# Influence of urban land use types and urban-rural gradient on Plant Functional Traits of Common Woody Plants of Delhi India and its implication on soil ecosystem Services provision in the Urban system

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Submitted By : Dr. MEENAKSHI CHAURASIA
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**PROPOSAL DETAILS**

( PDF/2023/002155 )

| Principal Investigator | Mentor & Host Institution |
|---|---|
| **Dr. MEENAKSHI CHAURASIA**<br>meenakshichaurasia2@gmail.com<br>Principal Investigator(School of Environmental Science)<br>**Contact No** : +919911033896<br>**Date of Birth** : 18-Jan-1991<br>**Name of Father/Spouse :**<br>ASHOK KUMAR CHAURASIA | **SATISH CHANDRA GARKOTI**<br>sgarkoti@yahoo.com<br>Professor(School of Environmental Sciences , Jawaharlal Nehru University)<br>**Jawaharlal Nehru University**<br>New mehrauli road, jnu ring rd, New delhi, Delhi-110067<br>**Contact No.** : +919871901971<br>**Registrar Email** : registrar@mail.jnu.ac.in<br>**No. of PHD Scholars** : 8<br>**No. Post-Doctoral Fellow** : 0 |

**Details of Post Doctorate**

**Ph.D. (Botany)**[ Degree Awarded on : 01-Aug-2023 ]

*IMPACT OF LAND USE ON SOIL CARBON AND NITROGEN STATUS IN PERI- URBAN LANDSCAPE*

**Research Supervisor/Guide & Institution :**

Professor Kottapalli Sreenivasa Rao

Department of Botany, University of Delhi

**Brief details of Thesis work :**

Rising population and urbanization accompanied by the expansion of urban spatial structure and the urban form have brought about drastic transformations in land use patterns and thereby are the key drivers of urban ecology. Peri-urban regions at the rural-urban interface are of specific concern because of their dynamic and complex land use pattern which negatively affect soil properties and processes. The present study was conducted in the peri-urban landscape of the Ghaziabad district of Uttar Pradesh, which is one of the fastest growing satellite towns. Here, to assess the impact of human-directed land use change on soil properties and processes and to understand how land use dynamics shape them, functional zoning approach in an intra-urban context was followed. For this, five different land-use categories (agriculture; AGR, parks; PAR, residential; RES, industrial; IND and bare land; BAR) were selected. Soil samples collected from these land use types were analyzed for different soil physico-chemical and microbiological properties and other related microbial processes. Soil physico-chemical properties exhibited wide spatial variability. -The soil was mildly acidic to moderately alkaline, with low soil organic carbon (SOC), but it was high in other nutrients such as total nitrogen (TN), calcium, potassium, sodium, and available phosphorus (AP). IND was differentiated from other anthropogenic land use by high bulk density. RES was separated from other overlapping land use types by high water holding capacity and Ca concentration. Soil physicochemical properties and microbiological properties i.e., basal respiration (BR), microbial biomass (MBC) and enzyme activities greatly varied across the five land use classes. Among all the land use types, the RES had highest soil organic carbon (SOC), total nitrogen (TN) and mineral nitrogen (1.33%, 0.13%, 84.0 mg/kg, respectively). While, the BR, MBC, microbial quotient ($QCO_2$), soil microbial activity (SMA) and dehydrogenase activity (DHA) (9.90 C μg/g/h[1], 300 μg/g[1], 0.045 μg/h/μg MBC, 9.0 μg/ml[1], 1.30 TPF/g/h, respectively) were highest under PAR. Soil $CO_2$ efflux and C mineralization were higher in RES and PAR compared to other land use types. The SOC and TN stock and $NO_3$-N content were highest in RES and lowest in PAR. The $NH_4$-N, MBC and MBN content was maximum in the PAR and lowest under BAR. Among the four anthropogenic land uses PAR had the highest MBC/SOC and MBN/TN. The net N mineralization rate in the studied soil varied from 7.06 to 51.2 μg/g/month and ammonification rate ranged from 0.57 to 36.0 μg/g/month and was comparably higher under PAR and RES. Nitrification rate varied from 0.65 to 26.5 μg/g/month and was highest in AGR. -Findings suggest that spatial variation in the soil microbiological activity was related to differences in the soil physico-chemical parameters induced by contrasting land use types. Soil macronutrients (SOC, TN and AP) and moisture content were identified as the most decisive factors in regulating the soil microbial activity and corresponding soil processes.

Anthropogenic disturbances and altered soil physiochemical and biological properties within and across ecosystems imply significant impacts on C and N dynamics. and their potential to accumulate and retain nutrients. -

Management practices (fertilization and irrigation) in urban green spaces (parks) may improve the soil physico-chemical conditions resulting in high $CO_2$ efflux, microbial biomass, qM and mineralization activity and consequently, may deplete the stored C and enhance the $CO_2$ emission. -

Parks land use (with high mineral N and NH4-N content and net N mineralization and ammonification rate) was found to be hot spots for nitrogen cycling and further high MBN/TN ratio in parks soils indicates their N retention potential. Lower N mineralization rate and microbial properties in industrial land use soils compared to other anthropic soils speculate the negative impact of anthropic land use changes on N dynamics processes. Overall data analysis suggests that anthropogenic land uses can significantly alter soil quality. Together, the results of the present study provide evidence for the significant impact of multifaceted anthropogenic disturbances including modification of parent material, extensive fertilization and irrigation, transportation and waste dumping entail significant changes in soil characteristics which are anticipated to have serious implications on ecosystem structure and function. The observed spatial variability in soil properties in this study indicates the predominance of local anthropogenic factors like management activities and biophysical disturbances in shaping the trends for soil characteristics in the peri-urban landscape. One major implication of the study is that soil biological properties and processes in the urban landscape can be managed by incorporating appropriate vegetation management activities, as it was established to be a key determinant for urban soil microbial activity and processes. The present study will help in providing insight into the ecological impact of such anthropogenic changes on soil in understated peri-urban systems. An improved understanding of topsoil quality and its relationship to existing land usage will help in the formation of pragmatic plans and policies for the management and preservation of soil

**Technical Details :**

**Research Area :** Earth & Atmospheric Sciences (Earth & Atmospheric Sciences)

**Project Summary :**

The rapid rise in population growth along with economic development has greatly escalated the expansion of urban areas. Although urbanization results in an improvement in social life and living standards. But it creates significant ecological issues, such as the formation of heat islands, loss of biodiversity, alteration of biogeochemical cycles and climate change [1]. Urban vegetation including natural and anthropogenically engineered green spaces is one of the critical component of cities for environmental protection. These spaces provide a variety of ecosystem services such as improving air quality, buffering of noise pollution, biodiversity conservation, mitigating Urban Heat Island effect, microclimate regulation, stabilization of soil, ground water recharge, and carbon (C) sequestration [2]. However, the drastic transformation of the urban landscape and other associated environmental changes (air, temperature, soil) affect the plant development and associated benefits provided by urban green space [3]. Plant responses to these environmental changes are mediated by plant functional traits that determine a plant's ability to acquire, utilize, and preserve resources and are essential components of adaption plant strategies [4]. Assessing traits associated with plants' adaptation to environmental change would be useful for revealing plant responses to urbanization and underlying ecological strategies. Plant functional traits control a variety of terrestrial ecosystem processes, including C storage which is a key component of the global C cycle. Plant traits directly and indirectly regulate net C storage in standing vegetation and soil via controlling C assimilation, its transfer and storage in belowground biomass, and its release from soil through respiration, and through modification of abiotic conditions [5]. Hence, the functional characteristics of plant communities, under a given regional climatic regime, should be a major driver of C sequestration in terrestrial ecosystems. However, our mechanistic understanding of these processes is still limited. Our knowledge of how plants adapt to highly complex urban environments through coordinated changes in plant functional traits is limited. Although, plant functional traits have been investigated widely to explore plant responses and adaptation to heterogeneous urban environments, the findings are highly discrepant because of the spatial heterogeneity of environmental factors in urban systems [3]. Moreover, the majority of urban vegetation studies focus on how plant functional traits are affected by the environment along urban-rural gradients. However, how plants respond to diverse urban factors within a dynamic urban system is still uncertain. Reference [1] Huang et al. 2013. 10.1007/s10661-012-2921-5 [2] Sharma et al. 2021. 10.3390/IECF2020-08075 [3] Su et al. 2021. 0.3389/fpls.2021.682274 [4] Xiao et al. 2021. 10.3389/fpls.2021.773676 [5] De Deyn et al. 2008. 10.1111/j.1461-0248.2008.01164.x

**Objectives :**

- To examine variation in different plant functional traits across different land use as well as along the urban–rural gradient,
- To investigate whether changes in soil nutrients and micro-climate across different land use types affect plant functional traits and
- To comprehend the trade-off relationship between plant functional traits and urban soil attributes for Carbon storage.

**Keywords :**

Urbanization, Urban vegetation, Plant functional traits, Carbon se

**Expected Output and Outcome of the proposal :**

Rapid urban expansion, and related anthropogenic activities have been shown to cause several environmental problems, including rise in temperature, air and water pollution, soil degradatios. Non-uniform spatial distribution of these environmental factors is likely to cause variability in plant functional traits along the urban–rural gradient, and across land use types. Assessment of these plant functional traits may provide easy to measure and cost-effective tool for monitoring urban habitat quality. Alteration of temperature, water and nutrients which are essential biophysical factors controlling plant development and growth may incur changes in plant traits. Therefore, alteration of soil substrate is expected to alter plant physiological and ecological processes, plant productivity, and at last, plant traits. In addition, changes in plant functional traits may further affect the ecosystem services (C sequestration, buffering of contaminants, etc) provided by urban vegetation and soil. Therefore, understanding the association between urban environmental factors and plant traits to these factors can address many environmental issues. Such efforts will help in optimizing the choice of vegetation for improving urban environment. findings of the proposed study will provide a theoretical basis for the selection of the appropriate and diverse mix of tree species and their allocation, utilization, and management in urban areas to derive the maximum benefits of urban vegetation.

**Reference Details :**

| S.No | Reference Details |
|---|---|
| 1 | **Dr. Ratul Baishya**<br>**Department of Botany, University of Delhi, North campus, Delhi - 110007[+09910807343]**<br>rbaishyadu@gmail.com |
| 2 | **Prof. K.S. Rao**<br>**Senior Professor & Dean, Faculty of Technology, University of Delhi, Delhi 110 007[+09313294607]**<br>rao.srkottapalli@gmail.com |

## Methodology

*Site selection*

1. To achieve the objectives mentioned above, the study area proposed is Delhi, which is the second largest urban agglomeration in India. In the proposed study, the direct and indirect impact of urbanization will be examined using urban-to-rural gradient and functional zoning approach. This will provide information on the traits variations within species, within locations, and across the gradients.
2. To form an urban-rural gradient, a buffer zone would be established from the existing administrative boundaries of the NCT, covering the adjoining peri-urban and rural areas of Haryana.
3. Along this gradient, different urban, peri- urban and rural sampling areas would be selected.
    - One urban area in New Delhi with high built-up density and anthropogenically engineered green spaces.
    - Two peri-urban areas in Delhi NCR region, outside the downtown core but in close proximity to the city and characterised by unsustainable development (illegal construction, tree cutting and encroachment) causing continuous disturbances to vegetation.
    - Two rural areas, majorly dominated by naturally occurring plant species and low built-up areas.

4. At least three typical study sites at each location would be selected to bracket the heterogeneous impact of urbanization.
5. To determine the dominant environmental factor controlling leaf functional traits, different contrasting urban land use types varying in the type of disturbances and management regimes would be selected.
    - Natural plantation- land use/cover types dominated by naturally occurring plant species such as protected forest areas.
    - Roadside plantation- included the disturbed green belt areas located on the sides of roads, where tree plantation is mainly done to improve the aesthetics and to attenuate the noise and air pollution.
    - Parks- refers to highly managed green spaces developed for recreational purposes.
    - Residential- composed of unmanaged localities in settlement areas, where the majority of plantation is done under the tree plantation scheme of the government.
6. The selection of dominant urban land use types in the selected study sites will be done based on field investigations, satellite images, and consultation with relevant experts and management units.

*Plant sampling and trait measurement*

1. Selection of landscape plants in each land use type will be done based on the following factors: (1) Distribution: common in all green spaces, (2) dominance: the plants that are dominant species in urban green space; (3) life forms: the species contained evergreen, deciduous, tree and shrub. This information will explain the differences in traits between the species.

2. A standardized plot protocols will be used for measuring the functional traits of vegetation and soil characteristics.
3. Functional traits and diversity parameters for all woody species will be collected and recorded in each plot for selected land use types. At least three individuals with average height and average diameter at breast height per species would be selected from each plots for replicating the response of each tree species.
4. To determine leaf functional traits, five healthy and fully expanded sunny leaves of each individual were selected for each species.
5. to minimize errors owing to the diurnal variation of specific leaf areas, leaves of different species at the same locations would be collected in the same time period.
6. The selected leaves were sealed in polyethylene bags and transported to the laboratory within 2 h for determination of leaf area and fresh weight. The detailed list of functional traits and diversity parameters is given in Table 1.
7. Above-ground and below-ground biomass and Carbon was also calculated to assess the C sequestration potential of the selected species.

*Soil sampling and Characterization of soil physicochemical parameters.*

1. To identify the factors responsible for variation in plant functional traits soils of different study sites were also characterised.
2. For soil characterization soil samples will be collected in triplicates from each sampling points from 0-30 cm soil depth. Soil sampled would be passed through 2 mm sieve and dry for further soil analysis. A detailed list of soil physico-chemical attributes is given in Table 1.
3. Other environmental factors including air temperature, relative humidity and air quality index will be also measured.

**Table 1: Plant functional traits and soil characters to measure.**

| Trait | Method |
|---|---|
| **Plant functional traits** | |
| Leaf area Index ($m^2$ $m^{-2}$) | Leaf area to ground area ratio |
| Specific leaf area ($cm^2$ $g^{-1}$) | Leaf area to leaf dry weigh ratio |
| Leaf size ($cm^2$) | Leaf area meter |
| leaf dry matter content | Leaf dry weight to water-saturated fresh weight |
| Leaf thickness | Micrometer |
| Leaf N content (g N $g^{-1}$) | Modified Kjeldahl method |
| Leaf P content (g N $g^{-1}$) | Molybdenum Blue colorimetric method |
| Leaf C content (g C $g^{-1}$) | Potassium dichromate method |
| Leaf K content (mg $g^{-1}$) | Inductively coupled plasma optical emission spectroscopy |
| Leaf shape | Simple, compound |
| Leaf habit | Evergreen, seasonal-deciduous and stress-deciduous |
| Stomatal density | Scanning electron microscopy |
| **Stem traits** | |
| DBH (Cm) | Diameter tape |
| Bark | Smooth; rough; corky, flaky |

| | |
|---|---|
| Spines | Present absent |
| **Allometric traits** | |
| Height (n) | |
| Canopy diameter (m) | |
| Canopy structure | Open with few stems vs. dense with many stems |
| **Others parameters** | |
| Above-ground biomass and Carbon (Kg) | Using allometric equations |
| Below-ground biomass and Carbon (Kg) | |
| **Soil parameters** | |
| Moisture content (%) | Gravimetric method |
| Bulk density (g $cm^{-2}$) | Soil corer method |
| Total porosity (%) | Derived from bulk density and particle density |
| Soil temperature (°C) | Soil thermometer |
| Soil pH | pH meter |
| Total organic C (%) | Potassium dichromate method |
| Total N (%) | Modified Kjeldahl method |
| Inorganic N (µg $g^{-1}$) | Colourimetric method |
| Soil exchangeable K (mg $kg^{-1}$) | Inductively Coupled Plasma Optical Emission Spectroscopy |
| Available P (mg $kg^{-1}$) | Molybdenum Blue colorimetric method |
| Heavy Metal concentrations (ppm) | Inductively coupled plasma optical emission spectroscopy |
| **Soil C pool** | |
| Soil Microbial biomass (µg $g^{-}$) | Chloroform fumigation-extraction method |
| Soil respiration ($CO_2$-C mg $g^{-1}$ $h^{-1}$) | Alkali trap method |
| Soil C density (Mg $ha^{-1}$) | Derived from organic carbon content, soil bulk density, and soil depth |
| Soil C mineralization (C mg $g^{-1}$ $d^{-1}$) | Lab incubation method |

<u>**PROFORMA FOR BIO-DATA (to be uploaded)**</u>

1. Name and full correspondence address: **MEENAKSHI CHAURASIA**
**E- 183/2 Yadav Nagar, Samaypur, Delhi-110042**
2. Email(s) and contact number(s): **meenakshichaurasia2@gmail.com;** Contact no. **+919911033896**

1. Institution: **Department of Botany, University of Delhi**

2. Date of Birth: **18th January 1991**

3. Gender (M/F/T): **Female**

4. Category Gen/SC/ST/OBC: **OBC**

5. Whether differently abled (Yes/No): **NO**

6. Academic Qualification (Undergraduate Onwards)

| | **Degree** | **Year** | **Subject** | **University/Institution** | **% of marks** |
|---|---|---|---|---|---|
| 1. | B. Sc. (Hons.) | 2012 | Botany | Banaras Hindu University | 73.1% |
| 2. | M.Sc. | 2014 | Botany | Banaras Hindu University | 80.8% |
| 3. | M.Phil. | 2018 | Botany | University of Delhi | 77.6% |

7. Ph.D thesis title, Guide's Name, Institute/Organization/University, Year of Award.

"**Impact of Land use on Soil Carbon and Nitrogen Status in Peri-Urban Landscape"** under supervision of **Professor K. S. Rao** from, **Department of Botany, University of Delhi** awarded in **2023**

8. Work experience (in chronological order).

| **S.No.** | **Position sheld** | **Name of the Institute** | **From** | **To** | **Pay Scale** |
|---|---|---|---|---|---|
| NA | | | | | |

9. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

| **S.No** | **Name of Award** | **Awarding Agency** | **Year** |
|---|---|---|---|
| NA | | | |

*10.* Publications *(List of papers published in SCI Journals, in year wise descending order).*

| **S.No.** | **Author(s)** | **Title** | **Name of Journal** | **Volume** | **Page** | **Year** |
|---|---|---|---|---|---|---|
| | Singh, A.A., **Chaurasia, M.**, Gupta, V., Agrawal, M. and Agrawal, S.B., | Responses of *Zea mays* L. cultivars 'Buland'and 'Prakash'to an antiozonant ethylene diurea grown under ambient and elevated levels of ozone. | *Acta Physiologiae Plantarum* | *40* | 1-15. | 2018 |
| | **Chaurasia, M.**, Patel, K., | Impact of dust accumulation on the physiological functioning of | *Environmental Science and* | *29*(53) | 80739-80754 | 2022 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Tripathi, I. and Rao, K.S. | selected herbaceous plants of Delhi, India. | *Pollution Research* | | | |
| | Patel, K., **Chaurasia, M**. and Rao, K.S. | Urban dust pollution tolerance indices of selected plant species for development of urban greenery in Delhi. | *Environmental Monitoring and Assessment* | *195*(1) | 16. | 2023 |
| | Patel, K., Chaurasia, M. and Rao, K.S., | Heavy metal accumulation in leaves of selected plant species in urban areas of Delhi. | *Environmental Science and Pollution Research* | *30*(10) | 27622-27635 | 2023. |
| | Patel, K., **Chaurasia, M.** and Rao, K.S | Impacts of Pb-Induced Oxidative Stress on Morphological, Physiological and Biochemical Properties of Tree Species. | *Environmental Processes* | *9*(4) | 60. | 2022 |
| | **Chaurasia, M.**, Patel, K. and Rao, K.S | Soil Organic Carbon and Nitrogen Status in Peri-urban Landscape. | *International Journal of Ecology and Environmental Sciences* | *49*(4) | 435-441 | 2023 |
| | **Chaurasia, M.**, Patel, K., Bhadouria, R. and Rao, K.S | Spatial variability in soil physicochemical parameters across land use classes in the peri-urban landscape | Environment, Development and Sustainability | https://doi.org/10.1007/s10668-023-03653-8 | | 2023 |

11. Detail of patents.

| **S.No** | **Patent Title** | **Name of Applicant(s)** | **Patent No.** | **Award Date** | **Agency/Country** | **Status** |
|---|---|---|---|---|---|---|
| NA | | | | | | |

12. Books/Reports/Chapters/General articles etc.

| S.No | Title | Author's Name | Publisher | Year of Publication |
|---|---|---|---|---|
| 1 | Phytoremediation Status and Outlook | Patel, K., Tripathi, I., Chaurasia, M. and Rao, K.S. | Wiley Online Library | 2021 |
| 2 | Wetland Conservation and Restoration | Patel, K., Chaurasia, M., Tripathi. I, Nagar S. | Wiley Online Library | 2021 |
| 3 | Climate Change and Nutrients Dynamics of Soil | Singh, R., Patel, K. and Chaurasia, M | Springer | 2021 |
| 4 | A Sustainable Approach to Combat Climate Change: Case Studies from Some Urban Systems. | Chaurasia, M., Patel, K., Singh, R. and Rao, K.S. | Wiley Online Library | 2022 |

13. Any other Information (maximum 500 words)

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-022-21484-4

RESEARCH ARTICLE

# Impact of dust accumulation on the physiological functioning of selected herbaceous plants of Delhi, India

Meenakshi Chaurasia[1] · Kajal Patel[1] · Indu Tripathi[1,2] · Kottapalli Sreenivasa Rao[1]

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## Abstract
Plants are now widely recognized for their potential role in improving the air quality by dispersion and deposition of atmospheric dust particles. However, suspended dust particles negatively affect plant growth and physiological development. The present study aims to assess the amount of dust accumulation on the leaf surface and to evaluate the effect of foliar dust on leaf gas exchange parameters, photosynthetic pigment, and metabolite content of five roadside herbaceous plant species (*Amaranthus viridis*, *Achyranthes aspera*, *Acalypha indica*, *Parthenium hysterophorus*, *Trianthema portulacastrum*). Two sites (site I and site II) were selected that differed in their surrounding anthropogenic activities and dust pollution levels. Results showed that the average amount of dust accumulated on the leaf surface was significantly greater in plants grown at the polluted site. Among the five species examined, the highest amount of foliar dust load was observed for *A. aspera* (0.49 mg $cm^{-2}$). Dust accumulation caused substantial changes in plant physiology as indicated by the significant decline in chlorophyll content, photosynthetic rate, stomatal conductivity, and transpiration rate in plants grown at the polluted site. Moreover, an increase in antioxidant activity, total ascorbate, and metabolite content, responsible for maintaining plant defense, was higher in plants at polluted site. Biochemical response of the individual plants studied was variable, which suggests that different plants adopted different mechanisms to cope with the stress induced by dust particles.

**Keywords** Antioxidant · Dust accumulation · Leaf gas exchange · Particulate matter · Photosynthetic pigment · Physiological performance

## Introduction

Over the last decade, deteriorating air quality has become a major environmental hazard at both regional and global scales. Approximately 6.5 million people die prematurely because of poor air quality all around the world every year (WHO 2016). The air quality conditions in developing countries such as India and Peoples Republic of China are more severe because of their large population and impromptu industrialization (van Donkelaar et al. 2015). Among all the air pollutants, particulate matter (PM) is the most prevalent one and poses the higher health risk than any other pollutants (UNEP 2017). Dust is one of the leading contributors to urban ambient PM pollution (Song et al. 2015). Approximately 30–40% of PM mass in Delhi is contributed by dust (Tripathi et al. 2019). Increased vehicular density, biomass burning, construction activities, and road dust have raised the atmospheric dust concentration beyond the WHO permissible limits in urban centers (Guttikunda et al. 2014). Dust is mainly a mixture of suspended solid particles of natural and anthropogenic origin. Atmospheric dust is the most concerned pollutant because of its high residence time and small aerodynamic diameter, thus enabling them to adsorb contaminants such as heavy metals and organic matter, thereby making them toxic. These suspended particles of varying sizes may cause a wide range of health issues in humans and acute to chronic injuries in plants. Thus, it has become very important to include measures to mitigate particulate pollution.

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Meenakshi Chaurasia and Kajal Patel contributed equally to the manuscript.

✉ Meenakshi Chaurasia
meenakshichaurasia2@gmail.com

[1] Department of Botany, University of Delhi, New Delhi 110007, India

[2] Department of Environmental Studies, University of Delhi, New Delhi 110007, India

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Urban vegetation, including roadside trees, shrubs, and other types of vegetation, can play a considerable role in improving the microclimate of urban settlements. Several studies have shown that trees and herbaceous plant species can improve the air quality by reducing the particulate pollutants through dispersion and deposition of particles on their leaf surface (Popek et al. 2017; Nowak et al. 2006; Ram et al. 2014; Sahu et al. 2021). Dust accumulation on plants is determined by several factors such as meteorological conditions and vegetation configuration (Litschke and Kuttler 2008). Tree species, ascribed to their large canopy structure, provide larger surface area for dust accumulation and hence are proficient in capturing dust particles in comparison with herbaceous species (Beckett et al. 1998). Considering the individual plants, the potential to accumulate dust may vary from species to species, depending upon their leaf morphological attributes such as the shape of leaf, presence of trichomes, raised epidermal cell, and epicuticular waxes (Leonard et al. 2016).

Dust particles that accumulate on the foliar surfaces affect the growth and development of plants. The impact of dust particles is associated with the deposition rate, its particulate size, and chemical composition (van Jaarsveld 2008; Chaturvedi et al. 2013). Coarse particles may reduce diffusive radiance (Rai 2016) and increase leaf temperature due to surface lining (Naidoo and Chirkoot 2004), while the small diameter particles may clog the stomatal aperture. Clogging of stomatal aperture affects the plant gaseous exchange and consequently reduces $CO_2$ assimilation and transpiration rate (Cape 2009). The effect of dust on plants is more associated with the chemistry of particles rather than the amount of dust deposited (Grantz et al. 2003). Inert dust particle exerts physical damage by abrasion, while chemically active particles may directly affect the plant metabolism by inducing a series of biochemical changes. Upon dissolution, toxic particles may enter the cell via stomata or cuticle fissure and interact with various cellular components (Lau and Luk 2001) and disrupt membrane integrity, denature proteins, and alter accumulation of secondary metabolites (Prajapati 2012). The response of plants to particulate pollution is species specific (Ulrichs et al. 2008). Noticeable variations can be observed for plant species in their response to stress caused by pollutants ascribing to microhabitat, genotype, and environmental conditions (Grote et al. 2016).

Urban vegetation bestows various ecosystem services such as carbon sequestration, air quality improvement, and soil nutrient retention and thus contributes in maintaining urban microclimate. For vegetation to be used for mitigating air pollution, it is prerequisite to select plant species with higher dust accumulation potential that can thrive in an environment characterized by high level of pollutants, especially particulate pollutant. Numerous studies evaluated the impact of various types of dust particles (viz. cement, fly ash, dust) on different plant species (Chaturvedi et al. 2013; Hariram et al. 2018; Chaudhary and Rathore 2018; Singh et al. 2021). However, most of the previous studies focused on the role of tree species, while the potential of other components of urban vegetation including hedges, lawns, and other herbaceous plants is yet to be explored. These ground cover vegetation could function to enhance the immobilization of dust by capturing the re-suspended dust particles (Weber et al. 2014). Hence, the present study focused on the evaluation of dust accumulation potential of five herbaceous plant species commonly growing along the roadside in the urban area of Delhi, India. Further, the effect of the accumulated dust on the plant's biochemical and photosynthetic parameters was also explored to understand the mechanism of action of dust on plant physiology. Specific objectives of the research were (1) to estimate the dust accumulation on the leaf surface, (2) to assess the impact of foliar dust on photosynthetic efficiency, and (3) to determine the biochemical and antioxidant response of selected herbaceous plants.

## Material and methods

### Study site

National capital territory of Delhi (28.70 41° N, 77.10 25° E) spreads over an area of about 1483 $km^2$ and is characterized by continental climate with dry hot summer and cold winters. The study was conducted in two locations with different levels of particulate pollution, i.e., site I and site II. Site selection was done based on prevailing surrounding anthropogenic activities.

Site I was located at the botanical garden of Department of Botany, University of Delhi, with hardly any vehicular traffic, no industrial influence, denser vegetation cover, and very low level of dust pollution, and hence served as control site. The tree species planted around the university were *Azadirachta indica*, *Millettia pinnata*, *Cassia fistula*, *Bombax ceiba*, *Delonix regia*, *Leucaena leucocephala*, *Morus alba*, *Ficus*, and other species. Common shrubs included *Callistemon lanceolatus*, *Hamelia patens*, *Murraya paniculata*, and others. Herbaceous species included a variety of ornamental plants and wild species such as *Vinca rosea*, *Duranta erecta*, *Crotalaria* sp., *Physalis minima*, *Euphorbia hirta*, *Mimosa pudica*, *Acalypha indica*, *Amaranthus viridis*, *Parthenium hysterophorus*, *Achyranthes aspera*, *Trianthema portulacastrum*, and others.

Site II, considered the polluted site (10 km away from site I), was located at a CNG gas station situated along the GT Karnal road (National Highway 44), one of the busiest transport corridor in the city. This route plus the connecting service roads carry very heavy traffic throughout the day. In addition, this location is a prime commercial center and is surrounded by nearby industries. The main source of atmospheric dust is exhaust from heavy vehicular traffic and road dust from the nearby unpaved slip roads and construction activities. Highway berms were sparsely vegetated, dominated by tree species, i.e., *Prosopis juliflora* and *Eucalyptus tereticornis*. Common growing shrubs include *Ricinus communis*, *Cascabela thevetia*, and *Calotropis procera* and herbaceous species like *A. indica*, *A. viridis*, *A. aspera*, *Blumea lacera*, *Pancium antidotale*, *P. hysterophorus*, *T. portulacastrum*, *Xanthium strumarium*, and others.

## Plant material and growth conditions

On the basis of species abundance at both sites and morphological features such as leaf shape, texture, and phyllotaxy, we selected five species of herbaceous plants commonly growing on the roadside, viz., *Amaranthus viridis* L., *Acalypha indica* L., *Achyranthes aspera* L., *Parthenium hysterophorus* L., and *Trianthema portulacastrum* L. (Table 1). Seeds of the selected plants were germinated in garden soil in pots with a diameter of 25 cm. After emergence, the seedlings were thinned to three plants per pot. For the entire study period, plants were watered regularly to maintain the optimum soil moisture. Twenty pots with 10-day-old plants of each species were transferred to the selected sites for exposing them to the varied levels of dust pollution.

## Sample collection

For dust accumulation, pigment content, metabolites, antioxidant, and sugar content estimation, fully expanded mature leaves were sampled in triplicates from three individuals of each plant species at three time periods, that is, 0, 20, and 40 days after treatment (0, 20, and 40 DAT), i.e., days after pots were transferred to respective sites. Plants were chosen at random for sampling and marked to avoid reselection for the following harvest period. Samples were collected in paper bag and stored at room temperature until further analysis. For the antioxidant assay, leaf samples were stored in the icebox and transported to the laboratory for analysis. A total of 270 samples were collected from the two sites (2 sites × 5 plant species × 3 sample harvest period × 3 plants × 3 leaves). Three leaves from one plant were treated as subsamples.

## Accumulation of dust

The total amount of unspeciated dust accumulated on the leaf surface was determined gravimetrically using the method by Prusty et al. (2005). Each leaf sample collected was thoroughly washed with distilled water in a pre-weighed petri plate ($p1$) to wash off any material deposited on the leaf surface. The liquid collected in the petri plate was evaporated by oven drying at 120 °C. After cooling, the petri plate was weighed again ($p2$). The difference between $p1$ and $p2$ gives the total dust mass accumulated on the leaf surface. The amount of dust accumulated per unit of leaf area (mg $cm^{-2}$) was calculated by using the following formula:

$$d = (p1 - p2)/A$$

where $d$ is the dust accumulated on leaf surface; $p1$ and $p2$ are the initial and final weight of the petri plate, respectively; and $A$ is the surface area of the leaf (calculated using graph paper method by Pandey and Singh 2011).

## Leaf gas exchange

LI-6400 XT gas exchange system (LI-COR, Lincoln, Nebraska, USA) was used for the measurement of net photosynthetic rate ($A$), stomatal conductance (Gs), and transpiration ($E$). For each site, 12 measurements were made for every plant species (4 leaves per plant × 3 plants per species) at 0, 20, and 40 DAT. For measurement, healthy mature leaves were clamped in leaf fluorometer chamber and measured until stable photosynthetic rate was obtained. All the measurements were conducted between 9:00 and 12:00 am on clear days. Measurement for net photosynthesis, transpiration, and stomatal conductance was performed at the ambient level of $CO_2$ and relative humidity, at a light intensity of 1200 μmol (photon) $m^{-2}$ $s^{-1}$. Instantaneous water use efficiency (WUE) was

**Table 1** Characteristics of the selected plant species for the study

| Plant species | Family | Leaf surface | leaf shape | Phyllotaxy | Shoot length (cm) |
|---|---|---|---|---|---|
| *Amaranthus viridis* L | Amaranthaceae | Glabrous to pubescent | Ovate to rhombic-oblong | Alternate | 48.47 |
| *Achyranthes aspera* L | Amaranthaceae | Pubescent | Ovate | Opposite, simple | 35.65 |
| *Acalypha indica* L | Euphorbiaceae | Glabrous to fine venation | Ovate | Alternate | 34.70 |
| *Parthenium hysterophorus* L | Asteraceae | Pubescent | Strongly dissected | Alternate | 32.39 |
| *Trianthema portulacastrum* L | Aizoaceae | Glabrous | Round-obovate | Opposite | 35.33 |

calculated as the ratio of carbon assimilation to transpiration (A/E) (Chaves et al. 2004).

### Chlorophyll a fluorescence

Chlorophyll a fluorescence was measured using LICOR 6400-XT on the same leaves used for leaf gas exchange measurement. Before measurements, plants were dark adapted for 45 to 60 min. After dark adaptation, measurement of minimal ($F_o$) and maximal ($F_m$) fluorescence was taken using a saturating pulse of high intensity light (630 nm, > 7000 µmol (photon) $m^{-2}$ $s^{-1}$). The maximum quantum yield of photosystem II ($F_v/F_m$) was calculated from the ratio of variable ($F_v = F_o - F_m$) and maximal fluorescence.

### Pigments, metabolites, and antioxidants

Photosynthetic pigment content that includes total chlorophyll, chlorophyll a (Chl a) and b (Chl b), and carotenoid were estimated using the spectrophotometric method of Hiscox and Israelstam (1979). Thiol content in the leaf extract was quantified using Ellman's methodology (Ellman 1959). The extent of lipid peroxidation was measured in terms of malondialdehyde (MDA) content by following the method of Hodges et al. (1999). Protocol by Shabnam et al. (2016) was used to estimate the proline content. Total phenolic content was assessed using Folin-Ciocalteu reagent (Ainsworth and Gillespie 2007). Total ascorbate was determined by following the modified protocol described by Gillespie and Ainsworth (2007). Antioxidant capacity was determined by assessing the capability of the plant to scavenge DPPH free radical (Brand-Williams et al. 1995). Total soluble sugar was estimated using the method of Dubois et al. (1956).

### Statistical analysis

Prior to statistical analysis, recorded data were checked for normal distribution using one sample Kolmogorov–Smirnov test. The statistical significance of difference between the two sites was analyzed using paired *t*-test. The data were subjected to three-way analysis of variance (ANOVA) and Tukey's test to determine the interactive effect of site, plant species, and duration of exposure (DAT). Two-tailed Pearson coefficients were calculated to observe the relationship between dust accumulated and various plant biochemical and physiological parameters. All the statistical analysis was performed using SPSS package (ver.20).

## Results

### Dust accumulation

The total amount of dust accumulated on the leaf surface was significantly higher for all the plant species grown at site II (Table 2). ANOVA result showed that site, species, and duration of treatment had a significant effect on foliar dust accumulation (Table 3). At 0 DAT, no foliar dust deposition was recorded for plants at either of the sites. Regardless of the site, the highest amount of foliar dust was noted on the leaves of *A. aspera* at both 20 and 40 DAT. Lowest dust accumulation was shown by *T. portulacastrum* at control site and *A. indica* at the polluted site, at both 20 and 40 DAT. The amount of dust accumulated on the leaf surface increased significantly with the duration of exposure to dust pollution in all the species studied.

### Leaf gas exchange

Result of ANOVA showed photosynthetic performance of plants was significantly affected by site, species, and duration of exposure, except transpiration rate and photosynthetic rate, for which the effect of site and DAT was not statistically significant, respectively (Table 3). The three-way interaction between the factors was significant for all parameters except stomatal conductance. At 0 DAT, leaf exchange parameters did not differ between the two sites, while at 20 and 40

**Table 2** Total amount of dust accumulated on leaf surface of different plant species (mean ± SE) at site I (control site) and site II (polluted site) at 20 and 40 days after treatment (DAT)

| Plant species | Dust accumulated (mg $cm^{-2}$) | | | |
|---|---|---|---|---|
| | 20 DAT | | 40 DAT | |
| | Site I | Site II | Site I | Site II |
| *Amaranthus viridis* | $0.054 \pm 0.003^b$ | $0.24 \pm 0.02^a$ | $0.062 \pm 0.00^b$ | $0.44 \pm 0.01^a$ |
| *Achyranthes aspera* | $0.061 \pm 0.003^b$ | $0.34 \pm 0.00^a$ | $0.067 \pm 0.008^b$ | $0.79 \pm 0.07^a$ |
| *Acalypha. indica* | $0.051 \pm 0.004^b$ | $0.18 \pm 0.01^a$ | $0.048 \pm 0.007^b$ | $0.26 \pm 0.01^a$ |
| *Parthenium hysterophorus* | $0.047 \pm 0.006^b$ | $0.19 \pm 0.00^a$ | $0.056 \pm 0.01^b$ | $0.58 \pm 0.06^a$ |
| *Trianthema portulacastrum* | $0.039 \pm 0.006^b$ | $0.26 \pm 0.01^a$ | $0.046 \pm 0.012^b$ | $0.45 \pm 0.04^a$ |

Different case letters indicate significant differences (at $p < 0.05$) between the two sites at specific time point determined using paired *t*-test

**Table 3** *F* value and significance level for dust accumulated and leaf biochemical and physiological parameters of different plant species at the two sites, at 0, 20, and 40 DAT, estimated using MANOVA

| | df | Dust | Chla | Chlb | Tchl | Carotenoid | MDA | Proline | Thiol | Tascorb | TAntiox | Phenolics | Tsugar | *A* | Gs | *E* | WUE | $F_v/F_m$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | **1** | **702*** ** | **55.8*** ** | **70.1*** ** | **70.1*** ** | 2.26 ns | **94.2*** ** | **653*** ** | **55.6*** ** | **22.2*** ** | **190*** ** | 7.94 ns | **107*** ** | **160*** ** | **20.8*** ** | 2.29 ns | **25.2*** ** | **13.7*** ** |
| Species | **4** | **22.9*** ** | **248*** ** | **16.9*** ** | **247*** ** | **90.0*** ** | **307*** ** | **532*** ** | **540*** ** | **180.6*** ** | **806*** ** | **363*** ** | **513*** ** | **141*** ** | **1683*** ** | **84.1*** ** | **36.3*** ** | **28.9*** ** |
| DAT | **2** | **402*** ** | **833*** ** | **62.0*** ** | **855*** ** | **429*** ** | **47.7*** ** | **306*** ** | **132*** ** | **363*** ** | **1220*** ** | **90.0*** ** | **680*** ** | 5.87 ns | **234*** ** | **36.08*** ** | **36.7*** ** | **53.7*** ** |
| Treatment × species | **4** | **19.4*** ** | **21.9*** ** | 2.10 ns | **23.7*** ** | 4.44 ns | **13.4*** ** | **76.6*** ** | **18.0*** ** | **6.71*** ** | **3812*** ** | **8.10*** ** | **39.0*** ** | **13.5*** ** | 2.012 ns | **5.79*** ** | 1.68 ns | 2.09 ns |
| Treatment × DAT | **2** | **259*** ** | **28.8*** ** | **32.9*** ** | **34.2*** ** | **6.45*** | **43.1*** ** | **187*** ** | **23.2*** ** | **23.2*** ** | **68.6*** ** | **1.91 ns** | **69.7*** ** | **41.7*** ** | 4.43 ns | **8.72*** ** | 4.59 ns | 3.39 ns |
| Species × DAT | **8** | **12.2*** ** | **40.6*** ** | **28.6*** ** | **41.1*** ** | **17.9*** ** | **5.16*** ** | **336*** ** | **11.6*** ** | **100*** ** | **189*** ** | **15.6*** ** | **108*** ** | **49.7*** ** | **130*** ** | **17.1*** ** | **37.2*** ** | **7.02*** ** |
| Treatment × species × DAT | **8** | **10.8*** ** | **23.8*** ** | **17.9*** ** | **21.8*** ** | **19.2*** ** | **8.01*** ** | **25.5*** ** | **9.52*** ** | **4.99*** ** | **47.2*** ** | **10.9*** ** | **31.1*** ** | **9.89*** ** | 2.36 ns | **7.21*** ** | **5.66*** ** | 2.00 ns |

Levels of significance after Bonferroni correction: $*p<0.003$; $**p<0.0006$; $***p<0.0006$; *ns* non-significant ($p>0.003$); significant *df*(residual) = 60

*Chl a* chlorophyll a, *Chl b* chlorophyll b, *Tchl* total chlorophyll, *Tascorb* total ascorbate, *TAntiox* total antioxidant, *TSS* total soluble sugar, *A* photosynthetic rate, *Gs* stomatal conductance, *E* transpiration rate, *WUE* water utilization efficiency, $F_v/F_m$ maximum quantum efficiency

DAT, plants grown at the polluted site were characterized with lower rate of photosynthesis and stomatal conductivity in comparison with the plants grown at the control site. However, the site-specific change in stomatal conductivity was non-significant at 20 DAT (Fig. 1a, b). Among all the species, maximum decline in photosynthetic rate and stomatal conductance in response to leaf dust accumulation were exhibited by *A. aspera* (40 and 39%, respectively) at 40 DAT, while the minimum change was recorded for *A. indica* (6.3 and 1%, respectively) at 20 DAT. Transpiration rate showed no evident variation in response to dust pollution in most of the study plants, but significantly higher transpiration rate was noted in *A. aspera* at 20 DAT (by 30%) and *A. indica* at 40 DAT (by 36%) grown at site II (Fig. 1c). Consequent to the reduction in photosynthesis and transpiration rate, WUE calculated for plants was on average lower at site II (by 8 and 12% at 20 and 40 DAT, respectively) than that of plants at site I. The effect of dust on WUE was most evident for *A. indica* at 40 DAT (Fig. 2a).

Three-way analysis of variance showed the maximum quantum yield ($F_v/F_m$) in the examined plants was significantly affected by all the factors, i.e., site, species, and duration of exposure, while their interactive effect was non-significant. On average, $F_v/F_m$ values were lower in the plants grown at site II (by 1.3 and 1.1% at 20 and 40 DAT, respectively) than in the case of plants grown at site I (Fig. 2b), though this site-wise change in the $F_v/F_m$ values in the individual plants was non-significant for most of the species, except for *A. viridis* and *P. hysterophorus* at 20 DAT, and *A. viridis* and *T. portulacastrum* at 40 DAT. Photosynthetic rate (−0.33) and $F_v/F_m$ and dust (−0.30) showed significant negative Pearson correlation coefficient with the amount of dust accumulated for the studied plant species. Other parameters did not show significant correlation with dust load (Table 4).

## Photosynthetic pigments

ANOVA result showed significant variation in photosynthetic pigments due to site, species, duration of treatment, and their interactions (Table 3). There was no significant site effect in carotenoid content. As shown in Fig. 3, site-specific variation in Chl a and b and total chlorophyll was non-significant at 0 DAT for all the species, excluding *P. hysterophorus*. At 20 DAT, total chlorophyll and Chl a content was significantly lower in the leaves of plants exposed to higher level of dust pollution than that of the plants exposed to lower level, except in the case of two species *A. viridis* and *T. portulacastrum*. At 40 DAT, no significant variation was observed between the two sites for most of the species, except for *T. portulacastrum* which showed significantly lower content of total chlorophyll (15%) and Chl a (18%) at site II compared to that at site I (Fig. 3a, c). Conversely,

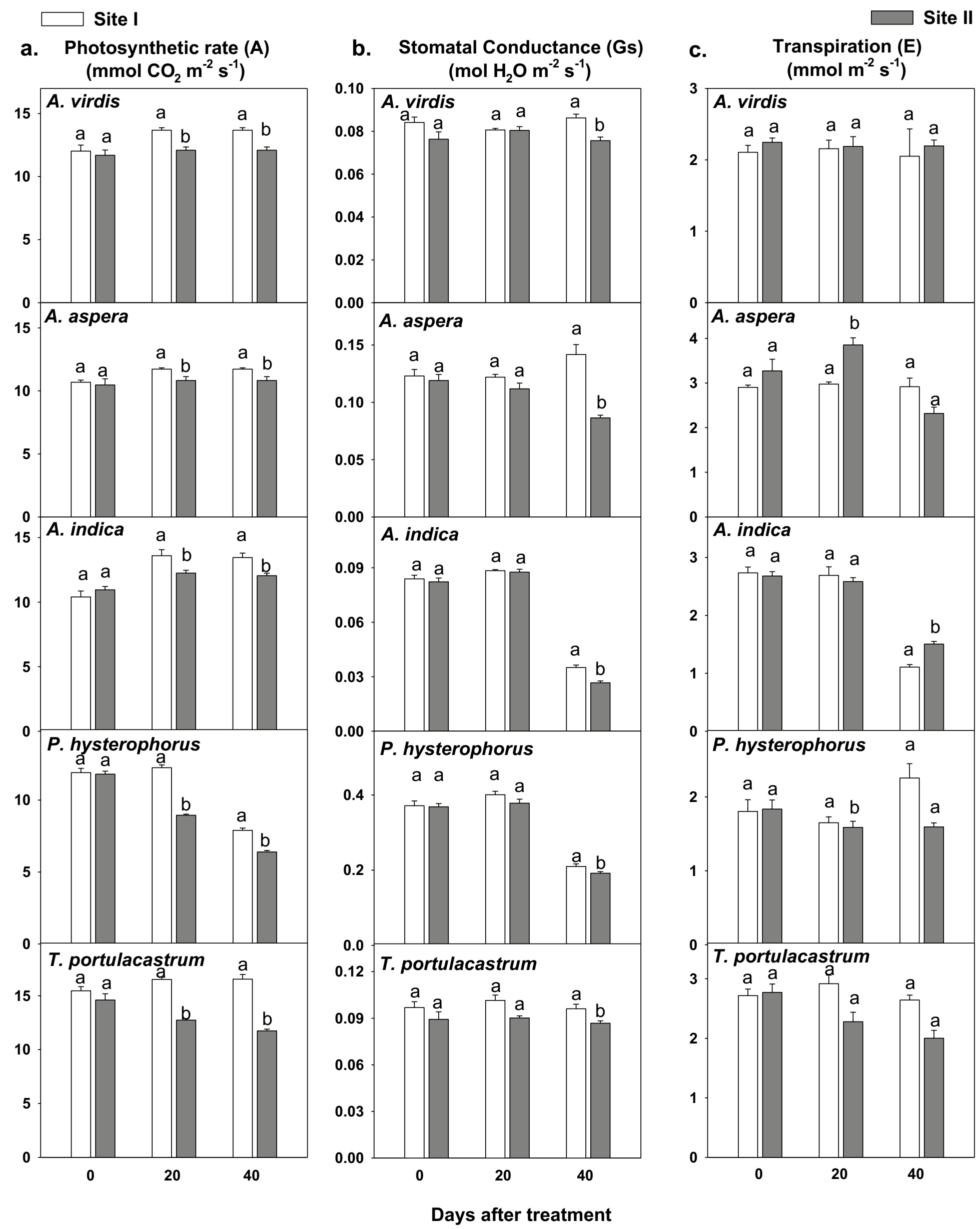

**Fig. 1** Photosynthetic rate (**a**), stomatal conductance (**b**), and transpiration rate (**c**) of five plant species at site I (control site) and site II (polluted site) at 0, 20, and 40 days after treatment (DAT). Data are mean ± SE. The different letters above bar indicate significant differences ($p < 0.05$) between the two sites at specific time point determined using paired *t*-test

average Chl b content of all the species was higher at site II than at site I (58 and 44%, at 20 and 40 DAT, respectively) (Fig. 3b). In general, site effect in carotenoid content was non-significant at 0 DAT, while at other two time points, i.e., 20 and 40 DAT, higher carotenoid content was observed at site II in most of the plant species. Contrarily, *A. aspera* and *T. portulacastrum* showed significant decline in carotenoid content at 20 and 40 DAT, respectively. Tukey's test showed significant variation across the three time points, with maximum photosynthetic pigment content in the examined plants at 20 DAT followed by 40 and 0 DAT. Pearson correlation coefficient was significant between carotenoid content and foliar dust accumulation (0.21) (Table 4).

## Metabolites and antioxidants

Antioxidant activity and other metabolite content varied significantly due to the effect of all the individual factors, i.e., site, plant species, duration of exposure, and their interactive effects (Table 3). Differences in the mean values of biochemical variables for the plant species studied between the two sites were non-significant at 0 DAT but showed variable trend at 20 and 40 DAT. Extent of stress caused by dust pollution, quantified in terms of MDA and proline content, was significantly higher in the plants with higher dust accumulation (Fig. 4a, b). The difference in MDA production between the two sites was most pronounced in *A. indica*, showing an increase of 22 and 62%

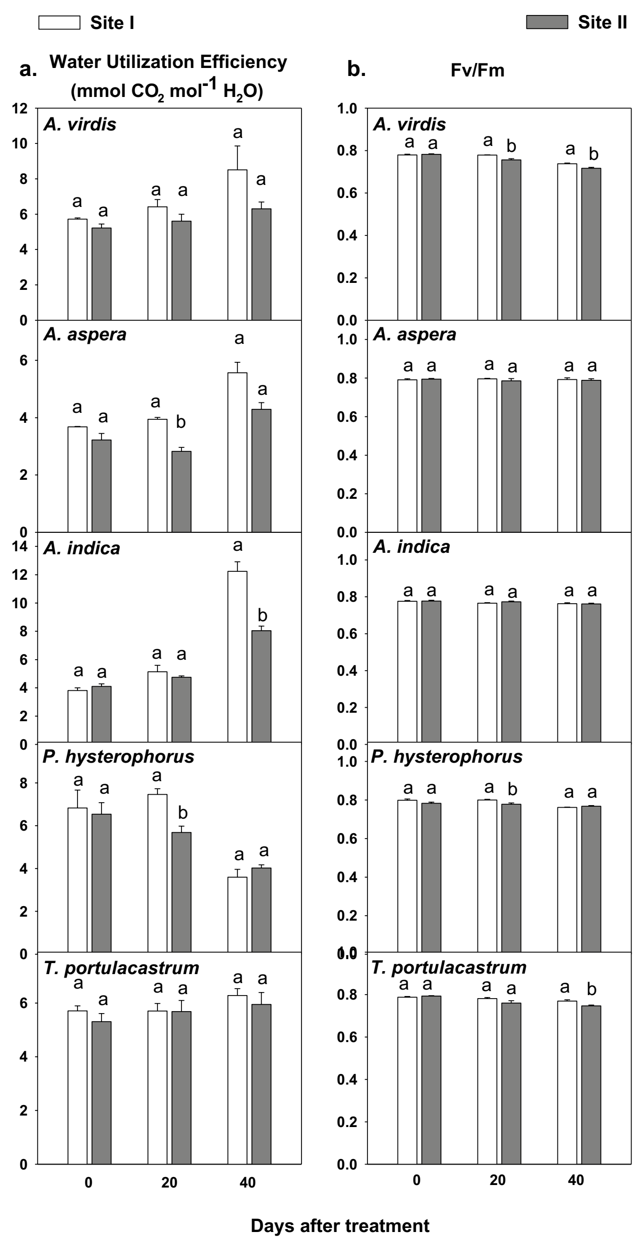


**Fig. 2** Water use efficiency (**a**) and maximum quantum efficiency ($F_v/F_m$) (**b**) of five plant species at site I (control site) and site II (polluted site) at 0, 20, and 40 days after treatment (DAT). Data are mean ± SE. The different letters above bar indicate significant differences ($p^{<}$ 0.05) between the two sites at specific time point determined using paired *t*-test

at 20 and 40 DAT, respectively, while *T. portulacastrum* exhibited least change in MDA content at both time points. Site-wise difference in proline content was maximum for *A. indica* while minimum change was exhibited by *P. hysterophorus* at both 20 and 40 DAT. Average thiol content was higher in the plants at polluted site, compared to the plants at control site (by 38 and 15% at 20 and 40 DAT, respectively) with highest increase in *P. hysterophorus* at 20 DAT (75%) (Fig. 4c).

In the present work, total ascorbate content showed no significant variation between the two sites at 20 DAT for all the tested species (Fig. 5a). At 40 DAT, all the species grown at site II accumulated comparatively high total ascorbate content compared with plants at site I. However, this site-wise change in the ascorbate content was observed to be significant only in the case of *P. hysterophorus* and *T. portulacastrum* (by 46 and 94%, respectively). Similar to total ascorbate content, no significant increase was observed in the total antioxidant activity at 20 DAT (Fig. 5b). At 40 DAT, an increase in total antioxidant activity was observed at site II in all the species. The greatest difference in antioxidant activity between the two sites was recorded in *T. portulacastrum* (118%) while no significant change was observed for *P. hysterophorus* and *A. indica*. As shown by Tukey's test, plants at both sites showed significant increase in the level of ascorbate and antioxidant content along with the duration of exposure. Most of the plants at polluted site showed overall higher level of phenolic content (by 6.4 and 8.2% at 20 and 40 DAT, respectively) in comparison with the plants grown at the control site except *A. aspera* and *T. portulacastrum* at 20 DAT and *A. indica* at 40 DAT. Total ascorbate content (37%) and antioxidant activity (52%) exhibited significant positive correlation with the dust accumulation (Table 4).

### Carbohydrate

Total soluble sugar content in the leaves showed marked variation due to site, plant species, and duration of exposure (Table 3). Total soluble sugar estimated was on average significantly lower in the plants at site II (by 30 and 1% at 20 and 40 DAT, respectively) than the plants at site I. Both *A. viridis* and *A. aspera* showed anomalous accumulation of total sugar at 40 DAT (Fig. 5d) as compared with other species.

## Discussion

### Dust accumulation potential of herbaceous plants

Urban air is characterized by a mixture of air pollutants, varying in their concentration and composition which greatly affect human health. Urban vegetation can play a significant role in reducing the ambient dust pollution through dispersion and interception, though the dust accumulation capacity of plants depends on several factors including plant morphological characteristics and their growing environment. In the present study, plants grown at site II accumulated higher amount of foliar dust as

**Table 4** Correlation between foliar dust accumulated and different biochemical and physiological parameters

| | Dust | Chla | Chlb | Tchl | Carotenoid | MDA | Proline | Thiol | Tascorb | TAntiox | Phenolics | Tsugar | *A* | Gs | *E* | WUE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chla | .114 | | | | | | | | | | | | | | | |
| Chlb | .09 | **.25**** | | | | | | | | | | | | | | |
| Tchl | .11 | **.99**** | **.21*** | | | | | | | | | | | | | |
| Carotenoid | **.21*** | **.89**** | **.48**** | **.88**** | | | | | | | | | | | | |
| MDA | **.20*** | **.42**** | **.33**** | **.41**** | **.47**** | | | | | | | | | | | |
| Proline | .006 | −.10 | **.23*** | −.11 | −.13 | −.07 | | | | | | | | | | |
| Thiol | .15 | .23* | **.20*** | **.22*** | **.27**** | **.63**** | −.013 | | | | | | | | | |
| Tascorb | **.37**** | **.30**** | −.013 | **.30**** | **.35**** | **.33**** | −.14 | **.33**** | | | | | | | | |
| TAntiox | **.52**** | **−.23*** | **−.39**** | **−.22*** | **−.26**** | **−.38**** | .06 | **−.41**** | .08 | | | | | | | |
| Phenolics | −.14 | **.33**** | .14 | **.32**** | **.23**** | **.43**** | **.31**** | **.47**** | −.003 | **−.34**** | | | | | | |
| Tsugar | .13 | **.38**** | **−.21*** | **.40**** | **.31**** | **.56**** | **−.34**** | **.66**** | **.46**** | −.17 | **.38**** | | | | | |
| *A* | **−.33**** | .015 | **−.32**** | .03 | −.11 | **−.34**** | .041 | **−.34**** | **−.24**** | **.31**** | .13 | −.048 | | | | |
| Gs | −.13 | .056 | .13 | .051 | .073 | **.19*** | **−.27**** | .016 | −.16 | **−.29**** | **−.41**** | −.003 | **−.30**** | | | |
| *E* | −.16 | **−.29**** | −.13 | **−.28**** | **−.26**** | **−.38**** | −.003 | **−.48**** | **−.39**** | **.242**** | −.02 | **−.40**** | .17 | **−.28**** | | |
| WUE | −.10 | **.21*** | −.13 | **.22*** | .13 | .14 | −.03 | **.29**** | .17 | −.030 | .13 | **.40**** | **.44**** | .002 | **−.72**** | |
| $F_v/F_m$ | **−.30**** | **−.21*** | .14 | **−.21*** | −.17 | −.17 | **−.27**** | **−.32**** | **−.55**** | **−.33**** | **−.23*** | **−.35**** | −.12 | **.33**** | **.27**** | **−.28**** |

Levels of significance: *$p > 0.05$ level; **$p > 0.01$ level ($n = 120$)

*Chl a* chlorophyll a, *Chl b* chlorophyll b, *Tchl* total chlorophyll, *Tascorb* total ascorbate, *TAntiox* total antioxidant, *TSS* total soluble sugar, *A* photosynthetic rate, *Gs* stomatal conductance, *E* transpiration rate, *WUE* water utilization efficiency, $F_v/F_m$ maximum quantum efficiency

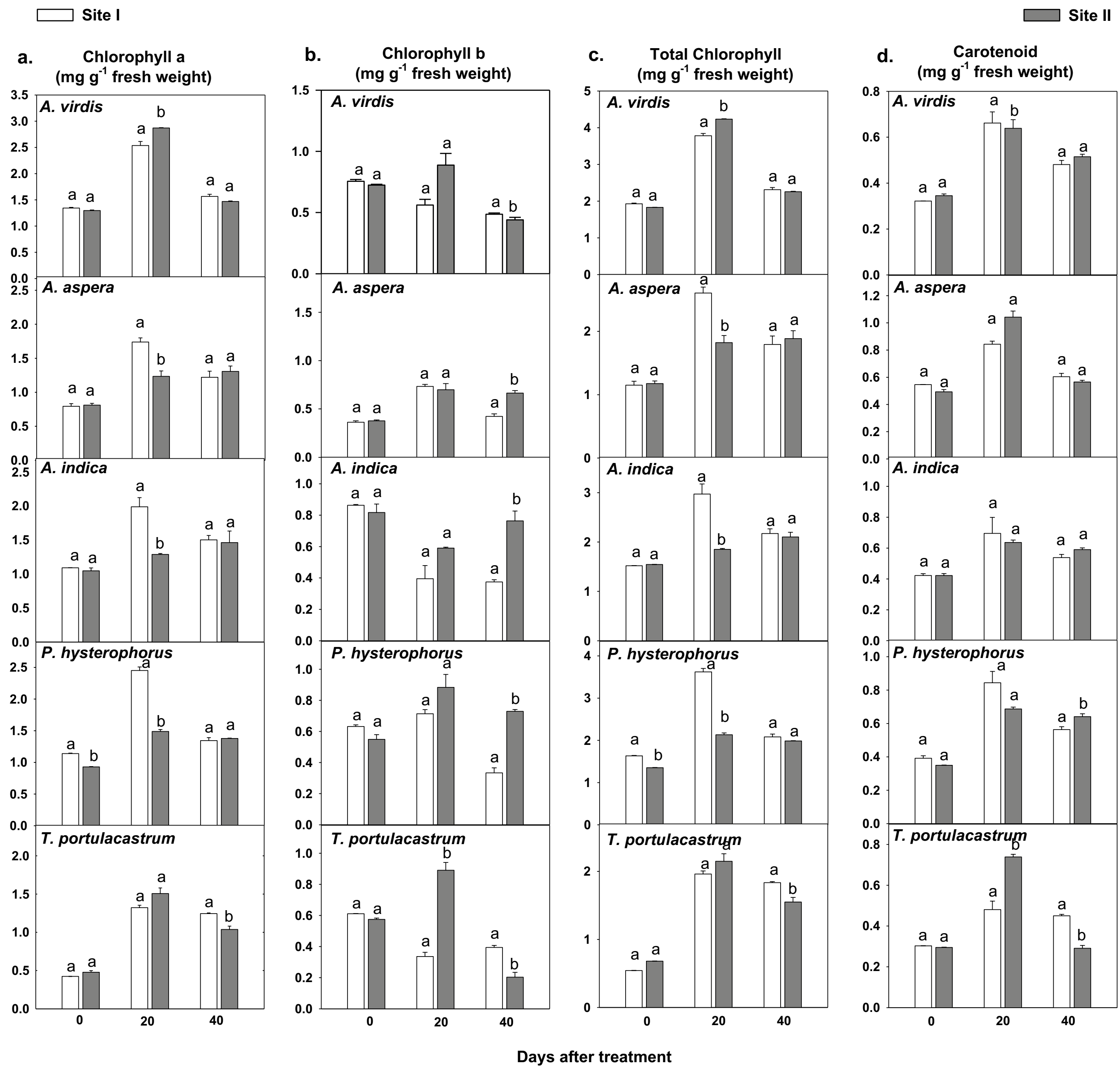


**Fig. 3** Chlorophyll (**a**), chlorophyll (**b**), total chlorophyll (**c**), and carotenoid (**d**) content of five plant species at site I (control site) and site II (polluted site) at 0, 20, and 40 days after treatment (DAT). Data are mean ± SE. The different letters above bar indicate significant differences ($p^{<}$ 0.05) between the two sites at specific time point determined using paired *t*-test

compared to plants at site I, corresponding to higher level of vehicular emission, dust resuspension from unpaved roads, and local industrial activities at this site. Previous studies also reported greater dust load on plant foliage at more polluted sites (Weber et al. 2014; Hariram et al. 2018; Chaudhary and Rathore 2019; Singh et al. 2021). Plants in this study significantly differed in their dust accumulation ability. Among the five species studied, *A. aspera* showed highest amount of foliar dust, attributed to large leaf area and pubescent leaf surface. Leaf morphological attributes such as large surface area, presence of trichomes, raised epidermal cells, and cuticular wax have been shown to enhance the potential of a leaf to trap the suspended particles by previous investigations (Leonard et al. 2016). The lower dust accumulation by *A. indica* and

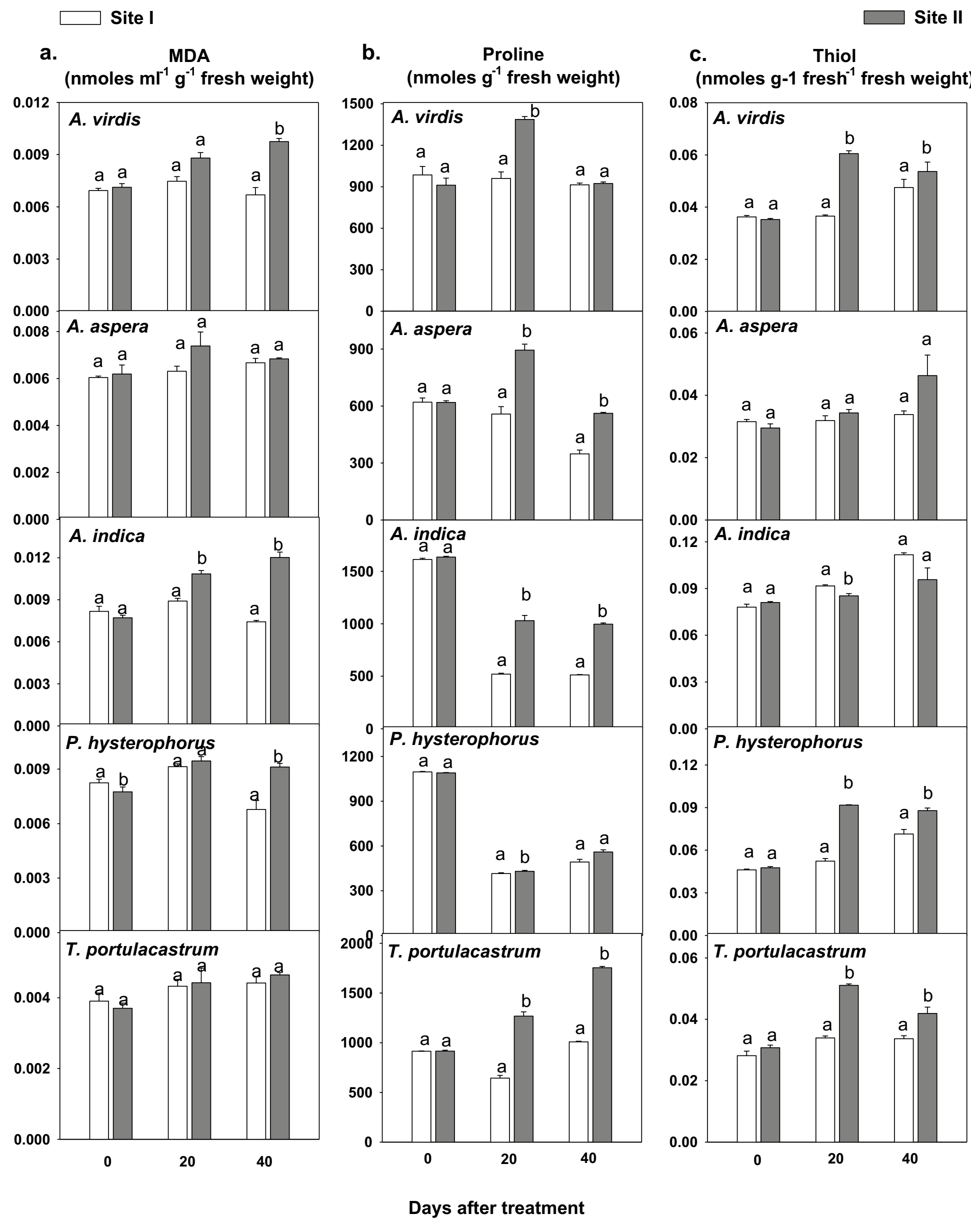


**Fig. 4** Malondialdehyde (MDA) (**a**), thiol (**b**), and proline (**c**) content of five plant species at site I (control site) and site II (polluted site) at 0, 20, and 40 days after treatment (DAT). Data are mean ± SE. The different letters above bar indicate significant differences ($p^{<}$ 0.05), between the two sites at specific time point determined using paired *t*-test

*T. portulacastrum* is likely due to the smooth and glabrous leaf surface.

## Impact of dust accumulation on leaf gas exchange

In the present study, plants grown at the relatively more polluted site exhibited reduced photosynthetic efficiency. Reduction in photosynthetic rate, stomatal conductance, transpiration, and WUE in plants at a relatively more polluted site demonstrates the negative impact of dust particles on leaf gaseous exchange of plants. Reduced leaf gas exchange measurements might be due to the physical blockage of stomatal disturbing stomatal activity. Clogged stomata can reduce stomatal conductivity and hence cause decline in photosynthetic and transpiration rate (Naidoo and Chirkoot 2004; Nanos and Ilias 2007). These findings were also validated in our study, in which the site-wise variation in stomatal conductivity and photosynthetic rate in all the species studies was greater at 40 DAT (with higher foliar dust deposition) as compared to 20 DAT. Also, it was observed that plants with higher dust accumulation, i.e., *A. aspera*, displayed the greatest reduction in the rate of photosynthesis while relatively poor dust accumulator *A. viridis* showed minimum reduction. Popek et al. (2017) also reported reduction in photosynthetic rate in two *Prunus* species corresponding to their PM accumulation ability. Moreover, the negative correlation between photosynthetic rate and amount of dust accumulated on the leaf surface speculates that extent of damage to photosynthetic machinery caused by dust particles is directly

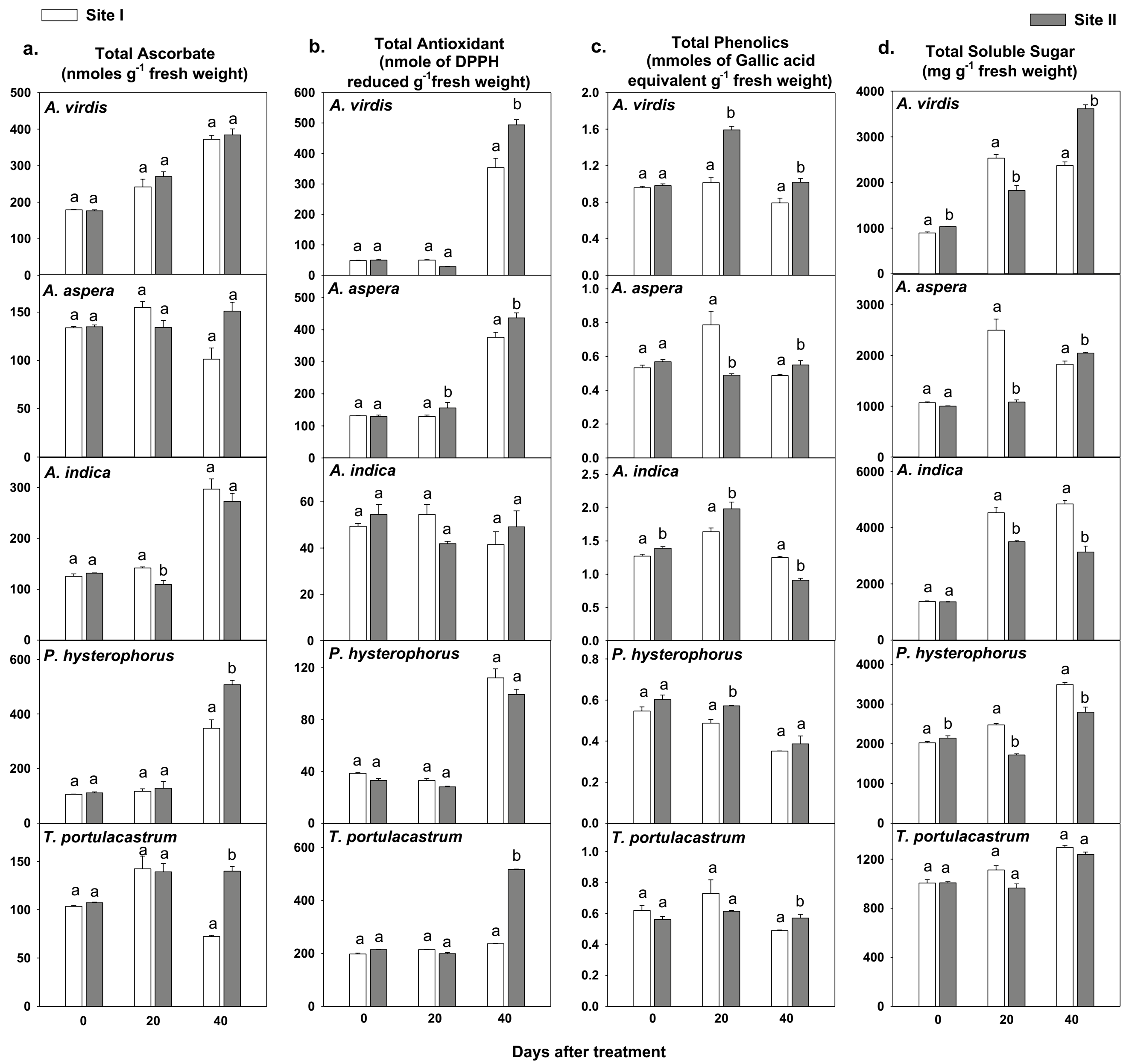


**Fig. 5** Total ascorbate (**a**), total antioxidant (**b**), and phenolics (**c**) and total soluble sugar content (**d**) of five plant species at site I (control site) and site II (polluted site) at 0, 20, and 40 days after treatment (DAT). Data are mean ± SE. The different letters above bar indicate significant differences (at $p< 0.05$) between the two sites at specific time point determined using paired *t*-test

correlated with the amount of foliar dust load. Reduction in photosynthetic rate could also result from decrease in the level of photosynthetically active radiation reaching the chlorophyll antenna due to dust lining on the leaf surface (Naidoo and Chirkoot 2004; Nanos and Ilias 2007).). The negative effect of dust on the rate of photosynthesis in plants treated with different types of dust particles has been shown in several studies (Kuki et al. 2008; Chaturvedi et al. 2013; Łukowski et al. 2020). Highest reduction in the stomatal conductivity in *A. aspera* with greatest foliar dust load reflects its potential adaptation strategy to resist the impact of airborne dust particles on leaf gas exchange (Popek et al. 2018).

The transpiration rate was not much affected by the dust deposition in most of the species (Table 3). A significant increase in transpiration rate in the case of *A. aspera* at 20 DAT and *A. indica* at 40 DAT could be the result of an increase in leaf temperature, consequent to the greater absorbance of incident radiation caused by dust accumulation (Hirano et al. 1995). Instantaneous WUE of plants, controlled by stomatal conductivity, reflects the physiological status of plants (Singh et al. 2020). In the present study, plants showed reduction in WUE with increased dust load, as also reported by Chaturvedi et al. (2013).

Site-wise difference in $F_v/F_m$ was non-significant for most of the species, even though the average $F_v/F_m$ values were relatively lower in the plants grown at the polluted site. Previous studies also reported decline in $F_v/F_m$ in response to various types of dust deposition on leaves (Popek et al. 2018; Łukowski et al. 2020). Generally, reduction in $F_v/F_m$ is considered a key indicator of dust pollution, as photosystem II are highly susceptible to damage to electron transport chain caused by decline in photosynthesis (Łukowski et al. 2020). Non-significant site-wise changes in $F_v/F_m$ in the present study suggest the impact of dust accumulation was mild enough to not affect the photosynthetic machinery of plants.

## Impact of dust accumulation on photosynthetic pigments

Urban vegetation, especially the roadside plants, is persistently exposed to various types of environmental constraints such as increased temperature, limited space, and light. These factors together affect the performance of plants and cause biochemical changes in the leaf tissues, which is manifested in the form of reduction in content of photosynthetic pigment and increase in antioxidant and other metabolite content. Reduction in Chl a and total chlorophyll content in *A. aspera*, *A. indica*, and *P. hysterophorus* at 20 DAT and *T. portulacastrum* at 40 DAT grown at the polluted site could be ascribed to the solubilization of fine dust particles containing various kinds of metal and hydrocarbons which create the alkaline condition and subsequently cause chlorophyll denaturation. Such observations of decline in chlorophyll content in response to various types of dust have been reported by many workers (Prajapati and Tripathi 2008; Shah et al. 2018; Singh et al. 2021). The present study showed that site-wise variation in Chl a and total chlorophyll was lower at 40 DAT as compared to 20 DAT in all the studied species (except *T. portulacastrum*). Comparatively lower variation in chlorophyll content at 40 DAT could be ascribed to significant reduction in stomatal conductivity which limited the entry of pollutants and increased antioxidant activity which regulated the damage caused by them. Lower levels of total chlorophyll in *T. portulacastrum* with high antioxidant level indicate that decreased photosynthetic pigment may also occur as a result of inhibition of pigment biosynthesis due to the shading effect of dust particles, as suggested by Prusty et al. (2005).

Increase in Chl b in the plants at the polluted site in our study conforms with the findings by Hariram et al. (2018) and Kuki et al. (2008), who also observed increase in Chl b content under dust pollution. Increase in Chl b content under stress corresponds to its stable and adaptive nature (Hariram et al. 2018).

Carotenoid, a class of lipid soluble pigments, acts as protective agent against photo-oxidation and reactive oxygen species (ROS). In the present investigation, foliar dust did not affect the carotenoid content in most of the species, while an increasing trend for carotenoid content was shown by *A. viridis* and *T. portulacastrum* at 20 DAT and *P. hysterophorus* at 40 DAT. An increase in the carotenoid content emphasizes the plant adaptation toward the phytotoxic effect of dust pollution. Other studies have also reported an increase in carotenoid content in response to various pollutants (Giri et al. 2013). An overall decline in photosynthetic pigment content with the duration of exposure in the studied plants at both sites could be associated with the natural phenomenon of plant aging (Rathore and Chaudhary 2021).

## Impact of dust accumulation on metabolites and antioxidants

Air pollution–induced oxidative stress is widely recognized (Tiwari et al. 2006). However, the specific effect of dust pollution on the defense system of plants remains unexplored. A higher level of MDA in the plants growing at the polluted site compared with plants at the control site as observed in the present investigation depicts the peroxidation of the membrane caused by dust particles. Higher MDA content in *A. viridis* and *A. indica* could be linked to their lower stomatal resistance, which might have facilitated the influx of dust particles and further caused oxidative stress which led to membrane damage (Singh et al. 2021). Consecutively, low MDA content in *T. portulacastrum* and *A. aspera* could be accredited to high proline content, primarily responsible for maintaining membrane integrity and antioxidant activity (Abuduwaili et al. 2016). Similar findings were also reported by Assadi et al. (2011) and Gupta et al. (2016). Thiol compounds like glutathione (GSH) play an important role in detoxifying the cytotoxic reactive oxygen species generated during oxidative stress. In the present study, plants grown at the polluted site showed increased thiol content compared to the plants at the control site except *A. aspera* for which no significant change was observed at all the time points which explains its least susceptibility. Pukacka and Pukacki (2000) also reported increased thiol content in the scot pine needles at the polluted site. Phenolic content which plays a putative role in plant response to different types of environmental stress has been shown to increase under air pollution by previous investigators (Pasqualini et al. 2003; Singh et al. 2021). However, our results showed an irregular trend in phenolic content for both sites and species.

Most experimental plants in our study showed non-significant site-wise differences in total ascorbate content which plays a primary role in providing tolerance to environmental stress. However, both *P. hysterophorus* and *T. portulacastrum* at 40 DAT exhibited significant increase in ascorbic acid content at polluted sites. An increase in foliar ascorbic content demonstrates the activation of defense mechanisms of plants to withstand the stress caused by the particles from vehicular emission and road dust. Similar results have been reported in several other studies also (Gupta et al. 2016; Prajapati and Tripathi 2008; Hariram et al. 2018). The non-significant changes in the case of other plant species could be due to the restrained entry of dust particles as a result of low stomatal conductivity. Similar to ascorbate content, antioxidant activity was also not significantly affected in most of the species at 20 DAT. An increase in antioxidant activity in *A. viridis*, *A. aspera*, and *T. portulacastrum* at 40 DAT suggests oxidative stress induced by dust particles. Qadir et al. (2016) and Singh et al. (2021) also observed increased antioxidant enzyme activity in response to dust pollution. Lower level of antioxidant activity in leaf tissue of *A. indica* suggests its susceptibility to pollution stress.

Under pollution stress, plants exhibit a number of adaptation strategies that allow them to maintain normal metabolic and physiological functions under such conditions. One such strategy is to increase intracellular antioxidant activity. The antioxidant activity of plants depends on the level, duration, and type of stress as well as on the tolerance level of plant species (Zouari et al. 2016). The present study also showed variation in biochemical response of plant with the duration of exposure to dust pollution. The lower site-wise variation in metabolites at 40 DAT (with higher amount of foliar dust load) in comparison to 20 DAT could be due to diversion of plant metabolism. At 20 DAT when the amount of foliar dust load was low, plants produced secondary metabolites like thiols and phenolics which is believed to be more energy-consuming process (Abrol et al. 2012), while at 40 DAT, cumulative stress induced by higher foliar dust load caused metabolic shift toward increasing primary acting antioxidants like ascorbic acid. Consequently, increased antioxidant activity at 40 DAT prevented further damage to the biological membrane and degradation of photosynthetic pigment. This selective shifting in plant metabolism suggests plant adaptation strategy to survive physiological and metabolic stress caused by dust particles. Moreover, as evident from the result of biochemical parameters, the variable site-wise differences in antioxidant and metabolite level among the five plant species imply that the species differed in their defense response depending on their susceptibility to dust pollution. However, further research into the intricate defense response of plants to different levels of dust pollution is needed to predict how dust interception affects plants overall physiology.

### Impact of dust accumulation on carbohydrate

Carbohydrate concentration in the leaf tissue indicates the physiological status of plants, as they play dynamic role in plant metabolism and hence are likely to change under stress. The present study showed lower total soluble sugar in the plants grown at the polluted site compared with plants grown at the control site as also reported by other studies (Sharma and Tripathi 2009; Gupta et al. 2016). Decreased sugar content attributing to leaf dust accumulation may correspond to reduction in $CO_2$ fixation (Qadir et al. 2016; Xiong-Wen 2001). The exceptional increase in total soluble sugar in *A. viridis* and *A. aspera* at polluted site at 40 DAT might be due to the degradation of complex carbohydrates into simpler forms to maintain cellular homeostasis under stress (Naya et al. 2007). Similar finding was reported by Assadi et al. (2011) confirming an increase in soluble sugar content in *Eucalyptus camaldulensis* in response to air pollution. Comparison among three time points, i.e., 0, 20, and 40 DAT, showed an increase in soluble sugar content with increase in time period which could be attributed to metabolic changes in plants during development from juvenile to mature stage (Rathore and Chaudhary 2021).

## Conclusion

The present study showed that leaves of herbaceous plant species growing along the road network also accumulated considerable amount of dust particles like the woody species. Nevertheless, dust particle deposition significantly affected the physiological performance of these ruderal species. Decline in photosynthetic efficiency and pigment content and rise in the level of different antioxidants and metabolites in response to foliar dust accumulation indicate the physical and chemical impact of dust particles and consequent activation of the plant defense system to cope with its phytotoxic effects. The magnitude of these impacts depended on the tolerance of plants against dust. Compared to other plant species, significant reduction in the stomatal conductivity concomitant with high antioxidant activity in *A. aspera* with highest foliar dust reflects its adaptation strategy to cope with stress. *A. indica* was shown to be most susceptible to phytotoxic effect of dust as evidenced by lower foliar antioxidant activity and greater membrane damage. The lower site-wise variation in thiol and phenolic content at 40 DAT in comparison to 20 DAT indicates that plant metabolism is preferentially directed from the production of secondary metabolites toward increasing primary acting antioxidants like ascorbic acid to maintain the physiological status under stress condition. Extending the understanding of impact of dust pollutants on plants would help in implying the idea of vegetation as bio-filter for pollutants, especially smaller vegetation like herbs which are the most perceptible element and easier to integrate in urban greenery. The present investigation also suggests that there is need to further investigate the long-term impact of dust pollution with more numbers of plants to allow the selection of better performing species for green belt development. Information regarding plant selection will help the town planner to maintain optimal green infrastructure in urban landscape for improving the poor air quality.

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**Author contribution** The study was proposed by KSR. The fieldwork and sampling were done by MC, IT, and KP. Various analyses were performed by MC and IT. Statistical analysis and data presentation were done by KSR, MC, and KP. Final manuscript drafting was done by MC and KSR.

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**Data availability** The authors confirm the material and data supporting the findings of the proposed study are supplemented with the article in a separate file.

The manuscript entitled “Impact of dust accumulation on physiological functioning of selected herbaceous plants” authored by Meenakshi Chaurasia, Kajal Patel, Indu Tripathi, and K. S. Rao submitted here is an original research article. It has not been published previously, either in full or part, and has not been considered to be published anywhere else.

## Declarations

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**CURRICULUM VITAE**

**Name:** SATISH CHANDRA GARKOTI

**Address for Communication:**
Professor
School of Environmental Sciences,
Rector II (Pro-Vice Chancellor)
Jawaharlal Nehru University
New Delhi – 110067
sgarkoti@yahoo.com

**Area of Specialization:** Forest Ecology, Traditional ecological Knowledge, Tree water relations, Plant invasions, Ecosystem restoration

**Membership of Professional Societies:**

- International Society for Tropical Ecology, India (Fellow)
- Ecological Society of America, USA (Member)
- British Ecological Society (Member)
- National Institute of Ecology, India (Fellow)
- International Association for Ecology (INTECOL)(Member)

**Administrative Experience:**

- Hostel Warden: March 2013- April 2016
- Rector (Pro Vice Chancellor), Jawaharlal Nehru University: April 2016- till present

**Research Supervision:**

*Number of Ph.D students present*

1. Rajman Gupta
2. Chandan Das
3. Priya Hansda
4. Ambuj Mishra
5. Anand Shankar
6. Manish Dhaulakhandi
7. Khushboo Kashyap
8. Padma Ladon

**Publications:**

*(a) Publications in Journals:*

1. Kalra Avneet, Rajendra Kr Joshi & S.C. Garkoti (2023). Ecophysiological trait differences between invasive Lantana camara L. and native Adhatoda

vasica Nees. shrubs in the semi-arid region. Brazilian Journal of Botany. 10.1007/s40415-023-00896-7.

2. Kumar Shailendra, Rajman Gupta, Rajendra Kumar Joshi & S.C. Garkoti. (2023). Rhizosphere soil properties and microbial biomass changes with the chronosequence of stand age of broadleaf banj oak and coniferous deodar forests in the central Himalaya, India. Rhizosphere. 10.1016/j.rhisph.2023.100761.
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1. Nepolion Borah, Florida Devi Athokpam, Ashesh Kumar Das, and S.C. Garkoti (2019). Aboveground Tree Carbon Stocks Along a Disturbance Gradient in Wet Tropical Forests of South Assam, India. In Tropical Ecosystems: Structure, functions and challenges in the face of global change. Springer. doi.org/10.1007/978-981-13-8249-9.

*(c) Books Published:*

1. SC Garkoti, RL Semwal, Nepolion Borah & Padma Ladon (2018). Glimpses of traditional societies and their knowledge systems in Indian Himalayan region. Task Force-5, NMSHE, JNU, ISBN: 978-93-5321-621-4.
2. SC Garkoti, Skip J Van Bloem, Peter Z Fule & RL Semwal (2019). Tropical ecosystems: Structure, Functions and Challenges in the Face of Global Change. Springer Nature, pp 320, (ISBN 978-981-13-8249-9) (Edited).

**Undertaking by the Fellow**

I, Meenakshi Chaurasia, Son/Daughter/Wife of Shri. Ashok Kumar Chaurasia, resident of -- Samaypur, Delhi --agree to undertake the following, If I am offered the SERB N-PDF

1. I shall abide by the rules and regulations of SERB during the entire tenure of the fellowship.
2. I shall also abide by the rules, discipline of the institution where I will be implementing my fellowship
3. I shall devote full time to research work during the tenure of the fellowship
4. I shall prepare the progress report at the end of each year and communicate the same to SERB through the mentor
5. I shall send two copies of the consolidated progress report at the end of the fellowship period.
6. I further state that I shall have no claim whatsoever for regular/permanent absorption on expiry of the fellowship.

Meenakshi Chaurasia

Date: 09/08/2023

Signature

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## Endorsement Certificate from the Mentor & Host Institute

This is to certify that:

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II. The fellowship will start from the date on which the fellow joins University/Institute where he/she implements the fellowship. The mentor will send the joining report to the SERB. SERB will release the funds on receipt of the joining report.
III. The applicant, if selected as SERB-N PDF, will be governed by the rules and regulations of the University/ Institute and will be under administrative control of the University/ Institute for the duration of the Fellowship.
IV. The grant-in-aid by the Science & Engineering Research Board (SERB) will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as indicated in the sanction letter/ order.
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VI. The University/ Institute will provide basic infrastructure and other required facilities to the fellow for undertaking the research objectives.
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IX. The University/ Institute shall settle the financial accounts to the SERB as per the prescribed guidelines within three months from the date of termination of the Fellowship.

**Dated:** 07/08/23

**Signature of the Mentor:**

Dr. C. GARKOTI
Professor
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi-110067

**Name & Designation:**

Dean, SES 7/8/23

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**Dated:** 9/8/23

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To

The Secretary
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Sir

I Meenakshi Chaurasia

herby certify that the research proposal titled Influence of urban land use types & urban-rural gradient on plant functional traits of common woody species of Delhi, India and its implication on soil ecosystem services provision in the urban system submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e. Ouriginal approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e. University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation, 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

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# Spatial variability in soil physicochemical parameters across land use classes in the peri-urban landscape

**Meenakshi Chaurasia**[1] · **Kajal Patel**[1] · **Rahul Bhadouria**[1] · **K. S. Rao**[1,2]

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## Abstract
Rising population and urban expansion have ushered drastic transformations in land use patterns, which can considerably affect soil components and processes. Peri-urban regions at the rural-urban interface are of specific concern because of their dynamic and complex land use pattern. Here, we investigated the spatial variability in soil physicochemical parameters of the surface soil (0–30 cm) in peri-urban landscape of Ghaziabad district, located in the upper Gangetic plain of Uttar Pradesh, India. A total of 45 sites belonging to five different land use classes namely agriculture, park, residential, industrial and bare land were sampled from December 2019 to January 2020. Descriptive analysis of data showed wide variability in the soil properties, with chemical properties being more variable than physical properties. We observed significant differences in soil properties across land use types and their heterogeneous distribution across the three sites. Industrial land use with low vegetation cover was distinctly differentiated from other anthropogenic land use and land cover by high bulk density. Residential land use with high nutrient input from domestic waste and physical disturbance from construction activities was separated from other overlapping land use types by high water-holding capacity and calcium (Ca) concentration. Overall, the results of the study suggest that multifaceted anthropogenic disturbances including modification of parent material, extensive fertilization and irrigation, transportation and waste dumping entail significant changes in soil characteristics and may have serious implications on soil structure and function. Such regional and local studies would help in developing scientifically informed practical measures to improve and maintain the soil quality. Hence, further detailed research exploring the impact of anthropogenic land uses on soil characteristics is needed for management and preservation of the soil mantle.

**Keywords** Soil physicochemical properties · Land use · Urban soil · Peri-urban · Nutrient

✉ Meenakshi Chaurasia
meenakshichaurasia2@gmail.com

1 Department of Botany, University of Delhi, New Delhi 110007, India

2 Department of Environmental Studies, Delhi College of Arts and Commerce, University of Delhi, New Delhi 110023, India

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## 1 Introduction

The process of urbanization has become a dominant demographic trend and a major driving force for landscape transformation. At present, over 55% the of total world's population resides in cities, and by 2050, this proportion is projected to increase to 68%. It is anticipated that 90% of this growth will occur in Asia and Africa (UN, 2019). Coupled with the increasing urban population, urban areas are dramatically expanding to meet the increasing demand for food and living spaces. Thus far, about 3–5% of the global land area has been converted to urban and developed land use (Seto et al., 2010). The transformation of the physical landscape from non-urban to urban land use driven by the rapid expansion of urban space is the most apparent result of urban development. Large amounts of agriculture and forest areas have been replaced with urban land use including managed green spaces, and industrial and residential areas with impervious surfaces. These conversions subsequently follow implications for other ecosystem components through resource exploitation, energy consumption and addition of contaminants (Patra et al., 2018).

Urban ecosystems are the most dynamic and intricate adaptive systems of any landscape (Dutta et al., 2021). Continuous biophysical and socio-economic disturbances dominate the components of the urban ecosystem, i.e., vegetation, water and soil. Of these components, soils have received increasing interest from government, policymakers and the scientific community because of their high susceptibility to legacy effects and their key role in providing important ecosystem services (Ziter & Turner, 2018). Human activities associated with urban development including land conversion, alterations in resource availability and microclimate influence the soil substrate and result in the mosaic of patches of soil (Pouyat et al., 2007). Overlain by this are modifications such as management of soils (e.g., mowing and irrigation in urban parks), transportation of soils (e.g., due to construction; Hooke, 2000), soil sealing, addition of waste and construction material, such as building sand and vegetation clearing that creates urban soil which has very distinct properties and function from their natural counterparts (Lorenz & Lal, 2009; Whitehead et al., 2021). However, their response to urbanity is not understood.

Urban soils are a key component of urban ecosystems and provide important ecosystem services such as habitat for living organisms, substrate for plant growth, hydrological regulation through infiltration, and maintenance of nutrient cycling, and as a medium for engineering (Brady & Weil, 2002; Morel et al., 2015). Soil ecosystem services are associated with soil properties, as soil structure regulates the flux of gas and water, leaching of nutrients and contaminants and rooting (Calzolari et al., 2020). As it serves crucial functions for environmental, atmospheric, and surface water purification, the soil indirectly influences the general ecological condition and the health of the urban population (Morel et al., 2015). These perturbations, nevertheless, alter their structure and hence impair their regular functioning. Several previous studies investigated the impact of different urban land uses on the soil at regional as well as local scales (Jim, 1998; Scharenbroch et al., 2005; Pouyat et al., 2007, 2008; Zhang et al., 2010; Livesley et al., 2016; Upadhyay et al., 2021) and suggested that changes in land use and land cover change have significantly altered the urban soil characteristics (Silva et al., 2017). Soil compaction in impervious surfaces alters bulk density, soil aggregate distribution and hydraulic properties, while sealing and erosion affect the exchange of gases, water and material which reduces soil fertility and restrict vegetation growth (Pouyat et al., 2007; Lorenz & Lal, 2009; O'Riordan et al. 2021. In addition to these mechanical disturbances, management practices such as fertilization, irrigation and removal of organic matter have been widely recognized to alter nutrient cycling in urban soil (Kaye et al., 2006; Whitehead et al., 2021). Heavy metal contamination and atmospheric N emission are frequent in soils in transportation and industrial area (Lu et al., 2009; Fang et al., 2019; Silva et al., 2021). Although a number of studies have highlighted land use change as a key cause for change in urban soil characteristics, there is still a large gap in our knowledge of the ecology of the urban ecosystem compared to natural and other non-urban systems. Therefore, further extensive studies are required to establish a coherent and comprehensive relationship between the urban elements and the soil properties for scientifically informed management and conservation of the brown infrastructure soil.

The present study was conducted in the peri-urban landscape of Ghaziabad city, which is one of the ten fastest growing cities in the world (Mayors, 2014). Owing to its proximity to the metropolis-Delhi, Ghaziabad is undergoing rapid change in its land use pattern, with agricultural land and open spaces being acquired for industrial and residential use (Horo & Punia, 2019). The peri-urban interface needs particular attention from an ecological perspective because of the high degree of informal development and its dynamic and overlapping land use pattern which cause soil quality to deteriorate (Dolley et al., 2020; Imbrenda et al., 2021). Rural-urban interfaces are crucial for food production and simultaneous economic growth and hence, need imperative investigation of soil quality. The main purpose of the present study was to evaluate the spatial variation in soil physicochemical properties across different land use types. Specifically, we focused on three objectives (i) to examine the soil physicochemical properties and the soil fertility status of a peri-urban landscape in Ghaziabad, India (ii) to assess the variability in physical and chemical properties across different land use and (iii) to ascertain the specific soil variables that are most influenced by land use change.

## 2 Materials and methods

### 2.1 Study area

Ghaziabad is the fastest growing satellite town of India with million-plus population. It is located within longitudes 77° 12′–77° 42′ E and latitudes 28° 36′–28° 55 ′N with an area of 1179 sq. km. It is situated in the middle of Ganga-Yamuna doab, underlain by Quaternary sediments. This area belongs to semi-arid ecoregion and experiences a continental climate. The maximum temperature may range up to 43 °C in summer, while the minimum may drop to 3 °C in winter and receive an average of 348.8 mm rainfall from June to September (Tyagi & Sarma, 2021). Geologically, it is part of the Indo-Gangetic plain and the soils are broadly classified as Fluvisol (Mishra et al., 2020). The soil texture of the selected study sites ranges from sandy to stiff clay (CGWB, 2009).

Ghaziabad has registered a high urban growth rate, i.e., 70.22% (Census of India, 2011). Due to rapid population growth and industrial development in and around the district, it has undergone rapid landscape transformation over the last two decades, with an increase in built-up area at the rate of 6.11 km$^2$ per annum, while agricultural land declined at the rate of 5.45 km$^2$ during 2005 to 2020 (Gupta, 2021).

## 2.2 Experimental design and soil sampling

Ghaziabad presents mixed features of a typical peri-urban area with rural hinterlands, urban residential, commercial and industrial areas (Chabukdhara et al., 2013). For the present study, three sites, i.e., (i) Site I (Galand), (ii) Site II (Karhera) and (iii) Site III Kavi Nagar) were selected to bracket the heterogeneity of the peri-urban setting of Ghaziabad

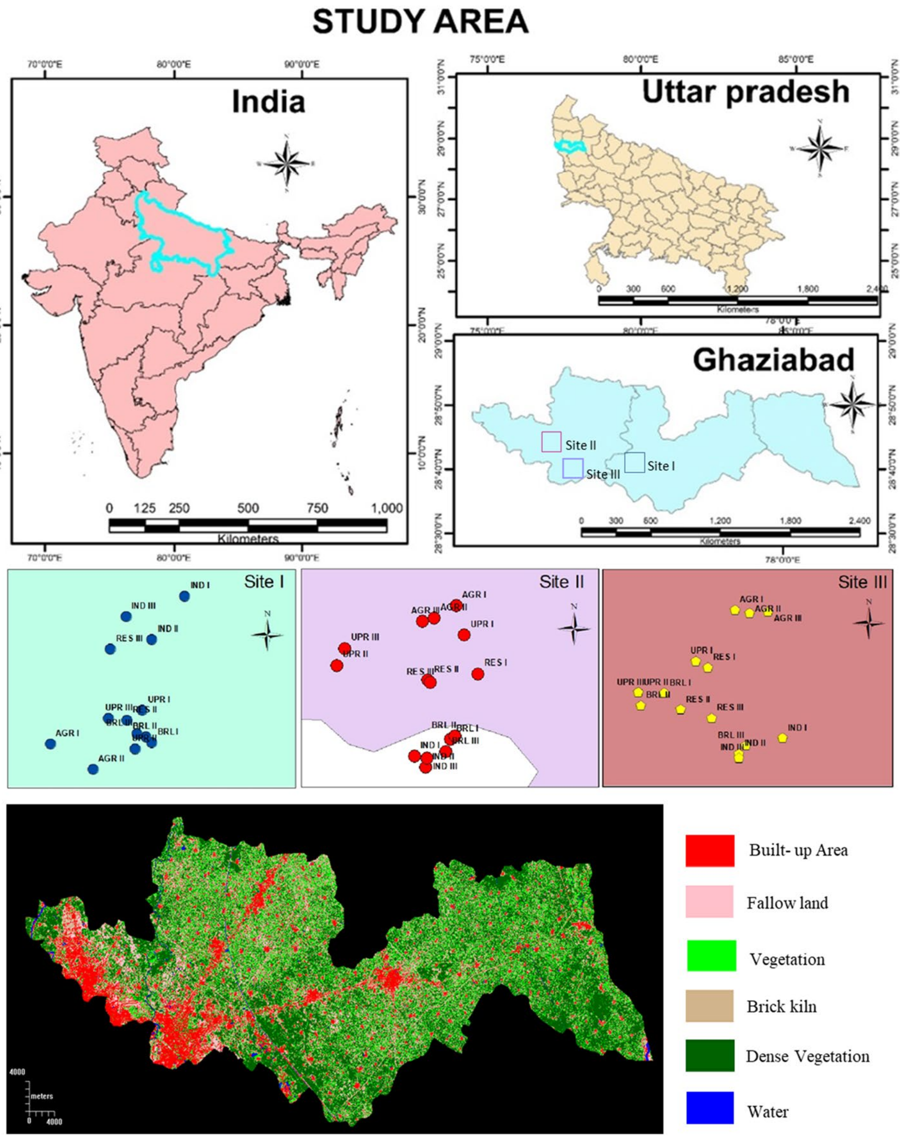


**Fig. 1** Simplified land use map of the study area and location of the study sites, i.e., (i) Site I (Galand), (ii) Site II (Karhera) and (iii) Site III (Kavi Nagar); having Agriculture (AGR), Park (PAR), Residential (RES), Industrial (IND) and Bare (BAR) land use classes

Fig. 1. These sites were classified based on their distance to the city center and population density (Pouyat et al., 2009). To observe the spatial variation in soil physicochemical properties, five representative land use classes, namely, agricultural land, residential/commercial, urban park, industrial and bare land were selected at each site. The sampling scheme used for the land use class selection was arbitrary, because of the mixed and non-uniform land use patterns of the selected sites. For each land use class, three adjacent typical patches were selected and at each patch, the soil was sampled in triplicate from three sampling points (no more than 10 m apart) from 0 to 30 cm soil depth. Subsequently, a total of 45 sites (with $n = 135$; 3 sites × 5 land use classes × 3 patches × 3 sampling points) were sampled from December 2019 to January 2020, for the present study. Three additional soil samples were taken from each sampling point using soil corer for bulk density measurement. At the same time, fundamental status of the landscape including vegetation cover, management and disturbance regimes of all the sites were surveyed and noted, as described in Table 1. Soil samples were brought to the laboratory, passed through 2 mm sieve and stored at 4 °C for further analysis.

### 2.3 Measurement of soil physical properties

Soil temperature (ST) was measured using a field soil thermometer (TP 3001 Digital Thermometer) at the time of sample collection. Soil moisture content (SMC) was estimated using the gravimetric method by oven drying soil at 105 °C for 12 h and calculating mass difference as percentage of oven-dried soil (Anderson & Ingram, 1993). Soil bulk density (BD) (dry weight per unit soil volume) was estimated from undisturbed soil samples using soil corer of known volume and weighing the oven-dried soil contained in the soil corer. BD was calculated using the following equation.

$$\mathrm{BD} = \frac{V}{\mathrm{dwt}}$$

Soil porosity (TP) was derived based on estimated bulk density and particle density (2.65 g $\mathrm{cm}^{-2}$) using the given equation (Brady & Weil, 2002).

$$\mathrm{SP} = \left(1 - \frac{\mathrm{BD}}{\mathrm{PD}}\right) \times 100$$

Water-holding capacity (WHC) was measured by using the method by Allen (1974). Water-filled pore space (WFPS) was calculated using estimated BD, SMC and SP (Linn & Doran, 1984).

### 2.4 Measurement of soil chemical properties

Soil pH and electrical conductivity (EC) were determined by dissolving field moist soil in distilled water in the ratio of 1:2.5 using pH meter (EUTECH pc 800) (Anderson & Ingram, 1993). Air dried samples were analyzed for soil organic carbon (SOC) and total nitrogen (TN) with Elementar CHNS analyzer. Available phosphorus (AP) concentration was estimated by following the ammonium molybdate blue method and exchangeable sodium (Na), potassium (K) and calcium (Ca) were measured in sodium acetate extract using flame photometer (SYSTRONICS Flame Photometer 128) as described by Allen (1974).

**Table 1** Descriptions of the selected five urban land use classes

| Land use class | Abbreviation | Description | Common plant species |
|---|---|---|---|
| Agriculture | AGR | Highly managed areas, used for growing crops and vegetables. Soil is continuously by management practices like irrigation, fertilization and tilling at regular intervals all around the year | *Sorghum bicolor*, *Brassica nigra*, *Spinacia oleracea*, *Oryza sativa*, |
| Park | PAR | Managed home garden, lawn and urban park with grasses and herbaceous species as the dominant vegetation. Management includes periodic irrigation and clipping, pruning. | *Cynodon dactylon*, E*vovulu*s spp, *Sporobolu*s spp., *Pennisetum clandestinum, Zoysia japonica*, *Rosa indica*, *Rosa sinensis*, *Dactyloctenium* spp., *Plumeria alba* |
| Residential | RES | Settlement area with tree plantation and hedges for aesthetic and recreational purposes with sporadic management. Dominated by permanent concentration of man-made structures, people and activities. Anthropogenic disturbances like construction, domestic garbage dumping and artifact addition are commonplace. | *Azadirachta indica*, *Saraca asoca*, *Millettia pinnata*, *Ficus religiosa*, *Plumeria alba*, *Nerium oleander*, *Mangifera indica*, *Callistemon* spp *Bougainvillea* spp. |
| Industrial | IND | Industrial and commercial areas with impervious surfaces with unmanaged, naturally occurring herbs and shrubs. Characterized by continuous disturbances like transportation, soil mixing and contamination. | *Vernonia angustifolia*, *Parthenium hysterophorus*, *Cyperus rotundus*, *Cassia toda*, *Amaranthus* spp., *Calotropis procera* |
| Bare land | BAR | Areas with no or very little vegetation, where soil exposure is apparent. | |

### 2.5 Statistical analysis

Analysis of variance (ANOVA) was performed to analyze the significance of variation in studied soil physicochemical characteristics across the selected sites and different land use classes followed by multiple comparisons using Tukey's HSD test to compare the effect of land use types on each parameter for the considered site. Pearson correlation analysis was carried out to observe the interrelation between different soil variables. Principle component analysis (PCA) was conducted to extract the variables responsible for variance in land use types. Stepwise discriminant analysis (DA) was performed to differentiate the land use types based on the difference in their soil characteristics. For grouping the land use types, best explanatory factors were identified using Mahalanobis procedure for forward selection. All the statistical analyses were conducted in SPSS (ver. 20).

## 3 Result

### 3.1 General characteristics of peri-urban soil in Ghaziabad

Descriptive statistics of each variable measured showed that inherent soil properties of the peri-urban region of Ghaziabad were notably variable across the sites (Table 2). The higher coefficient of variation (CV) for EC, TN, C:N and AP indicates a wide variation in soil

**Table 2** Descriptive statistics of surface soil properties (from 0 to 30 cm layer) from three sites in the peri-urban region of Ghaziabad

| Soil properties | Mean | Standard error | Min. | Max. | Median | CV (%) | Recommended range* |
|---|---|---|---|---|---|---|---|
| pH[a] | 7.47 | 0.03 | 6.05 | 9.13 | 7.42 | 6.82 | 7 |
| EC (μS $cm^{-1}$) | 328.51 | 9.40 | 28.00 | 1581.00 | 278.30 | 57.59 | – |
| SMC (%) | 14.76 | 0.27 | 5.39 | 27.88 | 15.09 | 36.24 | – |
| BD (g $cm^{-3}$) | 1.40 | 0.02 | 1.00 | 1.96 | 1.39 | 13.69 | 1.5 |
| TP (%) | 47.21 | 0.62 | 26.11 | 62.37 | 47.64 | 15.31 | – |
| WHC (%) | 46.12 | 0.59 | 30.80 | 62.33 | 46.67 | 14.98 | – |
| ST (°C) | 18.8 | 0.19 | 15.6 | 26.8 | 18.10 | 10.01 | – |
| WFPS (%) | 44.56 | 1.68 | 12.35 | 130.13 | 41.89 | 43.74 | – |
| SOC (%) | 1.04 | 0.03 | 0.17 | 5.49 | 0.96 | 49.62 | > 1 |
| TN (%) | 0.10 | 0.00 | 0.006 | 0.36 | 0.09 | 65.52 | 0.1–0.15 |
| C:N | 13.63 | 0.57 | 01.647 | 117.68 | 11.75 | 84.23 | 24:1 |
| Na (mg $kg^{-1}$) | 296.05 | 6.28 | 64.00 | 683.75 | 271.25 | 42.66 | – |
| K (mg $kg^{-1}$) | 193.78 | 6.18 | 37.25 | 796.00 | 160.00 | 64.17 | 171–912 |
| Ca (mg $kg^{-1}$) | 1385.58 | 34.05 | 36.25 | 3912.00 | 1203.50 | 49.45 | N/A |
| AP (mg$kg^{-1}$) | 57.79 | 2.014 | 7.70 | 192.3 | 49.19 | 70.15 | 27–135 |

*EC* electrical conductivity, *SMC* soil moisture content, *SOC* soil organic carbon, *AP* available phosphorus, *BD* bulk density, *TP* total porosity, *WHC* water-holding capacity, *WFPS* water-filled pore space, *TN* total nitrogen

*According to Whitcomb (1987), Hunt and Gikes (1992), Horneck et al. (2011)

– None found

chemical characteristics in comparison with the physical properties. The highest CV was observed for C:N (84.23%) while the lowest was for soil pH (6.82%). The minimum and maximum values of exchangeable Na, K, Ca and AP differed by more than 10-fold.

The pH of the peri-urban soils was observed to be neutral to moderately alkaline with an average value of 7.42. EC with high CV (57.59%) varied greatly from a minimum value of 38 μS $cm^{-1}$ to a maximum value of 1581 μS $cm^{-1}$. The SOC content and C:N ratio, with an average of 1.04% and 13.63, respectively, were considered low for the majority of soil samples. As to TN, K and AP concentrations (0.012%, 193.78 mg $kg^{-1}$ and 57.79 mg $kg^{-1}$, respectively) were found to be within the normal range (>0.1%, 171–912 mg $kg^{-1}$ and 27–135 mg $kg^{-1}$, respectively) recommended for efficient plant growth. Whereas, the exchangeable Ca concentration (1385 mg $kg^{-1}$) exceeded the upper limit of the critical range.

### 3.2 Soil physicochemical properties across the land use classes

Soil physicochemical properties across the five land uses are presented in Figs. 2, 3, 4 and 5. The result of two-way ANOVA (Table 3) showed significant variation (at $p<0.05$) among the different land use types for all the studied variables. The land use-wise comparison showed an increasing trend for soil BD in the order of park < agriculture < residential < industrial < bare land. Conversely, average TP and WHC were highest under park land use (50.73% and 51.61%, respectively) and lowest under bare land (43.9% and 38.46%, respectively). SMC and WFPS were significantly higher in residential (by 10% and 32%, respectively) and agricultural soil (by 9% and 29.7%, respectively) in comparison with the soil sampled from the park, while lower for bare and industrial land use. Soil temperature was higher in industrial and bare land (by 8.4% and 10%) in comparison with the residential area, while lower in park and agricultural land (by 6.8% and 6.42%) (Fig. 2).

Overall soil pH was found to be highest in the residential area (7.84) followed by the industrial area (7.5), while the lowest pH value was recorded for agricultural land (7.27); however, at the site I the difference among the land use classes was non-significant (Fig. 3a, Supplementary Table 1). Our result showed that EC was significantly higher in the residential area (462.8 μS $cm^{-1}$) in comparison with other land use classes (Fig. 3b). Overall, SOC content was significantly greater under residential, park and agricultural land use (by 72.4%, 50.4% and 40.6%, respectively) in comparison with bare land. TN content was highest in residential soil (0.14%), while no significant difference was observed between other land use classes. Although the overall impact of land use on C:N was non-significant, the impact of land use (analyzed at a particular site) was significant for site II and site III with the highest C:N value in agricultural land (8.64) and urban park (14.91), respectively (Fig. 4c). AP content was highest under park land use (102.5 mg $kg^{-1}$) and lowest under bare land use (25.4 mg $kg^{-1}$). Exchangeable K content across the five land use classes decreased in order as: residential > park > industrial > agriculture > bare land. In exception to other chemical properties, Na and Ca content was the highest in soil sampled from industrial area (340.1 mg $kg^{-1}$ and 1948 mg $kg^{-1}$, respectively), while residential and parks showed no significant difference in their Na and Ca content (Fig. 5).

PCA analysis performed for qualitative grouping of the studied soil physicochemical properties identified five components, explaining 75% of the total variance. Major variables associated with PC1 (27.63% variance) were WHC, WFPC, SMC, SOC and AP, while PC2 (20.97% of variance) represents BD, TP, ST and Ca (on the basis of the component matrix obtained, Supplementary Table 2). As shown in Fig. 6, the result of PCA analysis

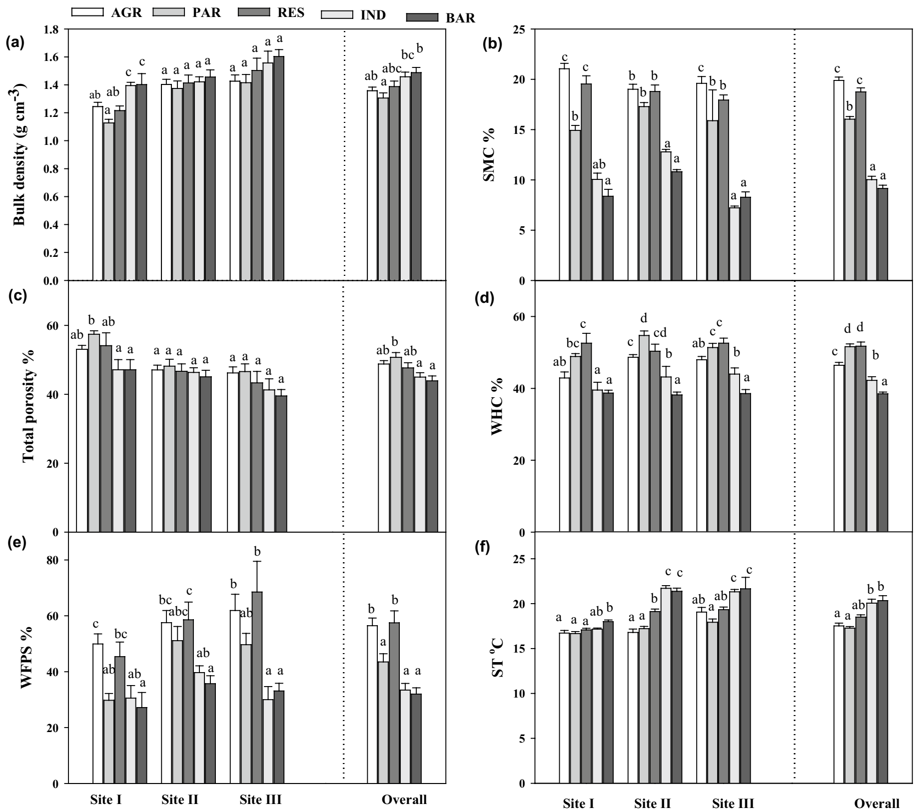

**Fig. 2** Variation in soil bulk density (**a**), soil moisture content (**b**) soil porosity (**c**), water-holding capacity (WHC) (**d**), water-filled pore space (WFPS) (**e**), and soil temperature (ST) (**f**) across different urban land uses classes (Data are mean ± SE). Different alphabetical letters written over the bars represent significant differences among different land use classes, i.e., AGR (agriculture), PAR (park), RES (residential), IND (industrial) and BAR (bare land) at $p < 0.05$ level

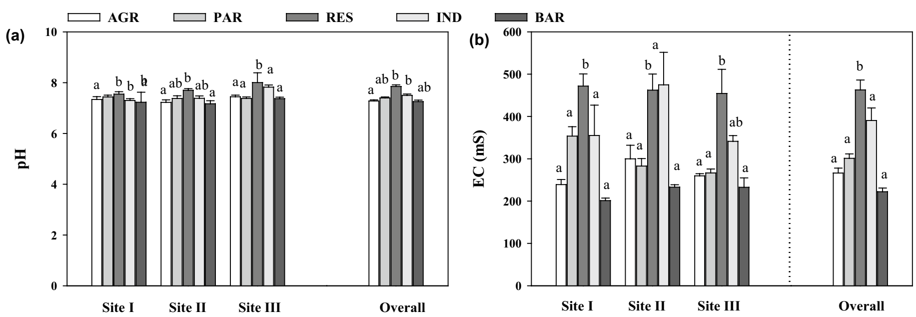

**Fig. 3** Variation in soil pH (**a**) and soil electrical conductivity (EC) (**b**) across different urban land uses classes (mean ± SE). Different alphabetical letters written over the bars represent significant differences among different land use classes, i.e., AGR (agriculture), PAR (park), RES (residential), IND (industrial) and BAR (bare land) at $p < 0.05$ level

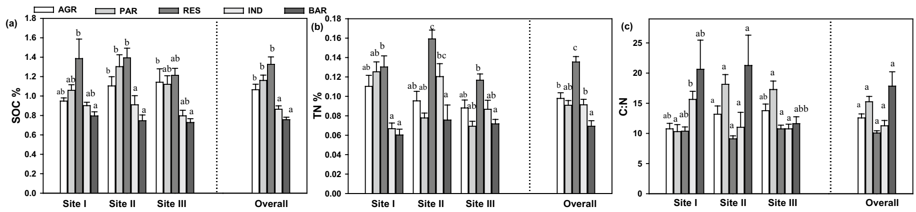


**Fig. 4** Variation in soil organic carbon (SOC) (**a**), soil total nitrogen (TN) (**b**) and C:N (**c**) (mean ± SE). Different alphabetical letters written over the bars represent significant differences among different land use classes, i.e., AGR (agriculture), PAR (park), RES (residential), IND (industrial) and BAR (bare land) at $p < 0.05$ level

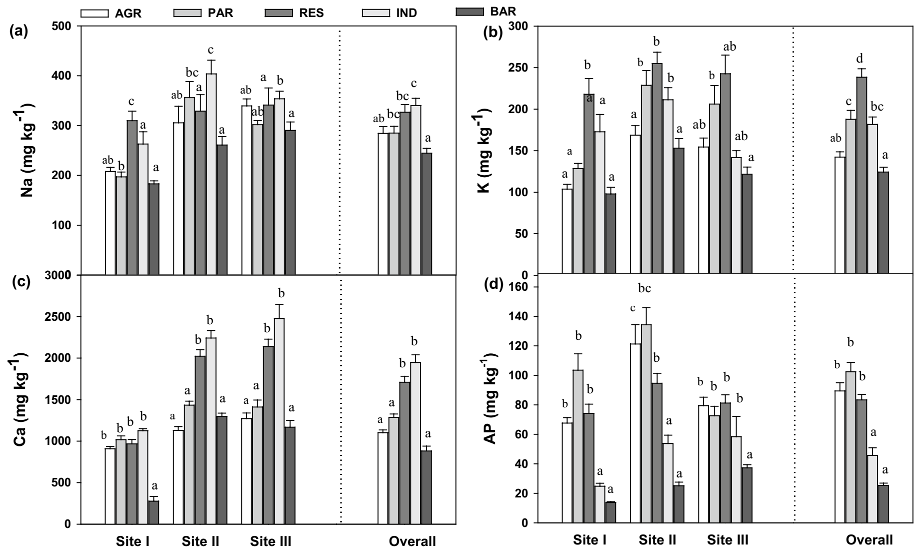


**Fig. 5** Variation in soil exchangeable sodium (Na) (**a**), potassium (K) (**b**) calcium (Ca) (**c**) and available phosphorus (AP) across different urban land uses classes (mean ± SE). Different alphabetical letters written over the bars represent significant differences among different land use classes, i.e., AGR (agriculture), PAR (park), RES (residential), IND (industrial) and BAR (bare land) at $p < 0.05$ level

showed overlapping in soil properties among the five land uses. Industrial and bare land was associated with BD and ST, whereas park and agricultural land exhibited an overlapping association with TP. Residential land use was more associated with SMC and WFPS than other land uses.

In DA analysis conducted for all variables, two canonical functions were considered accounting for a cumulative variance of 92.6% (Supplementary Table 3). The first function was related to SMC and separated agriculture, park and residential land with positive coefficients (high moisture content) from industrial and bare land with negative coefficients (low moisture content). Whereas, the second function was related to Ca concentration and WHC of soil, with bare land corresponding to negative coefficient values or lower Ca concentration and WHC. Industrial, residential and agricultural land use exhibited positive coefficient values or high Ca concentration and WHC (Fig. 7).

**Table 3** Two-way analysis of variance (ANOVA) for different soil physicochemical parameters across different land use classes, sites and land use class × sites interaction

| Factor | PH | EC | SMC | SOC | TN | C:N | Na | K | Ca | AP | BD | TP | WHC | WFPS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LU | 13.22*** | 26.14*** | 148.4*** | 9.65** | 12.11*** | 2.292ns | 11.51*** | 26.37*** | 43.34*** | 39.67*** | 5.74*** | 5.25*** | 49.9*** | 16.8*** |
| Site | 12.54*** | 4.27* | 38.74*** | 5.43** | 0.79ns | 4.31* | 13.68*** | 46.56*** | 93.41*** | 14.75*** | 20.77*** | 21.02*** | 4.96** | 9.13*** |
| LU × Site | 2.76** | 2.86** | 14.221 | 3.31** | 2.92** | 2.22* | 12.15*** | 5.99*** | 7.65*** | 12.27*** | 0.78ns | 0.97ns | 2.01ns | 1.15ns |

*EC* electrical conductivity, *SMC* soil moisture content, *SOC* soil organic carbon, *AP* available phosphorus, *BD* bulk density, *TP* total porosity, *WHC* water-holding capacity, *WFPS* water-filled pore space *TN* total nitrogen, Here, ns = not significant; * = significant at < 0.05, ** = significant at < 0.01, and *** = significant at < 0.001

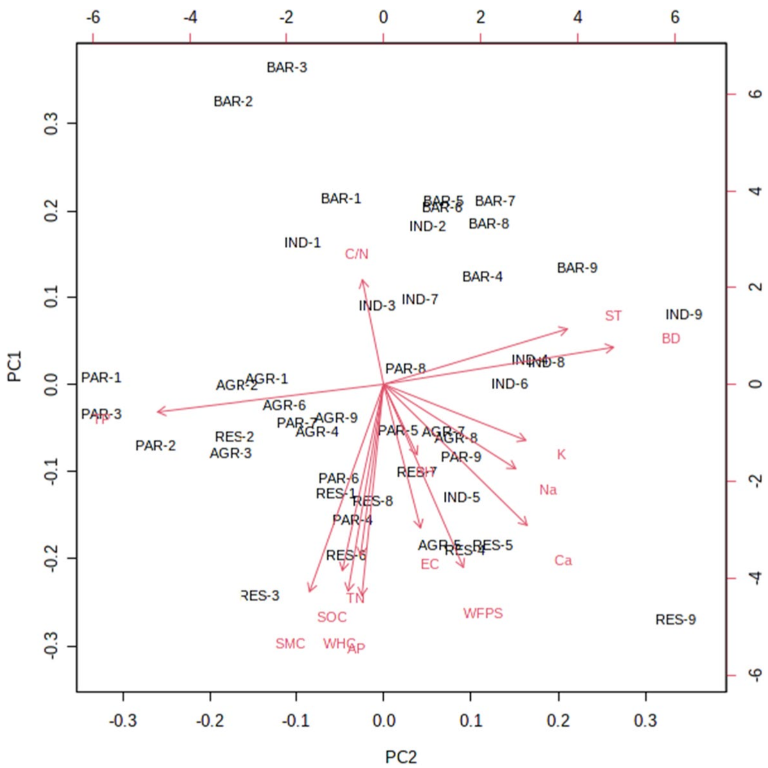


Fig. 6 PCA biplot of land use class-wise variation in different soil physicochemical properties

### 3.3 Spatial variation in soil properties in Ghaziabad

The three sites under study showed a significant impact on all the soil variables studied ($p < 0.05$, Table 3). As shown in Table 4, most of the soil characteristics were found to be lower in site I than in the other two sites. The site-wise comparison showed that BD and Ca content in soil was highest at site III (1.50 g $cm^{-3}$ and 1674 mg $kg^{-1}$, respectively) which was located nearest to the urban core, while the SOC and C:N content was highest in site II soil (1.09% and 0.17%, respectively). In contrast to SOC and C:N, no significant difference was found in TN between the three sites. The soil WHC, WFPS and macronutrient: Na and AP showed no significant difference between site II (44.47%, 36.55%, 232.9 mg $kg^{-1}$) and 56.19 mg $kg^{-1}$) and site III, but were significantly higher than site I (44.47%, 36.55%, 232.9 mg $kg^{-1}$ and 56.19 mg $kg^{-1}$, respectively). The soil pH value was significantly higher at site III (7.66) compared to the other two sites, whereas no significant variation was observed between site I and site II. Contrary to this trend, the exchangeable K content in site I and site II soil samples was higher (by 18% and 17%, respectively) than those in site III. SMC and TP value was observed to be lowest in site III.

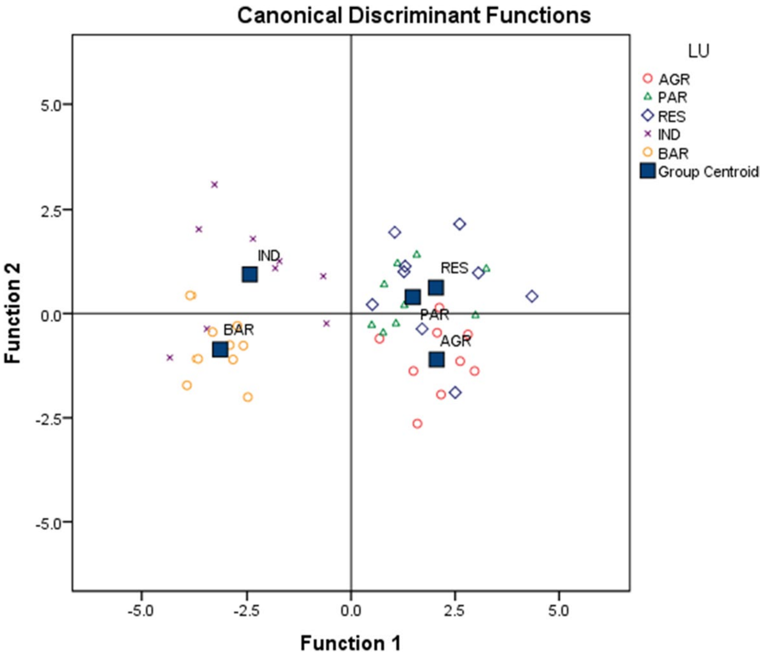


**Fig. 7** Scatter diagram of samples according to the sites of the five considered land use categories

**Table 4** Mean (± SE) surface soil properties (0–30 cm) of the three selected sites

| Soil properties | Site I | Site II | Site III |
|---|---|---|---|
| pH | 7.37 ± 0.042a | 7.36 ± 0.04a | 7.66 ± 0.071b |
| EC (μS $cm^{-1}$) | 324.1 ± 13.2a | 350.5 ± 20.2b | 310.9 ± 14.5ab |
| SMC (%) | 14.78 ± 0.51b | 15.73 ± 0.34c | 13.8 ± 0.49a |
| BD (g $cm^{-3}$) | 1.28 ± 0.024a | 1.41 ± 0.021b | 1.50 ± 0.044c |
| TP (%) | 51.59 ± 0.89c | 46.91 ± 0.76b | 43.37 ± 1.48a |
| WHC (%) | 44.47 ± 1.10a | 47.01 ± 1.016b | 46.87 ± 1.37b |
| ST (°C) | 17.12 ± 0.12a | 19.24 ± 0.33b | 19.96 ± 0.55b |
| WFPS (%) | 36.55 ± 2.32a | 48.50 ± 2.36b | 48.62 ± 3.64b |
| SOC (%) | 1.01 ± 0.047a | 1.09 ± 0.045b | 1.01 ± 0.041a |
| TN (%) | 0.09 ± 0.005 | 0.10 ± 0.007 | 0.09 ± 0.003 |
| C:N | 13.54 ± 1.09a | 14.55 ± 1.21b | 12.83 ± 0.51ab |
| Na (mg $kg^{-1}$) | 232.9 ± 7.88a | 330.8 ± 13.53b | 325.2 ± 8.35b |
| K (mg $kg^{-1}$) | 204.7 ± 15.1b | 203.3 ± 6.94b | 173.3 ± 8.06a |
| Ca (mg $kg^{-1}$) | 858 ± 30.36a | 1623 ± 46.7b | 1674 ± 66.1b |
| AP (mg $kg^{-1}$) | 56.19 ± 3.83a | 85.83 ± 5.26c | 65.81 ± 3.69b |

Different alphabetical letters written in a row represent significant differences among three sites at $p < 0.05$

*EC* electrical conductivity, *SMC* soil moisture content, *SOC* soil organic carbon, *AP* available phosphorus, *BD* bulk density, *TP* total porosity, *WHC* water-holding capacity, *WFPS* water-filled pore space, *TN* total nitrogen

**Table 5** Pearson correlation coefficient for various soil biophysical properties for overall land use classes

| | BD | TP | WHC | WFPS | ST | SMC | pH | EC | SOC | TN | C:N | Na | K | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP | −0.986** | | | | | | | | | | | | | |
| WHC | −0.118 | 0.110 | | | | | | | | | | | | |
| WFPS | 0.425** | −0.425** | 0.457** | | | | | | | | | | | |
| ST | 0.359** | −0.360** | −0.278** | −0.044 | | | | | | | | | | |
| SMC | −0.408** | 0.400** | 0.493** | 0.414** | −0.458** | | | | | | | | | |
| pH | 0.271** | −0.273** | −0.151 | −0.062 | −0.033 | −0.262** | | | | | | | | |
| EC | −0.115 | 0.088 | 0.318** | 0.238** | 0.108 | 0.250** | −0.315** | | | | | | | |
| SOC | −0.131 | 0.121 | 0.516** | 0.238** | −0.246** | 0.220** | −0.114* | 0.233** | | | | | | |
| TN | −0.160 | 0.140 | 0.407** | 0.165 | −0.066 | 0.230** | −0.088 | 0.337** | 0.496** | | | | | |
| C:N | 0.030 | −0.021 | −0.044 | 0.014 | −0.040 | −0.099* | −0.041 | −0.116* | 0.113* | −0.450** | | | | |
| Na | 0.002 | −0.019 | 0.207* | 0.026 | 0.204* | 0.015 | 0.012 | 0.274** | 0.084 | 0.144** | −0.100* | | | |
| K | −0.012 | 0.008 | 0.355** | 0.332** | 0.070 | 0.180** | −0.150** | 0.328** | 0.318** | 0.255** | −0.047 | 0.177** | | |
| Ca | 0.331** | −0.337** | 0.068 | 0.155 | 0.362** | 0.002 | −0.040 | 0.290** | 0.059 | 0.167** | −0.110* | 0.272** | 0.154** | |
| AP | −0.131 | 0.108 | 0.446** | 0.360** | −0.217* | 0.354** | −0.145** | 0.154** | 0.393** | 0.328** | −0.075 | 0.208** | 0.296** | 0.201** |

*EC* electrical conductivity, *SMC* soil moisture content, *SOC* soil organic carbon, *AP* available phosphorus, *BD* bulk density, *TP* total porosity, *WHC* water-holding capacity, *WFPS* water-filled pore space, *TN* total nitrogen

### 3.4 Correlation among different soil physiochemical parameters

Correlation analysis presented in Table 5 showed that SMC was strongly and positively correlated with WHC, WFPC and porosity, while negatively correlated with soil BD ($p < 0.01$). SOC and TN content also exhibited a significant positive correlation with WHC and WFPS ($p < 0.01$). Macronutrients like AP, K and Na were found to be positively correlated with EC, SOC, TN content and variables associated with soil-water characteristics like WHC and WFPS ($p < 0.01$). However, Ca was not found to be correlated with SOC and TN. Furthermore, Ca showed negative correlation with C:N and soil TP ($p < 0.01$). Similarly, bulk density was observed to be negatively correlated with C:N and TP. Among all the nutrients only AP showed significant positive correlation with SMC.

## 4 Discussion

### 4.1 Soil condition of the peri-urban region of Ghaziabad

Urban soils are constantly subjected to a range of disturbances that directly or indirectly affects the soil physical, chemical and biological properties (Pouyat et al., 2020). Soil physical properties that reflect water availability, retention, infiltration and soil-water balance are important for monitoring the soil quality and its functioning (Bünemann et al., 2018). In the present study, evaluation of the physical characteristics showed soil compaction attributed to high BD and low TP in the growing peri-urban region of Ghaziabad. Soil Bulk density which is very susceptible to changes in organic matter, water content and soil texture indicates the degree of soil compaction (Schoenholtz et al., 2000). Our result showed that measured BD was greater than 1.5 gm $cm^{-3}$ in 95% of samples, indicating resistance to plant roots, restricted movement and retention of water and nutrient (Hunt and Gikes, 1992; Somerville et al., 2020). The average value of BD in our result is comparable to the mean value reported by Chabukdhara et al. (2016) for Ghaziabad, but with high variability. Consistent with our result, studies from other cities around the world also recorded considerably higher bulk density in urban and peri-urban soil (Mao et al., 2014; Ferriera et al., 2015). Furthermore, the low TP value in the anthropogenically disturbed landscape as observed in the current work is in conformity with the findings of Upadhyay et al. (2021). The presence of utilities, denudation of topsoil and physical disturbances like soil amendment and trampling abrade soil aggregates and decrease soil pore size resulting in high bulk density and low porosity in urban soil compared to non-urban soil (Scharenbroch et al., 2005; Lorenz, 2015). Low porosity and high bulk density may result in low infiltration rate. Other physical properties such as WHC and WFPS are also observed to be influenced by soil compaction. WHC of soil primarily depends upon the soil structure, i.e., texture, aggregation and pore space, predicts the soil-water balance. Our result showed that WHC was below 50% for more than 67% of samples. Likewise, Upadhyay et al. (2021) also observed lower WHC in urban soil in comparison with non-urban soil. As indicated by descriptive analysis, the dispersion in physical properties in our study could be due to the inclusion of plots with no vegetation and management (bare land) to highly managed plots (park).

In comparison with physical properties, chemical properties exhibited a greater variance, except for pH. The soil pH varied from 6.5 to 9.13, comparable to the mean value reported by Chabukdhara et al. (2016). In our study, only 15% of samples were neutral, the rest 85% of the samples had soil pH values higher than neutral soil (pH = 7), which is considerably higher than the optimum range for plant growth recommended by Whitcomb (1987). Previous studies have also reported high pH values in urban soils (Pouyat et al., 2007; Li et al., 2013; Mao et al., 2014). Elevated soil alkalinity may further cause nutrient imbalance in urban soil (Kaye et al., 2006). For example, at alkaline pH, high Ca concentration may reduce the availability of phosphorus by forming Ca-P metal complex (Carriera et al., 2006). Although the soil EC in our study was in the range reported by an earlier study (Chabukdhara et al., 2016) but exhibited high variability (> 57%). High EC value in the soil as recorded in the present study can be indirectly ascribed to high salt concentration.

SOC is a crucial structural and functional component of soil and a key indicator of soil quality (Stockmann et al., 2015). Average SOC content and C:N ratio in the current study were found to be below the range conducive for plant growth (Li et al., 2013) and suggest in general organic matter deficiency in the soil of the study area. Although the SOC content was lower than the required amount but was higher than the background value (< 0.75%) reported by previous studies conducted in the Gangetic plain (Singh et al., 2012; Arora and Sanjay, 2020). Our result showed that more than 75% of samples from peri-urban region of Ghaziabad contained SOC concentrations higher than the agricultural system in the same region (Verma et al., 2013; Kumar et al., 2016). Moreover, soil investigations from other cities also noted higher SOC content and constrained C:N ratio in urban landscapes (Pouyat et al., 2002; Cleveland & Liptzin, 2007; Vasenev et al., 2013; Yang et al., 2021). High SOC in urban soils is derived from both natural and anthropic sources. The establishment of green coverage for aesthetic, organic waste input from residential areas, and disposal of waste from industrial and residue from fossil fuel combustion may contribute to relatively stable forms of carbon (Yang et al., 2021; Vasenev & Kuzyakov, 2018). The observed wide variation could be possibly due to the varying nature of urban soil organic matter from natural humic to anthropic organic particles and suggest a remarkable interference (Lorenz & Lal, 2009).

The TN content was evaluated to be comparable to the critical level of nitrogen in the soil and indicates N is not a limiting factor for plant growth in the area (Horneck et al., 2011). Urban areas have been witnessed to accumulate N through wet and dry deposition in the form of effluent discharge from industries, vehicular exhaust, and excessive N fertilization (Kaye et al., 2006; Fang et al., 2019; Yu et al., 2022). High concentrations of reactive N may have significant implications on the environment. N enrichment in urban soil has been speculated to impact important soil processes like decomposition and nutrient cycling triggered by the alteration in the soil microbial community (Wan et al., 2020).

Assessment of macronutrients showed that overall the nutrient level fell within the range required to support plant growth. While the concentration of Ca in the peri-urban soil of this region was excessive. High nutrient concentration compared to corresponding background values reflect the significant impact of human interference on soil fertility (Pratap et al., 2017; Golui et al., 2022). In concurrence with our results, several investigations documented high nutrient concentrations in urban, especially base cations (Pouyat et al., 2007; Nelson et al., 2022). High P and K in disturbed soil are contributed by extensive use of fertilizer and pesticide in managed green spaces, sewage sludge and effluent. High Ca concentration comes from the deposition of eroded construction materials such as concrete and limestone (Pickett & Cadenasso, 2009; Li et al., 2013). The abundance of divalent Ca ions may have consequences on the absorption of monovalent K in soil colloids. (Li et al., 2013).

### 4.2 Effect of land use on soil physicochemical properties

Ghaziabad is an industrial district, formerly dominated by agriculture and has been marked by dramatic changes in land use patterns (Randhawa & Marshall, 2014). The present investigation showed that the land use classes associated with changing landscape of the peri-urban region had a significant impact on the surface soil physicochemical properties. This variation across the selected land use classes can be largely attributed to the difference in their disturbance, management regime, resource apportionment and particularly to their vegetation cover as also observed by other studies (Pouyat et al., 2007; Silva et al., 2017; Upadhyay et al., 2021).

In this study, the heavily disturbed industrial and residential land use had a higher bulk density in comparison with other anthropic land uses. This possibly reflects the soil compaction caused by mechanical disturbances such as modifications of parent material (soil sealing, incorporation of foreign material) transportation and construction activities. Earlier studies have also characterized built-up areas with high bulk density and compacted soil (Edmondson et al., 2011; Pouyat et al., 2020). High soil bulk density may further influence other soil properties like porosity, water retention capacity and effective moisture content (Yang et al., 2021; Nawaz et al., 2013). Our result for other physical variables is consistent with this assertion. Industrial land use with high bulk density and little vegetation cover showed low porosity, moisture content, water-holding capacity and water-filled pore space as well. An increase in bulk density in organic matter depleted soil reduces the total pore space volume, limiting the infiltration rate and the diffusion of water and gases (Yang & Zhang, 2015).

Urban green spaces are frequently irrigated to optimize the soil moisture content for greater plant productivity (Zhu et al., 2006). However, in our study soil of the park contained low moisture content. We suspect the low moisture content could be related to the high infiltration rate owing to the preferential flow of water to the subsoil. Yang and Zhang (2011) also observed a higher infiltration rate for lawns with tree species. SOC has been known to increase the retaining capacity of the soil. Land uses receiving irrigation at regular intervals such as agriculture and park exhibited low soil temperature possibly due to their high soil moisture content.

Similar to soil bulk density, soil pH was higher in residential and industrial land use than in the other land use types most likely due to the prevalence of removal and mixing of the original soil with extraneous materials such as construction rubble and other activities like waste disposal in these areas. Previous studies have also documented the impact of the addition of such materials on the pH of urban soil (Li et al., 2013; Jorat et al., 2020). Construction materials such as brick, cement, and mortar are rich in alkalizing elements such as calcium and/or magnesium carbonates and may significantly contribute to soil alkalinity (Jim, 1998; Scharenbroch et al., 2005; Asabere et al., 2018). Moreover, we observed a higher concentration of exchangeable Ca in afore mentioned land uses and a significant positive correlation between pH and Ca. The EC measured was greatest in residential soil compared to other land uses presumably due to higher ion sorption capacity and high concentrations of base cations availed by their high porosity and water-filled pore space (Shannon et al., 2020).

Soil functions as source as well as sink for carbon, depending on the interactions between ecological processes (Srivastava et al., 2015). Urban land use and accompanying anthropogenic activities can greatly affect the potential of soil to retain and store carbon (Pouyat et al., 2010; Upadhyay & Raghuvanshi, 2020). In the present study, the occurrence of soil organic carbon content was significantly lower in industrial in comparison with other human modified land uses, perhaps due to its low vegetation cover, greater surface horizon destruction, and lack of organic matter accumulation (Livesley et al., 2016). Concurrently, the net difference in SOC content among other anthropogenic land use was non-significant, suggesting that the synergistic impact of management activities (fertilization, litter removal, and disposal of domestic waste) may outpace the impact of vegetation cover on SOC (Canedoli et al., 2020).

TN concentration was significantly affected by land use classes and was highest in the soil from residential (Fig. 3). This can be related to specific sources of N in residential areas such as deposition of NOx from automobiles and industries, wide application of chemical fertilizer for maintenance of residential gardens, domestic waste, urine and feces from pets (Lorenz & Lal, 2009). In support of our result, Vasenev and Kuzyakov (2018) also reported higher N stock in residential soils than that in industrial and other natural areas. The result of ANOVA showed that variation in corresponding C:N across the five land use classes was non-significant (Table 3).

Generally, it is presumed that anthropogenic disturbances have a concentrating effect on soil nutrient levels. Evidently, we found significantly higher concentrations (beyond the recommended limit) of macronutrients in disturbed and managed land uses in comparison with undisturbed and unmanaged bare land. Also, we observed significant variation between the four anthropogenic land use with varying degree of disturbances which suggest that these nutrients are consistently affected by urban factors as observed by Zhang et al. (2010), Li et al. (2013) and Nelson et al. (2022). Exchangeable Ca and Na concentrations were recorded to be highest in industrial soil, while K was highest in residential soil. We suspected the high Ca concentration in industrial soil could be because of the incorporation of alkaline materials like limestone, concrete, etc., during the built-up process and their vicinity to roads with heavy vehicular density. Deposition of particulate matter comprising Ca is another significant contributor to Ca concentration in the industrial area (Li et al., 2013). While high Na concentration could be probably due to nutrient imbalance caused by high soil pH as observed in our result (Messenger et al., 1986; Mao et al., 2014). It was assumed that the high concentration of K in residential land use emanated from the domestic use of fertilizer and pesticides (Taylor & Lovell, 2015). In contrast to these macronutrients soil available, phosphorus followed the same trend as SOC and was lowest under industrial land use, suggesting that organic matter is the primary source of phosphorus in our study area.

### 4.3 Key determinants of variation in soil properties across the land use

Extension of peri-urban settlement onset by urban-led demand for food and space creates a complex pattern of land use and land cover differing in their biophysical characteristics (Antrop, 2000; Hermosilla et al., 2012). Consequently, soil properties of these pervasive land use may vary greatly depending on the dominant anthropogenic activity (Pickett & Cadenasso, 2009). In accordance with the result of ANOVA, PCA suggests variation in soil physicochemical properties across the selected land use classes (Fig. 6). Highly disturbed industrial land use was defined by BD while, land use with low mechanical disturbances, i.e., park and agricultural land displayed an association with TP. Khaledian et al. (2017) also observed a similar association between BD and urban land use. Moreover, the association of residential land use with SMC and WFPC support our assertion that greater vegetation cover (including trees, shrub and herbaceous species) and activities related to their management (irrigation) contributed to high moisture content. Similarly, the grouping of variables in the PCA biplot indicated that physical properties were more related to land use with higher mechanical disturbances, whereas chemical properties were inclined toward land uses with higher anthropogenic resource apportion.

Discriminant analysis suggests that among the 15 subsets of variables, SMC (Function 1), Ca and WHC (Function 2) were the dominant variables responsible for the separation of the five land use types into three clusters. In particular, bare land with little or no vegetation cover, no disturbance and management was separated by both functions from the other typical anthropogenic land uses. Moreover, the first variate (SMC) distinguishably separated highly disturbed industrial land use from agriculture, park and residential land use. While the three land uses with relatively high vegetation cover clustered together. This suggests considerable overlapping in soil characteristics among these land uses probably due to their similarity in resource input from both natural (organic matter accumulation) and anthropogenic sources (fertilization and domestic waste). Further, park and residential land use grouped above origin (showed positive coefficient for the second function), which suggests these land use differentiated from agricultural land in their high Ca concentration and WHC. Overall, the result of the analysis suggests the difference in soil properties across land use classes was majorly due to the direct impact of disturbances rather than the indirect impact (Pouyat et al., 2007).

### 4.4 Spatial heterogeneity

Urban development process may create mosaic of patches with distinct features. These patches may vary in size and configuration depending on the degree and magnitude of prevailing urban factors such as population density, infrastructure requirement and pollution emission (Pouyat et al., 2009). These patches instigate additional spatial heterogeneity in soil characteristics, which may overlie the effect of change in land use and cover (Pickett & Cadenasso, 2009). In the present study, site-wise comparison was made to have an overview of the response of soil properties to dynamic urban land use for the study area. Our result showed that soil physicochemical properties measured were subject to high spatial variability across the sites, suggesting the heterogeneous distribution of these properties engendered by locally relevant urban factors. Most of the parameters were lower for site I, located farthest from the urban core in comparison with the other two sites which are relatively proximate to the city. Areas closer to urban centers are likely to be more affected by urban factors due to the greater intensity of transportation, per capita use, built-up utilities and energy consumption (Lu et al., 2009; Pouyat et al., 2020). Moreover, Luo et al. (2014) reported a significant negative correlation between carbon density and distance to the urban core. Furthermore, a higher concentration of macronutrients, high soil pH and bulk density in sites II and III in comparison with site I evidence the greater influence of anthropogenic disturbances on soil properties with increasing proximity to the urban center. The comparison between sites I and II showed higher bulk density, soil temperature and Ca accumulation at site III. This could be due to greater mechanical disturbance at site III, as this site had large-scale industries and was more commercialized than site II. While greater concentration of SOC, SMC, EC and high C:N in Site II reflect better management practices at site II with more dense residential settlements. The observation for the entire region suggests significant spatial variation across the study area and supports the assertion that variation in soil properties in urban landscape is more related to the direct impact of urban factors (physical disturbances and management practices) rather than indirect impact (urban heat land, altered hydrology and biodiversity) (Pouyat et al., 2007; Khaledian et al., 2017).

## 5 Conclusion

The present study investigates the status of soil quality in the peri-urban region of Ghaziabad. We found that the soil in this region was notably compacted and alkaline. The soil had low organic carbon (1.04%) but was enriched in other nutrients including TN, Ca, K, Na and AP. The soil properties exhibited wide variability, indicating the prevalence of external factors in shaping the trends for soil characteristics in an urban ecosystem. Further, the result of the study showed significant variation in soil physicochemical properties among the urban-related land uses. Residential and industrial land use with higher mechanical disturbances and extraneous nutrient inputs had greater BD, EC and macronutrients such as Ca, and K. On the contrary, in the case of park land use, human modifications such as artificial fertilization and irrigation maintained the soil conditions, i.e., high TP, WHC and AP optimum for plant growth. We speculated that the response of soil properties to anthropogenic land uses largely depended on dominant human activities such as physical disturbances, soil and plant management activities and vegetation cover. Among the studied variables BD, WHC and Ca were identified to be the most discerning variables for grouping the land use types. Moreover, the site-wise comparison indicates that the effect of these urban factors on soil was non-uniform across the study area. The spatial heterogeneous pattern of soil properties may lead to the formation of discrete land parcels as asserted by others also.

The present observational study could be an important step toward understanding how soils are affected by dynamic land use patterns in a demographically and socio-economically transforming landscape. Such regional and local studies would help in developing scientifically informed practical measures to improve and maintain the soil quality. Long-term experiments across multiple urban/peri-urban sites with different land use classes/types are essential to confirm the robustness of the results obtained in this study. We recommend further detailed research exploring the direct and indirect impact of anthropogenic land uses on soil characteristics to comprehend the magnitude and extent of the influence of these changes on soil structure and functioning. This will enable city planners and policy makers to form sustainable planning and management strategies for urban development in equilibrium with ecosystem conservation and restoration. A rational development plan can slow down soil degradation and would help in sustaining the vital ecosystem services provided by the soil and would help in achieving the ultimate goal of sustainable development.

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**Data availability** Authors confirm the material and data supporting the findings of the proposed study are supplemented with the article in a separate file.

**Code availability** Not Applicable.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

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# University of Delhi
# दिल्ली विश्वविद्यालय
Examination Wing, North Campus, Delhi-110007

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**Print Date : 03/08/2023**

**Student Id : S144257**

## *Provisional Certificate*

*(TO WHOMSOEVER IT MAY CONCERN)*

***** **This is to certify that Mr./Ms. MEENAKSHI CHAURASIA, Enrolment No. 17DBOTPLBO000005 Faculty/Department of Botany, who presented a thesis on 'Impact of Land use on Soil Carbon and Nitrogen Status in Peri-Urban Landscape' in her name for the degree of Doctor of Philosophy (Ph.D), has been declared to have qualified for the award of the Degree of Doctor of Philosophy(Ph.D) of the University of Delhi, vide University Notification REF.NO.EXAM.BR./PH.D/RESULT/2023/15 at Result Sr.No.:136 Dated 31/07/2023.**

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(S.K. DOGRA)
JOINT REGISTRAR EXAMINATIONS

(PROF. AJAY KUMAR ARORA)
CONTROLLER OF EXAMINATIONS

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ई-डिस्ट्रिक्ट के अन्तर्गत जारी

# उत्तर प्रदेश शासन

**FORM OF CERTIFICATE TO BE PRODUCED BY OTHER BACKWARD CLASSES APPLYING FOR APPOINTMENT TO POSTS UNDER THE GOVERNMENT OF INDIA**

जिला बनारस

तहसील बनारस

आवेदन क्र० 231970030136726

प्रमाणपत्र क्र० 672233060633

जारी दिनांक: 04/08/2023

This is to certify that **MEENAKSHI CHAURASIA** son/daughter of **ASHOK KUMAR CHAURASIA** mother's name **SANDHYA DEVI** R/o **B34/130A5-3 MANAS NAGAR VISTAR DURGAKUND** Tehsil बनारस District **बनारस** in the Uttar Pradesh state belongs to the **Tamoli** Community which is recognized as a backward class under the Government Of India, Ministry of Welfare Resolution No. 12011/68/93-BCC(C) dated 10th Sept. 1993, published in the Gazette of India Extra Ordinary Part-I Section-I Dated 13th Sept. 1993 and onwards till date.

**MEENAKSHI CHAURASIA** and/or his family ordinarily reside (s) in the **B34/130A5-3 MANAS NAGAR VISTAR DURGAKUND** of the Tehsil **बनारस** District **बनारस** of the Uttar Pradesh state.

This is also to certify that he/she does not belongs to the persons/sections (Creamy Layer) mentioned in column 3 of the schedule to the Government Of India, Department of Personnel & Training O.M.No. 36012/22/93 Estt(SCT) dated 08-09-93 or the latest notification of the Government of India which is modified vide OM No. 36033/3/2004 Estt.(Res.) dated 09/03/2004 and further modified vide OM No. 36033/3/2004-Estt. (Res.) dated 14/10/2008 or the latest notification of the Government of India.

जारी कर्ता केन्द्र: विवेक कुमार सिंह,विवेक सिंह गिलट बाजार

पद: विवेक कुमार सिंह, केन्द्र प्रभारी

स्थान : Gilat Bazar,बनारस,Varanasi

दिनाँक: 04/08/2023

हस्ताक्षर एंव मुहर

YOGENDRA SHARAN SHAH Digitally Signed by YOGENDRA SHARAN SHAH O=PERSONAL S=UTTAR PRADESH

सक्षम अधिकारी.तहसीलदार

डिजिटल हस्ताक्षरित

बनारस,बनारस

दिनाँक: 04/08/2023

यह प्रमाण पत्र इलेक्ट्रॉनिक डिलिवरी सिस्टम द्वारा तैयार किया गया है तथा डिजिटल सिग्नेचर से हस्ताक्षरित है। सम्बन्धित केन्द्र के अधिकृत कर्मी द्वारा प्रमाणित किया गया है। यह प्रमाण पत्र वेबसाइट http://edistrict.up.gov.in पर इसका पहले आवेदन क्र० फिर प्रमाणपत्र क्र० अंकित कर,सत्यापित किया जा सकता है।