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ROADSIDE VEGETATION IN AND AROUND THE MEGACITY OF KOLKATA ALONG AN URBANISATION GRADIENT

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Combustion of fossil fuels by the on-road vehicles is major contributor of air pollution which affects the surrounding vegetation and their habitat in addition to human health hazards. Study on the concurrence between vehicular greenhouse gas emissions and associated plant community is important to assess the present day problem scenario on environmental equilibrium. An ecological analysis has been carried out from five locations along roadside of the suburban interiors to the highly vehicle congested urban areas of Kolkata megacity. Quantitative study on naturally grown road side vegetation covering seedlings of tree and shrubby species, herbaceous annuals and perennials along the suitable length of each study area was conducted following standard methodology. Increasing vehicular pollution shows reciprocal correlation with species richness and species diversity. From community structure analyses across the emission gradient it was revealed that a few species exhibited tolerance to withstand increasing air contamination by successful population growth. Nevertheless, the present study might be worthwhile in assessing ecological status of the local plant communities subjected to varying level of vehicle traffic.

Key words: automobile emission; carbon footprint; roadway air pollution; road side vegetation; species diversity loss; species richness

INTRODUCTION

Species composition of urban habitat is affected by various disturbance factors such as trampling, soil quality and mowing, which results in lower species diversity and causes a higher proportion of disturbance-tolerant weed species. The dry and nutrient-rich environment, in urban habitats also leads to the homogenisation of the vegetation (Deák *et al.* 2016). In addition, the vehicle load or traffic in urban areas is an important driver for plant species composition because of the greenhouse gas emissions. Vehicular greenhouse gas emissions, caused by combustion of fossil fuels, are the utmost contributor of air contamination in an urban ecosystem. Besides creating numerous health hazards to human beings, these become phytotoxic to adjacently growing plant species and affect their habitat, too (Rai 2016, Shafiq and Iqbal

2012). Emission borne vehicular pollutants in urban area were found to have species-specific, direct effects on plant growth (Ashenden *et al.* 2003), which might lead to biodiversity pitfall (Rai 2016).

The total set of greenhouse gas (GHG) emitted by an individual or object at any unit time is considered as its carbon footprint (Wright *et al.* 2011). Therefore, emissions from fossil fuel incineration of running motor-vehicles and subsequent production of gasses like SO_x, NO_x, CO_2, CO, hydrocarbons (C_xH_y), etc. collectively stand for on-road vehicular carbon footprint. Moreover, the vehicle exhausts also releases different metals and heavy metals in the form of small suspended particulate matters, which after settling down, affect the surrounding habitat and thereby growth of roadside plants (Al-Khashman 2007, Juknevičius *et al.* 2007, Latimer *et al.* 1990, Lough *et al.* 2005, Yetimoğlu *et al.* 2007). Interestingly, certain species can withstand the polluted environment, become resilient and act as hyper-accumulator of some contaminating agents (Bakirdere and Yaman 2008, Okunola *et al.* 2007).

Successful growth of a tolerant species in adverse environmental condition may lead to progressive establishment of its population and uplifts their relative abundance. This investigation focused on dynamics of the community structure of roadside plant species grown naturally along a gradient of average automobile vehicle load in and around Kolkata, India.

MATERIALS AND METHODS

Study sites: The field survey based investigation conducted along roadsides of the suburban interiors to the highly vehicle congested urban areas of Kolkata megacity within similar climatic conditions (Fig. 1, Table 1). Five different sites were selected maintaining minimum 10 km distance between the sites. To have a gradient of automobile emissions in sampling sites, an increasing load of on-road vehicles was considered. In ascending order of traffic load, selected study sites have been designated as Site 1: Boksi road, Chandipur (22° 47′ 18.9″ N, 88° 45′ 48.0″ E) with very low load of vehicles; Site 2: Tentulia road, Chatra (22° 51′ 14.8″ N, 88° 45′ 03.4″ E) with low load of vehicles; Site 3: Jessore road near Sethpukur, Barasat (22° 42′ 59.1″ N, 88° 28′ 59.5″ E) with moderate load of vehicles; Site 4: National Highway 34, near N. S. C. Bose International Airport, Kolkata (22° 38′ 34.9″ N, 88° 25′ 52.6″ E) with high load of vehicles and Site 5: EM bypass, Kolkata (22° 33′ 07.6″ N, 88° 24′ 24.4″ E) with excessively busy traffic of light and heavy vehicles.

Determination of vehicle load and their carbon footprint: From each of the five study sites, appearance of all vehicles from both the directions was quantified type-wise per hour basis visually as well as recorded in movie and still cameras. Digital data supplemented the visual data with an accurate count of vehicle number and types encountered during the study hours. Data were taken

Table 1

Details of study sites noted in the year of investigation. Abbreviation: Alt. = altitude, T = temperature, Rain = Average annual rainfall

Site	Area	Alt. (m)	T (°C)	Humidity (%)	Rain (mm)	Road type and site properties
1	Boksi road, Chandipur	11	10–40	50–90	1,579	Village path; rural area
2	Tentulia road, Chatra	12	10–41	50–90	1,579	Junction road of several towns; semiurban area
3	Jessore road near Sethpukur, Barasat	4	10–41	50–90	1,579	Leading road toward Kolkata; city outskirts
4	National Highway 34, near N. S. C. Bose International Airport, Kolkata	10	11–43	58–83	1,582	Connecting road between Kolkata with the northern suburbs; road in the city
5	EM bypass, Kolkata	6	11–43	58–83	1,582	Major road on eastern side of Kolkata; urban site

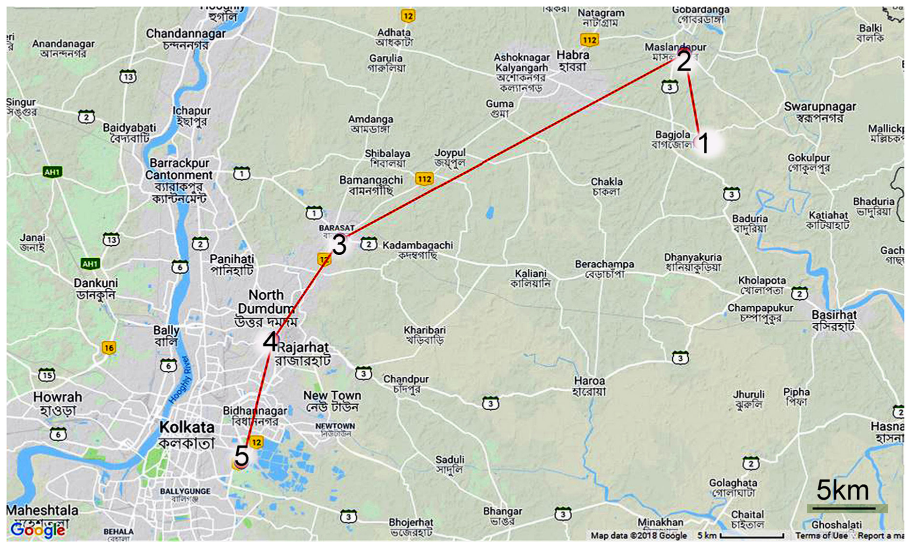

Fig. 1. Location map and study sites

hour wise during morning, midday and evening of the investigation days that include two weekdays and one weekend day of a week for each study site. On road vehicles were categorised into 5 different types: bus (for all mini bus, public bus, and school bus), heavy goods vehicle, light goods vehicle, car, other (auto-rickshaw, motor bike), etc. Standard figures from reference data sources (European Environment Agency and US Environmental Protection Agency) were considered to estimate the average load of GHG emitted in terms of equivalent weight of CO_2 (also called vehicular carbon footprint). The cumulative carbon footprint of the various kind of vehicles per hour per kilometre was estimated and implemented further as the metric of vehicle emission level in each study site.

Quantitative structure of roadside vegetation: The study on the quantitative structure analysis of the plant communities in the selected experimental sites was carried out by quadrat method (Priestley 1913). A total of ten quadrats of 80 cm × 80 cm area was laid down with regular spacing alternately along both sides of 1 km roadway passing over the study area. This quadrat size was determined as minimum suitable size of the sampling unit following species-area curve (Rosenzweig 1995) for appraisal of the naturally established plant community in each study sites. Study sites comprising roadside vegetation cover wider than minimum quadrat area, were chosen from the selected locations based on an initial survey. Total number of individuals of every species encountered within each of the quadrats was recorded during March to May of the year 2016. Species richness (Menhinick index) and species diversity (Shannon's and Simpson's index) were computed to estimate the quantitative attributes of naturally grown roadside vegetation.

Statistical analysis: The estimated values of vehicular carbon footprint among study sites were subjected to one-way ANOVA along with the Duncan test to check for significant differences between means ($p < 0.05$) using PASW (v18.0) desktop statistics application. Pearson's bivariate correlation was estimated among roadside vegetation indices and vehicular emission using R statistical package 'corrplot'. Relationship of strong and significantly associated parameters was shown in linear regression curve.

RESULTS

The GHGs emitted from various type of roadway vehicles was calculated by multiplying respective reference emission value (in equivalent CO_2) with their temporal count. The sum of corresponding equivalent metric ton (mt) CO_2 from selected study sites was designated as vehicular carbon footprint or function of automobile emission load in that site. From our survey the value has been found to be the highest as 0.6207±0.1213 mt CO_2/km in Site 5, EM Bypass, Kolkata. After that, carbon footprint gradually descended to

Table 2
Vegetation index and quantitative structure of roadside plants in selected sites

Study sites	Species richness	Evenness index (H/lnS)	Shannon's diversity	Simpson's diversity
Site 1	1.607	1.594	5.594	10.300
Site 2	1.301	0.588	1.981	3.913
Site 3	1.139	0.582	1.826	2.637
Site 4	0.873	0.571	1.682	3.082
Site 5	0.279	0.559	1.585	3.105

0.2298±0.0911 mt CO_2/km in Site 4, Dumdum; then to 0.1834±0.0312 mt CO_2/km in Site 3, Barasat; further to 0.0865±0.0092 mt CO_2/km in Site 2, Chatra. Finally, to the lowest level of 0.0061±0.0007 mt CO_2/km obtained in Site 1, Chandipur (Fig. 2A).

Study on plant community revealed that the species richness of the study sites was reciprocally associated with the level of vehicle pollution. Total of 74 species was enlisted in the present study covering all the 5 sites. Site 1 of lowest vehicular CF possesses, in total, 35 species, whereas Site 5 of highest CF possesses 17 species. Sites 2, 3 and 4 posses 27, 23 and 19 species, respectively maintained the similar inverse trend. The linear regression plot established a high r^2 with confidence of significance at $p \leq 0.01$ (Fig. 2B). Species evenness was strongly correlated with the diversity indices. Species diversity following Shannon's index was also observed to form reverse relation with the levels of vehicle load. In case of Simpson's index, a similar trend was followed up to Site 3, however, diversity amplified thereby (Table 2, Fig. 3).

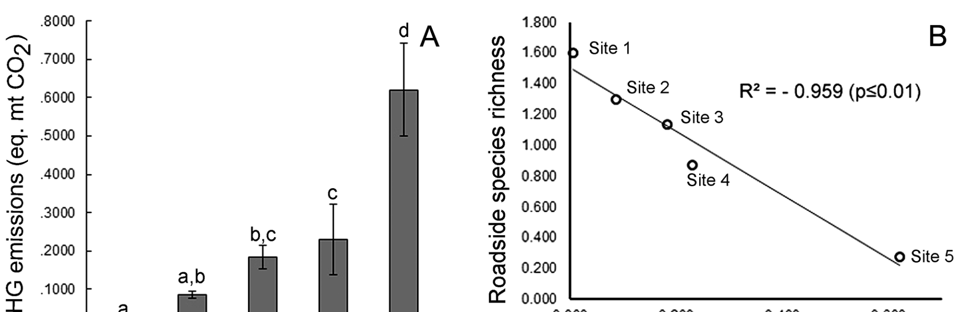

Fig. 2. Vehicular carbon footprint and associated roadside species richness, A = Varying load of vehicle caused greenhouse gas emission in study sites, B = Linear regression showing inverse relation of vehicle emission and associated plant species richness (species number per 0.64 m^2 sampling site). Different superscript letters indicate significant difference between sites (ANOVA and Duncan test, $p < 0.05$). Error bars showing standard deviations of the mean. The dots represent the mean of the 10 quadrats per site

Table 3
Relative abundances of species observed in this study categorised in six groups to extrapolate the diversity trends. Occurrence of species with their range of relative abundances at each study site has been given

Relative abundance	Group	Site 1	Site 2	Site 3	Site 4	Site 5
0.500 above	Group I	0	0	1	0	0
0.500–0.100	Group II	3	2	0	3	2
0.100–0.050	Group III	2	0	3	1	2
0.050–0.010	Group IV	13	11	12	12	5
0.010–0.005	Group V	8	4	2	2	3
0.005–0.001	Group VI	9	10	1	1	5

Based on the analysis of the quantitative structure of the plant communities over all the 5 sites, the relative abundance (RA) of the component species was categorised into six groups as RA I–VI (Table 3). The ecological analysis revealed that the relative abundance, of all the species over the study sites 1–5 ranges from 0.601 (*Cynodon dactylon* at Site 3) to 0.002 (*Polycarpon prostratum* at Site 1). *Cynodon dactylon* itself shared the topmost relative abundance in all the study sites. Its RA was of Gr-I (0.6) in the Site 3 but of Gr-II (0.488, 0.451, 0.413 and 0.215) in the Sites 5, 4, 2 and 1, respectively which possessed 1 to 2 other species in the same rank following *Cynodon*. In Site 3, next to *Cynodon*, three species – *Rumex dentatus*, *Alternanthera sessilis* and *Commelina benghalensis* with respective RA values – 0.064, 0.056 and 0.054 belonged to Gr-III. RA of this group was represented by *Cassia tora* and *Hemigraphis hirta* in Site 1, *Oldenlandia corymbosa* in Site 4 and *Ruellia tuberosa* and *Melochia corchorifolia* in Site 5. There were no species of Gr-III in Site 2. Species of RA of the Gr-IV were maximum in each of the five study sites. Community analyses by quadrat method revealed that the common grass *Cynodon dactylon* occupied all the five study sites as top ranking species in relative abundance.

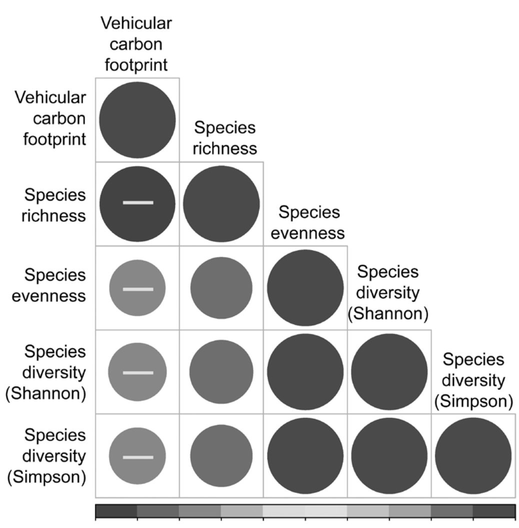

Fig. 3. Diagram based Pearson's correlation coefficients between vehicle emission and studied community structure. The colour and size of the circle reflect the strength of the correlation

In all the five sites it occurred in Gr-I or II category of RA. Next to *C. dactylon,* only 1–2 species showed closer RA value on the study sites except Site 3 where no other species showed RA value closer to it (Table 4).

Three species, *Rumex dentatus*, *Alternanthera philoxeroides* and *Commelina benghalensis* of RA, 0.063939 to 0.053708 had drastic difference with the same of *C. dactylon.* After all, only 1 to 3 species of RA Gr-IV category occurred in all the 5 sites. Out of six RA categories, the Gr-IV is maximum for all the 5 sites, which were 5 to 13 from Site 5 to Site 1, respectively. At Site 1, *C. dactylon*, *Desmodium triflorum*, *Evolvulus nummularius* occurred in high abundance (RA Gr-II) followed by the Gr-III belonging species *Cassia tora*, *Hemigraphis hirta.* Then 13 species occurred in RA Gr-IV, eight species in Gr-V and finally nine species occurred in Gr-VI. Positive amount of accomplishment was shown by *Desmodium triflorum*, *Evolvulus nummularius*, *Hemigraphis hirta* and fewer covers were found in case of *Achyranthes aspera*, *Polycarpon prostratum*, *Clerodendrum viscosum*, and *Acalypha indica*. Later, Site 2 was dominated by *Alternanthera philoxeroides* after *Cynodon dactylon.* Whereas, the average number was found in the case of *Rumex dentatus*, *Mecardonia procumbens*, *Scoparia dulcis* and less occurrence was shown by *Kyllinga brevifolia* and *Heliotropium indicum.* In Site 3, considerably high occurrence was shown by *Rumex crispus*, *Alternanthera philoxeroides*, *Commelina benghalensis* and *Croton bonplandianum*, *Euphorbia hirta*, *Ipomoea aquatica*, and *Blumea lacera* were much less in number. In Site 4, a desirable amount of occurrence was shown by *Oxalis corniculata*, *Evolvulus nummularius* and less frequent species were *Mikania scandens*, *Trema orientalis*, *Amaranthus viridis*. In Site 5, high values were found in case *Acalypha indica*, *Ruellia tuberosa*, *Melochia corchorifolia*, whereas *Phyllanthus niruri* and *Murraya koenigii* were least in number.

DISCUSSION

It is well known that use of fossil fuels is directly or indirectly related to greenhouse gas emissions from an area. The carbon footprint of roads, institutions, households or other areas gives us a perceptible data with which carbon sustainability level and carbon status can be compared using the data sources available from other similar kinds of areas. In parallel, its direct impact on associated vegetation can also be used to assess the local pollution exhaustion status. A carbon footprint measurement and evaluation program can provide a track record to analyse and improve future fuel efficiency. As road vehicle carbon footprints depend on the fossil fuel burning, increasing mass of vehicle users and technology dependant complex and fast lifestyle in the present day Kolkata metropolitan city expanding carbon footprints by a rapid increase in road vehicles and their run time. So it seems to be of great significance to study and analyse the current status of carbon footprints and possible impact on the adjoining plants, the natural pollution exhausters. It may help to identify the remedial measures to overcome the risk factors etc. due to vehicular pollution. In other words, carbon footprint can be used as a scale of pollution level in terms of greenhouse gas emission through all means in a particular area. Carbon footprints of on-road vehicles in our study sites were in line with the level of congestion. As the selected sites were from the interior of suburban to the busy areas of Kolkata, hence the CF has also been found to be elevated proportionately.

Gradients of anthropogenic disturbances are the major driver of urban ecosystem, which shapes the variable habitat patches in terms of species composition. Urbanised habitats have been characterised to harbour an increasing load of cosmopolitan and alien species as well as to decline the native flora (Deák *et al.* 2016). Vehicular pollution due to emission of greenhouse gases is one of the urbanisation specific disturbances which considerably affect the adjacent vegetation. Roadside plant species play the most important role in mitigating the pollution level in the atmosphere and in turn they are also the most impacted by roadside pollutants. Effects of air pollution on different plant species are a major ecological issue and have dynamic on roadside habitat (Karmakar *et al.* 2017, Kaur and Nagpal 2017, Rai 2016, Rai and Panda 2014, Sen *et al.* 2017). In our study, it was consistent that few species occurring in multiple sites were in an increasing abundance up to a particular pollution load (from Site 1 to 3) and then declined with higher pollution levels (Site 4 and 5). The only exception was found in the case of *Acalypha indica*, which was very few in number in the least polluted Site 1 but in an increasing order toward pollution level that abruptly rises in the study Site 5 of high CF level. Probably the species is successful mitigator of urban vegetation modulating air pollution challenges. The finding is in congruence with the earlier report (Indira Priya Darsini *et al.* 2015), which concluded *A. indica* as an air pollution tolerant species based on comparing some air pollution tolerance index values of different species.

In recent times, several attempts have already been made to assess the roadside habitat and adjacent vegetation influenced by particulate matter and black carbon (Brantley *et al.* 2014, Janhäll 2015, Rai 2016, Rotholz and Mandelik 2013). Vakhlamova *et al.* (2016) observed that national roads are important gateways of the introduction of alien species. Mitigation strategies for vehicular emission through roadside greeneries have also been reported by Neema and Jahan (2014). The species richness decreased from the suburban areas towards the city centre which also corresponded to an increasing level of greenhouse gas emission. A considerable decreasing order in species diversity with emission level was evident according to Shannon's diversity index. However, in case of Simpson's index, the index value elevated after third site. This might be due to the fact that Shannon's index is a statistical information index which assumes all species are represented in a sample and that they are randomly sampled. On the other side, Simpson's index is principally a dominance index, it gives more weight to common or dominant species. So in this case, a few rare species with only a few representatives probably could not affect the diversity.

The carbon dioxide and other 'greenhouse gas' emissions due to human activity are legally obliged to decrease by the UK government's Climate Change Act (Act 2008) at least 80% by 2050 relative to a 1990 baseline, with an instantaneous reduction target of 34% or greater by 2020. In December 2010, the UK Climate Change Committee published the Fourth Carbon Budget (Change 2010), recommending increasing the 2020 target to 37%. In the said direction it is of utmost importance to promote species richness and the growth of pollution tolerant plant species in the metropolitan cities with high vehicle load. Besides mass efforts should be there from the public and private vehicle owners to reduce the CF by multi-dimensional approaches.

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