classes of dust capture according to percentage foliar dust deposition. Among all the studied species 81.81% of species represented high frequency class of foliar dust deposition while 18.19% species represented medium frequency class of foliar dust deposition. *Ficus virens, Ficus religiosa, Ficus benghalensis, Bauhinia variegata, Plumeria alba, Cassia fistula, Terminalia arjuna, Plumeria alba, Anthocephalus cadamba, Morus alba* were classified into high frequency class of dust capturing potential and *Mangifera indica* and *Polyalthia longifolia* represented medium frequency class of dust capturing potential. Species with higher dust capturing potential in Pre- monsoon and Post-monsoon represented higher percentage foliar dust deposition.

4. Conclusion

The study was conducted to investigate role of existing tree species in Wazirpur industrial area in combating high dust pollution and potential in control of urban dust aerosol in an around it. The study concluded that the existing trees in Wazirpur industrial area are well adapted to prevailing high concentrations of dust in this area and had high potential in curbing the industrial point source emissions as well as diffused emissions from automobile exhausts in both pre and post monsoon seasons thus definitely these species can be choice of species for mitigation and monitoring of industrial and roadside urban dust aerosols. Most of the tree species investigated here in this study belonged to deciduous category and represented high pollution abatement capacity. In future these species should be considered for urban greening and roadside plantations in highly polluted zones like industrial areas. Although these species differed in the efficiency of particle interception and attenuation due to marked differences in the macro-morphological and micro-morphological foliar characteristics of trees but most of the species represented high tolerance to urban dust aerosols in the area with 81.81% of the total species representing high frequency class of percentage foliar dust deposition and only 18.19% species represented medium frequency class of foliar dust deposition. Species like *Ficus virens, Ficus religiosa, Ficus benghalensis, Bauhinia variegata, Plumeria alba, Cassia fistula, Terminalia arjuna, Plumeria alba, Anthocephalus cadamba,* represented high dust capturing potential in different seasons (Pre and post monsoon), *Mangifera indica* and *Polyalthia longifolia* represented medium dust capturing potential in different seasons (Pre and post monsoon).The present study was conducted for a limited time period so additional monitoring should be carried out to give more information about role of these trees in urban landscaping of industrial areas.

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