


RESEARCH

Open Access



# Roadside air pollution in a tropical city: physiological and biochemical response from trees

Ufere N. Uka<sup>1,2\*</sup> , Ebenezer J. D. Belford<sup>2</sup> and Jonathan N. Hogarh<sup>2</sup>

## Abstract

**Background:** The economic growth and social interaction of many developing countries have been enhanced by vehicular transportation. However, this has come with considerable environmental cost. The vehicular emissions of gases such as carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>) and volatile organic compounds (VOC's) among others are associated with vehicular transportation. The resultant effect can lead to respiratory infections in humans, as well as growth inhibition and death of animals and plants. An investigation was conducted to evaluate the impact of vehicular air pollutants on some selected roadside tree species in the Kumasi Metropolis, Ghana. *Ficus platyphylla*, *Mangifera indica*, *Polyalthia longifolia* and *Terminalia catappa*, which were abundant and well distributed along the road sides, were selected for the study. Three arterial roads in the Kumasi Metropolis, namely Accra Road (Arterial I), Offinso Road (Arterial II) and Mampong Road (Arterial III), were considered as different traffic volumes experimental sites. The KNUST campus was selected as a control site. Diurnal analysis of CO, NO<sub>2</sub>, SO<sub>2</sub> and VOC was monitored in the sample sites. Three replicates of each tree species were defined at a distance 10 m away from the edge of the road. Physiologically active leaves (20 to 25) from each tree species replicate were harvested for physiological and biochemical determination.

**Results:** The ambient air quality data showed higher levels at the arterial road sites, which were severely polluted based on air quality index. The biochemical studies revealed reductions in leaf total chlorophyll and leaf extract pH whilst leaf ascorbic acid and relative water contents increased at the arterial road sites.

**Conclusion:** It was found that the plants' tolerant response level to vehicular air pollution was in the order *T. catappa* > *F. platyphylla* > *M. indica* and *P. longifolia*. Based on anticipated performance index, it was revealed that *M. indica*, *F. platyphylla* and *T. catappa* might be performing some level of air cleaning functions along the arterial roads. Whilst *P. longifolia* was poor and unsuitable as a pollution sink.

**Keywords:** Air quality, Biochemical parameters, Air pollution Tolerance Index, Anticipated Performance Index

## Introduction

Vehicular emissions in developed countries have been largely controlled by improvement on vehicle parts and fuel content. However, such cannot be said of developing countries, where many old and poorly maintained vehicles ply the roads, coupled with the use of poor grade quality fuel. Transportation which is associated with the burning of diesel and gasoline in automobiles has high

consideration as a source of air pollution, both at regional and global levels. Motor vehicles discharge a large amount of exhaust emission like carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>), volatile organic compounds (VOCs) and particulate matter that represent 60–70% of the air contamination found in an urban area (Dwivedi and Tripathi 2007). The principal pollutants emitted from gasoline-fuelled vehicles are CO, hydrocarbons (HC), and NO<sub>x</sub> while particulate matter, NO<sub>x</sub>, SO<sub>2</sub> and polyaromatic hydrocarbons (PAH) are emitted by diesel-fuelled vehicles (Bhandarkar 2013).

\* Correspondence: [ufere.uka@ebsu.edu.ng](mailto:ufere.uka@ebsu.edu.ng)

<sup>1</sup>Department of Applied Biology, Faculty of Science, Ebonyi State University, P.M.B 048, Abakaliki, Ebonyi State, Nigeria

<sup>2</sup>Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

There is considerable proof to buttress the possibility of plants, particularly trees to function as sinks for gaseous pollutants. Pollution removal by plants occur either through deposition on plant surfaces and/or stomatal uptake. According to Nowak and Crane (2000), short-term air quality enhancement in urban territories with trees cover were 14% sulphur dioxide, 8% nitrogen dioxide, 0.05% carbon monoxide and 15% ozone. Air pollutants on entering the plants through the stomata undergo complex interactions within the cells leading to series of reactions, some of which enhances the capacity of the plant to adapt to the stress (Mittler 2002), and invariably show diverse morphological, biochemical, anatomical and physiological responses.

The biochemical and physiological reactions aid the plant species in pollution tolerance development against air pollution. The plants response to air pollutants is hypothetically measured using air pollution tolerance index (Singh and Rao 1983). This index is related to plant leaves ascorbic acid, relative water content, leaf pH and total chlorophyll. The change of these parameters reveals the sensitivity and plants' tolerance to air contamination. The distinguishing proof and arrangement of plants into delicate and tolerant groupings is vital on the grounds that the former can fill in as markers and the latter as sinks for the decrease of air contamination (Singh et al. 1991).

Trees are subjected to these emissions because of its stationary nature. The activity of the major physiological processes in the leaf makes it the most susceptible part to be influenced by air pollutants. Research on Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) had been done in India (Gupta et al. 2011; Pathak et al. 2011). However, studies on reaction of tree plants in view of APTI and API are yet to be carried out in other climes of the world and studies conducted from different nations are limited, for example, Iran (Esfahani et al. 2013) and Nigeria (Ogunkunle et al. 2015).

In Ghana, traffic intensity is high in many metropolitan areas. Unfortunately, the extent of vehicular air pollution levels in these cities is mostly not monitored. Such information, nevertheless, is necessary in controlling air pollution and to provide baseline studies on the air pollution in various metropolises in the country. Furthermore, knowledge of the plants that is able to tolerate vehicular air pollution and act as a sink for the toxic gases would be instrumental in controlling air pollution along major roads, especially those with heavy traffic and increased vehicular emissions. The findings from this study will contribute immensely towards developing effective measures for controlling air pollution in fast growing tropical metropolis, as well as provide vital information of tolerant plants species.

## Materials and methods

### Study area

Kumasi is the second biggest city in Ghana. It is situated around 270 km north of the national capital, Accra, 397 km south of Tamale (Northern Regional capital) and 120 km south-east of Sunyani (Brong Ahafo Regional capital). Kumasi is situated between latitude 6.6666° N and longitude 1.6163° W and has a land range of 254 km<sup>2</sup>. The minimum temperature in the area is around 21.5 °C with the maximum temperature of 33.7 °C. There are seven major arterial roads leading into and out of the Metropolis, out of which three major roads were selected (Fig. 1). Kumasi-Accra (Arterial road I), Kumasi-Offinso (Arterial II) and Kumasi-Mampong roads (Arterial III) were selected for sampling because these major roads experience extreme congestion using average vehicle speed as a parameter (Anin et al. 2013). These major arterial roads: Accra, Offinso and Mampong roads representing extreme, heavy and severe traffic congestion traffic flows respectively were considered as experimental arterial road sites, while Kwame Nkrumah University of Science and Technology Campus with normal traffic flow was selected as a control site.

### Air quality analysis

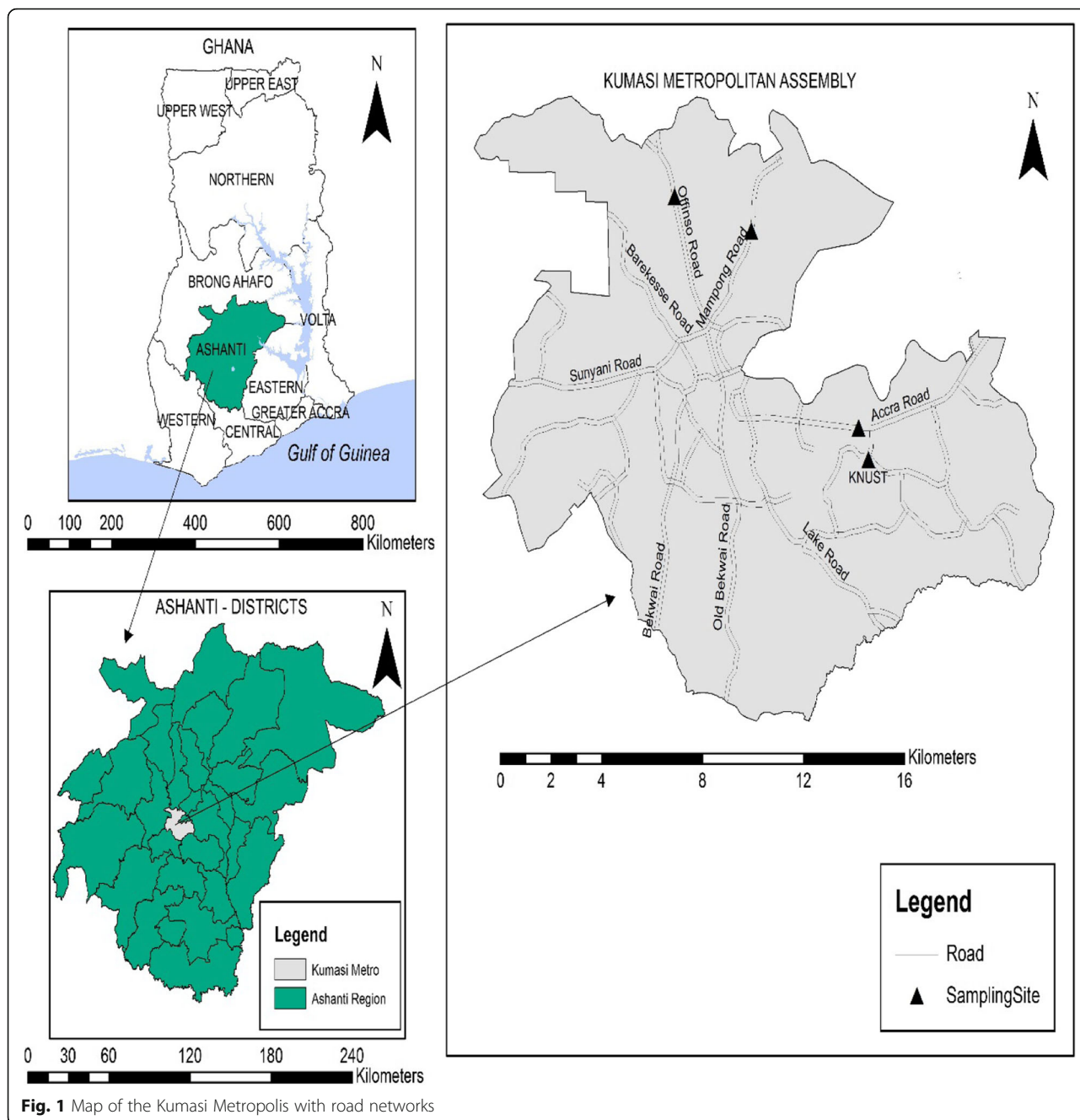
The diurnal analysis of CO, NO<sub>2</sub>, SO<sub>2</sub> and VOC was monitored at the sampling sites using Aeroqual Series 500 (S500) gas monitors (Aeroqual Limited, Auckland, New Zealand). The ambient air quality at each site was monitored for 6 days in 1 week at each site. The quality rates of CO, SO<sub>2</sub>, NO<sub>2</sub> and VOCs at the study sites were calculated using the equation adopted by Chattopadhyay et al. (2010):

$$Q = \frac{100 \times V}{V_s}$$

Where  $Q$  = quality ratings,  $V$  = observed value and  $V_s$  = permissible threshold value. The air quality rates of the four air pollutants (CO, SO<sub>2</sub>, NO<sub>2</sub> and VOC) were used to calculate air quality index by determining their geometric mean. The geometric mean ( $g$ ) (anti log  $\{(Q_{CO} + Q_{SO_2} + Q_{NO_2} + Q_{VOC})/4\}$ ) of their quality rating were computed and taken as the AQI.

### Tree species and collection of samples

Four tree species—*Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia*—were commonly identified along key arterial roads in the Kumasi Metropolis namely Accra Road (Arterial I), Offinso Road (Arterial II) and Mampong Road (Arterial III), as well as the Kwame Nkrumah University of Science and Technology campus road, which served as the control site. Leaf samples were collected fortnightly from these trees in the months of August–November, 2015



**Fig. 1** Map of the Kumasi Metropolis with road networks

before the onset of the harmattan season in December when trees shed their leaves. Three replicates of each tree species with diameter at breast height (DBH) greater than 10 cm and height between 5 and 10 m were sampled at a distance of 10 m away from the edge of the road. The distances between each tree species replicate ranged from 2 to 4.8 km along each road.

Twenty to 25 physiologically active leaves, third from the tip of the apical bud, were harvested from the side of the tree facing the road between 07:00 and 09:00 h for morpho-physiological and biochemical properties

determination. Samples for biochemical analysis were stored at  $-40^{\circ}\text{C}$  until used, while samples for morpho-physiological characteristics were processed immediately.

**Determination of physiological and biochemical parameters**

The total relative leaf water content was determined according to the method described by Liu and Ding (2008). The estimation of leaf-extract pH was determined according to the method described by Singh and

Rao (1983), while the technique of Keller and Schwager (1977) was adopted for the determining ascorbic acid.

Chlorophyll and carotenoid were analysed using standard spectrophotometric procedure (Arnon 1949; Wellburn 1994; Joshi and Swami 2009). Leaf samples (3 g) were weighed and homogenised in 10 ml of 80% acetone solution for 15 min. The homogenate was centrifuged at 2500 rpm for 3 min. Pigment absorbance values in supernatant were measured against a blank using CECIL 8000 UV-visible spectrophotometer at wavelengths 645 nm, 663 nm and 480 nm. The chlorophyll and carotenoid contents were determined as follows:

$$\text{Chlorophyll a} = 12.7 (A_{663}) - 2.69 (A_{645}) \times V/1000 \times W \text{ mg/g}$$

$$\text{Chlorophyll b} = 22.9 (A_{645}) - 4.68 (A_{663}) \times V/1000 \times W \text{ mg/g}$$

$$\text{Total chlorophyll} = 20.2 (A_{645}) - 8.02 (A_{663}) \times V/1000 \times W$$

$$\text{Carotenoids} = A_{480} + 11.4 (A_{663}) - 6.38 (A_{645} \text{ nm}) \times V/1000 \times W$$

Where  $A$  = absorbance of the extract,  $V$  = total volume of the chlorophyll solution (ml) and  $W$  = weight of the tissue extract (g).

#### Evaluation of tolerance and sensitivity of tree species to vehicular emissions

Leaf extract pH, relative water content (RWC), total chlorophyll content and ascorbic acid were used to determine (Thawale et al. 2011) tolerance and sensitivity of the tree species to vehicular emissions. They were taken as numerical expression to get an observed value indicating Air Pollution Tolerance Index (APTI) as proposed by Singh and Rao (1983).

APTI is given as:  $\text{APTI} = [\text{AA} (T + P) + R]/10$ ; where AA = ascorbic acid,  $P$  = pH,  $T$  = total chlorophyll content,  $R$  = relative water content.

APTI values of tree species obtained were grouped into distinct tolerance levels according to two categorisation methods. The first categorisation approach followed the works of Thakar and Mishra (2010), by comparing the APTI value of each tree species with the mean APTI value of all the studied tree species alongside with its standard deviation (SD), thus the following classification:

- Tree species APTI higher than mean APTI + SD = Tolerant
- Tree species APTI value between mean APTI and mean APTI + SD = Moderately tolerant
- Tree species APTI value between mean APTI-SD and mean APTI = Intermediate
- Tree species APTI lower than the mean APTI = Sensitive

In the second approach, APTI values of tree species obtained were categorised according to Padmavathi et al. (2013) classification:

- APTI value above 17 = Tolerant
- APTI between 12 and 16 = Intermediate
- Less than 12 = Sensitive

#### Anticipated Performance Index of studied tree species

On account of APTI value and some important biological and socio-economic characters, the Anticipated Performance Index (API) was determined for each tree species. A grading point was assigned to each tree species based on the method of Tiwari et al. (1993) with modification (Table 1). On the basis of the grading system, a tree can obtain a maximum point of 16 which can be expressed in percentages. The percentage obtained is then used to determine the API score category of the plant species in its use for urban greenery (Table 2).

#### Data analysis

One-way analysis of variance (ANOVA) was conducted to test for differences in plant morphological and biochemical features among the different roads; each time ANOVA revealed significant difference ( $p < 0.05$ ), a multiple comparison of the means using Turkey HSD test was performed. Regression analysis was carried out between independent variables namely chlorophyll, pH, RWC, ascorbic acid and dependent variable such as APTI.

#### Results

##### Air quality analysis in the sampled sites

The minimum, maximum and mean daylight concentrations of CO, SO<sub>2</sub>, NO<sub>2</sub> and VOC measured at the major arterial roads and the control site in the Kumasi Metropolis are presented in Table 3. The concentrations of the various ambient air pollutants were greater at the arterial roads compared to quite minimal levels recorded at the control site; the difference in mean values among the arterial roads and control sites was statistically significant for CO and SO<sub>2</sub> ( $p < 0.05$ ), but not significant for NO<sub>2</sub> and VOC (Table 3).

##### Effect of vehicular air pollution on relative water content

Relative water content of leaf samples of all the four tree species at the arterial road sites were higher but not significantly different from those at the control site ( $p = 0.41$ ) (Table 4). Relative water content of leaf samples at the arterial road sites ranged between 68.38 and 93.86%, whilst those at the control site were ranging from 64.42 to 79.94%. *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia* had higher relative water content at the arterial road sites than at the control site.

**Table 1** Tree species gradation based on air pollution tolerance index, morphological parameters and socio-economic importance

Grading character	Parameters	Pattern of assessment	Grade allotment (point)	
Tolerance	Air Pollution Tolerance Index	Less than 12	1	
		Between 10 and 16	2	
		Above 17	3 (Maximum)	
Morphological	Type of tree	Deciduous, Semideciduous	0	
		Evergreen	1 (Maximum)	
	Tree size (height)	Small: less than 30 ft (< 9.14 m)	0	
		Medium: 30–70 ft (9.17–21.34 m)	1	
		Large: above 70 ft (21.36 m)	2 (Maximum)	
	Canopy structure	Sparse, irregular, globular	0	
		Spreading crown, open, semi dense	1	
		Spreading dense	2 (Maximum)	
	Laminar structure	(a) Leaf size	Less than 225 mm <sup>2</sup>	1
			225–2025 mm <sup>2</sup>	2
			2025–4500 mm <sup>2</sup>	3
			4500–18,225 mm <sup>2</sup>	4 (Maximum)
		(b) Texture	Smooth	0
			Rough, coriaceous, leathery	1 (Maximum)
		(c) Hardness	Soft, delicate, fragile	0
Hardy, robust, sturdy			1 (Maximum)	
Socio-economic value		Food, fodder, timber, medicinal, raw material, erosion control, shade/shelter, ornamental, reclamation	Less than three uses	0
			Three or more uses	1
			Five or more uses	2 (Maximum)

Modified from Tiwari et al. (1993)

**Leaf extract pH**

Leaf extract pH of leaf samples of all the four tree species at the arterial road sites were lower than and significantly different from those at the control site ( $p = 0.000$ ). Leaf extract pH of leaf samples at the arterial road sites were more acidic ranging from 5.08 to 5.9 whilst those at the control site were slightly acidic ranging from 6.15 to 6.75 (Table 5).

**Ascorbic acid**

The ascorbic acid content of all the four tree species at the arterial road sites were higher and significantly

**Table 2** Anticipated Performance Index (API) of Tree species

Grade	Score (%)	Assessment category
0	Up to 30	Not recommended
1	31–40	Very poor
2	41–50	Poor
3	51–60	Moderate
4	61–70	Good
5	71–80	Very good
6	81–90	Excellent
7	91–100	Best

different than those of the control site ( $p = 0.000$ ). The mean concentration of ascorbic acid ranged from 12.09 mg/g in *Polyalthia longifolia* at Arterial road II to 19.81 mg/g in *Terminalia catappa* at the Arterial road I, while at the control site, ascorbic acid content range from 10.91 mg/g in *Polyalthia longifolia* to 14.38 mg/g in *Mangifera indica* (Table 6).

**Total chlorophyll**

The total chlorophyll content of all the four tree species at the arterial road sites were lower and significantly different than those of the control site ( $p = 0.000$ ). The mean concentration of total chlorophyll ranged from 0.53 mg/g in *Terminalia catappa* at Arterial road I to 1.13 mg/g in *Mangifera indica* at the Arterial road III, while at the control site, total chlorophyll content range from 1.21 mg/g in *Terminalia catappa* to 1.53 mg/g in *Mangifera indica* (Table 7).

**Carotenoid**

The carotenoid content of leaf samples of all the four tree species at the arterial road sites were lower than and significantly differed from those at the control site except for *Polyalthia longifolia* ( $p < 0.05$ ). The mean concentration of carotenoid ranged from 0.11 mg/g in *Terminalia catappa* collected from Arterial road III and to 0.17 mg/g in *Polyalthia longifolia* collected from Arterial road I. Whilst at the control site, carotenoid content ranged from 0.17 mg/g in *Mangifera indica* to 0.19 mg/g in *Terminalia catappa* and *Ficus platyphylla* (Table 8).

**Relationship between the ambient air quality and biochemical properties of the selected tree species**

The relationship between ambient air quality and biochemical properties of *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia* was investigated using the multiple regression analysis. Multiple regression analysis resulted in a significant relationship between the determined air pollutants (CO, SO<sub>2</sub>, NO<sub>2</sub> and VOC) as independent or predictive variables and the biochemical parameters (relative water content,

**Table 3** Ambient air quality of Kumasi Metropolis during the study period

Parameter/sampling sites	CO (ppm)	SO <sub>2</sub> (ppm)	NO <sub>2</sub> (ppm)	VOC (ppm)
Arterial road I	7.96 ± 1.62 <sup>b</sup>	0.15 ± 0.01 <sup>b</sup>	0.08 ± 0.00 <sup>a</sup>	0.12 ± 0.29 <sup>a</sup>
Arterial road II	6.81 ± 0.16 <sup>b</sup>	0.21 ± 0.02 <sup>b</sup>	0.08 ± 0.01 <sup>a</sup>	0.07 ± 0.02 <sup>a</sup>
Arterial road III	5.26 ± 0.06 <sup>b</sup>	0.21 ± 0.01 <sup>b</sup>	0.10 ± 0.00 <sup>a</sup>	0.08 ± 0.00 <sup>a</sup>
Control site	0.85 ± 0.24 <sup>a</sup>	0.07 ± 0.02 <sup>a</sup>	0.06 ± 0.01 <sup>a</sup>	0.01 ± 0.00 <sup>a</sup>

Mean ± SE in the same column with different letters in superscript are significantly different ( $P < 0.05$ )

leaf extract pH, ascorbic acid, total chlorophyll and carotenoid) as dependent variables. The result is presented using the Pareto chart of  $t$  values for the regression coefficients (Fig. 2). SO<sub>2</sub> pollution was significant as a predictive variable for total chlorophyll and pH; total chlorophyll and ascorbic acid in *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia* respectively (Fig. 2b–d). CO pollution related significantly with ascorbic acid content in *M. indica* (Fig. 2b), whilst NO<sub>2</sub> pollution was significant as a predictive variable for pH and total chlorophyll content in *Ficus platyphylla* (Fig. 2c).

#### Air Pollution Tolerance Index for selected tree species

In calculating Air Pollution Tolerance Index, the ascorbic acid, total chlorophyll, pH of leaf extract and relative water content were used in the assessment of level of tolerance to vehicular pollution (Table 9). The mean Air Pollution Tolerance Index (APTI) value of all the four tree species from the four study sites ranged from 15.69 to 20.52 with an overall mean APTI value of 18.37 and standard deviation of 1.33. The total mean APTI value of each tree species are as follows: *Terminalia catappa* (19.76); *Ficus platyphylla* (19.16); *Mangifera indica* (18.78) and *Polyalthia longifolia* (17.60).

The Pearson correlation values presented in Table 10 shows the association of the four biochemical parameters with the dependent parameter APTI.

#### Assessment of Anticipated Performance Index of the selected tree species

The gradation of the four studied tree species based on air pollution tolerance, morphological parameters and socio-economic importance is presented in Table 11. The tree species that suited into the grading model as

regards to their Anticipated Performance Index (API) were proposed for green belt improvement. Utilising the Anticipated Performance Index score class given in Table 2. Scores of the various studied tree species disclosed that *Mangifera indica* and *Ficus platyphylla* were assessed to be very good performers. *Terminalia catappa* was evaluated to be a good performer, while *Polyalthia longifolia* was identified as a poor performer.

## Discussion

#### Air quality in selected sampling sites

A higher concentration of CO, SO<sub>2</sub>, NO<sub>2</sub> and VOC values were recorded at the arterial road sites in comparison to the control. It has been reported by Saxena et al. (2012) that in the urban areas, traffic flow is among the foremost emission sources. Thus, the three arterial roads could had higher pollutant vehicular air pollutant levels than the control site.

In this study, *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia* had higher relative water content at the experimental sites than at the control site. Similar result was obtained by Jyothi and Jaya (2010). Thus, the higher relative water content at the arterial road sites might be responsible for normal functioning of biological processes in these tree plants. Under the condition of stress, high relative water content inside a plant's organs will keep up its physiological equilibrium.

pH signals the occurrence of detoxication process in plant necessary for tolerance (Thawale et al. 2011). *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia* leaf extract pH in this study were found to be acidic in nature at the arterial road sites. Similar observation was reported in *Gladiolus gandavensis* (Swami et al. 2004). Low pH values is an

**Table 4** Effect of vehicular air pollution on relative water content (%) of four street tree species in the Kumasi Metropolis

Sampling site	Tree species			
	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
Control	68.17 ± 7.76 <sup>a</sup>	64.42 ± 4.94 <sup>a</sup>	77.84 ± 2.77 <sup>a</sup>	79.94 ± 7.16 <sup>a</sup>
Arterial road I	86.11 ± 6.24 <sup>a</sup>	80.08 ± 4.90 <sup>a</sup>	85.42 ± 8.54 <sup>a</sup>	85.97 ± 1.89 <sup>a</sup>
Arterial road II	83.80 ± 4.61 <sup>a</sup>	68.39 ± 7.27 <sup>a</sup>	82.75 ± 3.53 <sup>a</sup>	84.49 ± 3.16 <sup>a</sup>
Arterial road III	92.81 ± 1.33 <sup>a</sup>	83.63 ± 3.04 <sup>a</sup>	92.19 ± 1.88 <sup>a</sup>	93.86 ± 3.01 <sup>a</sup>

Mean ± SE in the same column with different letters in superscript is significantly different ( $P < 0.05$ )

**Table 5** The effect of vehicular air pollution on leaf extracts pH of selected tree species in the Kumasi Metropolis

Sampling site	Tree species			
	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
Control	6.15 ± 0.03 <sup>c</sup>	6.11 ± 0.01 <sup>d</sup>	6.13 ± 0.04 <sup>d</sup>	6.75 ± 0.02 <sup>d</sup>
Arterial road I	5.48 ± 0.01 <sup>b</sup>	5.08 ± 0.04 <sup>a</sup>	5.73 ± 0.01 <sup>c</sup>	5.73 ± 0.02 <sup>a</sup>
Arterial road II	5.09 ± 0.06 <sup>a</sup>	5.60 ± 0.01 <sup>c</sup>	5.13 ± 0.02 <sup>a</sup>	5.85 ± 0.02 <sup>b</sup>
Arterial road III	5.10 ± 0.01 <sup>a</sup>	5.47 ± 0.01 <sup>b</sup>	5.42 ± 0.01 <sup>b</sup>	5.95 ± 0.02 <sup>c</sup>

Mean ± SE in the same column with different letters in superscript is significantly different ( $P < 0.05$ )

indication of sensitivity of the plant species to air pollutants, while high pH could provide tolerance to pollutants (Govindaraju et al. 2012; Saxena et al. 2012). Plants exposed to air pollutants (specifically, SO<sub>2</sub>) generate substantial H<sup>+</sup> to react with SO<sub>2</sub>, which enters through the stomata, resulting H<sub>2</sub>SO<sub>4</sub> and lowering of leaf pH (Zhen 2000). It has been reported that higher leaf extract pH values leads to higher plants absorption of SO<sub>2</sub> and NO<sub>x</sub> (Zou 2007). In study, lower pH values were recorded at the arterial roads, where SO<sub>2</sub> values were higher; this characteristics suggest that leaf extract pH could be used as an indicator for vehicular air pollution.

Ascorbic acid is an antioxidant commonly found in growth plants parts that depicts its resistance to air pollution (Pathak et al. 2011). In this investigation, ascorbic acid in the leaves of the studied plants were higher at the arterial road sites with respect to the control site in *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia*. This is in agreement with the reports of Nwadinigwe (2014) and Rai et al. (2013). However Rai and Panda (2014) reported higher ascorbic acid at the control site and reduced ascorbic acid at the experimental sites. The increased in ascorbic level reported in these tree species suggests their tolerance to the pollutants especially automobile exhausts and a defence mechanism of the respective plants. Previous studies have shown that ascorbic acid reduces reactive oxygen species (ROS) concentration in leaves, thus higher ascorbic acid content of a plant is a sign of its tolerance against SO<sub>2</sub> pollution (Jyothi and Jaya 2010; Varshney and Varshney 1984).

It was observed in this study that photosynthetic pigments in the tree species leaves were lowered with higher concentration of vehicular air pollutants in the

arterial roads lends credence to Tripathi and Gautam's (2007) assertion that chloroplast is the first site of attack by vehicular air pollutants which consist of SPM, SO<sub>2</sub> and NO<sub>x</sub>. This is in agreement with earlier studies (Wei et al. 2014). Air pollutants gain entry into the tissues across the stomata and partially denaturises the chlorophyll, thus a decrease pigment content in the polluted leaves cells (Pant and Tripathi 2012).

The reduction in chlorophyll has been credited to the interruption of the chloroplast layer because of SO<sub>2</sub> phytotoxic nature (Winner et al. 1985) bringing about leaching of pigment (Rath et al. 1994). The promotion of secondary processes which breakdown chlorophyll and kills the cells is believed to be associated with SO<sub>2</sub>. Acidic pollutants like SO<sub>2</sub> brings about phaeophytin formation by acidification of chlorophyll brings about reduction of leaf chlorophyll (Jyothi and Jaya 2010). Similar reduction in the photosynthetic pigment were observed in other studies (Mandal and Mukherji 2000; Wagh et al. 2006; Joshi and Swami 2009; Chauhan 2010). The study on cyto-architectonics' destruction of *Cucurbita moschata* under SO<sub>2</sub> and NO<sub>2</sub> stress showed a damaged chloroplast and mesophyll cells caused by air pollution (Ding and Lei 1987).

In this study, carotenoids content of the tree leaves species sampled at the arterial road sites were lower in comparison to the control site. Chauhan (2010) reported that carotenoids are sensitive to SO<sub>2</sub>. Since SO<sub>2</sub> is a by-product of vehicular air pollution, it is suggested that this pollutant could have caused the reduction of carotenoid content of the leaves of the studied species at the road sites. Several researchers had reported that carotenoid content reduced under air pollution (Sharma and Tripathi 2009; Tripathi and Gautam 2007; Verma and

**Table 6** The effect of vehicular air pollution on ascorbic acid contents (mg/g) of selected tree species in the Kumasi Metropolis

Sampling site	Tree species			
	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
Control	12.05 ± 0.01 <sup>a</sup>	14.38 ± 0.03 <sup>a</sup>	13.46 ± 0.10 <sup>a</sup>	10.91 ± 0.02 <sup>a</sup>
Arterial road I	19.81 ± 0.05 <sup>c</sup>	18.53 ± 0.04 <sup>d</sup>	15.97 ± 0.04 <sup>b</sup>	13.61 ± 0.05 <sup>c</sup>
Arterial road II	19.68 ± 0.19 <sup>c</sup>	17.18 ± 0.02 <sup>c</sup>	18.92 ± 0.04 <sup>c</sup>	12.09 ± 0.06 <sup>b</sup>
Arterial road III	15.41 ± 0.02 <sup>b</sup>	16.86 ± 0.05 <sup>b</sup>	16.03 ± 0.03 <sup>b</sup>	14.32 ± 0.15 <sup>d</sup>

Mean ± SE in the same column with different letters in superscript is significantly different ( $P < 0.05$ )

**Table 7** The effect of vehicular pollution on total chlorophyll (mg/g) contents of selected tree species in the Kumasi Metropolis

Sampling site	Tree species			
	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
Control	1.21 ± 0.01 <sup>d</sup>	1.53 ± 0.02 <sup>d</sup>	1.52 ± 0.01 <sup>d</sup>	1.41 ± 0.03 <sup>d</sup>
Arterial road I	0.53 ± 0.01 <sup>a</sup>	0.67 ± 0.03 <sup>a</sup>	0.97 ± 0.01 <sup>c</sup>	0.93 ± 0.01 <sup>c</sup>
Arterial road II	0.84 ± 0.01 <sup>b</sup>	1.01 ± 0.03 <sup>b</sup>	0.65 ± 0.01 <sup>a</sup>	0.58 ± 0.03 <sup>a</sup>
Arterial road III	1.02 ± 0.01 <sup>c</sup>	1.13 ± 0.01 <sup>c</sup>	0.70 ± 0.03 <sup>b</sup>	0.74 ± 0.01 <sup>b</sup>

Mean ± SE in the same column with different letters in superscript is significantly different ( $P < 0.05$ )

Singh 2006). The decrease in carotenoid contents of the tree species leaves at the arterial road sites agrees with Joshi and Swami (2009) that vehicular emission or vehicle-induced air pollution reduced photosynthetic pigments in tree leaves exposed to roadside pollution.

It was observed that the independent variable volatile organic compounds (VOCs) in all the tree species did not relate significantly to the dependent biochemical variables, which suggested that the dependent variable (VOC) may not be used to predict changes in the biochemical variables. It was not surprising from the result that not all the four biochemical variables (pH, relative water content, ascorbic acid and total chlorophyll) used in the computation of Air Pollution Tolerance Index (APTI) were significantly related to a single air pollutant. This reveals that APTI gives a general idea of pollution tolerance of plant rather than indicating its specific tolerance to air pollution and as such does not differentiate between various air pollutants.

In the present study, all the four tree species had mean APTI value of more than 17. Therefore, it is considered as tolerant to vehicular air pollution. Plants with higher APTI qualities were more tolerant to air pollution than those with low APTI values; those with low APTI qualities are sensitive plants and may go about as bio-pointers of air contamination (Shannigrahi et al. 2004; Chandawat et al. 2011). Hence, on the premise of their indices, different plants might be classified into tolerant, moderately tolerant, intermediate and sensitive plants (Chandawat et al. 2011).

Thakar and Mishra's (2010) approach is effective in the identification of comparatively tolerant species by comparing the tolerance grades between the plant species under the same environment irrespective of how

tolerant the investigated species is. Whilst, Padmavathi et al.'s (2013) approach is useful in the selection of the true tolerant plant species using three absolute APTI Index values in spite of the environmental conditions (Zhang et al. 2016). The combination of the tolerance results of the tree species based on the two approaches give a better tolerance evaluation. Tree species classified as tolerant based on Padmavathi approach could be used for urban greenery. But if classified as sensitive or intermediate based on Padmavathi approach, a reassessment as opposed to Thakar and Mishra method should be carried out. For instance, *Polyalthia longifolia* was classified as intermediately tolerant in Arterial road II and control site using Padmavathi's approach; on re-categorisation, this tree species were sensitive to the vehicular air pollution. Hence, its consideration for usage in urban greening should be the least priority. However, other tree species in the arterial road sites were moderately tolerant and/or tolerant based on the two approaches, thus they are highly recommended for urban greening. The consideration of these tree species for urban greenery stems from the fact that they are tolerant and moderately tolerant at least two or three of the studied sites. Zhang et al. (2016) opined that plant species with tolerant and moderately tolerant grades may be applied in green belt planning for urban and suburb areas. It was also observed that tree species had different tolerant grades at different study sites with different classification. This could be as a result of differentials in air pollution and other environmental factors that may have influenced the four parameters in the APTI formula.

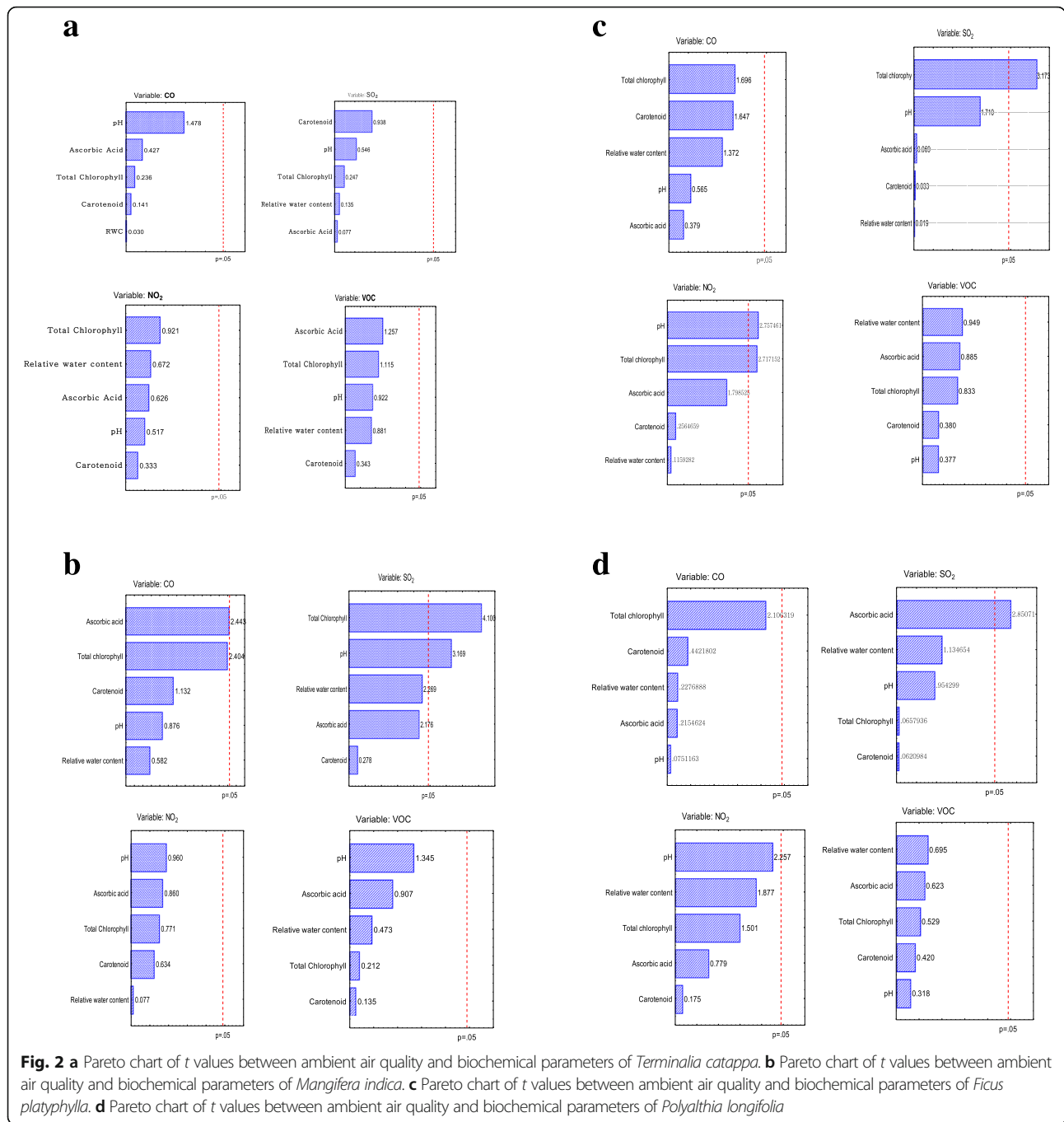
The association of the four biochemical parameters amongst them and with the dependent parameter APTI was illustrated in this study which suggests that total

**Table 8** The effect of vehicular air pollution on of carotenoids (mg/g) contents of selected tree species in the Kumasi Metropolis

Sampling site	Tree species			
	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
Control	0.19 ± 0.01 <sup>b</sup>	0.17 ± 0.02 <sup>b</sup>	0.19 ± 0.01 <sup>b</sup>	0.18 ± 0.02 <sup>a</sup>
Arterial road I	0.12 ± 0.03 <sup>a</sup>	0.14 ± 0.03 <sup>ab</sup>	0.16 ± 0.01 <sup>ab</sup>	0.17 ± 0.01 <sup>a</sup>
Arterial road II	0.16 ± 0.03 <sup>b</sup>	0.12 ± 0.01 <sup>a</sup>	0.14 ± 0.01 <sup>a</sup>	0.14 ± 0.01 <sup>a</sup>
Arterial road III	0.11 ± 0.02 <sup>a</sup>	0.13 ± 0.01 <sup>ab</sup>	0.14 ± 0.01 <sup>a</sup>	0.15 ± 0.02 <sup>a</sup>

Mean ± SE in the same column with different letters in superscript is significantly different ( $P < 0.05$ )





chlorophyll and ascorbic acid are the determinants on which the tolerance of the tree species depends on in Arterial road I. It also suggested that relative water content and total chlorophyll are the determinant of tolerance in the studied tree species in Arterial road II, whilst relative water content and ascorbic acid are the determinants of tolerance in the studied tree species in Arterial road III. At the control site, it was indicated that total chlorophyll and ascorbic acid are the most significant determining factors on which tolerance of tree species is dependent on.

Environmentalists have consistently advocated for urban greenery in urban areas and roadsides as well. Green belts naturally cleanse the atmosphere by absorption, diffusion of gaseous and particulate pollutant through their leaves that function as efficient pollutant trapping device (Thambavani and Prathipa 2012). Anticipated Performance Index is an evaluating framework where a tree species is graded in view of air pollution tolerance index, morphological characteristics and alongside socio-economic parameters. In

**Table 9** Air pollution tolerance index (APTI) and classification for selected tree species in the Kumasi Metropolis

Tree species	Ascorbic acid (mg/g)	Total chlorophyll (mg/g)	pH	Relative water content (%)	APTI	Classification	
						Thakar and Mishra's approach	Padmavathi's approach
Control site							
<i>Terminalia catappa</i>	12.05	1.21	6.15	68.17	15.69	Sensitive	Intermediate
<i>Mangifera indica</i>	14.38	1.53	6.11	64.42	17.43	Intermediate	Tolerant
<i>Ficus platyphylla</i>	13.46	1.52	6.13	77.84	18.08	Intermediate	Tolerant
<i>Polyalthia longifolia</i>	10.91	1.41	6.75	79.94	16.89	Sensitive	Intermediate
Arterial road I							
<i>Terminalia catappa</i>	19.81	0.53	5.48	86.11	20.52	Tolerant	Tolerant
<i>Mangifera indica</i>	18.53	0.67	5.08	80.08	18.66	Moderately tolerant	Tolerant
<i>Ficus platyphylla</i>	15.97	0.97	5.73	85.42	19.24	Moderately tolerant	Tolerant
<i>Polyalthia longifolia</i>	13.61	0.93	5.73	85.97	17.66	Intermediate	Tolerant
Arterial road II							
<i>Terminalia catappa</i>	19.68	0.84	5.09	83.8	20.05	Tolerant	Tolerant
<i>Mangifera indica</i>	17.18	1.01	5.60	68.39	18.19	Intermediate	Tolerant
<i>Ficus platyphylla</i>	18.92	0.65	5.13	82.75	19.21	Moderately tolerant	Tolerant
<i>Polyalthia longifolia</i>	12.09	0.58	5.85	84.49	16.22	Sensitive	Intermediate
Arterial road III							
<i>Terminalia catappa</i>	15.41	1.02	5.10	92.81	18.71	Moderately tolerant	Tolerant
<i>Mangifera indica</i>	16.86	1.13	5.47	83.63	19.49	Moderately tolerant	Tolerant
<i>Ficus platyphylla</i>	16.03	0.70	5.42	92.19	19.02	Moderately tolerant	Tolerant
<i>Polyalthia longifolia</i>	14.32	0.74	5.92	93.86	18.92	Moderately tolerant	Tolerant

the evaluating framework, a tree gets a greatest score of 16 points, which are scaled to rates and in the light of the score got; the class is determined. From this study, *Mangifera indica* and *Ficus platyphylla* were considered under very good category are highly recommended for planting as urban tree for auto exhaust mitigation. These tree species possess dense canopy of evergreen leaves as well as economic values. It has been reported also that *Mangifera indica* is fast growth tree and stores high amount of carbon in its tissues, thus its high priority rating (Miria and Khan 2013). *Terminalia catappa* was judged to be a good performer. *Polyalthia longifolia* was found to be unsuitable as a pollution sink because of its low anticipated performance.

## Conclusion

In the present study, all the four tree species had mean APTI value of more than 17; hence, which are tolerant to vehicular pollution. The tolerant response to vehicular pollution in the study area was as follows: *Terminalia catappa* > *Ficus platyphylla* > *Mangifera indica* and *Polyalthia longifolia*. These trees were classified as intermediately tolerant in Arterial road II and control site using Padmavathi's approach; on re-categorisation, this tree species were sensitive to the vehicular air pollution. Hence, its consideration for usage in urban greening should be the least priority. However, other tree species in the arterial road sites were moderately tolerant and/or tolerant based on the two approaches, thus they are highly

**Table 10** Correlation matrix between the APTI values and some studied parameters

Biochemical parameters	Arterial road I	Arterial road II	Arterial road III	Control site
	APTI	APTI	APTI	APTI
AA	0.807	0.250	0.684	0.552
TCHL	-0.597	0.907	0.377	0.953*
pH	-0.140	0.125	0.276	-0.121
RWC	0.157	-0.986*	-0.896	0.322

\*Correlation significant at 0.05 level

\*\* Correlation significant at 0.01 level

**Table 11** Evaluation of tree species gradation based on APTI, morphological parameters and socio-economic importance

S/no	Grading character	<i>Terminalia catappa</i>	<i>Mangifera indica</i>	<i>Ficus platyphylla</i>	<i>Polyalthia longifolia</i>
1	Air Pollution Tolerance Index	3	3	3	3
2	Type of plant	0	1	1	1
3	Plant size	1	1	1	1
4	Canopy structure	1	2	2	0
5	Laminar structure				
	(a) Leaf size	1	1	1	1
	(b) Texture	1	1	1	0
	(c) Hardiness	1	1	1	0
6	Socio-economic value	2	2	2	0
	Total (+)	10	12	12	6
	API (%)	62.50	75	75	37.50
	API Grade	4	5	5	2
	Assessment	Good	Very good	Very good	Poor

recommended for urban greening. Anticipated Performance Index revealed that *M. indica* and *Ficus platyphylla* were very good performers. Whilst *Terminalia catappa* was good performer and such could be planted along the roadsides for mitigation of auto exhaust pollution. *Polyalthia longifolia* was rated poorly and unsuitable as a pollution sink. The APTI/API was important for better air quality management and for the selection of suitable tree species for roadsides. This could be a strategy for reduction of air pollution in the Metropolis. It cannot be claimed that green belt plantation along the roads brings about total removal of air pollutants; however, it might potentially remove the toxic pollutants in substantial amounts.

#### Abbreviations

AA: Ascorbic acid; ANOVA: Analysis of variance; API: Anticipated Performance Index; APTI: Air pollution Tolerance Index; CO: Carbon monoxide; HC: Hydrocarbons; NOX: Nitrogen oxides; P: pH; PAH: Poly aromatic hydrocarbons; RWC: Relative water content; SD: Standard deviation; SO<sub>2</sub>: Sulphur dioxide; T: Total chlorophyll; VOC: Volatile organic compounds

#### Acknowledgments

Ufere N.Uka was grateful to Ebonyi State University for granting him Postgraduate Scholarship award sponsored by the Tertiary Education Trust Fund (TETFUND), Abuja-Nigeria.

#### Funding

Tertiary Education Trust Fund (TETFUND), Abuja-Nigeria was responsible for my fees payment and upkeep.

#### Availability of data and materials

All the data obtained during the study are presented in this manuscript. Any further enquiries for additional information are available upon request from the corresponding author.

#### Authors' contributions

All authors share in every step of this work and all the authors read and approved the final manuscript.

#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

#### Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 22 January 2019 Accepted: 15 April 2019

Published online: 07 June 2019

#### References

- Anin EK, Annan, J, Alexander OF (2013) Assessing the causes of urban transportation challenges in the Kumasi Metropolis of Ghana. *American Based research Journal* 2(6):1–12.
- Arnon DI (1949) Copper enzyme in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol* 24:1–15
- Bhandarkar S (2013) Vehicular pollution, their effect on human health and mitigation measures. *Vehicle Eng* 1(2):33–40
- Chandawat DK, Verma PU, Solanki HA (2011) Air pollution tolerance index (APTI) of tree species at cross road of Ahmadabad city. *Life Sci Leaflets* 20:935–943
- Chattopadhyay S, Gupta S, Saha RN (2010) Spatial and temporal variation of urban air quality: a GIS approach. *J Environ Prot* 1:264–277
- Chauhan A (2010) Photosynthetic pigment changes in some selected trees induced by automobile exhaust in Dehradun. *J New York Sci* 3(2):45–51
- Ding QX, Lei HL (1987) Influence of soot dust on the pumpkin leaves external injury and internal structure. *Environ Study Monit* 52:39–41 (In Chinese)
- Dwivedi AK, Tripathi BD (2007) Pollution tolerance and distribution pattern of plants in surrounding area of coal-fired industries. *J Environ Biol* 28:257–263
- Esfahani A, Amini H, Samadi N, Kar S, Hoodaji M, Shirvani M, Porsakhi K (2013) Assessment of air pollution tolerance index of higher plants suitable for green belt development in east of Esfahan city, Iran. *JOHP* 3(2):87–94
- Govindaraju M, Ganeshkumar RS, Muthukumaran VR, Visvanathan P (2012) Identification and evaluation of air-pollution-tolerant plants around lignite-based thermal power station for green belt development. *Environ Sci Pollut Res* 19:1210–1223
- Gupta S, Nayek S, Bhattacharya P (2011) Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index. *Chem Ecol* 27(4):381–392
- Joshi PC, Swami A (2009) Air pollution induced changes in the photosynthetic pigments of selected plant species. *J Environ Biol* 30(2):295–298

- Jyothi SJ, Jaya D (2010) Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. *J Environ Biol* 31:379–386
- Keller J, Schwager H (1977) Air pollution and ascorbic acid. *Env. J. Forests Pathol*; 7:338–350.
- Liu YJ, Ding H (2008) Variation in air pollution tolerance index of plants near a steel factory: implication for landscape-plant species selection for industrial areas. *WSEAS Trans Environ Dev* 4:24–32
- Mandal M, Mukherji S (2000) Changes in chlorophyll content, chlorophyllase activity, Hill reaction, photosynthetic CO<sub>2</sub> uptake, sugar and starch contents in five dicotyledonous plants exposed to automobile exhaust pollution. *J Environ Biol* 21(1):37–41
- Miria A, Khan AB (2013) Air pollution tolerance index and carbon storage of select urban trees—a comparative study. *Int J Appl Res Stud* 2:1–7
- Mittler R (2002) Oxidative stress, antioxidants and stress tolerance. *Trends Plant Sci* 7(9):405–410
- Nowak DJ, Crane DE (2000) The urban forest effects (UFORE) model: quantifying urban forest structure and functions. In: Hansen M, Burk T (eds) *Integrated tools for natural resources inventories in the 21st Century*. USDA Forest Service General Technical Report NC-212, St. Paul, pp 714–720
- Nwadinigwe A (2014) Air pollution tolerance indices of some plants around Ama industrial complex in Enugu state, Nigeria. *Afr J Biotechnol* 13:1231–1236
- Ogunkunle CO, Suleiman LB, Oyediji S, Awotoye OO, Fatoba PO (2015) Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. *Agrofor Syst* 89(3):447–454
- Padmavathi P, Cherukuri J, Reddy MA (2013) Impact of air pollution on crops in the vicinity of a power plant: a case study. *Int J Eng Res Technol* 12(2):3641–3651
- Pant PP, Tripathi AK (2012) Effect of Lead and Cadmium on morphological parameters of *Syzygium Cumini* Linn seedling. *Indian Journal of Science*, 1(1): 29–31.
- Pathak V, Tripathi BD, Mishra VK (2011) Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. *Urban For Urban Green* 10(1):61–66
- Rai PK, Panda LLS (2014) Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region. *Air Qual Atmos Health* 7:93–101
- Rai PK, Panda LLS, Chutia BM, Singh MM (2013) Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non industrial area (Aizawl) of India: an eco-management approach. *Glob J Environ Sci Technol* 1(1):027–031
- Rath S, Padhi SK, Kar MR, Ghosh PK (1994) Response of zinnia to sulphur dioxide exposure. *Ind J Ornamental Hort* 2(1&2):42–45
- Saxena P, Bhardwaj R, Ghosh C (2012) Status of air pollutants after implementation of CNG in Delhi. *Curr World Environ* 7(1):109–115
- Shannigrahi AS, Fukushima T, Sharma RC (2004) Anticipated air pollution tolerance of some plant species considered for green belt development in and around an industrial/urban area in India. An overview. *Int J Environ Stud* 61:125–137
- Sharma AP, Tripathi BD (2009) Biochemical response in tree foliage exposed to coal-fired power plant emission in seasonally dry tropical environment. *Environ Monit Assess* 158:197–212
- Singh SK, Rao DN (1983) Evaluation of plants for their tolerance to air pollution. In: *Proceedings of the Symposium on Indian Association for Air Pollution Control*, New Delhi, pp 218–224
- Singh SK, Rao DN, Agrawal M, Pande J, Narayan D (1991) Air pollution tolerance index of plants. *J Env Manag* 32:45–55
- Swami A, Bhatt D, Joshi PC (2004) Effects of automobile pollution on sal (*Shorea robusta*) and rohini (*Mallotus philippinensis*) at Asarori, Dehradun. *Himalayan J Environ Zool* 18(1):57–61
- Thakar B, Mishra P (2010) Dust collection potential and air pollution tolerance index of tree vegetation around Vedanta aluminium limited. *Jharsuguda The Bioscan* 3:603–612
- Thambavani SD, Prathipa V (2012) Biomonitoring of air pollution around urban and industrial sites. *J Res Biol* 1:007–014
- Thawale PR, Satheesh BS, Wakode RR (2011) Biochemical changes in plant leaves as a biomarker of pollution due to anthropogenic activity. *Environ Monit Assess* 177(1–4):527–535
- Tiwari S, Bansal S, Rai S (1993) Assessment of air pollution tolerance of two common tree species against sulphur dioxide. *Biome* 6(2):78–82
- Tripathi AK, Gautam M (2007) Biochemical parameters of plants as indicators of air pollution. *J Environ Biol* 28(1):127–132
- Varshney SRK, Varshney CK (1984) Effects of sulphur dioxide on ascorbic acid in crop plants. *Environ Pollut* 35:285–291
- Verma A, Singh SN (2006) Biochemical and ultrastructural changes in plant foliage exposed to auto-pollution. *Environ Monit Assess* 120:585–602
- Wagh ND, Shukla PV, Tambe SB, Ingle ST (2006) Biological monitoring of roadside plants exposed to vehicular pollution in Jalgaon city. *J Environ Biol* 27(2): 419–421
- Wei SZ, Yuan HJ, Zan YL (2014) Research on the SO<sub>2</sub> resistance in three kinds of foliage plants. *Chin Agric Sci Bull* 30(4):152–156 (In Chinese with English abstract)
- Wellburn AR (1994) The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *J Plant Physiol* 144(3):307–313
- Winner WE, Mooney HA, Goldstun RA (1985) *Sulphur dioxide and vegetation: Physiology, ecology, and policy issues*. Stanford, California: Stanford Univ. Press; pp. 593
- Zhang P, Liu Y, Chen X, Yang Z, Zhu M, Li Y (2016) Pollution resistance assessment of existing landscape plants on Beijing streets based on air pollution tolerance index method. *Ecotoxicol Environ Saf* 132:212–223
- Zhen SY (2000) The evolution of the effects of SO<sub>2</sub> pollution on vegetation. *Ecol Sci* 19(1):59–64 (In Chinese with English abstract)
- Zou XD (2007) Study on the air cleaning effects of urban greenspace system. *Shanghai Jiao Tong Univ.* (In Chinese with English abstract)

Submit your manuscript to a SpringerOpen<sup>®</sup> journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► [springeropen.com](https://www.springeropen.com)