

**AIR POLLUTION TOLERANCE INDEX
AND ANTICIPATED PERFORMANCE
INDEX OF SOME PLANT SPECIES IN
MORANG DISTRICT, NEPAL**



**A Dissertation Submitted for the Partial Fulfillment of the Requirements of a
Master's Degree in Botany**

By

Uma Shrestha

Symbol No: 938/077

TU Reg no: 5-2-37-842-2016.

Batch: 077/078

Department of Botany

Amrit Campus

Tribhuvan University

Lainchour, Kathmandu

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Declaration

I "Uma Shrestha", hereby declare that the research work in, "**Air Pollution Tolerance Index and Anticipated Performance Index of Some Plant Species in Morang District, Nepal**" is carried out by only me for the completion of Master degree in Science in Botany. All the procedures are done under the supervision of Dr. Anjana Devkota and Dr. Mukti Ram Paudel, Central Department of Botany and Prof. Dr. Bipana Devi Acharya, Amrit Campus.

I also declare that no parts of this research work has been submitted or published elsewhere for any academic purposes. This is the original copy of my research work with all the sources of information acknowledged.

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Recommendation

This is to certify Ms. Uma Shrestha has prepared this research entitled " **Air Pollution Tolerance Index and Anticipated Performance Index of Some Plant Species in Morang District, Nepal**" in this Department for the partial fulfillment of the requirement for the completion of Masters Degree in Science (Botany) for Tribhuvan University, Kathmandu Nepal. This research work was carried under our supervision and Guidance.

To the best of our knowledge, this work has not been submitted for any other academic purposes. I therefore, recommend the research for acceptance and approval.

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Letter of Approval

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Uma Shrestha

Abstract

Plant species around industrial areas can effectively interact with the pollutants and can mitigate the air pollution. The research investigated the air pollution tolerance index (APTI) and anticipated performance index (API) of various 28 plant species in Biratnagar and its adjoining areas in Morang district. APTI is calculated using four biochemical parameters (total chlorophyll content, ascorbic acid, pH of leaf extract and relative water content) of the plants whereas API is based on obtained APTI values, socio-economic and morphological parameters. Leaves along with dust were sampled from highly polluted industrial (Budhi Ganga and Gidhaniya), roadside, residential and less polluted Mahendra Morang campus areas during winter (January, 2024). Highest dust accumulation was in the industrial areas ($3.23\text{mg}/\text{cm}^2$) and lowest at campus areas ($0.32\text{mg}/\text{cm}^2$). Leaf traits (leaf area, leaf length and width and specific leaf area) were highly reduced at industrial areas followed by roadside and residential areas rather than campus area. Highest reduction was exhibited by *Azadirachta indica* in leaf area (13.25%), *Ficus religiosa* (20.48%) in SLA, *Mangifera indica* (33.81%) in leaf length and *Psidium guajava* (7.72%) in leaf width respectively from industrial areas. APTI values ranged from 6.58 to 33.69 in industrial, 5.90- 44.06 at roadside, 7.86-15.55 in residential and 6.77-14.44 in campus area. Notably, *Bombax ceiba* exhibited the highest APTI (44.06) and *Cryptomeria japonica* the lowest APTI (5.90) within the roadside. *Azadirachta indica*, *Bombax ceiba*, *Delonix regia*, *Ficus religiosa*, *Nephelium litchi* demonstrated high tolerance indicated by their elevated APTI values. Conversely, *Aegle marmelos*, *Moringa oleifera* and *Punica granatum* were identified as sensitive plants. In terms of API, *Ficus religiosa* (93.75) emerged as best performer followed by, *Bombax ceiba* (81.25), *Nephelium litchi* (75), *Artocarpus heterophyllus* (62.5), *Ficus benghalensis* (62.5), *Mangifera indica* (62.5) and *Neolamarckia cadamba* (62.5). Tolerant plants like *Ficus religiosa*, *Bombax ceiba*, *Nephelium litchi*, *Artocarpus heterophyllus*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* are recommended for plantation at urban green belts development on the other hand, sensitive plant like, *Aegle marmelos*, *Moringa oleifera* and *Punica granatum* are recommended to use as bio indicators to measure air pollution.

Keywords: APTI, Leaf traits, Dust, Industrial, Tolerant plant.

शोधसार

औद्योगिक क्षेत्र वरपरका वनस्पति प्रजातिहरूले प्रभावकारी रूपमा प्रदूषकहरूसँग अन्तरक्रिया गर्न सक्छन् र वायु प्रदूषणलाई कम गर्न सक्छन्। मोरङ जिल्ला र त्यसका आसपासका विभिन्न २८ प्रजातिका विरुवाहरूको वायु प्रदूषण सहिष्णुता सूचकांक (APTI) र अनुमानित कार्यसम्पादन सूचकांक (API)को अध्ययन गरेको थियो। APTI को लागि विरुवाको चार बायोकेमिकल मापदण्डहरू (Total chlorophyll content, Ascorbic acid, leaf extract of pH and Relative water content) प्रयोग गरेर गणना गरिन्छ भने API को लागि प्राप्त APTI मानहरू, सामाजिक-आर्थिक र रूपात्मक मापदण्डहरू प्रयोग गरिन्छ। जाडो (जनवरी, २०२४) महिनामा अत्याधिक प्रदूषित औद्योगिक, सडक छेउ, आवासीय र कम प्रदूषित महेन्द्र मोरङ क्याम्पस क्षेत्रहरूबाट धूलोसहित पातहरूको नमूना संकलन गरिएको थियो। पात (प्रति क्षेत्र) मा सबैभन्दा बढी धूलो औद्योगिक क्षेत्रमा (३.२३ ननरक्र^३) र सबैभन्दा कम क्याम्पस क्षेत्रका पातहरूमा (०.३२ mg/cm²) जम्मा भएको देखियो। पातको विशेषताहरू (पात क्षेत्र, पातको लम्बाइ र चौडाइ र Specific leaf area) औद्योगिक क्षेत्रमा धेरै कम भएको पाइयो भने क्याम्पस क्षेत्रमा बढी पाइयो। सबैभन्दा कम पातको क्षेत्रफल निम (१३.२५%) ले देखाएको थियो। क्रमशः औद्योगिक क्षेत्रबाट SLA मा पिपल (२०.२५%), पातको लम्बाइमा आँप (३३.८१%) र पात चौडाइमा अम्बाले (७.७२%) देखाएको थियो। औद्योगिक क्षेत्रमा ६.५८ देखि ३३.६९ सम्म, सडक छेउमा ५.९०- ४४.०६, आवासीयमा ७.८६-१५.५५ र क्याम्पस क्षेत्रमा ६.७७-१४.४४ सम्म APTI का मानहरू थिए। उल्लेखनीय रूपमा, सिमलले सडकको छेउमा उच्चतम APTI(४४.०६) र धुपीले सबैभन्दा कम APTI(५.९०) देखाएको थियो। APTI को मानहरू अनुसार निम, सिमल, गुल्मोहर, वर, पिपल, लिचिले उच्च सहिष्णुता प्रदर्शन गरेको पाइन्छ। यसको विपरित, वेल, शितल चिनि र अनारलाई संवेदनशील बोटको रूपमा पहिचान गरियो। API को सन्दर्भमा, पिपलको (९३.७५) धेरै थियो र त्यसपछि सिमल (८१.२५), लिचि (७५), कटहर (६२.५), वर (६२.५), आँप र कदम (६२.५) को थियो। सहर हरियो बेल्टको विकासमा पिपल, सिमल, लिचि, कटहर, वर, आँप र कदम जस्ता संवेदनशील बोटहरू रोपन सिफारिस गरिन्छ भने संवेदनशील बोटहरू जस्तै, वेल, शितल चिनि र अनार वायु प्रदूषण मापन गर्न जैविक संकेतक रूपमा प्रयोग गर्न सिफारिस गरिएको छ।

मुल शब्दहरू : APTI, औद्योगिक, धूलो, सिमल, सहनशील वनस्पति।

List of Abbreviations and Acronyms

AQI: Air Quality Index

APTI: Air Pollution Tolerance Index

API: Anticipated Performance Index

AA: Ascorbic Acid content

CFCS: Chloroflourocarbon

COPD: Chronic Obstructive Diseases

DMSO: Dimethyl Sulfoxide

DOI: Department of Industry

EDTA: EthylenediamineTetra-acetic Acid

MAI: Metal Accumulation Index

PM: Particulate Matter

pH: Potential of Hydrogen

RWC: Relative Water Content

ROS: Reactive Oxygen Species

RSP: Respirable Suspended Particles

SLA: Specific Leaf Area

TChl: Total Chlorophyll content

TSP: Total Suspended Particles

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1. Introduction

1.1 Background

Pollution is the addition of contaminants or pollutants into the natural environment which causes adverse impacts on it. Air pollution is the mixing of indoor and outdoor environments by any kinds of chemical, physical or biological agents which alters the environment. Particulate matter, gaseous (ozone, nitrogen dioxide, volatile compounds, carbon monoxide and sulfur dioxide) mainly contribute to air pollution (Harrison *et al.* 2002). Urban air pollution has become a significant issue in both developing and developed countries, posing threats to plants, animals and ecosystems globally (Rai & Panda, 2014). Pollution contributes to the degradation of livelihoods, ecosystem functioning, and biodiversity, ultimately leading to global warming and climate change (Fuller *et al.* 2022). Urban air quality in cities has been declining due to gaseous pollutants from increased vehicular traffic, negatively impacting human health (Deswal *et al.* 2019).

Rapid urbanization is a major factor contributing to the decline in air quality, particularly in developing countries (Zhang *et al.* 2022). Urban areas are hubs of resource consumption, leading to significant air pollution (Qian *et al.* 2022). Industrialization further contributes to air pollution by emitting gaseous pollutants, which are precursors to photochemical smog and acid rain. These pollutants can cause respiratory issues, such as asthma and are linked to serious health problems like lung cancer and global warming due to ozone depletion (Munsif *et al.* 2021).

Urbanization is on the rise in Nepal, contributing to increased air pollution. Key factors for air pollution in urban areas include industrial activities, vehicle emissions and poor solid waste management (Paudel & Neupane, 2020). On the basis of Environmental Performance Index, Nepal air quality ranked at 165th position out of 180 in 2024 (Block *et al.* 2024). The number of registered motor vehicles in Nepal surged from 218,737 in 2022 to 575,583 in 2023, including 183,078 motorcycles, 286 microbuses, 3,239 minibuses, 2,246 buses, 9,849 cars/vans and 2,519 tractors (CEIC, 2023). Air pollution has significantly damaged vegetation, reduced crop yields and lowered forest productivity (UNEP & C4, 2002).

Plants are directly exposed to pollutants, which can disrupt their life processes. Due to their sensitivity, plants serve as bioindicators of air pollution (Karmakar *et al.* 2021). They

also act as sinks for chemicals and pollutants emitted by industries and vehicles, making them valuable for developing green belts to mitigate air pollution (Tripathi & Gautam, 2007). Plants and pollution are closely linked within the biological ecosystem, with plants being particularly vulnerable to ambient air pollution. As stationary organisms, plants are continuously exposed to atmospheric pollutants, which can injure them and affect their physiological and biochemical processes (Sharma *et al.* 2007; Jitin & Jain, 2014). Air pollution significantly impacts plant processes, such as the photosynthetic system, leaf longevity and carbon assimilation. However, plants can also be used as an alternative to control air pollution through mechanisms like deposition, absorption, adsorption and accumulation of pollutants. Certain green plants, including *Populus euroamericana*, *Jacaranda* sp., *Callistemon* sp., *Eucalyptus* sp., *Grevillea robusta*, *Ficus religiosa*, play a crucial role in improving air quality by acting as sinks for harmful pollutants through gas exchange (Ter *et al.* 2020).

Leaves are particularly sensitive to air pollution and are often the first part of a plant to be affected (Rai & Panda, 2014). Due to their large surface area, plant leaves tend to trap dust particles from the air (Prajapati & Tripathi, 2008). The accumulation of pollutants on leaf surfaces creates stress that affects various biochemical parameters, including chlorophyll content, ascorbic acid levels, relative water content (RWC) and leaf pH (Yadav & Pandey, 2020). Dust deposition on leaves impacts the quality and quantity of light that reaches the plant surface, directly altering photosynthetic activities (Javanmard *et al.* 2019). As dust load on leaves increases, there is a rise in RWC and ascorbic acid levels, while chlorophyll content and leaf pH decrease (Pandey *et al.* 2015; Bharti *et al.* 2017; Karmakar *et al.* 2021; Sapkota & Shrestha, 2024). Specific Leaf Area (SLA) is an important indicator of how plants adapt to their environment, reflecting the rate of photosynthesis, biomass production, and respiration in different plant species (Liu *et al.* 2018).

Chlorophyll content serves as the primary photoreceptor in photosynthesis, crucial for capturing light energy. Chloroplasts, which are the initial sites impacted by dust accumulation on leaves, leading to a reduction in chlorophyll levels (Tripathi & Gautam, 2007). Under stress conditions, chlorophyll content decreases due to photochemical reactions such as oxidation, reduction and the generation of reactive oxygen species (ROS). This decline can result from changes in the morphological, physiological and biochemical characteristics of the plant (Pathak *et al.* 2011). Chlorophyll content can vary over time and between species depending on different environmental conditions (Giri *et al.* 2013). Ascorbic acid, a universal non-enzymatic antioxidant, plays a critical role in protecting the

thylakoid membranes from stress and regulating cell division and expansion. It enhances the plant's tolerance to abiotic stress by promoting growth, photosynthesis, transpiration and defense mechanisms (Akram *et al.* 2017). When calculating the air pollution tolerance index (APTI), ascorbic acid is significant because it is multiplied with the sum of total chlorophyll content and pH, making it a key determinant of a plant's tolerance level (Banerjee *et al.* 2022). The pH of leaves is a crucial stress indicator that plays a significant role in the physiological processes of plants (Karmakar & Padhy, 2019). Leaf pH influences stomatal permeability, which affects how pollutants enter the plant (Molnar *et al.* 2020). Plants with higher pH values are generally considered more tolerant to pollution (Singh & Verma, 2007). A shift in leaf pH towards acidity is often caused by the presence of sulfur dioxide (SO₂) and nitrogen oxides (NO_x) in the air, which diffuse into the stomata and interact with water (Banerjee *et al.* 2022). Relative water content (RWC) in plants is essential for balancing water uptake and release, particularly under harsh conditions. RWC helps to maintain physiological stability by increasing the transpiration rate (Gholami *et al.* 2016). Higher RWC enhances the plant's resistance to stress, making it more tolerant to the adverse effects of dust and pollutants (Nadg'orska–Socha *et al.* 2017).

The response of green plants to air pollution can be assessed by analyzing the air pollution tolerance index (APTI) and the anticipated performance index (API). APTI measures a plant's ability to withstand air pollution by evaluating parameters such as total chlorophyll content, total ascorbic acid, leaf extract pH and relative water content (Singh & Rao, 1983). Plants with higher APTI values are considered more tolerant to air pollution, while those with lower values serve as bio-indicators of pollution (Sapkota & Shrestha, 2024). APTI is crucial for studying the effects and interactions of air pollution on plants, offering insights for environmental management. Trees exposed to environmental pollutants absorb, accumulate and integrate these substances into their systems, with the extent depending on their sensitivity (Khureshi, 2013). However, APTI alone is not sufficient for selecting plant species for developing green belts. The anticipated performance index (API) is a more comprehensive method that considers APTI along with the socioeconomic benefits and biological parameters of plant species (Karmakar *et al.* 2021). API helps to identify plant species that can effectively combat air pollution while also providing recreational and socioeconomic benefits. Factors such as leaf size, canopy structure, habitat and economic value play a significant role in a plant's capacity to reduce pollution.

1.2 Rationale of the study

Nepal is ranked as third most polluted country in the world as the density of PM_{2.5} particles in the air was found higher in atmosphere (source: derived on August 30, 2024; <https://myrepublica.nagariknetwork.com>). Air Quality Life Index of 2024 reported that the average life expectancy of Nepali people has been decreased by 3.4 years due to the air pollution (Greenstone *et al.* 2024). In the 21st century, air pollution has become a global threat, not only to human health but also to ecosystems, contributing to issues such as climate change and biodiversity loss.

Biratnagar, the capital of Morang district and a key industrial hub in Nepal, faces significant air pollution leading to various health problems. Biratnagar recorded the highest value of PM₁₀, PM_{2.5}, ozone and nitrogen dioxide during January and lowest during July month respectively (Figure 1). The value of PM₁₀, PM_{2.5}, ozone and nitrogen dioxide in January was found to be higher (Annex 1) as compared to that of standard value provided by NAAQS (2012) (Figure 2).

The rising air pollution in this densely populated and polluted metropolitan city poses a growing threat to human health. Despite these challenges, there is a lack of comprehensive data on pollution and its impacts in the area. The city's tolerance capacity to air pollution remains unassessed, and as a result, critical mitigation strategies are not being implemented.

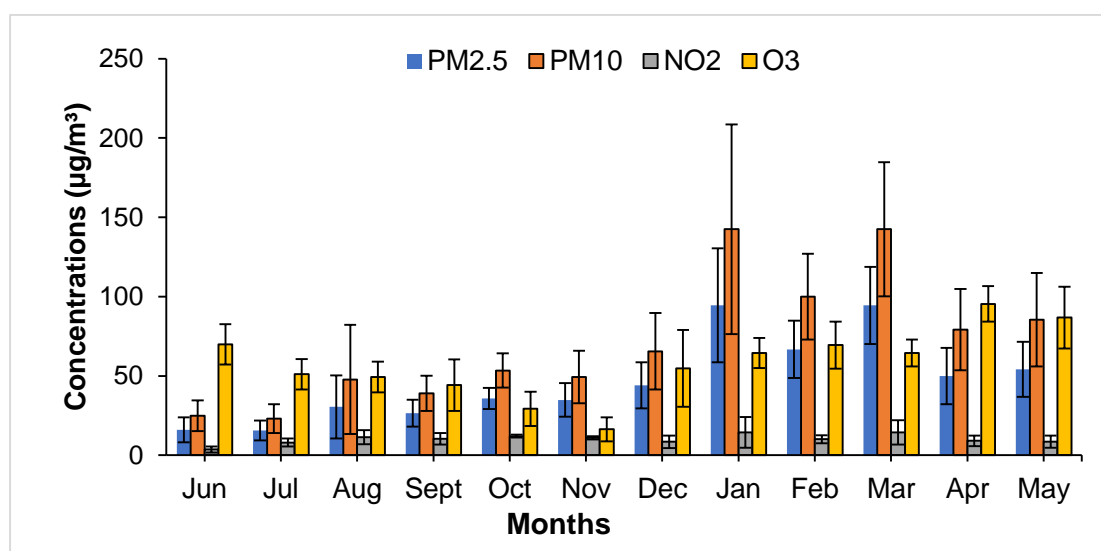


Figure 1: Ambient air quality of Biratnagar. (24 hours' average data of a year 2023/2024).

(Source: <https://air.plumelabs.com/>, Copernicus Atmosphere Monitoring Service Information 2024

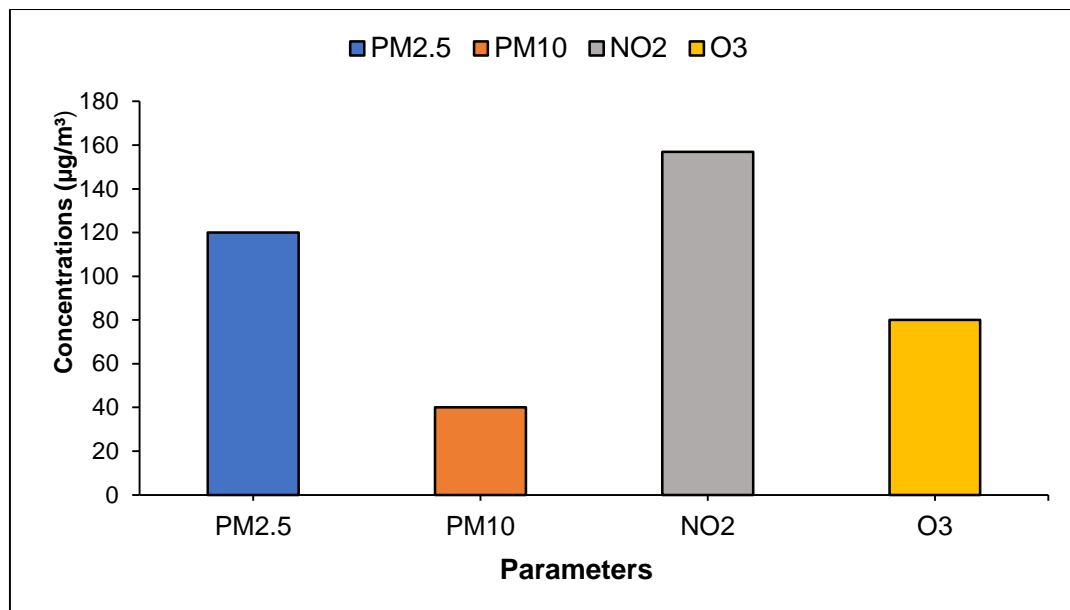


Figure 2: Standard Ambient Air Quality, (NAAQS, 2012).

The assessment of the air pollution tolerance index (APTI) of plants is crucial as the city is highly populated with various developmental activities being carried out leading to the higher rate of pollution. The study of plant tolerance to air pollution can significantly promote sustainable development, indirectly enhancing people's quality of life. The information on the resistivity and adaptability of plants in polluted areas is vital, as resistant plants can help to reduce pollution in industrial areas and also help the development of green belts across polluted areas of the country. This method also indirectly helps in mitigating global warming and climate change by highlighting the negative impacts of air pollution in plants and the potential benefits of using plants for controlling the air pollution.

Planting trees in polluted areas can promote sustainable urban planning, improve air quality and contribute to the city's aesthetic and socioeconomic status. Therefore, assessing the APTI and anticipated performance index (API) of plant species in the vicinity of Biratnagar is essential for controlling air pollution. It will help to identify plants' capacity of tolerating high levels of air pollution while offering multiple benefits, including enhancing the city's aesthetics and improving the socioeconomic status of its residents.

1.3 Research Questions

The study is mainly concentrated for answering following research questions:

1. What is the effect of air pollution on leaf morphology (leaf area, SLA, leaf length and width) of common plant species?
2. What are the effects of air pollution on biochemical parameters of plants along the study areas?
3. What is the pollution tolerance capacity of plants existing in the study area?

1.4 Objectives

The general objective of the study is to understand the impacts of air pollution on different physiological parameters of plant species and their air pollution tolerance index (APTI) in the selected study area of Biratnagar, Nepal.

The specific objectives of the study are:

1. To study the dust load accumulation on leaves on different study areas.
2. To investigate the effects of air pollution on macro morphology of collected leaf samples.
3. To calculate the biochemical parameters such as chlorophyll, ascorbic acid, relative water content and pH of the leaves.
4. To understand the air pollution tolerance index and anticipated performance index of some trees.

1.5 Limitations

1. All the plant species were not present in all the selected study areas. Among 28 plant species only 3 plants were found to be common from all the four study areas.
2. Samples collection were conducted only during winter seasons because of which seasonal variations could not be understood.

2. Literature Review

Industrialization, urbanization and rapid population growth are the major factors which are responsible for the air pollution. Air pollution leads to various major issues with the ecosystem and human health. Pollution and plants have a significant relationship. Various literatures have been reviewed to gather information about the impacts of air pollution and dust accumulation on the biochemical and morphological parameters of the plants under the topic of APTI and API.

2.1 Pollution and Plants

The role of plants in the reduction of air pollution has been studied in recent years as plants act as natural sinks for absorbing harmful pollutants (Shannigrahi *et al.* 2003; Singh & Verma, 2007). Morphological and biochemical parameters of plants can be used as pollution indicators and tolerant plant species are useful for controlling the pollution (Govindaraju *et al.* 2012; Banerjee *et al.* 2022). Plant leaves adsorb, absorb, metabolize and detoxify pollutants through various morphological and biochemical variables like leaf size, stomatal frequency, trichomes, ascorbic acid, pH, RWC, etc. (Rai, 2019; Javanmard *et al.* 2019; Adhikari *et al.* 2022; Mondal & Singh, 2022). Plants provide a cost effective and eco- friendly way to mitigate the air pollution (Bharti *et al.* 2017). Anake *et al.* (2022) had identified *Syzygium malaccense*, *Mangifera indica* and *Ficus auriculata* as bio indicators and green belt development plants for restoring the polluted ecosystem. Also, *Shorea robusta*, *Acacia auriculiformis*, *Eucalyptus globulus* and *Azadirachta indica* were found to be useful in reducing the air pollution (Karmakar & Padhy, 2019). Ter *et al.* (2020) had identified *Cinnamomum camphora*, *Ficus elastica*, *Ficus religiosa*, *Ficus benghalensis* and *Grevillea robusta* were tolerant tree species whereas *Phyllanthus emblica* and *Schima wallichii* were found to be sensitive tree species. It was also found that *Mangifera indica*, *Ficus religiosa*, and *Azadirachta indica* have good potential for sustainable reduction in air pollution for long-term management and green eco-management development (Enitan *et al.* 2022). Roadside vegetation helped to reduce the adverse effect of gaseous and particulate pollutants as plants act as natural filters (Rai & Panda, 2014).

2.2 Morphology of Leaf and Dust load

Plant leaf surfaces get directly exposed to the pollutants (Rai & Panda 2014). Pollutants absorbed by plants' bodies play a negative role on photosynthesis, respiration and life span

of the plants (Tripathi *et al.* 2009). Accumulation of dust particles depend upon leaf morphology, structures, shape, size, phyllotaxy and texture of the leaf (Singh, 1977; Rai & Panda, 2014). Broad leaved plant species with rough surfaces accumulate more dust particles rather than the smooth surfaces (Beckett *et al.* 2000; Lu *et al.* 2018). Broad and coriaceous leaf texture accumulated more dust in comparison to that of smaller leaf size and smooth leaf surface area (Joshi & Bora, 2011). Timalisina *et al.* (2022) found the dust deposition on leaf surface in the order of *Cryptomeria japonica*>*Buddleja asiatica*>*Sambucus canadensis*>*Mangifera indica*> *Pinus roxburghii*. Comparatively there was a significant ($p<0.05$) reduction of leaf area, leaf length, width, area and petiole length in polluted areas than that of less polluted areas. The previous study also showed that the overall reduction % in leaf length, width, area and length of petiole during different seasons at polluted sites with respect to those of non-polluted sites was found maximum (Leghari & Zaidi, 2013). *Butea monosperma* and *Calotropis procera* showed higher dust load due to their rough leaf surface and large size, their unique shape and small petioles but *Ficus benghalensis* and *Ricinus communis* leaves showed low dust load due to waxy coating of leaves, slightly folded margins (Meravi *et al.* 2021). The previous study done alongside National Highway (NH-7) in Sirmaur, Himachal Pradesh, India found the trend of dust accumulation as follows: *Ficus roxburghii* (38.30 mg m⁻²)>*Shorea robusta* (26.94 mg m⁻²)>*Mallotus philippensis* (22.31 mg m⁻²)>*Woodfordia fruticosa* (16.70 mg m⁻²). Leaf dust accumulation decreased with increasing distance from the national highway. The findings suggest that strategic planting of certain species, such as *Ficus roxburghii* and *Shorea robusta*, which exhibit higher dust interception, could be effective in mitigating dust pollution in areas close to highways (Pandit *et al.* 2017). Total chlorophyll content and relative water content decreased with increasing dust load. The pH of leaf extract increased with increasing dust load. There was a significant negative correlation between dust deposition and both RWC and total chlorophyll content. There was a significant positive correlation between dust deposition and leaf extract pH. The highest dust deposition rates were observed in *Ficus benghalensis* and lowest dust deposition rates were observed in *Artocarpus heterophyllus* (Rai, 2019).

Specific leaf area (SLA) is the measure of leaf surface area per unit mass. SLA indicated the plant photosynthetic capacities and adaptation to the environment. SLA is one of the widely accepted leaf factors used to study leaf traits (Kraft *et al.* 2008). In the various stress conditions like drought and water stress SLA of the leaf was found to be decreased than the normal conditions leaf (Marron *et al.* 2003). Prasai (2021) showed decrease in SLA of most of the plant species near the factory area. Hamal & Chettri (2017) had also recorded

a lower SLA value in polluted areas than that of less polluted ones. Yang *et al.* (2023) showed lower SLA in polluted areas. Hamal (2023) observed the maximum leaf area in *Ficus religiosa* at polluted sites and maximum SLA in *Prunus cersoides* at polluted sites.

2.3 Biochemical Parameters

2.3.1 Total Chlorophyll Content

Total chlorophyll content decreases in polluted areas due to the oxidation, reduction, reversible, bleaching and production of reactive oxygen species (ROS), in the chloroplast to overcome the stress (Prajapati & Tripathi, 2008; Pathak *et al.* 2011). Factors like age of leaf, pollution level and biotic and abiotic conditions prevailing in the particular area affects the total chlorophyll content (Rai & Panda, 2014). Anake *et al.* (2022) reported a lower concentration of total chlorophyll contents in industrial states (1.09-2.93 mg/g) than that of non- industrial communities (1.03-2.25 mg/g). Budhanilkantha area of Kathmandu valley recorded the highest total chlorophyll content in *Cinnamomum camphora* in polluted sites and *Nyctantbes arbor-tristis* recorded the lowest value (Ter *et al.* 2020). The total chlorophyll ranged from 0.52-0.65 in polluted sites whereas that in control sites is 0.73 to 0.85 mg/g showing more value in *Callistemon viminalis* (0.62) in both the study area of Kathmandu valley (Sapkota & Shrestha, 2024). The study done by Zahid *et al.* (2023) found that *Saraca asoca* had maximum chlorophyll content on residential areas and *Melia azedarach* showed maximum chlorophyll content on roadside areas. Reduction in the total chlorophyll content differs from plant species to species due to the level of exposure of plants to pollutants (Rai *et al.* 2013). Plant growth is directly associated with chlorophyll concentration. The study found an increase of the chlorophyll amount due to the increasing level of pollutants. Total chlorophyll content ranged from 0.59 to 1.42 mg/g in industrial sites whereas in control sites it ranged from 0.82 to 1.49 mg/g respectively. Total chlorophyll content showed the inverse relation with the dust accumulation on the leaves surfaces as it may affect the photosynthetic activities (Patel & Kumar, 2018). Among the studied 25 plant species, total chlorophyll content ranged from 0.59-1.49 mg/g (Bharti *et al.* 2017).

2.3.2 Ascorbic Acid

Ascorbic acid is an antioxidant influencing the resistance of plants in adverse environmental conditions by involving in the defense against ROS production. Higher amounts of ascorbic acid is produced as a result of protection of thylakoids membrane

under the various stress conditions (Prajapati & Tripathi, 2008). Ascorbic acid of control site on plants *Ficus benjamina*, *Buddleja asiatica*, *Jacaranda mimosifolia* and *Cinnamomum camphora* was found to be at lower range than that of polluted sites. Ascorbic acid was found in the range of 2.74 to 3.37 mg/g in control sites comparatively lower than the polluted sites showing more value in *Jacaranda mimosifolia* and *Callistemon viminalis* (Sapkota & Shrestha, 2024). The ascorbic acid content found the maximum in *Azadirachta indica* (8.2 ± 0.3605 mg/g) while the minimum in *Acacia nilotica* (0.9 ± 0.1 mg/g) which was found less in the polluted area. Ascorbic acid was reduced maximum in *Tectona grandis* (74.4%), followed by *Annona squamosa* (25.8%) and *Acacia nilotica* (25.0%), (Tak & Kakade, 2017). Plant species like *Azadirachta indica*, *Polyalthia longifolia*, *Ficus benghalensis*, *Mangifera indica*, *Acacia arabica* and *Peltophorum pterocarpum* collected from Baroda city of Gujarat (Bhattacharya *et al.* 2013) and *Azadirachta indica*, *Mangifera indica*, *Carica papaya*, *Ricinus communis*, *Polyalthia longifolia*, *Calotropis gigantea*, *Eucalyptus musoresins*, *Nerium indicum*, *Psidium guajava*, *Parthenium hysterophorus*, *Bougainvillea glabra*, *Muntingia calabura*, *Terminalia catappa* and *Tamarindus indica*, collected around Shivamogga city of Karnataka, India (Adamsab *et al.* 2011) higher ascorbic acid in polluted areas than the controlled areas. Total chlorophyll content showed the inverse relation with dust amount on the leaf surfaces which relatively decreases the photosynthetic rate of the plants (Leghari & Zaidi, 2013). The ascorbic acid in the industrial site (Rourkela) was in the range of 0.2 to 0.53 mg/g whereas that on non-industrial site (Aizawl) was found in the range of 0.1 to 0.24 mg/g. The ascorbic acid of the leaves surfaces was found to be more in polluted areas due to increase in rate of ROS production due to photo oxidation process (Rai *et al.* 2013). The study revealed that 57.14 % of the sampled plant species increased the ascorbic acid concentration in experimental/ polluted sites than that of control sites indicating that the tree on experimental sites developed the tolerance capacity in response to the pollutants (Sahu *et al.* 2020).

2.3.3 pH of Leaf Extract

pH level of the leaf extract plays as a stress indicators showing the relationship with physiological functioning like stomatal activity, photosynthetic rate and enzymatic reactions (Karmakar & Padhy, 2019). High pH of the leaf extract improves the tolerance capacity of plants to the pollution (Agarwal, 1986). pH value of the controlled sites was found to be in a higher range compared to that of polluted sites when the study was performed in the Kathmandu Valley by Sapkota & Shrestha, (2024). Higher pH value indicated the increase in tolerance level by accelerating ascorbic acid formation (Mandal &

Dhal, 2022). Comparatively, sensitive plant species showed higher pH than the tolerant plant species (Deswal *et al.* 2019). Higher pH of leaf extract at control sites rather than at controlled ones may be due to presence of high pollutants which helps to increase the tolerance capacity of the plants (Ter *et al.* 2020). *Azadirachta indica* from the control sites showed the minimum pH value in the winter season (Goswami *et al.* 2023). Plant species which were nearer to the industrial areas showed the lower pH value due to the presence of heavy pollutants like SO₂, NO₂, and particulate matters (PM) (Banerjee *et al.* 2022). The road side and residential areas of Lahore, Punjab of Pakistan showed highest pH value of *Bougainvillea glabra* with the value of 7.98 and 6.79 respectively (Zahid *et al.* 2023). The pH of the plant collected from the industrial areas exhibited the acidic range due to the presence of acidic pollutants like SO₂, NO₂. Low pH in the industrial areas leads to the decrement of the photosynthetic activities (Bharti *et al.* 2017).

2.3.4 Relative Water Content (RWC)

RWC acts as a significant role in various physiological and metabolic functions of the plants (Rai & Panda, 2014). Higher level of RWC is associated with the adaptation of plants in adverse stress conditions of the environment (Bharti *et al.* 2017; Shrestha *et al.* 2021). RWC was found maximum in *Mangifera indica* followed by *Dendrocalamus strictus*, *Putranjiva roxburghii*, *Ficus benghalensis* (Prajapati & Tripathi, 2008). Mostly, RWC in polluted areas was found to be higher as compared to that of controlled sites in both angiosperm and gymnosperms (Kanwar *et al.* 2016; Hamal, 2023). RWC in industrial sites was found in the range of 52.34 to 98.62 % whereas that of control sites was 41.34 to 92.37 % which was comparatively lower than the polluted sites (Bharti *et al.* 2017). The previous study done in Lahore, Punjab of Pakistan had shown the maximum RWC in *Alstonia scholaris*, *Pingamia pinnata*, *Dalbergia sissoo* and *Morus alba* in residential area on the other hand *Mangifera indica*, *Eucalyptus globulus*, *Alstonia scholaris* and *Melia azedarach* showed the maximum value (Zahid *et al.* 2023). RWC of the plant collected from industrial sites (Rourkela) were found to be higher than that of non- industrial areas (Aizal). *Bougainvillea spectabilis* and *Hibiscus rosa-sinensis* recorded the lowest and highest RWC in industrial areas but *Mangifera indica* and *Lantana camara* recorded the maximum and minimum value respectively (Rai *et al.* 2013). Higher water content in the plant body helped to maintain the turgidity under the adverse environmental conditions and served as indicators for during the drought conditions. Pollution reduced the transpiration rate and could damaged the plants body. *Eucalyptus globulus* recorded the highest amount of RWC at polluted sites (96%), (Lohe *et al.* 2015).

RWC was found to be high in the response to the high availability of soil, water content and lower evaporation and transpiration rate (Patel & Kumar, 2018).

2.3.5 Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API)

The maximum APTI values was recorded in the order of *Cinnamomum camphora*>*Callistemon lanceolatus*> *Grevillea robusta*> *Ficus religiosa*> *Jacaranda mimosifolia*> *Populus euramericana* and their respective highest APTI values were 12.51>12.55>13.08>13.97>14.61>15.67. *Callistemon lanceolatus* (of Dhumbarahi), *Cinnamomum camphora* (of Dhumbarahi), *Ficus religiosa* (of Narayanthan), *Grevillea robusta* (of Airport), and *Jacaranda mimosifolia* (of Dhumbarahi), whereas in *Populus euramericana* tolerant category was recorded at five sites (at Airport, Balaju, Bansthali, Dhumbarahi and Narayanthan).was found to be Tolerant species (Hamal, 2023). The tree species like *Jacaranda mimosifolia*, *Pinus roxburghii*, *Ficus benjamin*, *Celtis australis*, *Alnus nepalensis*, *Callistemon lanceolatus*, *Schima wallichii*, *Pyrus pyrifolia*, *Celtis australis* and *Punica granatum* fall in the sensitive species to air pollution, whereas *Mussaenda grandiflora*, *Ficus elastica*, *Cinnamomum camphora* and *Eucalyptus alba* fall in the intermediately tolerant species (Kanwar *et al.* 2016). The previous study showed that the control sites has more APTI than the polluted sites (Tak & Kakade, 2017). It was found that *Tectona grandis* (5.2 ± 0.3247) recorded minimum APTI which belongs to the sensitive category on the other hand *Azadirachta indica* (13.5 ± 0.4404) recorded maximum APTI value belonging to the intermediate category. The previous study found the APTI value in the range of 6.33 to 36.0 from Kathmandu Valley of the plants species like *Cinnamomum camphora*, *Ficus* sp., *Nerium oleander*, *Thuja* sp., *Dyopsis lutescens*, *Albizia julibrissin*, *Schefflera pueckleri*, *Psidium guajava* and *Ficus benjaminia* (Shrestha *et al.* 2021). Higher APTI value was found in polluted sites (6.92 to 10.62) than at the controlled sites (6.83 to 10.22). Among the 18 plant species the APTI value ranged from 9.53 to 23.90. APTI value was found in the order of *Mangifera indica* (23.90), followed by *Peltophorum pterocarpum* (22.13), *Ficus benghalensis* (19.53), *Polyalthia longifolia* (19.02) and *Saraca asoca* (18.51). *Mangifera indica* and *Peltophorum pterocarpum* were categorized as tolerant plant species whereas *Artocarpus heterophyllus*, *Aegle marmelos*, *Phyllanthus emblica*, *Alstonia scholaris* and *Syzygium cumini* were intermediate species. *Saraca asoca* and *Ficus benghalensis* found to be the excellent performers (Karmakar *et al.* 2021). Among the selected 21 plant species, an increase in APTI value was seen in polluted sites than in control ones (Ter *et al.* 2020). *Syzygium cumini* (56.25%) was a moderate performer (Rai & Mandal, 2020). Among the studied plants, *Mangifera indica* had

the highest APTI value (10.62), whereas *Buddleja asiatica* (6.92) recorded the lowest APTI value (Timalsina *et al.* 2022).

Syzygium cumini and *Ficus benghalensis* were found to have higher APTI value from the Railway junction and residential areas (Marimuthu & Lavanya, 2014). Among the studied 10 plant species on Bhopal, Madhya Pradesh, India *Neolamarckia cadamba*, *Dalbergia sissoo*, *Mangifera indica* *Psidium guajava* and *Azadirachta indica* were excellent, *Ficus benjamina* was very good, *Cassia fistula*, *Nerium oleander* and *Ficus religiosa* were good and *Bougainvillea glabra* was moderate plant performer in polluted areas (Garg *et al.* 2021). Jyoti & Jaya (2010) reported highest APTI value on *Polyalthia longifolia* followed by *Mangifera indica* suggesting *Mangifera indica*, *Alstonia scholaris*, *Eupatorium odoratum* and *Hyptis suaveolens* as bio-monitor in polluted areas of Kerala, India. In industrial sites, APTI value was found to be the highest of *Ficus benghalensis* and lowest of *Polyalthia longifolia* by Bharti *et al.* (2017). Rai *et al.* (2013) obtained the result that industrial sites have higher APTI value than non-industrial sites revealing that *Mangifera indica* and *Bougainvillea spectabilis* as bio-monitors plants helping in the mitigation of air pollution.

Cinnamomum camphora (87.50%), *Mangifera indica* (81.25%) and *Ficus elastica* (81.25%) were excellent performers whereas *Pinus roxburghii* and *Celtis australis* were good performer because of their higher API value (Timalsina *et al.* 2022). APTI value ranged from 11.18 to 26.66 in Chiang Mai City of Thailand which was maximum in *Mangifera indica* and minimum in *Alstonia scholaris*. The API value of *Mangifera indica* was highest being categorized under best performer followed by excellent performer (*Ficus religiosa* and *Butea monosperma*), (Yousafzai *et al.* 2018). The plant species *Azadirachta indica* (75.00 %) and *Callistemon citrinus* (37.50%) were found to be very good and very poor performers in all sites and seasons of Haldwani City of India (Goswami *et al.* 2023). Out of 45 plant samples, it was found that 23.81 % of total plant species were under poor to very poor performers indicating themselves as bio indicators, 33.33 % were in moderate to good category and 42.86 % were in good to best performer category. *Ficus religiosa*, *Madhuca indica*, *Azadirachta indica*, *Artocarpus heterophyllus*, *Mangifera indica*, *Ficus benghalensis* and *Syzygium cumini* were suitable for controlling the air pollution (Sahu *et al.* 2020). *Ficus infectoria*, *Mangifera indica* and *Ficus religiosa* were likely to be excellent performers. *Ficus benghalensis* and *Dalbergia sissoo* were very good performers and *Azadirachta indica* and *Pinus roxburghii* were good performers. *Psidium guajava*, *Syzygium cumini*, *Semecarpus anacardium*, *Tectona grandis*, *Zizyphus mauritiana* and *Mangifera indica* were predicted to be moderate performers (Prajapati & Tripathi, 2008).

Among 12 plant species, highest APTI was found in the winter seasons in the order of *Ficus benghalensis* > *Polyalthia longifolia* > *Ficus religiosa* > *Cassia fistula* > *Michelia champaca* > *Azadirachta indica* > *Adina cordifolia* > *Cassia siamea* > *Cascabela thevetia* > *Alstonia scholaris* > *Nerium odorum*. Based on API value, *Ficus benghalensis* was found to be excellent whereas *Ficus religiosa* was found to be the very good performer (Patel & Kumar, 2018). Deswal *et al.* (2019) studied API of forty plant species from Haryana, India, where *Syzygium cumini* was best performer while *Thevetia peruviana*, *Tectona grandis*, *Grevillea robusta*, *Alstonia scholaris*, *Olea paniculata*, *Delonix regia*, *Casuarine equisetifolia* and *Pinus roxburghii* were the excellent performer. *Albizia lebbbeck*, *Nerium oleander*, *Artocarpus heterophyllus* were found to be good performer.

2.4 Research Gap

The study of air pollution is a broad topic which deals with the health issues in human beings as well as to plants and animals. The ecosystem becomes imbalanced due to increase in air pollution in the country. The study of the impacts of pollution on plants mainly focused on the physiological parameters of plants to determine the air pollution tolerance index value. Also, this study provided some valuable information about the biochemical parameters of the plants found in the polluted study area. Further, the tolerance capacity of plants on those industrial areas could be understood which would be very helpful for the identification of potential plants useful for the reduction of pollution. On the other hand, plantations of pollution tolerant species would also indirectly decrease the respiratory health issues of the people and promote the socio- economic status of the people. The study could also encourage the policymakers and citizens to take action to improve the city's air quality.

Majority of the research work is confined to Kathmandu valley which lies in sub-tropical vegetation zone. But such a study has not been conducted so far in Terai and very limited information of plants growing in these areas are available. Hence, the present study intended to conduct research on one of the densely populated and industrial cities of Nepal to generate the information about the air pollution tolerance of plant species and their anticipated performance index.

3. Materials and Methods

3.1 Study Area

Biratnagar, the study area is located in Morang District within Koshi Province, approximately 399 km east of capital city of Nepal, Kathmandu. Morang District, spanning 1,855 square kilometers, borders India to the south and is situated in the outer Terai region of Eastern Nepal. Biratnagar, the capital city of Morang, is a major industrial center with a geographical location of 26°28'60" N latitude and 87°16'60" E longitude in the Eastern Terai of Nepal. It is one of the most densely populated cities in Nepal, encompassing nine municipalities and eight rural municipalities.

According to Industrial Statistics for the fiscal year 2078/79 (DOI, 2022), Morang District is home to 302 industries, providing employment to 26,105 individuals. Biratnagar is a key city within the Greater Birat Development Area and hosts Nepal's first large-scale industry, Biratnagar Jute Mills, making it a central point for Nepal's industrial sector. The district is well-connected by the Mahendra National Highway and Koshi National Highway.

Morang District has a population of 1,147,186 with a literacy rate of 78.6% (CBS, 2021). The population includes various ethnic groups, such as Pahadis, Madhesis, Tharus, and a significant Muslim community. The primary languages spoken are Nepali, Maithili, Tharu, and Rajbanshi.

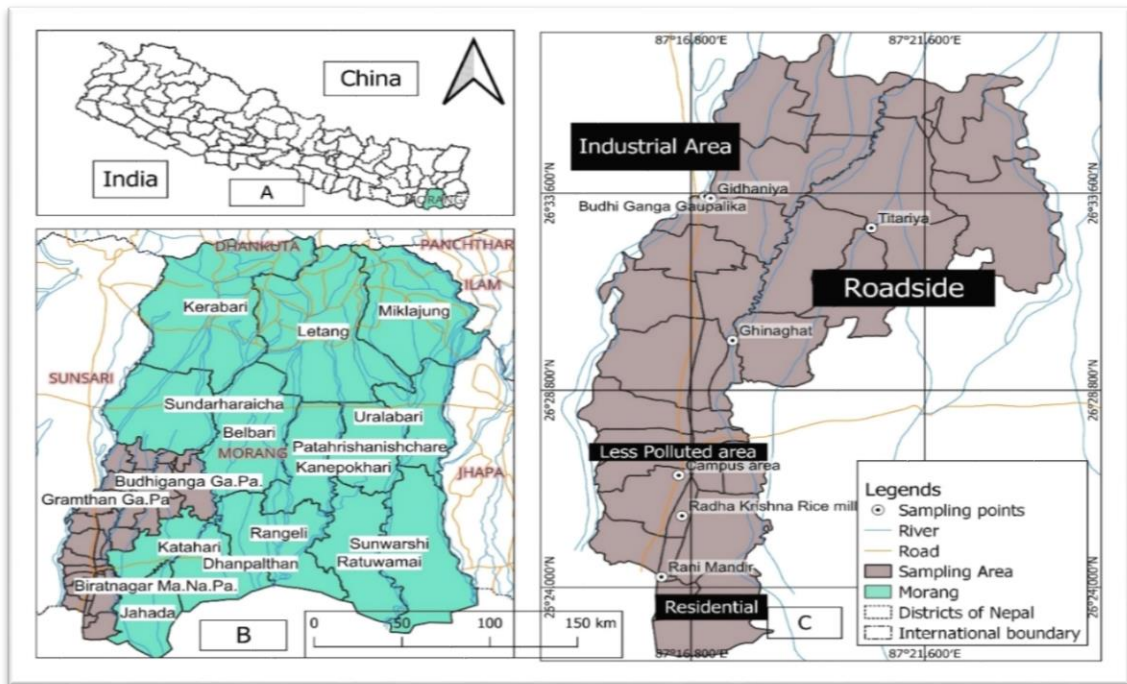


Figure 3: Map of Morang district showing the seven different sampling area (A= Map of Nepal, B= Map of Morang District, C= sampling areas) (Source: Q-GIS version 3.28).

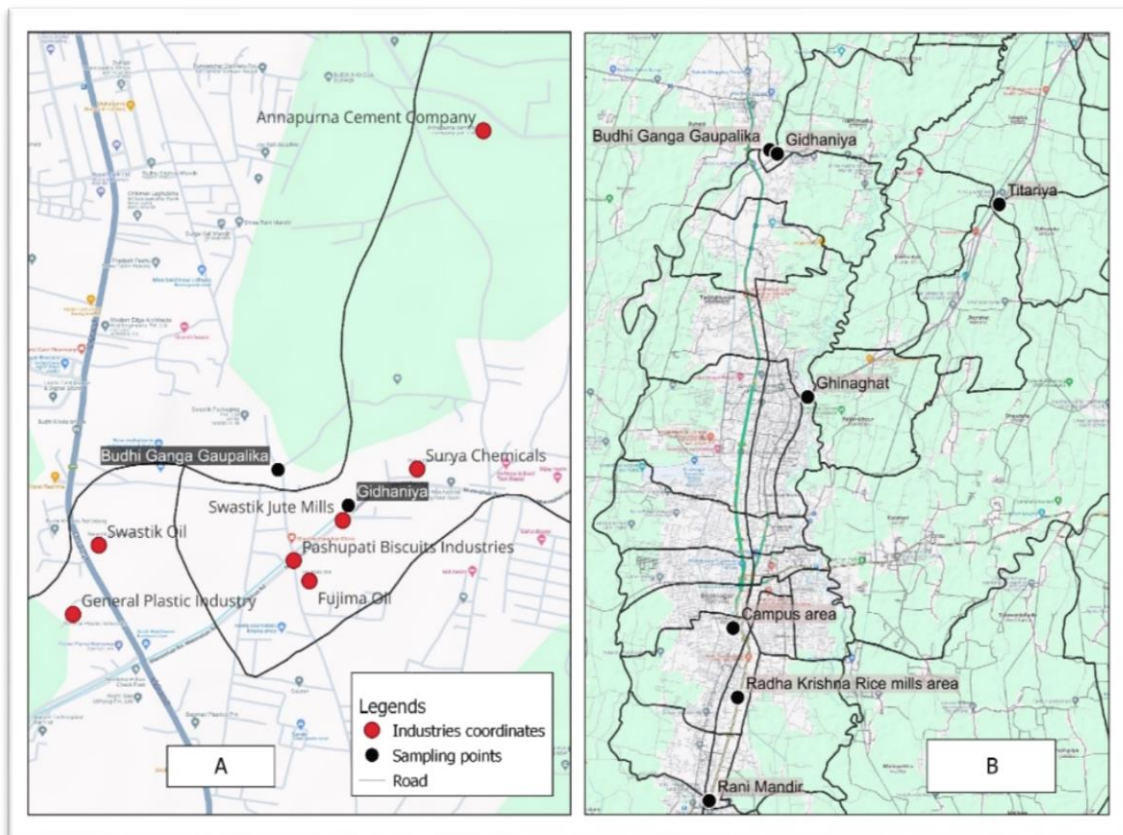


Figure 4: Map of industrial areas (A); roadside, residential and campus (B).

3.2 Description of the Studied Area

Field visit was conducted during the winter season in January 2024 to Morang district because winter seasons recorded the highest level of ambient air quality (Figure 1). The study sites were categorized based on the accumulation of particulate matter, respirable suspended particles (RSP) and total suspended particles (TSP) on different selected sites (Table 1) which were recorded by using sampler (Aeroqual) during field visit.

Table 1: Categories of study areas on the basis of average particulate matter (mean \pm SD, n=60), respirable suspended particles and total suspended particles on the different study areas ($\mu\text{g}/\text{m}^3$).

Study area	PM ₁	PM _{2.5}	PM ₁₀	RSP	TSP
Industrial	32.95 \pm 3.86	46.20 \pm 4.63	75.70 \pm 12.27	56.05 \pm 6.23	86.68 \pm 17.22
Roadside	26.71 \pm 0.99	34.17 \pm 1.14	64.37 \pm 1.92	43.09 \pm 1.55	80.62 \pm 2.38
Residential	21.67 \pm 1.85	25.28 \pm 1.42	31.77 \pm 2.30	28.39 \pm 1.83	34.28 \pm 2.60
MM Campus	17.10 \pm 0.99	22.78 \pm 1.18	36.87 \pm 1.89	28.87 \pm 1.76	42.84 \pm 2.27

(Source: Sampler Aeroqual)

The industrial areas were selected from Budhi Ganga Gaupalika and Gidhaniya areas, which are near Budhi Khola and the Sunsari district. This area is surrounded by various industries, including Swastika Jute Mills, Surya Chemical Pvt. Ltd, Fujima Oils, and Koshi Gas Udhyyog all within an aerial distance of 250 to 500 meters (Figure 2). The industrial areas were found to be highly polluted, with particulate matter levels recorded 32.95, 46.20, 56.05, 75.70, and 86.68 of PM₁, PM_{2.5}, PM₁₀, RSP, and TSP respectively.

Roadside areas were selected from Gramthan Gaupalika and Biratnagar Metropolitan City (Titariya, Ghinaghat and Malaya road), where road networks were directly connected to Biratnagar (Figure 2). The road was seen to be recently graveled and was found to be moderately polluted.

The residential areas were selected near Rani Temple, close to the Biratnagar Customs Office on the Indo-Nepal border (Jogbani). This areas were populated and well-connected with road networks and transportation facilities. It was found to be less polluted compared to the roadside and industrial areas (Table 1).

Mahendra Morang Multiple Campus (MM Campus) areas which were considered as less polluted areas. This area was considered less polluted as most of the particulate matter (PM₁, PM_{2.5}, PM₁₀, RSP and TSP) was found to be comparatively less than other polluted areas (17.10, 22.78, 28.87, 36.87 and 42.84 respectively), (Table 1).

3.3 Selection of Plants

Altogether 28 species were selected on the basis of availability of the plants, common occurrence and ecological significance in the selected areas (Table 2). Twenty-five angiosperms and three gymnosperms were collected from the different areas. All the selected plant species were not present on all the four study areas because the study tried to list all the plant species present on Morang and its surrounding.

3.4 Sampling Design

Field sampling was carried out during January 2024. On the basis of the availability of plant species, purposive sampling was conducted. The plants were collected from the seven different sites of Budhiganaga Gaupalika, Gramthan Gaupalika and Biratnagar Mahanagarपालिका (Figure 1). Sampling was done in almost iso-ecological conditions from all sides of each tree from 3m height (Campbell *et al.* 2020). Approximately, 25-30 broad and matured leaves samples from available individuals were plucked by the help of pruner mostly during the morning time because the physiological activities of plants and pollutants are highly active during the morning time. Altogether, 28 different plant species leaves were collected from the field. The collected leaves samples were labeled properly and then were kept in the zip-locked bags. Then the triplicate collected samples of each plant species were kept in ice-boxes and were brought to the Central Department of Botany, Kirtipur, Kathmandu.

Table 2: List of plant species collected with their characteristics.

SN	Name of Plant Species	Common name	Tag no.	Family
1	<i>Annona squamosa</i> L.	Sarifa	1	Annonaceae
2	<i>Artocarpus heterophyllus</i> Lam.	Katar/ Jackfruit	7	Moraceae
3	<i>Azadirachta indica</i> A.Juss.	Neem	11	Meliaceae
4	<i>Aegle marmelos</i> (L.) Corrêa	Bel	24	Rutaceae

5	<i>Albizia lebbbeck</i> (L.) Benth.	Jungali siris	26	Fabaceae
6	<i>Bombax ceiba</i> L.	Simal	4	Malvaceae
7	<i>Bixa orellana</i> L.	Sindure	16	Bixaceae
8	<i>Citrus maxima</i> (Burm). Merr.	Bhogate/ Pomelo	3	Rutaceae
9	<i>Cascabela thevetia</i> (L.) Lippold	Yellow Karbir	15	Apocynaceae
10	<i>Cryptomeria japonica</i> (Thunb. ex L. f.) D. Don	Japanese cedar	Cryp	Cupressaceae
11	<i>Dalbergia sissoo</i> Roxb. ex DC.	Sissoo	21	Fabaceae
12	<i>Delonix regia</i> (Bojer ex Hook.) Raf.	Gulmohar	25	Fabaceae
13	<i>Eucalyptus globulus</i> Labill.	Masala	22	Myrtaceae
14	<i>Ficus benghalensis</i> L.	Bar/Banyan	13	Moraceae
15	<i>Ficus religiosa</i> L.	Peepal	14	Moraceae
16	<i>Mangifera indica</i> L.	Mango	2	Anacardiaceae
17	<i>Moringa oleifera</i> Lam.	Moringa	17	Moringaceae
18	<i>Neolamarckia cadamba</i> (Roxb.) Bosser	Kadam	5	Rubiaceae
19	<i>Nephelium litchi</i> Steud.	Litchi	18	Sapindaceae
20	<i>Nerium oleander</i> L.	Karbir	8	Apocynaceae
21	<i>Nyctantbes arbor-tristis</i> L.	Parijat	12	Oleaceae
22	<i>Psidium guajava</i> L.	Guava	9	Myrtaceae
23	<i>Punica granatum</i> L.	Pomegranate	10	Lythraceae
24	<i>Pinus roxburghii</i> Sarg.	Chir Pine	Pin	Pinaceae
25	<i>Syzygium cumini</i> (L.) Skeels	Jamun	6	Myrtaceae
26	<i>Saraca asoca</i> (Roxb.) Wild.	Ashoka	19	Fabaceae
27	<i>Tectona grandis</i> L. f.	Teak	20	Lamiaceae
28	<i>Thuja occidentalis</i> L.	Northern White- Cedar	Thu	Cupressaceae

3.5 Laboratory Analysis

3.5.1 Morphological Characteristics

For the morphological characteristics, the collected leaf samples of the different 28 plant species were observed thoroughly (Annex 2). The leaves morphology (Leaves types, laminar size and texture, leaf margin, leaf tip and base) were studied. Triplicate leaves samples were taken from each plant species. The leaf length, leaf width and petiole length of the respective plant species were measured using ImageJ Software version 1.54 (Hamal, 2023).

3.5.2 Dust Load

Firstly, three matured leaf/leaflets samples of each species from each study areas were taken and weighted with dust on its surface and then they were cleaned properly. Then the cleaned leaves were again weighted by digital balance (S303, 0.001g). The area of the leaf was calculated by using ImageJ software version 1.54g. The dust load accumulated on the leaves was calculated by following Prusty *et al.* (2005):

$$W(mg/cm^2) = \frac{W_1 - W_2}{A}$$

Where, W= dust load, W₁= weight of leaves with dust, W₂= weight of leaves without dust and A= area of leaves

3.5.3 Specific Leaf Area (SLA)

For the measurement of specific leaf area, broad and matured leaves/leaflets samples were selected and their photographs were taken with the help of mobile phones (Redmi mobile). Triplicate samples of leaves were taken. Then, the following leaves were oven dried at 70°C and their dry weight was recorded using digital balance (S303, 0.001g). The fresh area of leaves was calculated by using the ImageJ software version 1.54g. The SLA of each leaf was determined by using the formula (Cornelissen *et al.* 1996).

$$SLA(cm^2/g) = \frac{A}{DW}$$

Where, A= Projected area of leaves, DW= Dry weight of leaves.

3.6 Biochemical Analysis

3.6.1 Total Chlorophyll Content

Discs of fresh leaves (0.007- 0.09g weight range) was punched using punching machine and was kept in eppendorf tube containing 1ml of DMSO₄ (Dimethyl Sulfoxide) solvent immediately after collecting the leaves samples following the modified protocol of Barnes *et al.* (1992). Triplicate samples of each leaf were dipped in DMSO₄ and were left for 24-48 hours in an ice box for transportation. After reaching the laboratory, the eppendorf tubes with samples were kept in a water bath at 60 °C for 1-2 hrs. Then, the extract was pipetted using micro pipette in microplate and the absorbance at 665 nm and 648 nm wavelength was measured using Microplate Spectrophotometer (BioTek Epoch 2). Chlorophyll content in the leaves was calculated by the formula given by Barnes *et al.* (1992).

$$\text{Chlorophyll a}(\text{mg/g F.W}) = (14.85 \times A_{665} - 5.14 \times A_{648}) \times \frac{V}{(W \times 1000)}$$

$$\text{Chlorophyll b}(\text{mg/g F.W}) = (25.48 \times A_{648} - 7.36 \times A_{665}) \times \frac{V}{(W \times 1000)}$$

$$\text{Total Chlorophyll}(\text{mg/g F.W}) = (7.49 \times A_{665} + 20.34 \times A_{648}) \times \frac{V}{(W \times 1000)}$$

Where, V= volume of DMSO solvent, W= weight of fresh leaves used

3.6.2 Ascorbic Acid (AA)

Fresh leaf samples (0.25g) was taken in 100 ml test tubes containing 4 ml mixture of oxalic acid and Ethylene-Diamine Tetraacetic Acid extracts (5 g oxalic acid and 75 g EDTA in 1000 ml distilled water), 1 ml ortho-phosphoric acid, 1 ml 5% Sulphuric acid, 2 ml ammonium molybdate (5 g ammonium molybdate in 500 ml distilled water) and 3 ml distilled water. Triplicate sample solutions were allowed to stand for 15 minutes to get the extract by following the Bajaj & Kaur, (1981). The extract was pipetted using a micropipette into a microplate and the reading of absorbance at 765 nm was recorded by the help of Micro plate reader (BioTek Epoch 2). The standard ascorbic acid curve was prepared using different concentrations of acid by following the same methods. Lastly, the equation was obtained from the standard ascorbic acid curve. The concentration of ascorbic acid in the leaves was calculated from the absorbance and the equation obtained using following formula:

$$AA \text{ (mg/g)} = (\text{value obtained from equations}) \times \frac{V}{1000 \times W}$$

Where, V=Volume of extract solution, W= weight of fresh leaves sample

3.6.3 Leaf Extract pH

Two gram fresh leaf samples were weighed and 20 ml distilled water was added to it (Apriyantono *et al.* 1989). Triplicate leaves samples of each plant species were crushed using mortar and pestle and the leaves extract was collected. pH was determined by using the digital pH meter (pH700, Apera, USA).

3.6.4 Relative Water Content (RWC)

Triplicate freshly collected clean leaves samples were weighted using digital balance (S303, 0.001g) and were soaked in the water in a big tray for 24 hours. Then, the turgid weight was recorded and again the same leaves were oven dried at 70°C for 24 hours then dry weight was taken (Barrs & Weatherly, 1962).

$$RWC (\%) = \frac{FW - DW}{TW - DW} \times 100$$

Where, FW= Fresh weight of leaf sample, DW= Dry weight of leaf sample, TW= Turgid weight of leaf samples.

3.6.5 Air Pollution Tolerance Index (APTI)

The air pollution tolerance index was calculated using the equation prescribed by Singh & Rao, (1983). The equation is given by:

$$APTI = \frac{[A(T + P)] + R}{10}$$

Where, A = ascorbic acid (mg/g) of leaf sample, T = total chlorophyll (mg/g) of leaf sample

P = leaf extract pH of leaf sample, R = relative water content (%) of leaf sample

3.6.6 Air Pollution Tolerance Index (APTI) Categories

According to Thakar & Mishra (2010), tolerance levels of the plants were categorized into different groups depending on their APTI values. Depending on the APTI mean value of all the plant species and their obtained standard deviation, Thakar & Mishra (2010) categorized the APTI of the plant species on the following four types.

- a) Tree species APTI higher than Mean APTI + SD= Tolerant
- b) Tree species APTI value between Mean APTI and Mean APTI+ SD = Moderately Tolerant
- c) Tree species APTI value between Mean APTI- SD and Mean APTI= Intermediate
- d) Tree Species APTI lower than Mean APTI- SD = Sensitive

3.6.7 Anticipated Performance Index (API)

The APTI values of the plant species along with their morphological, ecological and socio-economic values were observed and recorded for the calculations of anticipated performance index (Table 3). The modified method of Parjapati & Tripathi, (2008) was followed to assign the grades to each characteristic of the plant species. Maximum grades that can be obtained by the plant is 16. The evaluation of categories of plant species based on API percentage (Table 4).

Table 3: Grade allotment of plant species on APTI, biological characters and socio-economic values (modification of Prajapati & Tripathi, 2008)

SN	Grading	Characteristics	Pattern of assessment	Grade Allotted
1	Tolerance	APTI	≤ 12	+
			12.1-15	++
			15.1-18	+++
			18.1-21	++++
			21.1-24	+++++
			>24	++++++
2	Biological characters	a) Plant habit	Small	-
			Medium	+
			Large	++
		b) Canopy Structure	Sparse/ Irregular/ Globular	-
			Spreading crown/ Open/ Semi dense	+

			Spreading dense	++
		c) Type of plant	Deciduous	-
			Evergreen	+
		d) Laminar structure		
		i) Size	Small	-
			Medium	+
			Large	++
		ii) Texture	Smooth	-
			Coriaceous	+
		iii) Hardness	Delineate	-
			Hardy	+
3.	Socio-economic characteristics	Economic Value	< 3 uses	-
			3 or more uses	+
			5 or more uses	++

The API score (%) can be calculated by using the equation of Parjapati & Tripathi, (2008):

$$API = \frac{\text{No of Grade}(+) \text{ obtained}}{\text{Total number of } +} \times 100$$

Table 4: Categories for plant species based on API % (Prajapati & Tripathi, 2008)

Score (%)	Category	Score (%)	Category
Up to 30	Not recommended	61-70	Good
31-40	Very Poor	71-80	Very good
41-50	Poor	81-90	Excellent
51-60	Moderate	91-100	Best

3.7 Statistical Analysis

All the data calculations were done in MS Excel 2013 and statistical analysis were performed in IBM SPSS statistics 20 Version. Firstly, normality tests for the data were performed for normal distribution of data. Then, One-way ANOVA was done to determine here were significant differences between the means of various biochemical parameters, air pollution tolerance index (APTI), dust load, specific leaf area (SLA), leaf area, leaf length, and leaf width among plant species from different study areas followed by Duncan's multiple range test to identify which specific means differed from each other. Pearson's Correlation test was performed to know the relationship between biochemical parameters and dust load per leaf area as well as between leaf morphology and dust load. Scatter plot was drawn to visualize the relationships between pairs of variables. One-way ANOVA was also used to assess significant differences in the percentage decrease of SLA, leaf area, leaf length, and leaf width. Bar graphs were used to interpret the mean values of each biochemical parameter across different study areas. These approaches allowed us to comprehensively analyze and interpret the data, revealing significant insights into the impact of air pollution on plant species.

4. Results

4.1 Dust accumulation (mg/cm²) in plant species

The dust accumulation on the leaf surface was recorded during the winter season as winter seasons was dry season. Among the four different study areas, average dust load per leaf area was recorded to be maximum in the industrial areas i.e., (3.23±0.40 mg/cm²) and lowest at campus areas (0.32±0.04 mg/cm²), (Table 5).

Table 5: Dust load (mg/cm²) on leaves of different plant species at different four study areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, *p*≤0.05. (n=27 to 69))

Plant species	Industrial	Roadside	Residential	Campus
<i>Annona squamosa</i>	1.19±0.08 ^a	-	-	-
<i>Artocarpus heterophyllus</i>	1.05±0.10 ^a	0.48±0.09 ^{ab}	-	0.26±0.10 ^{abc}
<i>Azadirachta indica</i>	1.89±0.64 ^a	2.61±0.43 ^g	-	0.23±0.09 ^{ab}
<i>Aegle marmelos</i>	-	0.41±0.08 ^a	0.37±0.2 ^a	-
<i>Albizia lebbek</i>	-	-	-	0.54±0.2b5 ^{cd}
<i>Bombax ceiba</i>	11.78±0.54 ^c	0.54±0.07 ^{abc}	2.04±0.23 ^c	-
<i>Bixa orellana</i>	1.34±0.66 ^a	-	0.90±0.27 ^{ab}	-
<i>Citrus maxima</i>	9.60±0.89 ^{bc}	1.84±0.32 ^{efg}	-	0.24±0.14 ^{ab}
<i>Cascabela thevetia</i>	1.46±0.28 ^a	0.19±0.04 ^a	1.09±0.37 ^{ab}	-
<i>Dalbergia sissoo</i>	-	0.12±0.09 ^a	-	-
<i>Eucalyptus globulus</i>	0.26±0.03 ^a	-	-	-
<i>Ficus benghalensis</i>	1.73±0.22 ^a	0.88±0.19 ^{abcde}	-	0.63±0.21 ^{cd}
<i>Ficus religiosa</i>	1.87±0.13 ^a	1.71±0.32 ^{defg}	-	0.27±0.06 ^{abc}
<i>Mangifera indica</i>	6.99±0.94 ^b	1.56±0.29 ^{cdef}	1.45±0.29 ^{bc}	0.40±0.10 ^{abcd}
<i>Moringa oleifera</i>	2.17±0.95 ^a	0.34±0.17 ^a	-	-

<i>Neolamarckia cadamba</i>	1.78±0.16 ^a	0.70±0.19 ^{abcd}	0.87±0.13 ^{ab}	0.16±0.05 ^{ab}
<i>Nephelium litchi</i>	3.14±0.24 ^a	0.66±0.12 ^{abcd}	-	0.13±0.03 ^a
<i>Nerium oleander</i>	2.09±0.32 ^a	0.78±0.06 ^{abcd}	-	-
<i>Nyctanthes arbor-tristis</i>	0.96±0.11 ^a	0.99±0.22 ^{abcde}	0.80±0.20 ^{ab}	-
<i>Psidium guajava</i>	0.87±0.02 ^a	1.51±0.29 ^{bcdef}	0.84±0.15 ^{ab}	0.15±0.03 ^{ab}
<i>Punica granatum</i>	0.65±0.22 ^a	0.75±0.13 ^{abcd}	-	-
<i>Syzygium cumini</i>	2.89±0.23 ^a	2.23±0.39 ^{fg}	-	0.67±0.08 ^d
<i>Saraca asoca</i>	2.64±0.029 ^a	-	2.20±0.57 ^c	0.33±0.04 ^{abcd}
<i>Tectona grandis</i>	12.29±2.51 ^c	1.57±0.41 ^{cdef}	-	0.12±0.03 ^a
F-value	14.12	5.16	4.25	2.53
Average	3.23±0.40	1.13±0.09	1.18±0.14	0.32±0.04

The order of dust load accumulation at different four study areas was found to be industrial areas>residential areas>roadside>campus areas. Average dust load at residential areas was 1.18±0.14 mg/cm² and at roadside areas was 1.13±0.09 mg/cm². On comparing the four studied areas, *Tectona grandis* and *Bombax ceiba* at industrial areas and *Azadirachta indica* at roadside recorded significantly ($p<0.05$) highest amount of dust load. Similarly *Bombax ceiba* and *Saraca asoca* recorded significantly ($p<0.05$) highest dust load at residential areas. *Syzygium cumini* recorded highest dust load at campus areas. *Tectona grandis* at campus areas recorded the lowest amount of dust load. The dust levels in residential areas were higher than those near the roads due to ongoing construction and increased vehicle movement. These activities contributed to higher pollution levels in the residential areas.

4.2 Macro Morphology of Leaves

Macro morphology like leaf area, specific leaf area (SLA), and leaf length and leaf width was measured from the different four study areas.

Table 6. Leaf traits at industrial areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different areas are indicated by different letters. (Duncan multiple test, $p \leq 0.05$. (n=63))

Plant Species	SLA (cm ² /g)	Leaf Area (cm ²)	Leaf length (cm)	Leaf width (cm)
<i>Annona squamosa</i>	140.14±22.30 ^{efg}	57.13±5.30 ^{bcde}	17.44±0.60 ^{efg}	4.87±0.22 ^{def}
<i>Artocarpus heterophyllus</i>	97.03±14.74 ^{abcde}	67.91±9.25 ^{de}	12.08±0.36 ^c	9.48±0.32 ^h
<i>Azadirachta indica</i>	150.28±1.69 ^g	8.63±0.23 ^a	6.11±0.32 ^{ab}	3.39±0.02 ^{bcd}
<i>Bombax ceiba</i>	71.13±5.50 ^{abc}	51.30±4.47 ^{bcd}	14.96±0.87 ^{cde}	5.55±0.26 ^{ef}
<i>Bixa orellana</i>	106.44±9.31 ^{cdefg}	157.78±20.38 ^h	17.85±0.91 ^{fg}	13.61±1.16 ^j
<i>Citrus maxima</i>	102.99±2.50 ^{bcdef}	55.66±1.27 ^{bcde}	21.55±0.93 ^h	7.51±0.56 ^g
<i>Cascabela thevetia</i>	219.74±4.18 ^h	9.80±0.79 ^a	12.87±0.32 ^{cd}	1.18±0.06 ^a
<i>Eucalyptus globulus</i>	89.49±7.69 ^{abcd}	36.49±1.62 ^b	14.24±0.42 ^{cde}	4.08±0.07 ^{cde}
<i>Ficus benghalensis</i>	82.61±3.74 ^{abcd}	89.64±8.60 ^f	12.36±0.28 ^{cd}	12.15±0.72 ⁱ
<i>Ficus religiosa</i>	85.69±0.23 ^{abcd}	74.30±3.64 ^{ef}	13.57±0.17 ^{cd}	10.85±0.46 ^{hi}
<i>Mangifera indica</i>	82.46±2.54 ^{abcd}	60.36±5.04 ^{cde}	14.14±0.51 ^{cde}	6.33±0.49 ^{fg}
<i>Moringa oleifera</i>	401.63±40.38 ⁱ	5.73±0.46 ^a	3.19±0.23 ^a	1.90±0.18 ^{ab}
<i>Neolamarckia cadamba</i>	146.60±10.77 ^{fg}	114.48±2.75 ^g	17.20±0.86 ^{efg}	11.17±0.80 ⁱ
<i>Nephelium litchi</i>	82.44±6.60 ^{abcd}	39.84±5.02 ^{bc}	13.64±1.48 ^{cd}	5.14±0.13 ^{ef}
<i>Nerium oleander</i>	56.94±3.19 ^{ab}	14.69±1.05 ^a	12.10±0.59 ^c	1.99±0.02 ^{ab}
<i>Nyctanthes arbor-tristis</i>	124.01±5.40 ^{defg}	56.92±3.55 ^{bcde}	13.30±0.29 ^{cd}	7.58±0.01 ^g
<i>Psidium guajava</i>	80.62±8.01 ^{abcd}	73.91±7.43 ^{ef}	15.78±0.64 ^{def}	7.87±0.75 ^g
<i>Punica granatum</i>	145.06±31.72 ^{fg}	12.70±3.19 ^a	7.88±0.76 ^b	3.13±0.04 ^{bc}
<i>Syzygium cumini</i>	142.33±12.67 ^{fg}	51.34±4.30 ^{bcd}	20.31±0.76 ^{gh}	3.41±0.17 ^{bcd}
<i>Saraca asoca</i>	55.10±0.95 ^a	50.77±4.69 ^{bcd}	23.31±3.44 ^h	4.74±0.42 ^{de}
<i>Tectona grandis</i>	105.00±3.37 ^{cdefg}	174.13±12.35 ^h	40.41±1.31 ⁱ	22.84±0.93 ^k
F-value	29.305	43.748	51.909	102.212

At industrial areas, minimum leaf areas was in *Moringa oleifera* ($5.73 \pm 0.46 \text{ cm}^2$) while *Moringa oleifera* recorded maximum specific leaf area ($401.63 \pm 40.38 \text{ cm}^2/\text{g}$) at industrial areas (Table 6). *Tectona grandis* recorded the maximum leaf surface area ($174.13 \pm 12.35 \text{ cm}^2$) and *Saraca asoca* recorded minimum SLA ($55.10 \pm 0.95 \text{ cm}^2/\text{g}$). Leaf length of the selected plant species was found in the range of $3.19 \pm 0.23 \text{ cm}$ to $40.41 \pm 1.31 \text{ cm}$ whereas the leaf width varied from $1.18 \pm 0.06 \text{ cm}$ to $22.84 \pm 0.93 \text{ cm}$. Maximum leaf length and leaf width was found to be of *Tectona grandis*. The SLA, leaf area, leaf length and width showed significant result ($p < 0.05$).

There was a significant difference ($p < 0.05$) in SLA among the leaf samples from roadside. At roadside, SLA ranged from $16.58 \pm 0.02 \text{ cm}^2/\text{g}$ in *Punica granatum* to $574.37 \pm 177.97 \text{ cm}^2/\text{g}$ in *Nyctanthes arbor-tristis* (Table 7). Similarly, *Tectona grandis* was recorded to have highest leaf area ($194.98 \pm 7.85 \text{ cm}^2$) and *Moringa oleifera* was recorded to have lowest leaf area ($7.81 \pm 1.04 \text{ cm}^2$). *Tectona grandis* was found to have the highest leaf length and width ($41.44 \pm 0.79 \text{ cm}$, $22.30 \pm 0.54 \text{ cm}$). However, *Azadirachta indica* showed minimum leaf length ($8.26 \pm 1.08 \text{ cm}$) and *Cascabela thevetia* showed minimum leaf width ($2.76 \pm 1.06 \text{ cm}$) respectively.

Table 7: Leaf traits at roadside areas. (The data were expressed as Mean \pm S.E and statistical analysis using one way ANOVA for obtaining F and p value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$. (n=63))

Plant species	SLA (cm^2/g)	Leaf Area (cm^2)	Leaf length (cm)	Leaf width (cm)
<i>Artocarpus heterophyllus</i>	84.86 ± 6.86^{ab}	68.55 ± 12.73^{efg}	15.03 ± 0.46^{abcd}	10.36 ± 0.59^{fgh}
<i>Azadirachta indica</i>	187.93 ± 2.52^{ab}	8.71 ± 0.22^a	8.26 ± 1.08^a	3.36 ± 0.02^a
<i>Aegle marmelos</i>	170.71 ± 11.18^{ab}	63.34 ± 9.17^{efg}	18.31 ± 2.51^{bcd}	8.49 ± 0.85^{defg}
<i>Bombax ceiba</i>	124.28 ± 39.44^{ab}	45.36 ± 1.39^{cdef}	17.54 ± 1.91^{bcd}	6.92 ± 0.44^{bcdef}
<i>Cascabela thevetia</i>	226.85 ± 34.25^{ab}	15.91 ± 1.61^{ab}	19.72 ± 6.05^{cd}	2.76 ± 1.06^a
<i>Citrus maxima</i>	123.49 ± 15.71^{ab}	58.30 ± 5.47^{defg}	22.08 ± 0.95^d	8.15 ± 0.51^{cdef}
<i>Dalbergia sissoo</i>	171.22 ± 54.93^{ab}	15.61 ± 5.58^{ab}	11.79 ± 3.70^{ab}	5.38 ± 1.40^{abcde}
<i>Delonix regia</i>	66.57 ± 9.14^a	32.82 ± 27.15^{abcd}	17.76 ± 0.18^{bcd}	4.77 ± 2.89^{abc}

<i>Ficus benghalensis</i>	55.54±7.08 ^a	86.40±5.45 ^{gh}	16.35±0.79 ^{bcd}	12.19±0.85 ^h
<i>Ficus religiosa</i>	76.09±28.76 ^{ab}	66.39±6.41 ^{efg}	14.61±0.188 ^{abcd}	11.70±0.21 ^{gh}
<i>Mangifera indica.</i>	55.06±1.99 ^a	64.79±4.74 ^{efg}	21.29±0.21 ^d	6.90±0.40 ^{bcdef}
<i>Moringa oleifera</i>	521.03±46.95 ^c	7.81±1.04 ^a	8.35±3.34 ^a	5.24±1.80 ^{abcd}
<i>Neolamarckia cadamba</i>	130.95±1.43 ^{ab}	106.83±4.35 ^h	19.86±1.42 ^{cd}	12.64±0.41 ^h
<i>Nephelium litchi</i>	77.78±7.81 ^{ab}	41.13±2.75 ^{bcde}	18.31±1.90 ^{bcd}	5.59±0.40 ^{abcde}
<i>Nerium oleander</i>	287.61±195.92 ^b	22.10±4.95 ^{abc}	19.02±3.13 ^{bcd}	3.45±0.15 ^{ab}
<i>Nyctanthes arbor-tristis</i>	574.37±177.97 ^c	25.33±14.05 ^{abc}	13.20±2.86 ^{abc}	4.63±1.54 ^{abc}
<i>Psidium guajava</i>	89.22±1.00 ^{ab}	71.61±3.95 ^{fg}	20.93±1.87 ^{cd}	8.81±0.60 ^{efg}
<i>Punica granatum</i>	16.58±0.02 ^a	11.59±0.40 ^a	19.26±0.37 ^{bcd}	7.81±0.08 ^{cdef}
<i>Syzygium cumini</i>	49.68±3.10 ^a	56.72±6.90 ^{def}	17.00±0.49 ^{bcd}	9.58±1.40 ^{fgh}
<i>Tectona grandis</i>	94.84±7.27 ^{ab}	194.98±7.85 ⁱ	41.44±0.79 ^e	22.30±0.54 ⁱ
F-value	5.550	24.997	8.888	17.699

At residential areas, significant difference ($p < 0.05$) in SLA of leaf samples ranged from $59.82 \pm 6.99 \text{ cm}^2/\text{g}$ in *Mangifera indica* to $210.23 \pm 74.88 \text{ cm}^2/\text{g}$ in *Nyctanthes arbor-tristis* respectively (Table 8). The leaf area was obtained maximum in *Bixa orellana* ($114.88 \pm 14.82 \text{ cm}^2$) and minimum in *Cascabela thevetia* ($22.02 \pm 0.54 \text{ cm}^2$) respectively. *Saraca asoca* showed the maximum leaf length ($25.18 \pm 2.37 \text{ cm}$) and *Nyctanthes arbor-tristis* showed the minimum leaf length ($14.34 \pm 2.45 \text{ cm}$). Similarly, *Bixa orellana* recorded the highest leaf width ($15.74 \pm 1.65 \text{ cm}$) and *Cascabela thevetia* recorded the smallest leaf width ($2.30 \pm 0.17 \text{ cm}$) from residential areas.

Table 8: Leaf traits at residential areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$. (n=27))

Plant species	SLA (cm ² /g)	Leaf area (cm ²)	Leaf length (cm)	Leaf width (cm)
<i>Aegle marmelos</i>	140.29±11.80 ^{ab}	41.43±3.36 ^{ab}	14.37±1.62 ^a	8.07±1.21 ^e
<i>Bombax ceiba</i>	132.21±29.19 ^{ab}	76.05±3.44 ^d	23.16±1.09 ^{cd}	8.56±0.64 ^c
<i>Bixa orellana</i>	88.60±3.02 ^a	114.88±14.82 ^e	17.47±0.63 ^{cd}	15.74±1.65 ^e
<i>Cascabela thevetia</i>	191.47±9.75 ^b	22.02±0.54 ^a	24.38±1.19 ^{cd}	2.30±0.17 ^a
<i>Mangifera indica</i>	59.82±6.99 ^a	65.87±13.20 ^{cd}	20.90±0.30 ^{bcd}	7.40±0.59 ^{bc}
<i>Neolamarckia cadamba</i>	96.66±4.13 ^a	112.01±3.84 ^e	19.58±0.67 ^{bc}	11.82±0.07 ^d
<i>Nyctanthes arbor-tristis</i>	210.23±74.88 ^b	40.62±9.00 ^{ab}	14.34±2.45 ^a	6.74±0.87 ^{bc}
<i>Psidium guajava</i>	88.94±4.72 ^a	70.74±4.84 ^{cd}	21.66±2.47 ^{bcd}	8.98±0.67 ^c
<i>Saraca asoca</i>	99.04±4.82 ^a	48.41±2.38 ^{bc}	25.18±2.37 ^d	5.03±0.43 ^b
F-value	3.348	16.824	6.094	20.629

At campus (control) areas, significant difference ($p < 0.05$) in SLA was found maximum in *Nyctanthes arbor-tristis* (574.37±177.97 cm²/g) but *Punica granatum* (16.58±0.02 cm²/g) recorded minimum SLA. *Tectona grandis* was large in structure recording maximum leaf area (194.98±7.85 cm²) but *Azadirachta indica* leaflets was small in size recording 8.26±1.08cm² leaf area (Table 9). The leaf length varied from 3.56±0.05 cm in *Azadirachta indica* to 42.52±0.93 cm in *Tectona grandis*. Similarly, *Tectona grandis* showed maximum leaf width (22.30±0.54 cm) whereas *Cascabela thevetia* showed minimum leaf width (2.76±1.06 cm).

Table 9: Leaf traits at campus areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=72))

Plant species	SLA (cm ² /g)	Leaf area (cm ²)	Leaf length (cm)	Leaf width (cm)
<i>Artocarpus heterophyllus</i>	84.86±6.86 ^{ab}	68.55±12.73 ^{efg}	15.03±0.46 ^{abcd}	10.36±0.59 ^{fgh}
<i>Azadirachta indica</i>	187.93±2.52 ^{ab}	8.71±0.22 ^a	8.26±1.08 ^a	3.36±0.02 ^a
<i>Aegle marmelos</i>	170.71±11.18 ^{ab}	63.34±9.17 ^{efg}	18.31±2.51 ^{bcd}	8.49±0.85 ^{defg}
<i>Bombax ceiba</i>	124.28±39.44 ^{ab}	45.36±1.39 ^{cdef}	17.54±1.91 ^{bcd}	6.92±0.44 ^{bcd}
<i>Cascabela thevetia</i>	226.85±34.25 ^{ab}	15.91±1.61 ^{ab}	19.72±6.05 ^{cd}	2.76±1.06 ^a
<i>Citrus maxima</i>	123.49±15.71 ^{ab}	58.30±5.47 ^{defg}	22.08±0.95 ^d	8.15±0.51 ^{cdef}
<i>Dalbergia sissoo</i>	171.22±54.93 ^{ab}	15.61±5.58 ^{ab}	11.79±3.70 ^{ab}	5.38±1.40 ^{abcde}
<i>Delonix regia</i>	66.57±9.14 ^a	32.82±27.15 ^{abcd}	17.76±0.18 ^{bcd}	4.77±2.89 ^{abc}
<i>Ficus benghalensis</i>	55.54±7.08 ^a	86.40±5.45 ^{gh}	16.35±0.79 ^{bcd}	12.19±0.85 ^h
<i>Ficus religiosa</i>	76.09±28.76 ^{ab}	66.39±6.41 ^{efg}	14.61±0.188 ^{abcd}	11.70±0.21 ^{gh}
<i>Mangifera indica</i>	55.06±1.99 ^a	64.79±4.74 ^{efg}	21.29±0.21 ^d	6.90±0.40 ^{bcd}
<i>Moringa oleifera</i>	521.03±46.95 ^c	7.81±1.04 ^a	8.35±3.34 ^a	5.24±1.80 ^{abcd}
<i>Neolamarckia cadamba</i>	130.95±1.43 ^{ab}	106.83±4.35 ^h	19.86±1.42 ^{cd}	12.64±0.41 ^h
<i>Nephelium litchi</i>	77.78±7.81 ^{ab}	41.13±2.75 ^{bcd}	18.31±1.90 ^{bcd}	5.59±0.40 ^{abcde}
<i>Nerium oleander</i>	287.61±195.92 ^b	22.10±4.95 ^{abc}	19.02±3.13 ^{bcd}	3.45±0.15 ^{ab}
<i>Nyctanthes arbor-tristis</i>	574.37±177.97 ^c	25.33±14.05 ^{abc}	13.20±2.86 ^{abc}	4.63±1.54 ^{abc}
<i>Psidium guajava</i>	89.22±1.00 ^{ab}	71.61±3.95 ^{fg}	20.93±1.87 ^{cd}	8.81±0.60 ^{efg}
<i>Punica granatum</i>	16.58±0.02 ^a	11.59±0.40 ^a	19.26±0.37 ^{bcd}	7.81±0.08 ^{cdef}
<i>Syzygium cumini</i>	49.68±3.10 ^a	56.72±6.90 ^{def}	17.00±0.49 ^{bcd}	9.58±1.40 ^{fgh}
<i>Saraca asoca</i>	152.94±11.55 ^{bc}	51.95±4.13 ^{bc}	11.48±6.50 ^{bc}	5.31±0.38 ^c
<i>Tectona grandis</i>	94.84±7.27 ^{ab}	194.98±7.85 ⁱ	41.44±0.79 ^e	22.30±0.54 ⁱ
F-value	5.550	24.997	8.888	17.699

4.3 Reduction on Morphology of Leaf

While comparing the different study areas with less polluted campus areas (i.e. control), 12 common plants were observed with industrial areas, 10 common plant species were recorded with roadside and 4 common plants were recorded with residential areas. Statistically, the % of reduction on leaf area and SLA data were found to be insignificant ($p>0.05$), (Tables 11 and 12).

Leaf area: Leaf area was found to be decreasing at industrial areas than the campus areas. At industrial areas, the % of decreases in the leaf area varied from 0.42 % in *Ficus religiosa* to 13.25 % in *Azadirachta indica* (Table 10). At the roadside, there was a slight reduction in leaf area where maximum reduction was in *Neolamarckia cadamba* (12.65 %) and minimum was in *Citrus maxima* (0.35%). Among the four common plants between the campus and residential areas, maximum leaf area was observed in *Neolamarckia cadamba* (8.55 %) whereas minimum leaf area was observed in *Psidium guajava* (6.32%) respectively (Figure 5).

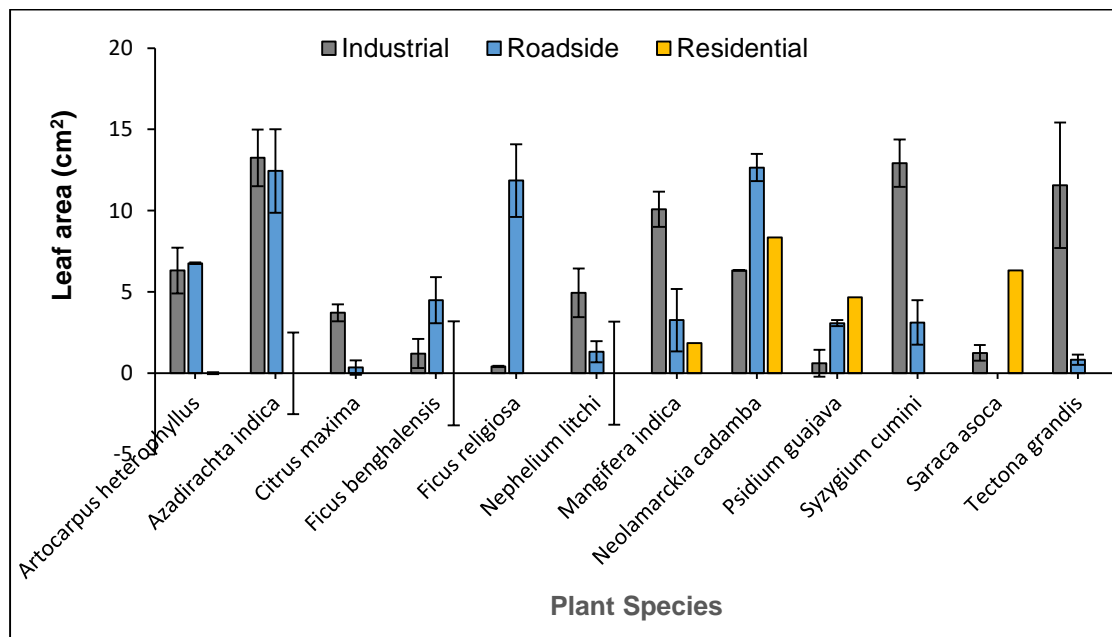


Figure 5: Percentage of reduction in leaf area of plant species

Table 10: Percentage (%) decrease in leaf area at different study areas in comparison to less polluted campus areas. (The data were expressed as Mean \pm S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=12 to 36))

Plant species	Industrial	Roadside	Residential
<i>Artocarpus heterophyllus</i>	6.32 \pm 1.41 ^a	6.76 \pm 0.05 ^{ab}	-
<i>Azadirachta indica</i>	13.25 \pm 1.74 ^a	12.44 \pm 2.57 ^b	-
<i>Citrus maxima</i>	3.72 \pm 0.52 ^a	0.35 \pm 0.44 ^a	-
<i>Ficus benghalensis</i>	1.21 \pm 0.90 ^a	4.49 \pm 1.42 ^{ab}	-
<i>Ficus religiosa</i>	0.42 \pm 0.04 ^a	11.85 \pm 2.24 ^{ab}	-
<i>Mangifera indica</i>	10.08 \pm 1.49 ^a	3.27 \pm 0.65 ^{ab}	1.86 \pm 0.06 ^a
<i>Neolamarckia cadamba</i>	6.32 \pm 1.08 ^a	12.65 \pm 1.92 ^b	8.35 \pm 2.51 ^a
<i>Nepbelium litchi</i>	4.95 \pm 0.02 ^a	1.33 \pm 0.84 ^{ab}	-
<i>Psidium guajava</i>	0.61 \pm 0.83 ^a	3.08 \pm 0.19 ^{ab}	4.67 \pm 3.20 ^a
<i>Syzygium cumini</i>	12.92 \pm 1.46 ^a	3.12 \pm 1.37 ^{ab}	-
<i>Saraca asoca</i>	1.25 \pm 0.48 ^a	-	6.32 \pm 3.17 ^a
<i>Tectona grandis</i>	11.57 \pm 3.86 ^a	0.83 \pm 0.32 ^{ab}	-
F-value	1.482	1.821	0.085
<i>p</i> -value	0.202	0.116	0.966

SLA: SLA was reduced at industrial areas and roadside as compared to that at campus areas (Table 11). At industrial areas, the % of SLA decrease ranged from 1.39 % in *Nepbelium litchi* to 20.48 % in *Ficus religiosa*. Similarly, at residential areas, maximum reduction on SLA was observed in *Mangifera indica* (35.55%) and minimum was observed in *Azadirachta indica* (3.71%). At residential areas, maximum SLA reduction was in *Neolamarckia cadamba* (37.08%) whereas minimum SLA reduction was in *Psidium guajava* (4.89 %) respectively (Figure 6). SLA was found to be significant to each other ($p < 0.05$) in the residential sites but were insignificant on remaining study areas.

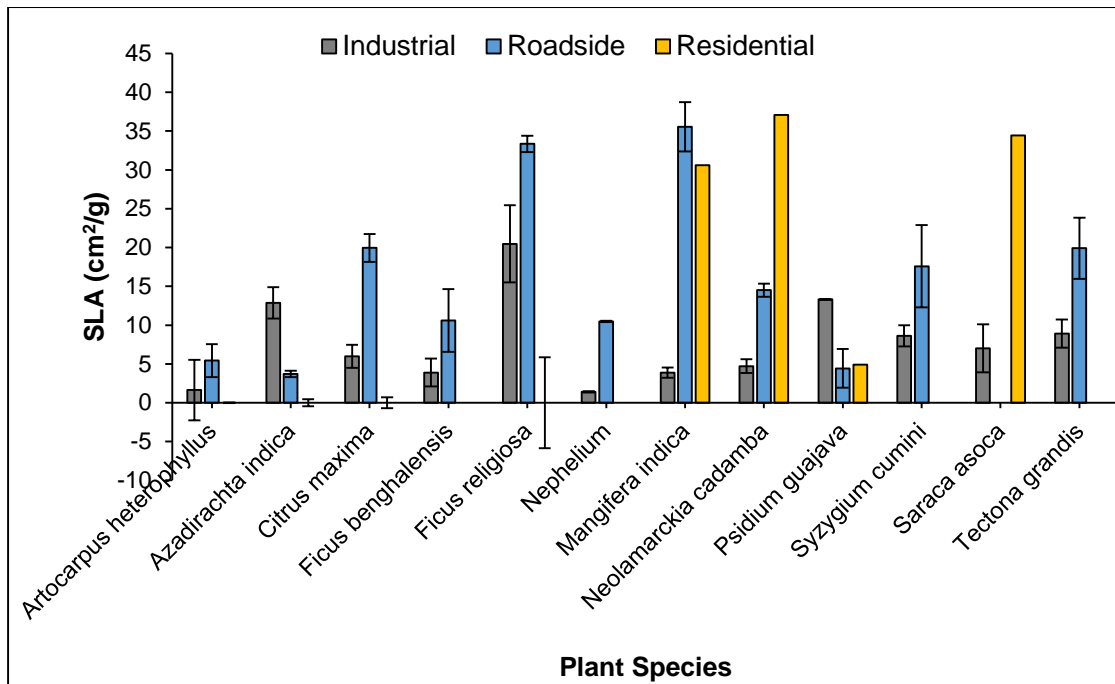


Figure 6: Percentage of reduction in SLA of plant species

Table 11: Percentage (%) decrease in SLA at different study areas in comparison to less polluted campus areas. (The data were expressed as Mean ± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=12 to 36))

Plant species	Industrial	Roadside	Residential
<i>Artocarpus heterophyllus</i>	1.64 ± 3.90 ^a	5.44 ± 2.12 ^a	-
<i>Azadirachta indica</i>	12.86 ± 2.02 ^a	3.71 ± 0.43 ^a	-
<i>Citrus maxima</i>	5.97 ± 1.49 ^a	19.95 ± 1.80 ^a	-
<i>Ficus benghalensis</i>	3.89 ± 1.79 ^a	10.60 ± 4.04 ^a	-
<i>Ficus religiosa</i>	20.48 ± 4.97 ^a	33.35 ± 1.07 ^a	-
<i>Mangifera indica</i>	3.88 ± 0.19 ^a	35.55 ± 6.08 ^a	30.62 ± 0.04 ^b
<i>Neolamarckia cadamba</i>	4.71 ± 0.66 ^a	14.51 ± 3.19 ^a	37.08 ± 0.46 ^b
<i>Nephelium litchi</i>	1.39 ± 0.09 ^a	10.46 ± 0.84 ^a	-
<i>Psidium guajava</i>	13.31 ± 0.03 ^a	4.43 ± 0.50 ^a	4.89 ± 0.71 ^a
<i>Syzygium cumini</i>	8.64 ± 1.36 ^a	17.59 ± 5.30 ^a	-

<i>Saraca asoca</i>	7.00±3.09 ^a	-	34.46±5.84 ^b
<i>Tectona grandis</i>	8.90±1.81 ^a	19.91±3.95 ^a	-
F-value	0.274	0.621	7.788
<i>p</i> -value	0.985	0.780	0.009

Leaf length: Comparing the reduction on leaf length at different study areas, polluted and roadside showed more reduction than other areas. The % of decrease in leaf length ranged from 4.76 to 28.93 in the industrial areas (Table 12). Leaf length reduction was maximum in *Syzygium cumini* and minimum reduction in *Citrus maxima*. The % of reduction on leaf length was found to be significant ($p<0.05$) in industrial areas. *Neolamarckia cadamba* (0.38%) recorded the minimum reduction on leaf length whereas *Ficus religiosa* (5.21%) recorded the maximum reduction on leaf length at roadside. Among the four common plants, maximum leaf length reduction was seen in *Saraca asoca* (5.43 %) whereas minimum reduction was observed in *Neolamarckia cadamba* (0.07 %) respectively in residential areas (Figure 7). The % of reduction on leaf length was found to be significant to each other ($p<0.05$) at industrial and residential areas whereas insignificant ($p>0.05$) at roadside.

Table 12: Percentage (%) decrease in leaf length in different study areas in comparison to less polluted campus areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p\leq 0.05$, (n=63))

Plant species	Industrial	Roadside	Residential
<i>Artocarpus heterophyllus</i>	20.87±0.52 ^{abcd}	0.46±0.09 ^a	-
<i>Azadirachta indica</i>	25.03±9.94 ^{abcd}	1.52±1.59 ^a	-
<i>Citrus maxima</i>	4.76±1.69 ^a	1.11±1.33 ^a	-
<i>Ficus benghalensis</i>	28.05±3.90 ^{cd}	2.44±0.96 ^a	-
<i>Ficus religiosa</i>	9.25±3.45 ^{ab}	5.21±1.68 ^a	-
<i>Mangifera indica</i>	33.81±2.96 ^d	2.25±2.20 ^a	2.25±0.46 ^{ab}
<i>Neolamarckia cadamba</i>	11.69±7.48 ^{abc}	0.38±1.94 ^a	0.07±0.74 ^a

<i>Nepbelium litchi</i>	27.29±0.25 ^{cd}	2.26±3.53 ^a	-
<i>Psidium guajava</i>	22.82±1.09 ^{bcd}	2.05±1.14 ^a	3.58±0.43 ^b
<i>Syzygium cumini</i>	28.93±9.29 ^{cd}	2.30±1.59 ^a	-
<i>Saraca asoca</i>	13.17±5.52 ^{abc}	-	5.43±1.67 ^b
<i>Tectona grandis</i>	4.89±3.35 ^a	1.97±1.34 ^a	-
F-value	3.732	0.446	5.438
p-value	0.003	0.907	0.025

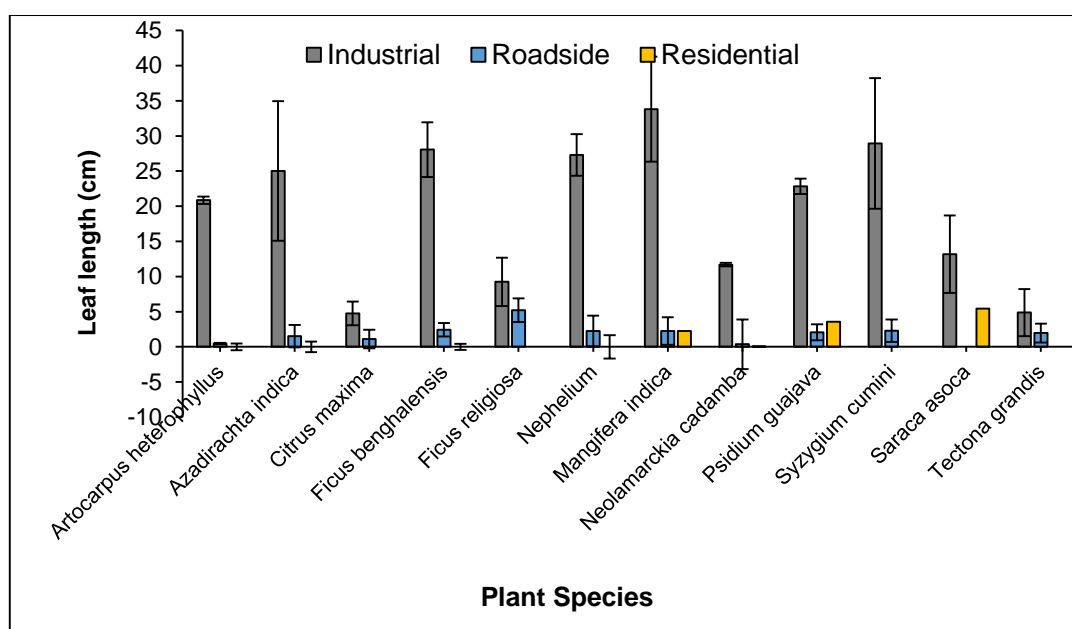


Figure 7: Percentage of reduction in leaf length of plant species

Leaf width: Statistically, the % of reduction on leaf width was found to be insignificant ($p > 0.05$) in all the study areas. Among the common plants from industrial and campus areas, the % of decrease in leaf width ranged from 4.80 % in *Azadirachta indica* to 13.42 % in *Psidium guajava* (Table 13). At roadside, *Neolamarckia cadamba* recorded the minimum reduction on leaf width (0.69%) whereas *Syzygium cumini* recorded minimum reduction on leaf width (12.39%) respectively. Among the four common plants, maximum leaf width reduction was in *Saraca asoca* (5.30 %) whereas minimum reduction was observed in *Neolamarckia cadamba* (0.92 %) respectively (Figure 8).

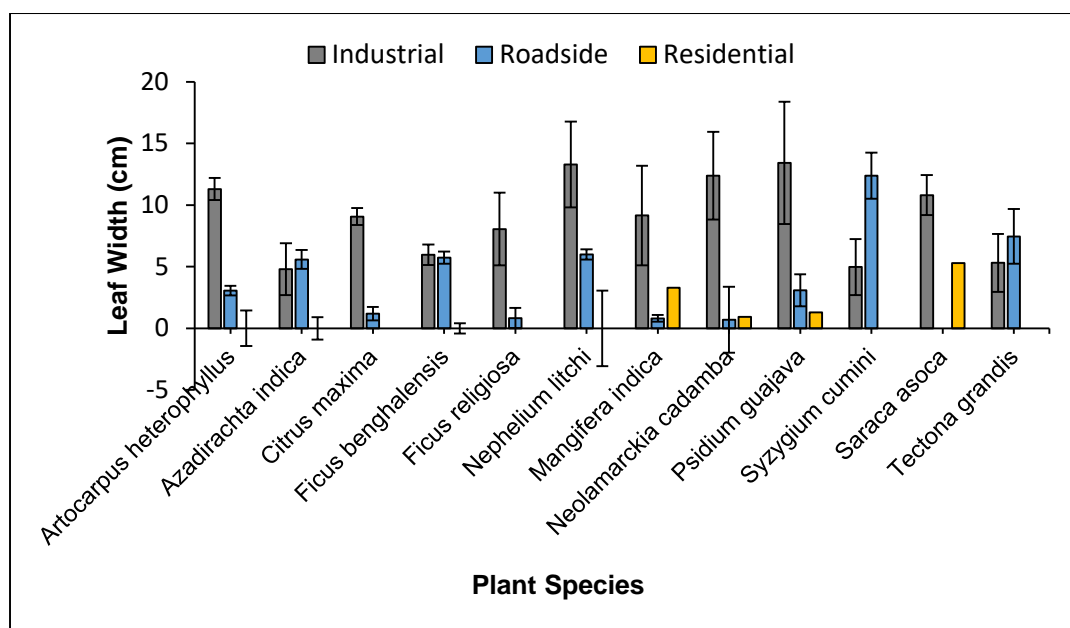


Figure 8: Percentage of reduction in leaf width of plant species

Table 13: Percentage (%) decrease in leaf width at different study areas in comparison to less polluted campus areas. (The data were expressed as Mean \pm S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=12 to 36))

Plant species	Industrial	Roadside	Residential
<i>Artocarpus heterophyllus</i>	11.30 \pm 0.89 ^a	3.07 \pm 0.39 ^{ab}	-
<i>Azadirachta indica</i>	4.80 \pm 2.11 ^a	5.59 \pm 0.77 ^{ab}	-
<i>Citrus maxima</i>	9.07 \pm 0.69 ^a	1.19 \pm 0.55 ^a	-
<i>Ficus benghalensis</i>	5.97 \pm 0.83 ^a	5.74 \pm 0.50 ^{ab}	-
<i>Ficus religiosa</i>	8.06 \pm 2.95 ^a	0.84 \pm 0.82 ^a	-
<i>Mangifera indica</i>	9.16 \pm 3.48 ^a	0.81 \pm 0.41 ^a	3.30 \pm 1.44 ^a
<i>Neolamarckia cadamba</i>	12.39 \pm 4.04 ^a	0.69 \pm 0.28 ^a	0.92 \pm 0.91 ^a
<i>Nephelium litchi</i>	13.30 \pm 3.56 ^a	6.00 \pm 2.67 ^{ab}	-
<i>Psidium guajava</i>	13.42 \pm 4.97 ^a	3.08 \pm 1.30 ^{ab}	1.29 \pm 0.41 ^a
<i>Syzygium cumini</i>	4.97 \pm 2.27 ^a	12.39 \pm 1.87 ^b	-

<i>Saraca asoca</i>	10.81±1.63 ^a	-	5.30±3.06 ^a
<i>Tectona grandis</i>	5.31±2.36 ^a	7.46±2.22 ^{ab}	-
F-value	1.333	1.296	0.529
p-value	0.267	0.292	0.675

On comparing the three common plants from all the sites, *Psidium guajava* showed the lowest reduction in leaf area (0.62%) and *Mangifera indica* recorded the minimum reduction in SLA (3.88) from industrial area. At residential areas, minimum leaf length reduction was in *Neolamarckia cadamba* (0.03%). Similarly, at roadside, *Neolamarckia cadamba* showed the minimum leaf width reduction (0.69%) respectively. In overall, *Artocarpus heterophyllus*, *Azadirachta indica*, *Citrus maxima*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica*, *Neolamarckia cadamba*, *Psidium guajava* and *Tectona grandis* were found to be tolerant to air pollutants.

4.4 Biochemical Parameters

4.4.1 Total Chlorophyll Content

At industrial areas, *Tectona grandis* showed the lowest total chlorophyll content (0.15 ± 0.01 mg/g) while *Saraca asoca* showed highest chlorophyll content (2.47 ± 0.15 mg/g), (Table 14) which were significant ($p < 0.05$). At roadside, *Pinus roxburghii* recorded minimum total chlorophyll (0.14 ± 0.01 mg/g) while *Nyctanthes arbor-tristis* had maximum chlorophyll content (2.28 ± 0.15 mg/g). At residential areas *Mangifera indica* and *Psidium guajava* recorded the maximum amount of total chlorophyll content with 1.38 ± 0.25 mg/g and 1.35 ± 0.23 mg/g respectively whereas *Cryptomeria japonica* recorded the minimum value with 0.17 ± 0.02 mg/g in the residential area. At campus area, highest chlorophyll content was recorded in *Neolamarckia cadamba* (1.69 ± 0.08 mg/g) whereas lowest was recorded in *Delonix regia* (0.13 ± 0.01 mg/g). Average total chlorophyll content was found to be higher in industrial areas and lowest was in residential areas (Figure 9).

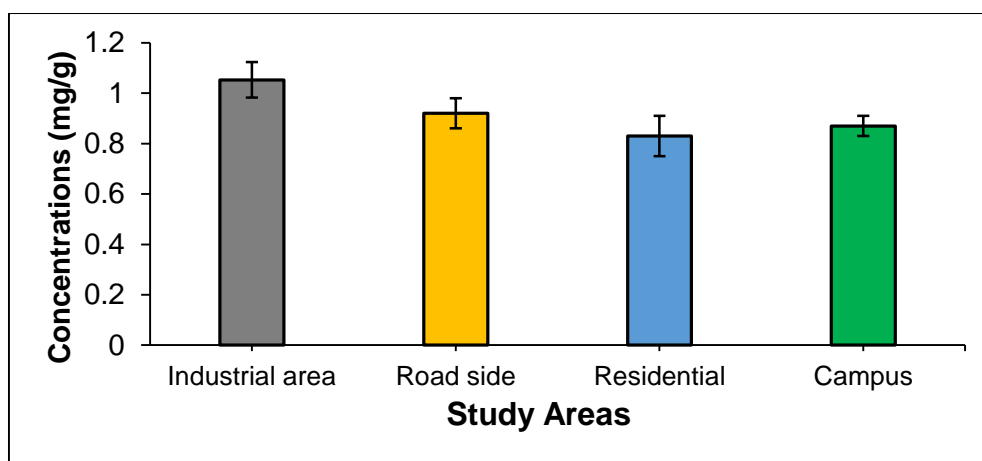


Figure 9. Average total chlorophyll content (mg/g) of different studied areas.

Table 14: Total chlorophyll content (mg/g) at different plant species at different study areas. (The data were expressed as Mean \pm S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=30 to 69))

Plant species	Industrial	Roadside	Residential	Campus
<i>Annona squamosa</i>	0.78 \pm 0.11 ^{bcd}	-	-	-
<i>Artocarpus heterophyllus</i>	1.62 \pm 0.11 ^{fg}	0.91 \pm 0.09 ^{ef}	-	1.37 \pm 0.09 ^d
<i>Azadirachta indica</i>	0.72 \pm 0.07 ^{abc}	0.79 \pm 0.12 ^{de}	-	0.62 \pm 0.02 ^c
<i>Aegle marmelos</i>	-	0.20 \pm 0.01 ^{abc}	0.72 \pm 0.04 ^{cd}	-
<i>Albizia lebbbeck</i>	-	-	-	0.26 \pm 0.04 ^{ab}
<i>Bombax ceiba</i>	0.73 \pm 0.03 ^{abc}	0.32 \pm 0.02 ^{abcd}	0.61 \pm 0.05 ^{bc}	-
<i>Bixa orellana</i>	0.34 \pm 0.05 ^{ab}	-	0.25 \pm 0.08 ^{ab}	-
<i>Citrus maxima</i>	0.55 \pm 0.03 ^{abc}	0.71 \pm 0.04 ^{cde}	-	0.57 \pm 0.02 ^{bc}
<i>Cascabela thevetia</i>	1.04 \pm 0.04 ^{cde}	1.57 \pm 0.31 ^{ghi}	1.15 \pm 0.06 ^{ef}	-
<i>Cryptomeria japonica</i>	-	0.09 \pm 0.01 ^a	0.17 \pm 0.02 ^a	-
<i>Dalbergia sissoo</i>	-	0.44 \pm 0.05 ^{abcde}	-	-
<i>Delonix regia</i>	-	0.27 \pm 0.07 ^{abc}	-	0.13 \pm 0.01 ^a
<i>Eucalyptus globulus</i>	1.41 \pm 0.27 ^{efg}	-	-	-

<i>Ficus benghalensis</i>	0.30±0.04 ^{ab}	0.68±0.14 ^{bcd}	-	0.73±0.04 ^c
<i>Ficus religiosa</i>	0.60±0.06 ^{abc}	1.40±0.11 ^{fgh}	-	0.80±0.07 ^c
<i>Mangifera indica</i>	1.72±0.16 ^{fg}	1.28±0.13 ^{fg}	1.38±0.25 ^f	1.25±0.11 ^d
<i>Moringa oleifera</i>	1.87±0.09 ^g	2.03±0.09 ^{ij}	-	-
<i>Neolamarckia cadamba</i>	1.01±0.16 ^{cde}	1.78±0.15 ^{hi}	0.55±0.03 ^{abc}	1.69±0.08 ^e
<i>Nephelium litchi</i>	1.44±0.32 ^{efg}	0.90±0.19 ^{ef}	-	0.52±0.03 ^{bc}
<i>Nerium oleander</i>	0.53±0.06 ^{abc}	0.41±0.08 ^{abcde}	-	-
<i>Nyctanthes arbor-tristis</i>	0.99±0.14 ^{cde}	2.28±0.15 ^j	1.04±0.14 ^{def}	-
<i>Psidium guajava</i>	1.68±0.11 ^{fg}	1.33±0.09 ^{fgh}	1.35±0.23 ^f	1.41±0.18 ^{de}
<i>Punica granatum</i>	0.18±0.04 ^a	0.21±0.07 ^{abc}	-	-
<i>Pinus roxburghii</i>	-	0.14±0.01 ^a	-	-
<i>Syzygium cumini</i>	1.30±0.27 ^{def}	1.30±0.27 ^{fgh}	-	1.11±0.07 ^d
<i>Saraca asoca</i>	2.47±0.15 ^h	-	0.79±0.82 ^{cde}	1.25±0.23 ^d
<i>Tectona grandis</i>	0.15±0.01 ^a	0.20±0.01 ^{abc}	-	0.48±0.04 ^{bc}
<i>Thuja occidentalis</i>	-	0.17±0.01 ^{ab}	-	-
F-value	14.20	18.33	10.82	22.89

4.4.2 Ascorbic Acid

The ascorbic acid content in leaf samples ranged from 0.33 mg/g to 53.81 mg/g at industrial areas and 0.98 mg/g to 49.96 mg/g at roadside areas whereas 1.72 mg/g to 10.15 mg/g at the residential and 0.61 mg/g to 7.83 mg/g at less polluted, campus areas (Table 15) and was significant ($p < 0.05$). At industrial areas, *Bombax ceiba* showed the highest ascorbic acid value whereas *Annona squamosa* showed the lowest value respectively. At the roadside, *Bombax ceiba* recorded maximum ascorbic acid (49.96 ± 4.89 mg/g) whereas minimum value was recorded to be of *Cryptomeria japonica* and *Syzygium cumini*. At the residential area, ascorbic acid was found to be highest on *Saraca asoca* and lowest on *Mangifera indica* and *Cryptomeria japonica*. At the campus areas, *Azadirachta indica* recorded highest ascorbic acid and *Tectona grandis* recorded lowest ascorbic acid. Average ascorbic

acid was minimum on campus areas as it was less polluted whereas industrial areas showed maximum ascorbic acid due to the presence of various factories and kilns (Figure 10).

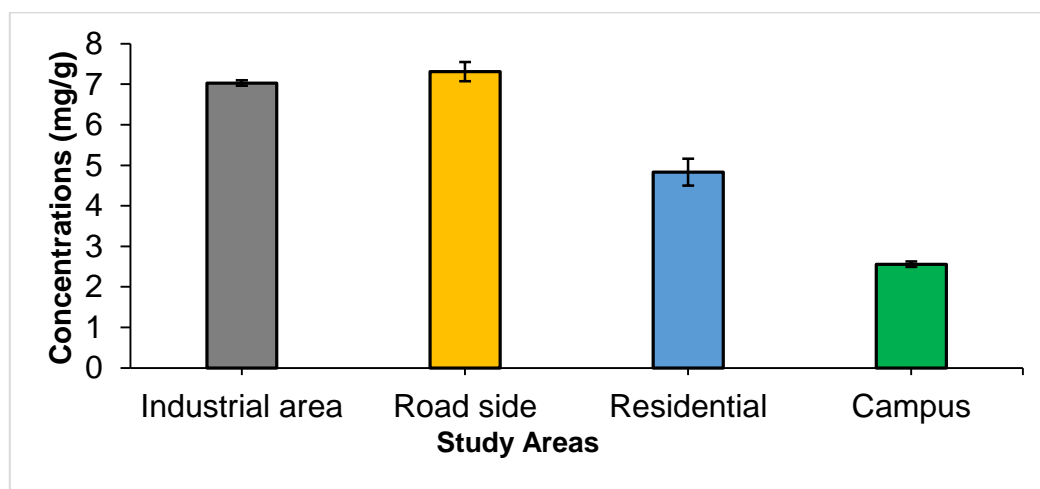


Figure 10: Average ascorbic acid (mg/g) of different studied areas

Table 15: Ascorbic Acid (mg/g) of different plant species at different study areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=30 to 69))

Plant species	Industrial	Roadside	Residential	Campus
<i>Annona squamosa</i>	0.33±0.04 ^a	-	-	-
<i>Artocarpus heterophyllus</i>	4.18±1.19 ^{bcde}	2.26±0.40 ^a	-	1.33±0.01 ^{abc}
<i>Azadirachta indica</i>	14.69±0.18 ^f	19.55±1.99 ^e	-	7.83±0.46 ^e
<i>Aegle marmelos</i>	-	2.84±0.40 ^a	3.76±2.02 ^{ab}	-
<i>Albizia lebbek</i>	-	-	-	7.19±1.50 ^e
<i>Bombax ceiba</i>	53.81±4.68 ^g	49.96±4.89 ^f	5.29±0.52 ^{bc}	-
<i>Bixa orellana</i>	7.44±0.35 ^e	-	3.81±0.67 ^{ab}	-
<i>Citrus maxima</i>	7.00±0.23 ^e	4.71±1.23 ^{ab}	-	2.98±0.36 ^c
<i>Cascabela thevetia</i>	7.05±0.12 ^e	6.17±0.44 ^{ab}	4.18±0.48 ^{ab}	-
<i>Cryptomeria japonica</i>	-	0.98±0.21 ^a	1.72±0.40 ^a	-
<i>Dalbergia sissoo</i>	-	9.23±2.06 ^{bc}	-	-

<i>Delonix regia</i>	-	18.53±0.20 ^{de}	-	4.92±1.29 ^d
<i>Eucalyptus globulus</i>	2.28±0.77 ^{abc}	-	-	-
<i>Ficus benghalensis</i>	6.40±1.41 ^{de}	2.65±0.15 ^a	-	2.74±0.28 ^{bc}
<i>Ficus religiosa</i>	15.01±0.21 ^f	13.57±3.98 ^{cd}	-	2.19±0.23 ^{abc}
<i>Mangifera indica</i>	4.96±0.83 ^{cde}	4.59±0.56 ^{ab}	1.91±0.09 ^a	1.31±0.32 ^{abc}
<i>Moringa oleifera</i>	1.07±0.25 ^{ab}	1.49±0.40 ^a	-	-
<i>Neolamarckia cadamba</i>	2.42±0.37 ^{abc}	3.96±0.37 ^{ab}	3.34±0.69 ^{ab}	0.80±0.04 ^{ab}
<i>Nephelium litchi</i>	3.89±0.70 ^{abcde}	9.29±2.20 ^{bc}	-	0.66±0.04 ^a
<i>Nerium oleander</i>	4.82±0.85 ^{bcde}	1.91±0.40 ^a	-	-
<i>Nyctanthes arbor-tristis</i>	5.20±0.49 ^{cde}	4.87±0.50 ^{ab}	6.35±0.40 ^{bc}	-
<i>Psidium guajava</i>	5.73±1.03 ^{cde}	2.23±0.34 ^a	7.79±1.37 ^{cd}	1.32±0.53 ^{abc}
<i>Punica granatum</i>	2.93±0.98 ^{abcd}	1.59±0.81 ^a	-	-
<i>Pinus roxburghii</i>	-	1.77±0.24 ^a	-	-
<i>Syzygium cumini</i>	2.69±0.74 ^{abcd}	0.98±0.21 ^a	-	0.75±0.16 ^a
<i>Saraca asoca</i>	11.35±1.67 ^f	-	10.15±0.77 ^d	1.22±0.30 ^{abc}
<i>Tectona grandis</i>	2.46±0.39 ^{abc}	2.49±0.57 ^a	-	0.61±0.09 ^a
<i>Thuja occidentalis</i>	-	18.81±2.28 ^{de}	-	-
F-value	81.13	28.90	8.32	16.34

4.4.3 pH of Leaf Extract

At industrial areas, *Ficus religiosa* and *Ficus benghalensis* had recorded highest (6.93) and lowest (3.96) pH value of leaf extract respectively. The pH value at industrial areas and roadside was in the range of 3.93 to 6.83 (Table 16) which was significant ($p < 0.05$). The pH value ranged from 5.63 to 6.50 at the residential areas and 5.73 to 7.36 at less polluted areas which were slightly acidic in nature. At roadside, significant highest pH value was found of *Bombax ceiba* and *Cascabela thevetia* whereas lowest pH value was found to be of *Pinus roxburghii*. Similarly at campus areas, *Ficus religiosa* showed more value whereas *Syzygium*

cumini recorded less value. Average pH of leaf extract was higher at less polluted (campus) areas (Figure 11) whereas lowest pH was at the industrial areas.

Table 16: pH of leaf extract of different plant species at different study areas. (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=30 to 69))

Plant species	Industrial	Roadside	Residential	Campus
<i>Annona squamosa</i>	4.40±0.00 ^a	-	-	-
<i>Artocarpus heterophyllus</i>	6.40±0.06 ^{def}	6.50±0.23 ^{efghi}	-	6.26±0.16 ^b
<i>Azadirachta indica</i>	5.86±0.03 ^{cde}	6.23±0.03 ^{cdefg}	-	6.46±0.03 ^{bc}
<i>Aegle marmelos</i>	-	6.06±0.33 ^{bcd}	6.36±0.33 ^{cd}	-
<i>Albizia lebbbeck</i>	-	-	-	6.63±0.03 ^{cde}
<i>Bombax ceiba</i>	4.40±0.05 ^a	6.83±0.33 ^{ijk}	5.90±0.05 ^b	-
<i>Bixa orellana</i>	5.95±0.11 ^{cde}	-	5.63±0.03 ^a	-
<i>Citrus maxima</i>	6.30±0.20 ^{def}	6.65±0.13 ^{ghijk}	-	6.86±0.08 ^{ef}
<i>Cascabela thevetia</i>	4.56±0.06 ^{ab}	6.83±0.06 ^{ijk}	6.20±0.00 ^c	-
<i>Cryptomeria japonica</i>	-	6.20±0.10 ^{cdegf}	6.23±1.33 ^c	-
<i>Dalbergia sissoo</i>	-	6.80±0.00 ^{hijk}	-	-
<i>Delonix regia</i>	-	5.90±0.00 ^{bcd}	-	6.63±0.03 ^{cde}
<i>Eucalyptus globulus</i>	6.13±0.03 ^{cdef}	-	-	-
<i>Ficus benghalensis</i>	3.96±0.21 ^a	7.06±0.03 ^{jk}	-	6.90±0.05 ^f
<i>Ficus religiosa</i>	6.93±0.08 ^f	7.11±0.26 ^k	-	7.36±0.03 ^g
<i>Mangifera indica</i>	4.63±0.58 ^{ab}	6.28±0.07 ^{cdefg}	5.93±0.03 ^b	6.43±0.03 ^{bc}
<i>Moringa oleifera</i>	6.16±0.03 ^{cdef}	6.43±0.03 ^{defghi}	-	-
<i>Neolamarckia cadamba</i>	5.66±0.07 ^{cd}	6.01±0.13 ^{bcde}	5.90±0.05 ^b	6.26±0.03 ^b
<i>Nephelium litchi</i>	6.20±0.10 ^{cdef}	6.73±0.09 ^{ghijk}	-	6.60±0.00 ^{cd}
<i>Nerium oleander</i>	6.20±0.00 ^{cdef}	5.96±0.03 ^{bcde}	-	-
<i>Nyctantbes arbor-tristis</i>	6.70±0.05 ^{ef}	6.90±0.00 ^{ijk}	6.50±0.00 ^d	-

<i>Psidium guajava</i>	5.35±0.05 ^{bc}	6.23±0.03 ^{cdefg}	6.20±0.00 ^c	6.80±0.15 ^{def}
<i>Punica granatum</i>	5.76±0.32 ^{cd}	5.86±0.03 ^{bc}	-	-
<i>Pinus roxburghii</i>	-	3.93±0.03 ^a	-	-
<i>Syzygium cumini</i>	5.66±0.03 ^{cd}	5.66±0.08 ^b	-	5.73±0.12 ^a
<i>Saraca asoca</i>	6.30±0.08 ^{def}	-	6.30±0.10 ^c	6.80±0.00 ^{def}
<i>Tectona grandis</i>	6.08±0.25 ^{cdef}	6.56±0.10 ^{ghij}	-	6.50±0.05 ^{bc}
<i>Thuja occidentalis</i>	-	6.26±0.03 ^{cdefg}	-	-
F-value	8.89	15.36	18.57	23.09

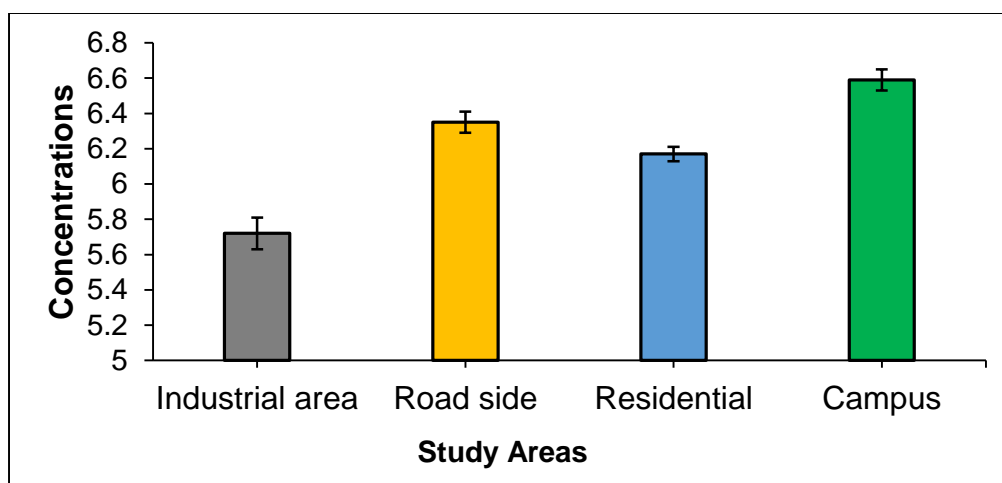


Figure 11: Average pH of leaf extract of different studied areas

4.4.4 Relative Water Content

RWC ranged from 54.14-87.24 % at industrial areas, 48.54-92.96 % at roadside, 47.91-88.45% at residential areas and 57.60-98.52 % at less polluted campus areas which were significant ($p < 0.05$). At industrial areas, *Azadirachta indica* showed the maximum whereas *Tectona grandis* showed minimum RWC value respectively. At roadside, RWC was maximum in *Pinus roxburghii* whereas minimum value was in *Thuja occidentalis*. At the residential area, RWC was maximum in *Aegle marmelos* and minimum in *Cascabela thevetia*. At campus areas, it was maximum in *Saraca asoca* and minimum in *Artocarpus heterophyllus*. Average RWC was highest at campus area followed by roadside. Industrial areas showed the lowest average RWC value (Figure 12).

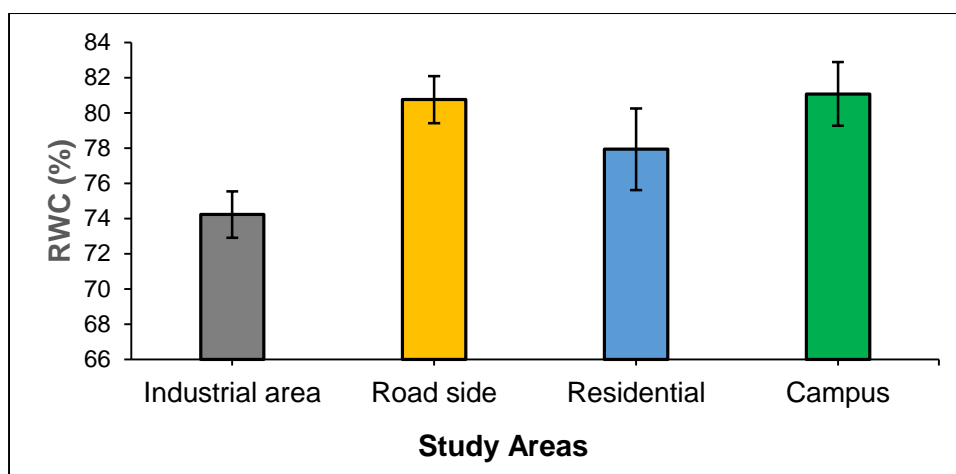


Figure 12: Average relative water content (%) of different studied areas

Table 17: RWC (%) of different plant species at different study areas. (The data were expressed as Mean \pm S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$, (n=30 to 69))

Plant species	Industrial	Roadside	Residential	Campus
<i>Annona squamosa</i>	64.08 \pm 2.03 ^{abcd}	-	-	-
<i>Artocarpus heterophyllus</i>	86.39 \pm 3.57 ^g	86.23 \pm 3.80 ^{de}	-	57.60 \pm 0.70 ^a
<i>Azadirachta indica</i>	87.24 \pm 5.66 ^g	92.14 \pm 5.78 ^e	-	88.87 \pm 2.74 ^{de}
<i>Aegle marmelos</i>	-	82.92 \pm 0.69 ^{cde}	88.45 \pm 2.62 ^d	-
<i>Albizia lebbeck</i>	-	-	-	81.32 \pm 6.56 ^{cd}
<i>Bombax ceiba</i>	61.48 \pm 1.95 ^{abc}	83.24 \pm 1.26 ^{cde}	78.98 \pm 1.40 ^{bcd}	-
<i>Bixa orellana</i>	73.59 \pm 1.91 ^{bcdefg}	-	74.15 \pm 4.09 ^{bc}	-
<i>Citrus maxima</i>	66.66 \pm 5.33 ^{abcde}	88.62 \pm 2.76 ^{de}	-	86.83 \pm 4.24 ^d
<i>Cascabela thevetia</i>	61.02 \pm 0.08 ^{ab}	68.20 \pm 3.48 ^b	47.91 \pm 3.64 ^a	-
<i>Cryptomeria japonica</i>	-	52.85 \pm 5.87 ^a	71.76 \pm 7.48 ^b	-
<i>Dalbergia sissoo</i>	-	66.07 \pm 1.47 ^b	-	-
<i>Delonix regia</i>	-	73.10 \pm 1.27 ^{bc}	-	64.69 \pm 6.69 ^{ab}
<i>Eucalyptus globulus</i>	62.31 \pm 4.79 ^{abc}	-	-	-

<i>Ficus benghalensis</i>	78.87±3.29 ^{efg}	91.57±1.83 ^e	-	85.65±2.86 ^d
<i>Ficus religiosa</i>	83.40±2.35 ^{fg}	88.74±3.07 ^{de}	-	84.86±1.08 ^d
<i>Mangifera indica</i>	84.15±1.52 ^{fg}	91.62±1.25 ^e	85.15±3.77 ^d	87.06±1.37 ^d
<i>Moringa oleifera</i>	79.68±5.07 ^{efg}	67.34±2.72 ^b	-	-
<i>Neolamarckia cadamba</i>	81.12±2.77 ^{fg}	85.13±3.30 ^{de}	88.02±2.31 ^{cd}	85.04±1.73 ^d
<i>Nephelium litchi</i>	76.52±3.82 ^{defg}	87.22±1.51 ^{de}	-	88.92±4.29 ^{de}
<i>Nerium oleander</i>	79.60±0.98 ^{efg}	91.31±1.15 ^e	-	-
<i>Nyctantbes arbor-tristis</i>	75.42±7.15 ^{cdefg}	72.43±1.62 ^{bc}	76.69±3.33 ^{bcd}	-
<i>Psidium guajava</i>	71.91±6.09 ^{bcdef}	89.29±5.79 ^e	84.65±1.71 ^{cd}	71.43±2.79 ^{bc}
<i>Punica granatum</i>	85.76±3.77 ^{fg}	77.32±5.24 ^{bcd}	-	-
<i>Pinus roxburghii</i>	-	92.96±3.89 ^e	-	-
<i>Syzygium cumini</i>	75.18±5.36 ^{cdefg}	67.56±3.09 ^b	-	72.92±4.44 ^{bc}
<i>Saraca asoca</i>	61.97±4.26 ^{abc}	-	83.57±3.05 ^{bcd}	98.52±0.90 ^e
<i>Tectona grandis</i>	54.14±2.37 ^a	67.67±2.94 ^b	-	81.30±0.86 ^{cd}
<i>Thuja occidentalis</i>	-	48.54±2.60 ^a	-	-
F-value	6.23	13.18	10.45	9.34

4.4.5 Air Pollution Tolerance Index (APTI)

AT industrial areas, significant ($p < 0.05$) APTI values ranged from 6.58 ± 0.18 to 33.69 ± 2.25 . At industrial areas, maximum APTI value was recorded in *Bombax ceiba* but *Annona squamosa* showed the minimum APTI value. At roadside, *Azadirachta indica*, *Bombax ceiba* and *Ficus religiosa* were found to be tolerant plant species. *Bombax ceiba* showed the highest APTI value (44.06) but *Cryptomeria japonica* showed lowest APTI value (5.90). In residential areas, APTI was higher on *Saraca asoca* (15.55) whereas *Cryptomeria japonica* and *Cascabela thevetia* recorded lowest APTI value (8.29 and 7.86) respectively. Four of the plants were recorded to have an intermediate tolerance level and rest of them were moderately tolerant at residential areas. At campus areas, significant ($p < 0.05$) APTI values ranged from 6.77 ± 0.16 to 14.44 ± 0.49 showing maximum value in *Azadirachta indica* and minimum value

in *Artocarpus heterophyllus*. Mostly, the plant was found under intermediate tolerance level but *Artocarpus indica*, *Albizia lebbek* and *Delonix regia* were recorded to be mostly tolerant species at campus areas (Table 18). There were 5 tolerant, 6 moderately tolerant and 12 intermediate plant species recorded at roadside areas. *Azadirachta indica*, *Bombax ceiba*, *Delonix regia*, *Ficus religiosa* and *Nepbelium litchi* were recorded as tolerant plants at roadside. *Citrus maxima*, *Cascabela thevetia*, *Dalbergia sissoo*, *Mangifera indica*, *Neolamarckia cadamba* and *Nyctanthes arbor-tritis* were recorded under moderately tolerant species at roadside.

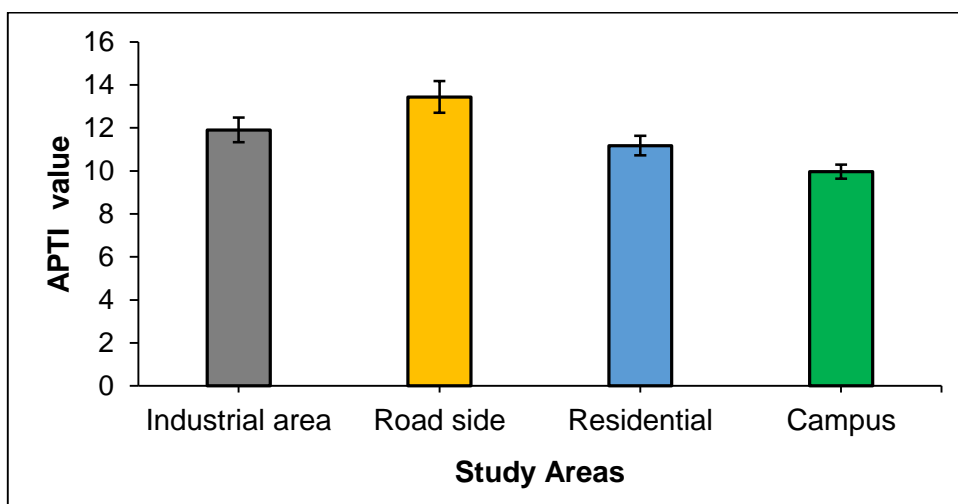


Figure 13: Average air pollution tolerance index of different studied areas

Among the selected four study areas (industrial, roadside, residential and less polluted campus areas), only 3 plant species were common from all study areas. The common plant species (*Mangifera indica*, *Neolamarckia cadamba* and *Psidium guajava*) were recorded under intermediate to moderately tolerant. None of the plant species were under sensitive category. *Azadirachta indica* and *Bombax ceiba* were recorded under moderately tolerant to tolerant species. Gymnosperms (*Cryptomeria japonica*, *Pinus roxburghii* and *Thuja occidentalis*) were recorded under intermediate category. *Tectona grandis*, *Syzygium cumini* and *Nepbelium litchi* were under intermediate in all the areas (Table 19). Comparatively, *Artocarpus heterophyllus*, *Azadirachta indica*, *Citrus maxima*, *Ficus religiosa*, *Ficus benghalensis*, *Mangifera indica*, *Neolamarckia cadamba*, *Psidium guajava* and *Tectona grandis* recorded higher APTI value which are resistant to the air pollutants. Average APTI was found to be maximum at roadside followed by industrial areas, residential and campus areas (Figure 13).

Table 18: Air Pollution Tolerance Index (APTI) and Category (Thakar and Mishra, 2010) of four different areas

Plant species	Industrial		Roadside		Residential		Less polluted	
	APTI	Category	APTI	Category	APTI	Category	APTI	Category
<i>Annona squamosa</i>	6.58±0.18 ^a	I	-	-	-	-	-	-
<i>Artocarpus heterophyllus</i>	12.06±1.35 ^e	MT	10.26±0.60 ^{abc}	I	-	-	6.77±0.16 ^a	I
<i>Azadirachta indica</i>	18.40±0.51 ^{fg}	T	22.90±1.80 ^h	T	-	-	14.44±0.49 ^f	MT
<i>Aegle marmelos</i>	-	-	10.07±0.30 ^{abc}	I	11.52±1.68 ^{bcd}	MT	-	-
<i>Albizia lebbek</i>	-	-	-	-	-	-	13.10±0.46 ^f	MT
<i>Bombax ceiba</i>	33.69±2.25 ^h	T	44.06±3.27 ⁱ	T	11.34±0.44 ^{bc}	MT	-	-
<i>Bixa orellana</i>	12.05±0.41 ^e	MT	-	-	9.65±0.37 ^{ab}	I	-	-
<i>Citrus maxima</i>	11.47±0.78 ^{de}	MT	12.41±0.79 ^{bcd}	MT	-	-	10.90±0.50 ^e	I
<i>Cascabela thevetia</i>	10.05±0.30 ^{cde}	I	12.00±0.43 ^{bcd}	MT	7.86±0.67 ^a	I	-	-
<i>Cryptomeria japonica</i>	-	-	5.90±0.50 ^a	I	8.29±0.75 ^a	I	-	-
<i>Dalbergia sissoo</i>	-	-	13.27±1.54 ^{cde}	MT	-	-	-	-
<i>Delonix regia</i>	-	-	18.75±0.28 ^{fgh}	T	-	-	9.80±1.44 ^{cde}	MT
<i>Eucalyptus globulus</i>	7.92±0.99 ^{abc}	I	-	-	-	-	-	-
<i>Ficus benghalensis</i>	10.68±0.80 ^{de}	MT	11.21±0.09 ^{bcd}	I	-	-	10.66±0.49 ^e	I

<i>Ficus religiosa</i>	19.65±0.20 ^g	T	21.03±3.51 ^{gh}	T	-	-	10.27±0.13 ^{de}	I
<i>Mangifera indica</i>	11.43±0.56 ^{de}	MT	12.66±0.40 ^{bcd}	MT	9.91±0.37 ^{ab}	I	9.71±0.11 ^{cde}	I
<i>Moringa oleifera</i>	8.83±0.60 ^{abcd}	I	8.00±0.61 ^{ab}	I	-	-	-	-
<i>Neolamarckia cadamba</i>	9.71±0.45 ^{cde}	I	11.59±0.52 ^{bcd}	MT	10.95±0.34 ^{bc}	I	9.14±0.16 ^{bcd}	I
<i>Nepbelium litchi</i>	10.52±0.60 ^{cde}	I	15.55±1.47 ^{def}	T	-	-	9.36±0.46 ^{bcd}	I
<i>Nerium oleander</i>	11.20±0.46 ^{de}	I	10.35±0.14 ^{abc}	I	-	-	-	-
<i>Nyctanthes arbor-tristis</i>	11.55±1.09 ^{de}	MT	11.73±0.35 ^{bcd}	MT	12.47±0.12 ^{cd}	I	-	-
<i>Psidium guajava</i>	11.08±0.14 ^{de}	I	10.62±0.33 ^{abcd}	I	14.30±1.08 ^{de}	MT	8.20±0.68 ^{abc}	I
<i>Punica granatum</i>	10.32±0.52 ^{cde}	I	8.69±0.32 ^{abc}	I	-	-	-	-
<i>Pinus roxburghii</i>	-	-	10.02±0.41 ^{abc}	I	-	-	-	-
<i>Syzygium cumini</i>	9.24±0.58 ^{bcd}	I	7.45±0.30 ^{ab}	I			7.81±0.46 ^{ab}	I
<i>Saraca asoca</i>	16.11±0.88 ^f	MT	-	-	15.55±0.30 ^e	MT	10.82±0.14 ^e	I
<i>Tectona grandis</i>	7.00±0.21 ^{ab}	I	8.42±0.37 ^{abc}	I	-	-	8.55±0.13 ^{bcd}	I
<i>Thuja occidentalis</i>	-	-	16.97±1.52 ^{efg}	I	-	-	-	-
F-value	44.19		23.49		10.45		14.00	

(I: Intermediate, MT: Moderately Tolerant, T: Tolerant) (The data were expressed as Mean± S.E and statistical analysis using one way ANOVA for obtaining F and *p* value. Significance mean value among different plant species are indicated by different letters. (Duncan multiple test, $p \leq 0.05$. (n=30 to 69))

4.4.6 Anticipated Performance Index (API)

The biochemical, morphological and socio-economic parameters of 28 plant species from different areas of Biratnagar and its adjoining areas in Morang were studied for the calculation of API (anticipated performance index) value (Annex 3). *Ficus religiosa* was recorded under the best plant (93.75 %) species scoring grade 7. It was followed by *Bombax ceiba* under the excellent category (81.25). *Nepheleium litchi* was recorded as a very good category whereas *Artocarpus heterophyllus*, *Azadirachta indica*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* were recorded under the good category. *Annona squamosa*, *Cascabela thevetia* and *Albizia lebbbeck* with 31.25% were found as very poor plant species with grade 1 (Table 19). *Moringa oleifera*, *Aegle marmelos* and *Punica granatum* were found as very sensitive plants.

Table 19: API of 28 plant species collected from different study area

Plant species	Obtained grade	Score (%)	Grade	Category
<i>Ficus religiosa</i>	15	93.75	7	Best
<i>Bombax ceiba</i>	13	81.25	6	Excellent
<i>Nepheleium litchi</i>	12	75	5	Very good
<i>Artocarpus heterophyllus</i>	10	62.5	4	Good
<i>Azadirachta indica</i>	10	62.5	4	Good
<i>Ficus benghalensis</i>	10	62.5	4	Good
<i>Mangifera indica</i>	10	62.5	4	Good
<i>Neolamarckia cadamba</i>	10	62.5	4	Good
<i>Saraca asoca</i>	9	56.25	3	Moderate
<i>Citrus maxima</i>	8	50	2	Poor
<i>Delonix regia</i>	8	50	2	Poor
<i>Eucalyptus globulus</i>	8	50	2	Poor
<i>Syzygium cumini</i>	8	50	2	Poor
<i>Tectona grandis</i>	8	50	2	Poor
<i>Bixa orellana</i>	7	43.75	2	Poor

<i>Cryptomeria japonica</i>	7	43.75	2	Poor
<i>Dalbergia sissoo</i>	7	43.75	2	Poor
<i>Pinus roxburghii</i>	7	43.75	2	Poor
<i>Nerium oleander</i>	6	37.5	1	Very poor
<i>Nyctanthes arbor-tristis</i>	6	37.5	1	Very poor
<i>Psidium guajava</i>	6	37.5	1	Very poor
<i>Albizia lebbbeck</i>	5	31.25	1	Very poor
<i>Annona squamosa</i>	5	31.25	1	Very poor
<i>Cascabela thevetia</i>	5	31.25	1	Very poor
<i>Moringa oleifera</i>	4	25	0	Not recommended
<i>Aegle marmelos</i>	3	18.75	0	Not recommended
<i>Punica granatum</i>	2	12.5	0	Not recommended

4.5 Correlation

4.5.1 Correlation of dust load with macro morphology of leaves (SLA, leaf area, leaf length and leaf width)

SLA correlated significantly with positive relation to dust load ($r=0.688$, $p<0.05$). APTI showed significant negative relation with SLA ($r=-0.262$, $p<0.05$) in the industrial areas (Table 22). Dust load showed positive and significant correlation with leaf area, leaf length and leaf width ($p<0.05$) and negative insignificant relation with SLA and APTI ($p>0.05$) in roadside. Leaf area correlates positively with dust load with significant results ($p<0.05$) at residential areas. Dust load was significant to leaf length ($p<0.05$) whereas others were insignificant in result at residential areas. SLA correlated positively with APTI with significant relation ($p<0.01$, $r=0.0588$). Dust load showed negative correlation with leaf area, SLA and leaf length with insignificant result ($p>0.05$) at campus areas (Annex 4).

4.5.2 Correlation of dust load with biochemical parameters and APTI

Statistically, the obtained dust load data of industrial areas showed strong positive relationship ascorbic acid ($r=0.322, p<0.05$) and negative relation with relative water content ($r=-0.34, p<0.05$). The correlation result showed that the obtained data of dust load was found to be insignificant ($p>0.05$) in other study areas (Annex 4). pH of the leaf and RWC showed negative correlation whereas APTI showed positive correlation with dust load.

4.5.3 Relation of dust load with biochemical parameters and leaf traits

The analysis of dust load and specific leaf area showed the inverse relation between to each other (Figure 14a). Dust load was found to be directly related with leaf area (Figure 14b). This indicates that a leaf having a larger leaf area can collect the maximum dust load and vice versa.

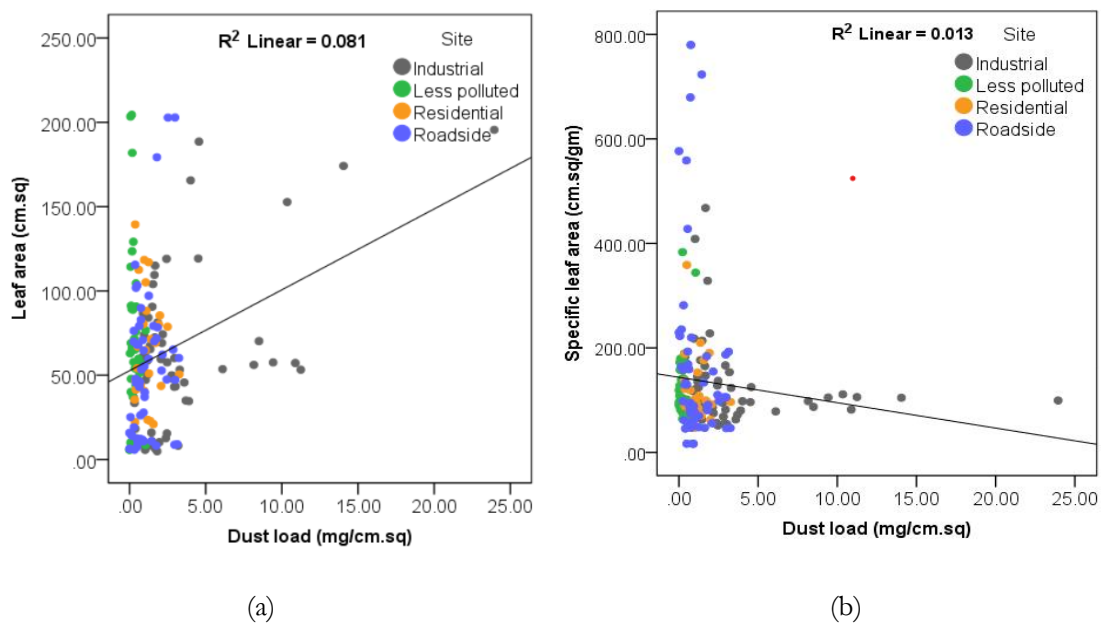


Figure 14: Scatter plot of SLA and dust load (a) and Leaf area and dust load (b)

From the correlation analysis, it was observed that the dust load and APTI were directly proportional to each other (Figure 15a). It means that when dust load per leaf area increases, the APTI also increases and vice versa. Similarly, the correlation between the dust load and total chlorophyll content showed an inverse relation i.e. the total chlorophyll content decreases with increases in amount of dust load on the leaf surface (Figure 15b).

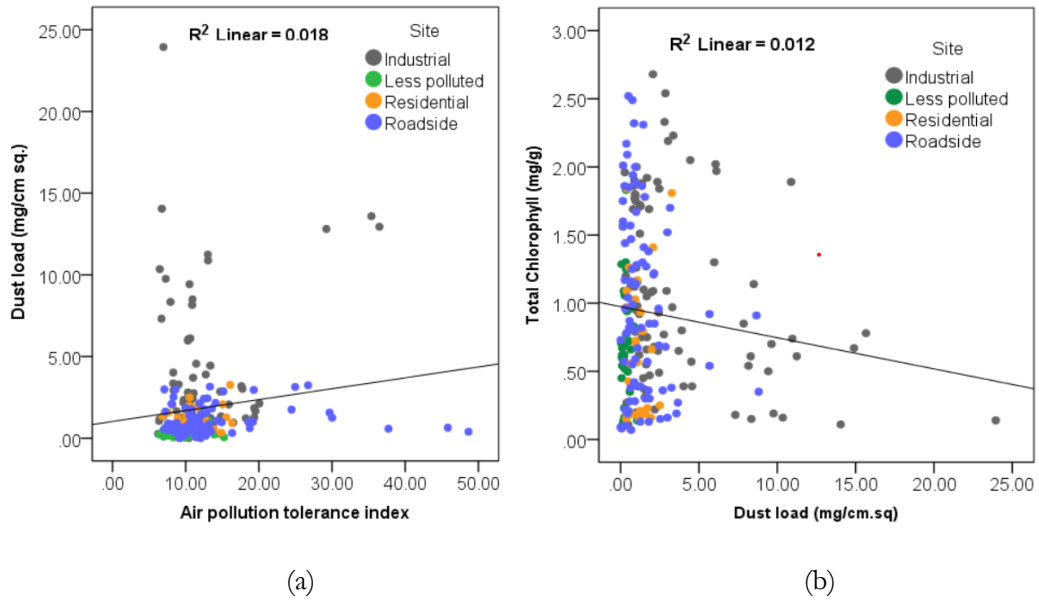


Figure 15: Scatter plot of dust load and air pollution tolerance index (a) and dust load and total chlorophyll (b)

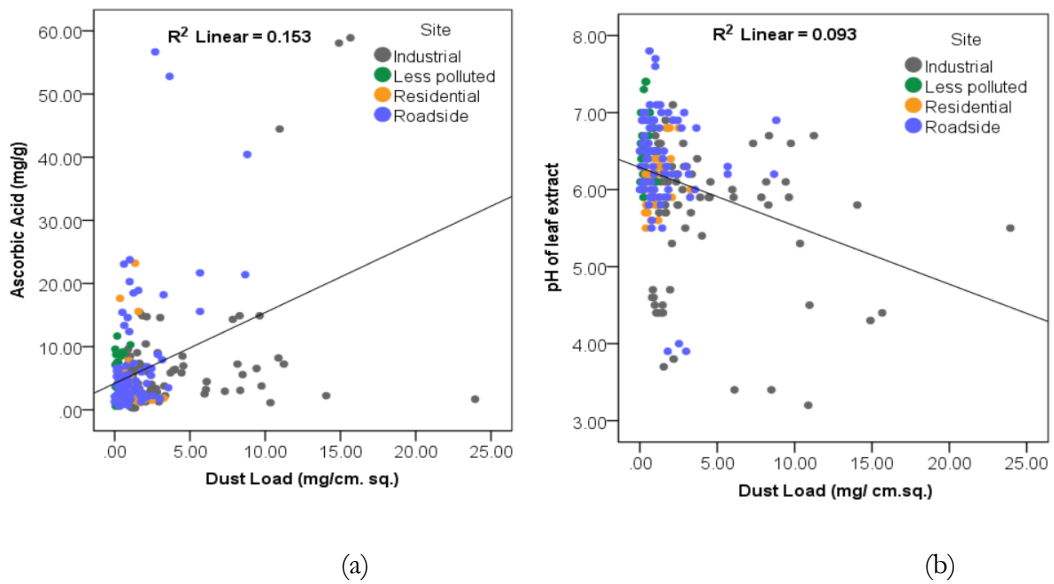
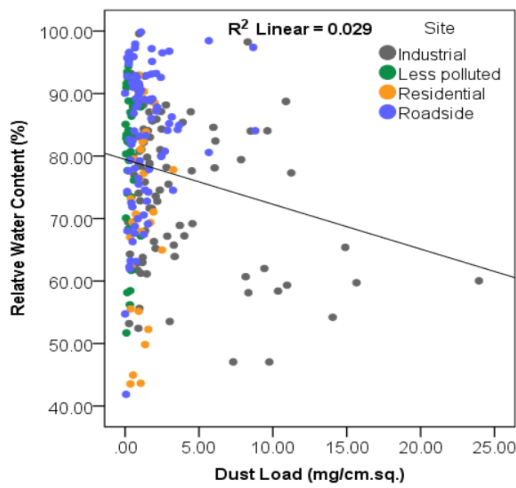
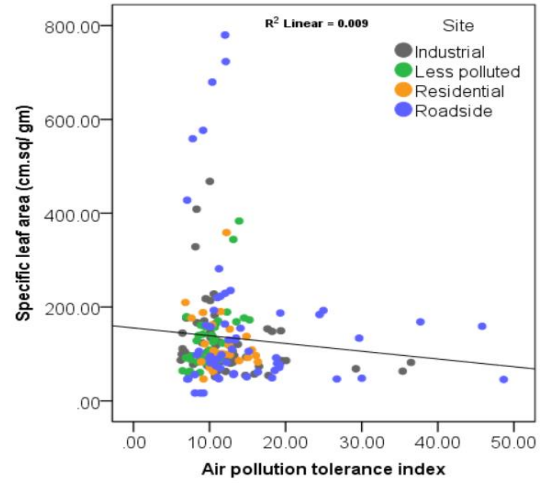


Figure 16: Scatter plot of Ascorbic acid and dust load (a) and dust load and pH of leaf extract (b).

The relation between dust load and ascorbic acid were directly proportional to each other. This means that when dust load increases, ascorbic acid also increases (Figure 16a). Negative correlation was found between dust load and pH of leaf (Figure 16b) i.e., the dust load decreases with increase in pH of leaf.



(a)



(b)

Figure 17: Scatter plot of dust load and Relative water content (a) and SLA and APTI (b)

The correlation between the dust load and RWC showed an inverse relation i.e. the RWC decreases with increases in the amount of dust load on the leaf surface (Figure17a). It means that RWC decreases with increase in dust load accumulation per leaf area. Specific leaf area and air pollution tolerance index scatter plot (Figure 17b) showed the negative relation to each other i.e, when SLA decreases with increase in air pollution tolerance index value.

5. Discussion

5.1 Dust Load Accumulation

The dust load on the industrial area was comparatively high due to the presence of more of industries, kilns and factories and also the particulate matter was found to be higher in these areas than other areas. High dust load was also reported by Chaturvedi *et al.* (2013) in industrial areas. Roadside and residential areas were reported as moderately polluted due to construction of roads and heavy traffic. The dust holding capacity of the plants depends on various morphological characters. Plants growing nearer to the busy road, polluted areas like industries are highly affected by dust (Leghari & Zaidi, 2013; Gostin, 2009). High dust load was found in leaves with thick, rough, textured, abrupt and hairy surfaces whereas low dust was accumulated on smooth, thin, shiny and small leaf surface areas in this study, which also resembled with the study of Javanmard *et al.* (2019). In the present study trees species from industrial areas with rough surfaces, large surface areas with short petiole accumulated more dust like *Tectona grandis* whereas plants with smooth, flat and small surface area accumulated less dust like *Eucalyptus globulus* (Annex 2). Dust deposition was more on *Ficus benghalensis* and *Artocarpus heterophyllus* than on other leaves as their leaf structures were coriaceous, hairy and waxy which was also reported by Rai & Panda (2014).

5.2 Leaf Macro-morphology

Leaf area reduction was more at industrial areas followed by roadside and residential areas. Similarly, SLA and leaf length were mostly reduced at industrial areas compared to roadside and residential areas while leaf width was decreased the most at the residential areas compared to that of roadside and industrial areas. Hamal & Chettri, (2017) and Hamal (2023) had reported the reduction of leaf area and SLA in polluted areas as compared to that of controlled areas which coincides with the present study. Several studies had reported the effect of dust on plant morphological structures in different species (Rai & Panda, 2014; Lu *et al.* 2018). The reduction of SLA near the polluted area was also reported by Prasai (2021). Leghari & Zaidi (2013) and Jahan & Iqbal (1992) reported the reduction in leaf length, leaf width, leaf area at polluted areas than the non-polluted one which was similar to the present study. The reduction on the leaf area, leaf length and leaf width may be due to the reduction of gaseous exchanges for photosynthesis and productivity of leaf as the pollutants blocked the stomata (Bhatti & Iqbal, 1988; Leghari & Zaidi, 2013). Leaf

area reduction was the result from air pollution that can block a plant's ability to undergo photosynthesis effectively and reduce its resilience in coping with the strains posed by air pollutants stressors (Tiwari *et al.* 2006). Plants growing to the polluted areas showed lower SLA (Yang *et al.* 2023).) Plants species thriving in the environments were characterized by limited amounts of nutrients, shortage of water and light exhibited lower SLA values (Cornelissen *et al.* 1996). The findings that when the dust load increases then SLA of the plant species decreases simultaneously near the polluted areas was supported by Hamal (2023). Numerous studies had shown that when the plants were exposed to the pollutants for longer time then the leaf area, specific leaf area, leaf length and width are reduced (Meerabi *et al.* 2012). Plants with higher APTI value showed the lower reduction in leaf traits indicating their tolerance against air pollution.

5.3 Biochemical Parameters

5.3.1 Total Chlorophyll Content

The present study recorded total chlorophyll content in the range of 0.15- 2.47mg/g at industrial areas and 0.09 to 2.28 mg/g at roadside. At residential areas, total chlorophyll ranged from 0.17 to 1.35 mg/g whereas at campus areas it was 0.12 to 1.69 mg/g respectively. *Azadirachta indica*, *Citrus maxima*, *Cascabela thevetia*, *Ficus benghalensis*, *Ficus religiosa*, *Neolamarckia cadamba* and *Tectona grandis* showed lower total chlorophyll content in polluted sites than on residential, roadside and campus areas. The accumulation of dust particles on the leaves surfaces ultimately resulted to reduction of the chlorophyll content. Many researchers have also reported the reduction on total chlorophyll content in polluted areas (Bharti *et al.* 2017; Karmarkar *et al.* 2021; Hamal, 2023; Sapkota & Shrestha, 2024). It might be due to the stress from dust accumulation on leaf surface inhibiting their growth and development (Woo & Jee, 2006). The decrease in chlorophyll content on leaf in industrial areas might be because of photochemical reactions (Puckett *et al.* 1973). On the other hand, *Nephelium litchi*, *Mangifera indica*, *Psidium guajava*, *Syzygium cumini*, *Saraca asoca* showed higher chlorophyll content value at polluted areas than at less polluted areas indicating their resistivity to air pollution. Hamal (2023) also reported high chlorophyll content on some plant species and has suggested it might be due to high concentration of carbon dioxide. Higher concentration of chlorophyll from polluted areas was also reported by Tripathi & Gautam (2007). The chlorophyll content also depended on intensity of pollution, leaf age and other biotic and abiotic factors (Yadav & Pandey, 2020; Karmakar *et al.* 2021). *Cryptomeria japonica* was found to have higher chlorophyll content on residential

areas than on roadside. Higher concentration of chlorophyll might be because of the plant withstanding the polluted environment. Chlorophyll content played a vital role in physiological activities and biomass formation of plants. Total chlorophyll content got decreases with increases in dust particles showing inverse relation to each other. Several studies found that dust and total chlorophyll content have negative correlation (Rai & Panda, 2014; Rai, 2019). During the stress conditions, the pollutants blocked the stomata (Sawidis *et al.* 2012) and phaeophytin formation (Joshi & Bora, 2011). The accumulation of dust in plants exposed to cement dust pollutants found that *Azadirachta indica*, *Nerium oleander*, *Mangifera indica* and *Dalbergia sissoo* showed reduction in chlorophyll contents supporting (Giri *et al.* 2013) study.

5.3.2 Ascorbic Acid

The present study showed higher ascorbic acid concentration at industrial areas than at the less polluted areas as polluted areas recorded maximum accumulation of dust. Dust load showed positive and direct relation with ascorbic acid which matches with Rai & Panda (2014). Ascorbic acid in leaves was high at polluted areas as compared to that of less polluted areas and similar findings was also reported by previous works of Karmakar *et al.* (2021) and Sapkota & Shrestha, (2024). High ascorbic acid might be due to an increase in the rate of production of reactive oxygen species during photo oxidation process (Lima *et al.* 2000). Increase in ascorbic acid acted as a very useful defense mechanism to overcome the stress condition generated due to air pollution (Mandal & Dhal, 2022; Anake *et al.* 2022). Ascorbic acid was considered to be the most important antioxidant found in all plants during stress conditions (Singh *et al.* 1991; Noctor *et al.* 2014; Shafiq *et al.* 2014). Ascorbic acid was resistant to adverse environmental conditions such as air pollution, drought (Lima *et al.* 2000; Rai and Panda, 2014). The direct positive relation of ascorbic acid with dust load accumulation on leaf surfaces was similar with observation recorded by other researchers (Kanwar *et al.* 2016; Patil *et al.* 2023; Bharti *et al.* 2017). Tripathi & Gautam (2007) also recorded that ascorbic acid has a direct relation with the pollutants. Increases in ascorbic acid in polluted areas helped to protect the chloroplast from pollutants like SO₂ and H₂O₂. It reduced the amount of ozone which penetrates the cell wall and reaches the inner cell membrane. Pollutants' load increment on the leaves increases the ascorbic acid content which helped to overcome the stressed conditions (Bharti *et al.* 2017). Plant species having higher ascorbic acid content resulted in higher APTI value (Govindaraju *et al.* 2012; Pandey *et al.* 2015). The present study was conducted

during higher polluted and dry time (i.e. winter season) and ascorbic acid content was reported to be high during dry and polluted seasons in response of a defense mechanism against the stress conditions which was supported by study of Yousafzai *et al.* (2018).

5.3.3 pH of Leaf Extract

pH of the leaf extract acts as a stress indicator by playing a significant role in physiological processes (Karmakar & Padhy, 2019). The study showed an acidic to slightly acidic pH range in polluted and roadside areas due to the more amount of dust load accumulation and pollution as these sites were nearer to the factories and traffic areas whereas higher pH at less polluted sites. The study recorded pH value 3.96 to 6.93 in industrial areas and 3.93 to 7.11 in roadside. Similarly, pH value ranged from 5.63 to 6.50 and 5.72 to 7.36 on residential and campus areas respectively. Acidic to slightly acidic pH value was found in the roadside areas due to traffic and construction activities. Plant species having more than 7 pH value were tolerant to pollution (Singh *et al.* 1991). There was reduction in photosynthetic rate because of lower pH value whereas tolerance capacity of plants toward pollution was observed due to higher pH value (Bharti *et al.* 2017). The present study showed that pH of leaf extract showed a negative relation to the dust load. At low pH range, the photosynthetic activities also decreased making the plant sensitive to the pollutants (Prajapati & Tripathi, 2008; Kaur & Nagpal, 2017). Shahrukh *et al.* (2023) reported 6.89 to 7.46 pH value from polluted sites and that of controlled was 6.75 which was lower than polluted sites which matched with the present study. The pH value of leaves less than 7 were considered as acidic because of the presence of pollutants like SO₂, NO_x, CO₂ (Zhang *et al.* 2015). pH was found to be indirectly proportional to the dust load in the present study which was supported by (Rai & Panda, 2014). It might be due to the dissolution of dust particles in the cell sap leading to the formation of alkaline solution. The increased in pollutants increases the cell sap pH towards the acidic side.

5.3.4 Relative Water Content

RWC from the industrial areas was 54.14 to 86.39 % and from roadside it was 52.85 to 92.96 % Likewise, RWC varied from 47.91 to 88.45% and 57.60 to 98.52 % at residential and campus areas. *Artocarpus heterophyllus*, *Azadirachta indica*, *Aegle marmelos*, *Bombax ceiba*, *Citrus maxima*, *Ficus benghalensis*, *Ficus religiosa*, *Nephelium litchi*, *Mangifera indica*, *Neolamarckia cadamba*, *Nerium oleander*, *Pinus roxburghii*, *Psidium guajava* and *Saraca asoca* reported more

than 80% RWC at industrial and roadside areas and hence could be considered as tolerant species to combat air pollutants. Plant species in dry seasons showed higher RWC to adapt in the harsh conditions (Tsega & Prasad, 2014; Tak & Kakde, 2017). Plant species got adapted in polluted environments by decreasing in transpiration rate due to closure of stomata. This study also showed that increment on dust load accumulation on the leaf decreases the RWC which lined with earlier studies of Javanmard *et al.* (2019). RWC might be low in polluted areas due to the reaction of dust particles with cell membrane resulting in the foliar injury (Prajapati & Tripathi, 2008). The decrease in RWC in polluted areas might also be due to deposition of dust on the foliage which directly hampered the rate of transpiration (Elloumi *et al.* 2017). Chaturvedi *et al.*, (2013) also reported the reduction of RWC lining with the present study. Depending on the nature of the plant species, RWC could range from 30 to 40% in leaves of plants in extreme dried areas and up to 98% in fully irrigated areas (Zhang *et al.* 2015). Same plant possessed different RWC from different areas due to the variations in irradiance, temperature, soil parameters and pollution (Sapkota & Shrestha, 2024). The increment of RWC in polluted areas might be due to the enhanced resistance of plants caused by change in activities of stomata as dust block the stomatal pores (Rai, 2020; Anake *et al.* 2022). Dust load showed negative correlation with RWC of leaf which means that RWC decreases with increase in dust load. Dust absorbed the water through the non –cutinized surfaces of plants and evaporation rate increases which resulted in decrease in RWC of plants from polluted areas (Rai & Panda, 2014).

5.3.5 Air Pollution Tolerance Index (APTI)

APTI helped to determine the ability of plants in air pollution tolerance. Hence, the plant species with lower APTI could be used as an indicator of pollution whereas plants with higher APTI value could be used as tolerant species (Singh & Rao, 1983; Kanwar *et al.* 2016). APTI varied from 6.58 to 16.11 at industrial, 5.90 to 44.06 at roadside, 7.86 to 15.55 at residential and 6.77 to 13.10 at campus areas respectively. *Azadirachta indica*, *Bombax ceiba*, *Delonix regia*, *Ficus religiosa* were found to be tolerant species whereas *Artocarpus heterophyllus*, *Albizia lebbbeck*, *Citrus maxima*, *Dalbergia sissoo*, *Ficus benghalensis*, *Mangifera indica*, *Saraca asoca* were found to be moderately tolerant species which was found to be similar to the previous studies (Pandey *et al.* 2015; Bharti *et al.* 2017; Tak & Kakade, 2017; Entiana *et al.* 2022). The results revealed that tree species from different sites exhibited different types of APTI results which means same plants was found to be moderately tolerant in one sites and

sensitive in other study areas like *Ficus benghalensis*, *Mangifera indica*, *Azadirachta indica*, *Artocarpus heterophyllus* which coincided with Rai, (2019) and Shahrukh *et al.* (2023) studies. Depending on the nature and tolerance capacity, plants responded differently (Jyoti & Jaya, 2010; Rai, 2019). Prajapati & Tripathi, (2008) found higher APTI values in *Mangifera indica*, *Ficus benghalensis*, *Azadirachta indica* and *Psidium guajava* which was similar to this present study to some level. *Psidium guajava*, *Mangifera indica* and *Ficus benghalensis* recorded a high APTI value more than 17 and were categorized as the most tolerant plant to be grown in industrial areas. This study supported the findings of Mondal *et al.* (2011). Bharti *et al.* (2017) found a high APTI value of *Ficus benghalensis* followed by *Ficus religiosa*, *Eucalyptus globulus*, *Azadirachta indica* and *Syzygium cumini*, which also resembled with this study.

5.3.6 Anticipated Performance Index (API)

Altogether API of 28 tree species were calculated in this study. The present study found *Ficus religiosa* as best performer followed by *Bombax ceiba* as excellent performer. *Nephelium litchi* was very good performer and *Artocarpus heterophyllus*, *Azadirachta indica*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* were good performer whereas *saraca asoca* was moderate performer. The API value showed the suitable plant species for mitigation of air pollution by considering their biological, socio-economic and APTI characters (Pathak *et al.* 2011). *Aegle marmelos*, *Albizia lebbbeck*, *Artocarpus heterophyllus*, *Ficus benghalensis* and *Mangifera indica* API values were studied by Karmakar *et al.* (2021) and some of the results were found similar to the present study. *Punica granatum* was found with very low API scoring aligning to the study of Sharma *et al.* (2007). *Thuja occidentalis* was found to be poor a performer with 16.97 APTI value which was similar to the Timalisina *et al.* (2022). Some of the present API value matched with previous studies of Panda *et al.* (2018) and Deswal *et al.* (2019). Govindaraju *et al.* (2012) and Priya & Senthil (2021) reported *Ficus benghalensis* as a good performer and it could be used for enhancing air quality of urban areas which was similar to the present study. Contrary Yadav & Pandey (2020) reported *Azadirachta indica* as an excellent performer but the present study recorded it under good category. Timalisina *et al.* (2022) reported *Pinus roxburghii* as good performer (APTI value 9.71) and *Cryptomeria japonica* as moderate performer (7.37 APTI values) whereas the following study recorded them under poor category; it might be due to variation on its morphological characters as the plant species were collected from different areas. This study found *Mangifera indica*, *Ficus benghalensis* and *Ficus religiosa* as good performers which was similar to the study conducted by Sharukh *et al.* (2023). *Psidium guajava* was recorded as

best performer while *Ficus benghalensis*, *Mangifera indica*, and *Artocarpus heterophyllus* were excellent and *Ficus religiosa* were considered as good performer, which resembled with the study of Rai (2019) to some extent. Mondal *et al.* (2011) identified *Ficus benghalensis*, *Mangifera indica* and *Saraca indica* as tolerant plant species suitable for developing green belt which supported the present research. *Mangifera indica*, was considered to be the best performer, *Ficus religiosa* as excellent performer by Yousafzai *et al.* (2018) which co-lined with the present study.

6. Conclusion and Recommendations

6.1 Conclusion

The present study emphasized that the air pollutants have more impacts on the trees growing around the industrial and roadside as compared to that of residential and campus areas. Among the four different study areas, the industrial areas was found to be more polluted as compared to other areas on the basis of dust accumulation on the leaf surface. Leaves having rough and large surface area (*Tectona grandis*) exhibited higher dust accumulation whereas that of leaf with smooth and small leaf area (*Dalbergia sissoo*, *Eucalyptus globulus* or *Cascabela thevetia*) exhibited lower dust load from the polluted areas. Leaf area, SLA, leaf length and leaf width of tree species were significantly reduced across the industrial, roadside and residential areas in comparison to that of campus areas. *Nephelium litchi* and *Artocarpus heterophyllus* showed the least reduction in various leaf traits which could be used to control pollution.

On the basis of APTI value obtained, *Azadirachta indica*, *Bombax ceiba*, *Delonix regia*, *Ficus religiosa*, *Nephelium litchi* were observed to be tolerant species on the other hand *Artocarpus heterophyllus*, *Bixa orellana*, *Citrus maxima*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* found to be moderately tolerant species. The API value of *Aegle marmelos*, *Moringa oleifera* and *Punica granatum* showed them to be the sensitive plant indicating their very poor performance whereas, *Ficus religiosa*, *Bombax ceiba*, *Nephelium litchi*, *Artocarpus heterophyllus*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* were tolerant and intermediate tolerant indicating them to be good performers. The plant species having higher APTI and API values are considered to be stress tolerant and are recommended for plantation in urban areas.

6.2 Recommendations

1. Plants with high tolerance capacity like *Ficus religiosa*, *Bombax ceiba*, *Nephelium litchi*, *Artocarpus heterophyllus*, *Ficus benghalensis*, *Mangifera indica* and *Neolamarckia cadamba* are recommended for the plantation around the industrial and roadside area due to their high APTI and API value.
2. Both APTI and API values of the plant species must be known for the better coping of the pollution near the industrial areas.
3. Research should not only be limited to the urban areas but also reach to suburban areas where the new infrastructure developments are in progress in the country for a better environment.
4. More study on the impacts of dust accumulation on plant growth and development is suggested.

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Annexes

Annex 1. Ambient air quality of Biratnagar (24 hours' average data of a year 2023/2024).

Month	PM _{2.5} (µg/m ³)	PM ₁₀ (µg/m ³)	NO ₂ (µg/m ³)	O ₃ (µg/m ³)
June	16±7.96	24.92±9.70	3.62±1.98	69.85±12.76
July	15.58±6.26	23.06±9.03	8.03±2.50	51.03±9.50
August	30.52±19.89	47.77±34.42	11.42±4.46	49.29±9.65
September	26.5±8.52	39.07±11.10	10.33±3.56	44.17±16.18
October	35.87±6.67	53.39±10.77	12.06±0.98	29.29±10.81
November	34.87±10.62	49.27±16.59	10.93±0.96	16.37±7.57
December	44±14.51	65.5±24.11	8.45±3.98	54.83±24.28
January	94.51±36.01	142.48±66.13	14.39±9.59	64.45±9.48
February	66.69±18.07	99.96±27.08	10.06±2.50	69.41±14.89
March	59.71±24.31	93.77±42.30	10.35±7.62	79.87±8.39
April	49.93±17.73	79.13±25.65	9.06±3.36	95.43±11.27
May	54.09±17.39	85.45±29.38	8.54±3.88	86.77±19.55

Annex 2. Morphological characteristics and economic uses of selected plant species

SN	Name of Plant Species	Vegetation	Canopy type	Type of leaves	Laminar size/texture	Leaf margin	Leaf tip and base	Hardiness	Economic Uses
1	<i>Annona squamosa</i>	Evergreen Tree	Open and Irregular	Simple	Medium/ Smooth	Entire	Acute/ rounded	Delineate	High in nutrition, use in decoction, juice making (Seth, 2004).
2	<i>Artocarpus heterophyllus</i>	Evergreen Tree	Semi dense	Simple	Medium/ Coriaceous	Entire	Acute/ rounded	Hardy	As vegetables, as a fruit, for aroma and medicine (Ranasinghe <i>et al.</i> 2019)
3	<i>Azadirachta indica</i>	Deciduous Tree	Semi dense	Pinnately compound leaf	Small/ Smooth	Asymmetrical and dentate	Pinnate/ Imparipinnate	Delineate	As an insecticides, culinary purposes, for food, preparing medicine, fertilizers, animal feed, drought resistance (Alzohairy, 2016).
4	<i>Aegle marmelos</i>	Deciduous Tree	Irregular	Trifoliolate leaves	Small/ Smooth	Crenulate	Acuminate/ Rounded	Delineate	Uses for Culinary purposes, medicinal purposes, for religious purposes (Monika <i>et al.</i> 2023).
5	<i>Albizia lebeck</i>	Deciduous Tree	Semi dense	Bipinnate	Small/ Smooth	Entire	Elliptical or Oblique/ Obtuse	Delineate	Uses as antioxidant, environmental management, fodder, medicine and wood (Seth, 2004).
6	<i>Bombax ceiba</i>	Deciduous tree	Spreading Crown	Digitately compound	Medium/ Coriaceous	Entire	Acute/ Obtuse	Hardy	As a medicine, food, fodder, pesticides (Raut <i>et al.</i> , 2017).
7	<i>Bixa orellana</i>	Evergreen tree	Globular	Simple and Spirally arranged	Large/ Smooth	Entire	Acuminate/ Cordate	Delineate	To prepare paints, lipsticks, dyes and spices, medicinal purposes (Vilar <i>et al.</i> 2014).

8	<i>Citrus maxima</i>	Evergreen tree	Semi dense	Obovate to elliptical compound leaves	Medium/ Coriaceous	Entire to crenate	Obtuse/ Rounded or Subcordate	Hardy	Traditionally used for preparations of medicines like cholera, epilepsy, ulcers, diabetes; as a food, for preparations of oils, apiculture, juice extraction (Seth, 2004).
9	<i>Cascabela thevetia</i>	Evergreen shrub/ tree	Irregular canopy	Simple and Unifoliolate	Small/ Coriaceous	Entire	Acute/ Attenuate	Hardy	Used as ornamental plants and biological pest control, consumed for eye infections, fever, leprosy and hemorrhoids (Ahmad <i>et al.</i> 2017).
10	<i>Cryptomeria japonica</i>	Evergreen Tree	Sparse	Needle like/ Spirally arranged	Small/ Smooth	Entire	Awl shaped/ Curving inward	Delineate	For soft and insect resistant timber, ornamental purposes, as a medicine (Seth, 2004).
11	<i>Dalbergia sissoo</i>	Deciduous Tree	Spreading Crown	Pinnately compound	Small/ Smooth	Entire	Acuminate/ Ovate	Delineate	Used as Timber, fodder, firewood, traditional medicine, pesticides and construction materials (Tyagi <i>et al.</i> 2020).
12	<i>Delonix regia</i>	Deciduous Tree	Spreading Crown	Compound and Alternate	Small/ Smooth	Entire	Obtuse/ Oblong or Ovate	Delineate	Useful for fuel, medicines, timber, production of oil, as a fertilizers; grown as ornamental value (Seth, 2004).
13	<i>Eucalyptus globulus</i>	Evergreen Tree	Irregular	Simple, Opposite and Sessile	Medium/ Coriaceous	Entire	Acute/ Rounded	Hardy	As timber, production of pulpwood, essentials oil, herbal tea and phenolic (Seth, 2004).

14	<i>Ficus benghalensis</i>	Evergreen Tree	Spreading dense	Broad, simple	Medium/ Coriaceous	Entire	Ovate/ Obovate	Hardy	Got religious and cultural importance, provide shade and used in ethno-medicine (Tripathi <i>et al.</i> 2015).
15	<i>Ficus religiosa</i>	Deciduous Tree	Spreading dense	Cordate and simple	Medium/ Coriaceous	Entire	Tapering abruptly / Rounded or Cordate	Hardy	Provide shelter to birds, fodder, and got religious and cultural importance, used in medicine, used as soil leveler (Seth, 2004).
16	<i>Mangifera indica</i>	Evergreen Tree	Spreading dense	Simple and alternate	Medium/ Coriaceous	Entire	Acute/ Cuneate	Hardy	Fruit is used as food, timber is insect resistant, used in medicine, and has got religious values (Seth, 2004).
17	<i>Moringa oleifera</i>	Deciduous Tree	Open	Tripinnately compound	Small/ Smooth	Entire	Emarginated to rounded Rounded	Delineate	Leaves and fruits are taken as vegetables, seed are used for oil production, useful for making traditional medicine, forage (Patel <i>et al.</i> 2010).
18	<i>Neolamarckia cadamba</i>	Evergreen Tree	Spreading dense	Simple	Medium/Smooth	Entire	Acuminate/ Obtuse or truncate	Delineate	Fruits are edible while leaves are taken as fodder. Grown as ornamental purposes, timber, paper, dye production (Mojiol <i>et al.</i> 2014).
19	<i>Nepbelium litchi</i>	Evergreen Tree	Spreading dense	Pinnately compound	Medium/ Coriaceous	Entire	Acuminate/ Cuneate	Hardy	Used as food and medicine. Has got health benefits as it has got antioxidants, maintain sugar level,

									enhances digestion and prevent cancer (Seth, 2004).
20	<i>Nerium oleander</i>	Evergreen Shrub/ tree	Sparse	Simple and opposite	Medium/ Coriaceous	Entire	Acute/ Cuneate	Hardy	Used as rat poison and an insecticides. Also used as ornamental plants and dye preparation (Puranik, 2014).
21	<i>Nyctanthes arbor-tristis</i>	Deciduous tree	Irregular	Simple	Medium/ Smooth	Entire	Acute or Acuminate/ Cuneate to sub-cordate	Delineate	Useful in Ayurvedic medicine and Homoeopathy, dye preparation, garland preparation (Seth, 2004).
22	<i>Psidium guajava</i>	Deciduous Tree	Sparse	Simple and opposite	Medium/ Coriaceous	Entire	Obtuse to acuminate/ Rounded to Sub-cuneate	Hardy	Consumed as fruit, preparation of traditional medicine, for fuel and firewood (Seth, 2004).
23	<i>Punica granatum</i>	Deciduous Tree	Sparse	Simple	Small/Smooth	Entire	Obtuse/ Attenuate	Delineate	Consumed as edible fruit. Used in making baking, beverages and medicines (Ain <i>et al.</i> 2023).
24	<i>Pinus roxburghii</i>	Evergreen Tree	Sparse	Needle like	Small/ Coriaceous	Entire	Acute/ Rounded or Tapered	Hardy	Pine oil, resins, adhesive extraction, timber and firewood, preparation of medicines for kidney and bladder (Seth, 2004).

25	<i>Syzygium cumini</i>	Evergreen Tree	Spreading dense	Simple and Opposite	Medium/ Coriaceous	Entire	Acuminate/ Attenuate	Hardy	Fruit is consumed, leaves as fodder, for firewood and fodder and medicine preparation (Seth, 2004).
26	<i>Saraca asoca</i>	Evergreen Tree	Semi dense	Pinnately compound	Medium/Smooth	Entire	Acute- Acuminate/ rounded	Delineate	Bark is used for medicines and perfumes preparation, ornamental decoration (Seth, 2004).
27	<i>Tectona grandis</i>	Deciduous Tree	Spreading dense	Simple and opposite	Large/Smooth	Entire	Obtuse/ Acute	Delineate	Used to make furniture and boat decks, traditional medicines, fodder and firewood (Seth, 2004).
28	<i>Thuja occidentalis</i>	Evergreen tree	Globular	Scale- like	Small/ Coriaceous	Entire	Ovate/ Obtuse or acute	Hardy	Stem is used to prepare medicines, fruits and roots for oil extraction, timber and incenses (Caruntu <i>et al.</i> 2020).

Annex 3. Grade allotment to different plant species

Plant species	APTI	Habitat	Canopy Structure	Type of tree	Laminar		Economic Imp.	Hardiness	Obtained grade
					Size	Texture			
<i>Ficus religiosa</i>	5+	2+	2+	-	+	+	2+	+	15
<i>Bombax ceiba</i>	6+	2+	+	-	+	+	+	+	13
<i>Nepelium litchi</i>	3+	2+	2+	+	+	+	+	+	12
<i>Artocarpus heterophyllus</i>	2+	2+	+	+	+	+	+	+	10
<i>Azadirachta indica</i>	5+	2+	+	-	-	-	2+	-	10
<i>Ficus benghalensis</i>	+	2+	2+	+	+	+	+	+	10
<i>Mangifera indica</i>	2+	2+	+	+	+	+	+	+	10
<i>Neolamarckia cadamba</i>	+	2+	2+	+	+	+	2+	-	10
<i>Saraca asoca</i>	3+	2+	+	+	+	-	+	-	9
<i>Citrus maxima</i>	2+	-	+	+	+	+	2+	-	8
<i>Delonix regia</i>	4+	2+	+	-	-	-	+	-	8
<i>Eucalyptus globulus</i>	+	2+	-	+	+	+	+	+	8

<i>Syzygium cumini</i>	+	-	2+	+	+	+	+	+	8
<i>Tectona grandis</i>	+	2+	2+	-	2+	-	+	-	8
<i>Bixa orellana</i>	2+	-	-	+	2+	-	2+	-	7
<i>Cryptomeria japonica</i>	+	2+	-	+	-	+	+	+	7
<i>Dalbergia sissoo</i>	2+	2+	+	-	-	-	+	+	7
<i>Pinus roxburghii</i>	+	2+	-	+	-	+	+	+	7
<i>Nerium oleander</i>	+	-	-	+	+	+	+	+	6
<i>Nyctanthes arbor-tristis</i>	2+	-	-	+	+	-	2+	-	6
<i>Psidium guajava</i>	2+	-	-	-	+	+	+	+	6
<i>Albizia lebbbeck</i>	2+	+	+	-	-	-	+	-	5
<i>Annona squamosa</i>	+	+	-	+	+	-	+	-	5
<i>Cascabela thevetia</i>	+	-	-	+	-	+	+	+	5
<i>Moringa oleifera</i>	+	+	+	-	-	-	+	-	4
<i>Aegle marmelos</i>	+	+	-	-	-	-	+	-	3
<i>Punica granatum</i>	+	-	-	-	-	-	+	-	2

Annex 4. Pearson's correlation test between dust load and other parameters of different four sites.

Parameters	Industrial		Roadside		Residential		Campus	
	correlation coefficient	Sig. (2-tailed)	correlation coefficient	Sig. (2-tailed)	correlation coefficient	Sig. (2-tailed)	correlation coefficient	Sig. (2-tailed)
Total Chlorophyll	-0.235	0.032	0.018	0.869	-0.033	0.871	-0.074	0.655
Ascorbic Acid	0.322**	0.003	0.046	0.677	0.299	0.129	0.175	0.287
pH	-0.179	0.104	-0.111	0.316	-0.155	0.440	-0.133	0.420
RWC	-0.344**	0.001	0.135	0.220	-0.071	0.725	-0.068	0.683
APTI	0.193	0.079	0.080	0.469	0.183	0.360	0.101	0.539
SLA	-0.157	0.220	-0.195	0.146	-0.203	0.311	0.075	0.639
Leaf area	0.529**	0.000	0.304*	0.022	-0.030	0.881	-0.133	0.402
Leaf length	0.688**	0.000	0.247	0.064	0.569**	0.002	-0.253	0.106
Leaf width	0.599**	0.000	0.300*	0.024	-0.242	0.223	0.014	0.0930
**. Correlation is significant at the 0.01 level (2-tailed).								
*. Correlation is significant at the 0.05 level (2-tailed).								

Photos Templates of selected plants



Annona squamosa L.



Artocarpus heterophyllus Lam.



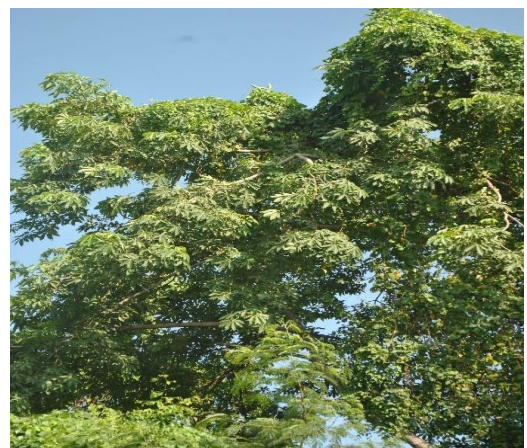
Aegle marmelos (L.) Corrêa



Azadirachta indica A.Juss.



Bixa orellana L.



Bombax ceiba L.



Citrus maxima (Burm.) Merr.



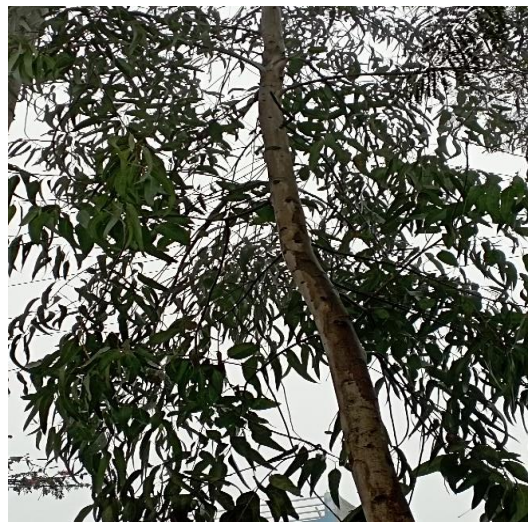
Casabela thevetia (L.) Lippod



Dabergia sissoo Roxb. ex DC



Delonix regia (Bojer ex Hook.) Raf.



Eucalyptus globulus Labill.



Ficus religiosa L.



Ficus benghalensis L.



Mangifera indica L.



Nephelium litchi Steud.



Neolamarckia cadamba (Roxb.) Bosser



Psidium guajava L.



Syzygium cumini (L.) Skeels



Saraca asoca (Roxb.) Wild



Tectona grandis L. f.

Photo Templates of sampling area and work done



Photos of using DMSO₄ Solvent and eppendorf tube for chlorophyll extraction



Photos of weighing and filling microplate using micropipette



Photos of Mahendra Morang Multiple Campus/ Less polluted area



Photos taken around industrial areas

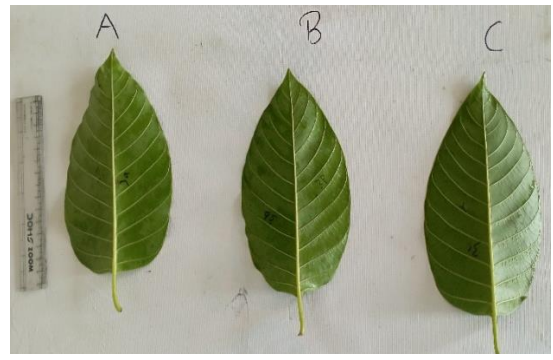


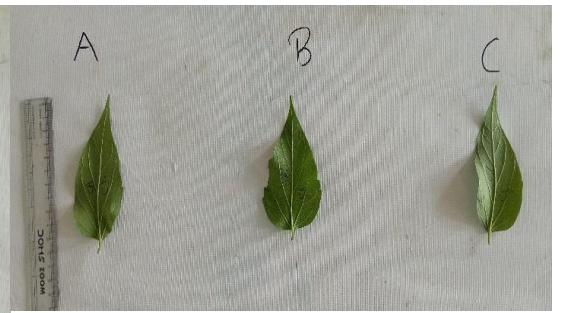
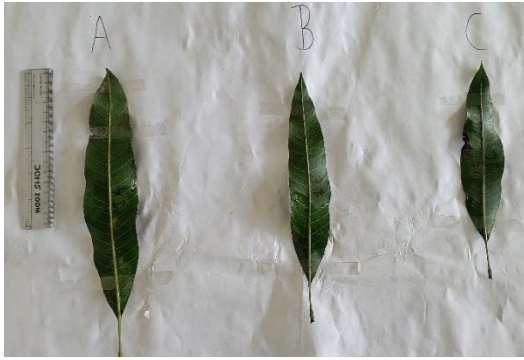
Photos around the sampling areas




Photos taken around roadside

SLA Photo Templates





Permisson Letter from Biratnagar Metropolitan Office

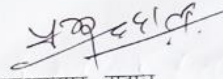
**विराटनगर महानगरपालिका**
नगर कार्यपालिकाको कार्यालय
विराटनगर, मोरङ
प्रदेश नेपाल
मिति: २०८०/०९/२०

प.स. ६९३८

विषय: अनुसन्धान कार्य एवं तथ्यांक संकलनको अनुमति सम्बन्धमा ।

जो जस संग सम्बन्धित छ ।

उपरोक्त सम्बन्धमा त्रिभुवन विश्वविद्यालय, विज्ञान तथा प्रविधि अध्ययन सस्थानको वनस्पति शास्त्र केन्द्रीय विभाग, किर्तिपुर काठमाण्डौको ०६-०८०/०८१, मिति २०८०/०४/०३ गतेको पत्रानुसार यस विराटनगर महानगरपालिकाको भौगोलिक क्षेत्राधिकार भित्र अनुसन्धान टोलीलाई अनुसन्धान तथा तथ्यांकहरू संकलन गरी यस कार्यालयलाई तयार प्रतिवेदन उपलब्ध गराउने शर्तमा अनुमति दिएको व्यहोरा अनुरोध छ ।


पुनमकुमार दाहाल
वातावरण अधिकृत (सातौं)
विराटनगर महानगरपालिका