

**AIR POLLUTION TOLERANCE INDEX OF SOME SELECTED
TREES AROUND GHORAHİ CEMENT INDUSTRY IN DANG,
WESTERN NEPAL**



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PARTIAL FULFILMENT OF THE REQUIREMENT FOR
THE MASTER'S DEGREE IN BOTANY

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DECLARATION

I, “Anu Sharma” hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement and has not been published or submitted elsewhere, in whole or in part for the requirement for any other degree or professional qualification. Any literature, data or works done by others are cited within this thesis has been given due acknowledgement and listed in the reference section.



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Anu Sharma

LIST OF ACRONYMS AND ABBREVIATIONS

AA	Ascorbic acid content
APTI	Air pollution tolerance index
API	Anticipated performance index
ANOVA	Analysis of variance
CO	Carbon monoxide
Cox	Carbon oxides
CO ₂	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Disease
DMSO	Dimethyl sulfoxide
EDTA	Ethylene diamine tetra acetic acid
EPI	Environmental Performance Index
ESC	Electrostatic Precipitators
GCIL	Ghorahi cement Industry Limited
HEI	Health effect institute
H ₂ O ₂	Hydrogen peroxide
IHEM	Institute for health matrices evaluation
Km	Kilometer
Ltd.	Limited
MTPD	Metric tones per day
NH ₃	Ammonia
NO	Nitric Oxide
NO _x	Nitrogen oxides

NO ₂	Nitrogen dioxide
OH	Hydroxide
pH	Potentiality of hydrogen
PM	Particulate matter
ROS	Reactive Oxygen Content
RWC	Relative water content
SLA	Specific Leaf Area
SPM	Suspended Particulate Matter
Sox	Sulfur oxides
SO ₂	Sulphur dioxide
SO ₃	Sulfur trioxide
TChl	Total chlorophyll
TPD	Tons per day
UNEP	United Nations Environment Program
VOCs	Volatile organic compounds
WHO	World Health Organization
et al.,	And others
Mg	Milligram
ml	Milliliter
Nm	Nanometer
G	Gram
%	Per cent
µm	Micrometer

ABSTRACT

The Air Pollution Tolerance Index (APTI) is a pivotal tool for evaluating the resilience of plant species to air pollutants. This study aims to assess the effectiveness of APTI in distinguishing between commonly available and dominant tree species, specifically *Mangnifera indica*, *Psidium guajava*, *Litchi chinensis*, *Artocarpus heterophyllus*, and *Syzygium cumini*. The study considers physiological parameters such as Relative Water Content (RWC), Total Chlorophyll Concentration (TChl), Leaf Extract pH, and Ascorbic Acid (AA) across three distances: (200-500m, 500-800m and beyond 800m) in four directions (East, West, North, and South). Leaf area and specific leaf area (SLA) were also measured. Well-developed leaf samples were selected for the analysis. The study reveals a correlation between plant physiological changes and air pollution, emphasizing the utility of APTI as an indicator of pollution impact. Through field observations near a cement industry, it was found that plant species exhibit varying APTI values based on their proximity to the pollution source. Species like *Psidium guajava*, *Mangnifera indica*, and *Syzygium cumini* displayed higher APTI values, suggesting tolerance to air pollution, while *Litchi chinensis* and *Artocarpus heterophyllus* exhibited lower APTI values, indicating sensitivity near the industry at (200-500 m) range. Furthermore, the mean values of biochemical characteristics were as follows: RWC ranged from 70.77% in *Litchi chinensis* to 97.00% in the same species; AA ranged from 0.10 mg/g in *Litchi chinensis* to 14.08 mg/g in *Psidium guajava*; TChl ranged from 0.56 mg/g in *Litchi chinensis* to 5.06 mg/g in *Psidium guajava*; and leaf extract pH ranged from 4.17 in *Syzygium cumini* to 6.97 in *Litchi chinensis*. Notably, the study delineates a geographical influence on APTI mean values ranged from 6.23 in *Artocarpus heterophyllus* to 18.97 in *Psidium guajava*, with higher pollution levels observed in the west direction of the cement industry. Furthermore, there was a decrease in SLA values near the industrial site. SLA exhibited significantly negative correlation with APTI of studied five tree species in all four directions. This study highlights the importance of APTI in assessing plant tolerance to air pollution, especially in industrial settings. Identifying tolerant, intermediate, and sensitive species helps in creating effective green belts around industrial areas, reducing pollution effects. Furthermore, sensitive species act as valuable bio-indicators for air pollution monitoring. Overall, this research emphasizes the significance of plant-based strategies in mitigating air pollution around the cement industry.

Keywords: *Ascorbic Acid content, Leaf extract pH, Relative water content, Specific leaf area, Total chlorophyll concentration.*

शोधसार

दाङ, पश्चिमी नेपालको घोराही सिमेन्ट उद्योगको आसपासका केही छानिएका रुखहरूको वायु प्रदूषण सहिष्णुता सूचकाङ्क

यस अध्ययनले सामान्यतया सिमेन्ट उद्योग वरिपरि उपलब्ध र प्रमुख रुख प्रजातिहरू, विशेष गरी *Magnifera indica*, *Psidium guajava*, *Litchi chinensis*, *Artocarpus heterophyllus* र *Syzygium cumini* हरबीच वायु प्रदूषण सहिष्णुता सूचकाङ्क प्रभावकारिताको मूल्याङ्कन गर्ने लक्ष्य राखेको छ । यसमा फिजिल्योजिकल प्यारामेटरहरू जस्तै सापेक्ष पानी, कुन क्लोरोफिल, लीफ एक्स्ट्याक्ट pH, एस्कर्विक एसिड (AA) लाई तीनवटा दूरीहरूमा (२००-५०० मिटर ५००-८०० मिटर र ८०० मिटरमाथि) र चार दिशाहरूमा (पूर्व, पश्चिम, उत्तर र दक्षिण) अध्ययन गरिएको थियो । पात क्षेत्र र विशिष्ट पात क्षेत्र (SLA) पनि मापन गरियो । विश्लेषणको लागि राम्रोसँग विकसित पातहरू चयन गरियो । अध्ययनले विरुवाको फिजिलोजी परिवर्तन र वायु प्रदूषणबीचको सम्बन्ध प्रकट गर्दछ । प्रदूषण प्रभावको सूचकको रूपमा APTI को उपयोगितालाई जोड दिन्छ । सिमेन्ट उद्योग नजिकैको फिल्ड अवलोकनहरूमाफत विरुवाका प्रजातिहरूले प्रदूषण स्रोतको दूरीको आधारमा फरक-फरक APTI को मान देखाए । *Psidium guajava*, *Magnifera indica*, *Syzygium cumini* जस्ता प्रजातिहरू को उच्च APTI मान प्रदर्शन गरे, जसले वायु प्रदूषणलाई सहिष्णुताको सुझाव दिन्छ, जबकि *Litchi chinensis* र *Artocarpus heterophyllus* को कम APTI मान प्रदर्शन गर्‍यो । जसले उद्योगको नजिक (२००-५००) मा संवेदनशीलता देखायो । यसबाहेक वायोकेमिकल विशेषताहरूको औसत मानहरू निम्नानुसार थिए : RWC; *Litchi chinensis* मा 70.77 % देखि 97.00 % सम्म AA; *Litchi chinensis* मा 0.10 mg/g देखि *Psidium guajava* मा 14.08 mg/g सम्म, TChl; *Litchi chinensis* मा 0.56 mg/g देखि *Psidium guajava* मा 5.06 mg/g सम्म र pH; *Syzygium cumini* मा 4.17 देखि *Litchi chinensis* मा 6.97 सम्म । उल्लेखनीय रूपमा अध्ययनले सिमेन्ट उद्योगको पश्चिम दिशामा प्रदूषण स्तर सहित *Artocarpus heterophyllus* मा 6.23 देखि *Psidium guajava* मा 18.97 सम्मको APTI औसत मानहरूमा भौगोलिक प्रभावलाई चित्रण गरेको छ । यस बाहेक, औद्योगिक साइड नजिकै SLA मानहरूमा कम आएको थियो । SLA ले चारै दिशामा अध्ययन गरिएका पाँच प्रजातिका रुखहरूसँग उल्लेखनीय रूपमा नकारात्मक सम्बन्ध देखायो । यस अध्ययनले वायु प्रदूषणमा विरुवाको सहिष्णुता, विशेष गरी औद्योगिक क्षेत्रमा वायु प्रदूषण सहिष्णुता सूचकाङ्कको महत्वलाई हाइलाइट गर्दछ । सहनशिल विरुवाहरूका प्रजातिको पहिचानले औद्योगिक क्षेत्र वरपर प्रभावकारी हरित बेल्टहरू सिर्जना गर्न र प्रदूषणको प्रभाव कम गर्न मद्दत गर्दछ । यस बाहेक संवेदनशिल प्रजातिहरूले वायु प्रदूषण अनुसन्धानका लागि बहुमूल्य जैविक सूचकहरूको रूपमा काम गर्दछन् । समग्रमा यस अनुसन्धानले सिमेन्ट उद्योगको वरिपरि वायु प्रदूषण कम गर्न विरुवाको महत्वलाई प्रोत्साहन गर्छ ।

मुख्य शब्दहरू : एस्कर्विक एसिड अनुपात, लीफ एक्स्ट्याक्ट, सापेक्ष पानी अनुपात, विशिष्ट पात क्षेत्र, कूल क्लोरोफिल अनुपात ।

TABLE OF CONTENTS

DECLARATION	ii
RECOMMENDATION	iii
APPROVAL	iv
ACKNOWLEDGEMENTS	v
LIST OF ACRONYMS AND ABBREVIATIONS	vi
ABSTRACT	viii
शोधसार	ix
TABLE OF CONTENTS	x
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF APPENDEXES	xv
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Rationale of the study.....	5
1.3 Research questions	6
1.4 Research Objectives	6
1.5 Limitations	6
CHAPTER 2: LITERATURE REVIEW	7
2.1 Reviews on different parameters of APTI.....	13
2.1.1 Relative Water Content (RWC).....	13
2.1.2 Ascorbic acid (AA).....	15
2.1.3 Total chlorophyll content (TChl).....	16
2.1.4 Leaf extract pH	17
2.2 Specific leaf area (SLA).....	17
2.3 Research gap	18

CHAPTER 3: MATERIALS AND METHODS	20
3.1 Study area	20
3.2 Climate and Hydrology	21
3.3 Study species	22
3.4 Methods	23
3.4.1 Sample collections and designs	23
3.4.2 Biochemical analysis for Air Pollution Tolerance Index (APTI)	24
3.4.2.1 Relative leaf water content (RWC)	24
3.4.2.2 Ascorbic acid (AA)	25
3.4.2.3 Chlorophyll estimation	25
3.4.2.4 Leaf extract pH	25
3.4.2.5 Air pollution tolerance index (APTI)	26
3.4.3 Categorization of plants	26
3.4.4 Leaf area	26
3.4.5 Specific leaf area (SLA)	26
3.4.6 Data analysis	27
CHAPTER 4: RESULT	28
4.1 Air pollution tolerance index (APTI)	28
4.1.1 Relative water content (RWC)	28
4.1.2 Ascorbic Acid Content (AA)	29
4.1.3 Total Chlorophyll content (TChl)	30
4.1.4 Leaf extract pH	32
4.1.5 Air pollution tolerance index (APTI)	34
4.2 Leaf Area	35
4.3 Specific leaf area (SLA)	37
4.4 Correlation of RWC with APTI in four directions (East, West, North and South)	38

4.5 Correlation of AA with APTI in four directions (East, West, North and South)	38
4.6 Correlation of TChl with APTI in four directions (East, West, North and South)	39
4.7 Correlation of leaf extract pH with APTI in four directions (East, West, North and South).....	40
4.8 Correlation of SLA with APTI in four directions (East, West, North and South)	41
CHAPTER 5. DISCUSSION	42
5.1 Air pollution tolerance index.....	42
5.1.1 Relative Water Content	42
5.1.2 Ascorbic Acid (AA).....	44
5.1.3 Total Chlorophyll Content.....	45
5.1.4 Leaf extract pH	47
5.1.5 Air pollution tolerance index (APTI).....	48
5.2 Leaf area.....	50
5.3 Specific leaf area (SLA).....	51
5.4 Correlation of biochemical parameters (RWC, AA, TChl and leaf extract pH) with APTI in four directions (East, West, North and South)	53
5.5 Correlation of SLA with APTI in four directions (East, West, North and South)	53
CHAPTER 6: CONCLUSION AND RECOMMENDATION.....	55
6.1 Conclusion.....	55
6.2 Recommendations	56
REFERENCES.....	57
APPENDICES	I

LIST OF TABLES

Table 1. List of the studied five Plant species.....	23
Table 2. Mean value and standard error of Relative water content (%) in leaves of various tree species at various distance and directions from Ghorahi Cement Industry.	28
Table 3. Mean value and standard error of Ascorbic acid content (mg/g) in leaves of various tree species at various directions and distance from the Ghorahi Cement Industry.....	30
Table 4. Mean value and standard error of chlorophyll content (mg/g) in leaves of various tree species at various directions and distance from the Ghorahi Cement Industry.....	31
Table 5. Mean value and standard error of Leaf extract pH in leaves of various tree species at various directions and distance from the Ghorahi cement Industry.	33
Table 6. Mean value and standard error of APTI of various tree species at various directions and distance from the Ghorahi cement industry.	35
Table 7. Mean value and standard error of Leaf area (cm ²) of various tree species at various directions and distance from the Ghorahi cement Industry.	36
Table 8. Mean value and standard error of Specific leaf area (cm ² /g) of various tree species at various directions and distance from the Ghorahi Cement Industry.	37
Table 9. Correlation of RWC with APTI in Four directions (n=9).....	38
Table 10. Correlation of AA with APTI in Four directions (n=9).....	39
Table 11. Correlation of TChl with APTI in Four directions (n=9).....	40
Table 12. Correlation of leaf extract pH with APTI in Four directions (n=9).....	41
Table 13. Correlation of SLA with APTI in Four directions (n=9).....	41

LIST OF FIGURES

Figure 1. Map of Study area around the Ghorahi cement Industry Limited, Ghorahi Dang	21
Figure 2. Meteorological graph of average monthly temperature and precipitation of last ten years (2012-2022) in Dang, Nepal (Source: Department of Hydrology and Meterology, Babarmahal, Government of Nepal).	22
Figure 3. A diagram representing the study area, displaying various distances (200-500 m, 500-800 m, and beyond 800 m) and directions (east, west, north and south).	24

LIST OF APPENDICES

Appendix I. Photos of studied plant species.....	I
Appendix II. Photos of leaf samples with reference scale for leaf area and SLA measurement.....	II
Appendix III. Photos of Ghorahi cement industry.....	III
Appendix IV. Photos of Lab Work.....	IV
Appendix V. Certificate of Appreciation from Ghorahi Sub-Metropolitan City.....	V

CHAPTER 1: INTRODUCTION

1.1 Background

Air, as an indispensable resource for sustaining life, is essential for the proper growth and development of all creatures. The term "air pollution" denotes any atmospheric state wherein specific substances reach concentrations that result in undesirable effects on both humans and ecosystems (Seyyednejad *et al.*, 2017). It encompasses the presence of harmful elements in the air, posing threats to humans, animals, and the environment. These elements manifest as gases, particulate matter, or biological molecules. The origins of air pollution are diverse, arising from both natural phenomena such as wildfires, volcanic eruptions, and dust storms, and human-induced activities like transportation, industrial processes, agriculture, and energy production. The consequences of air pollution span a spectrum, ranging from respiratory issues and cardiovascular diseases in humans to the occurrence of acid rain and harm to crops and forests (WHO, 2021). Shockingly, air pollution stands as a significant hazard to life, attributing to 11% of annual deaths (WHO, 2016). Moreover, it contributes to climate change by elevating the levels of greenhouse gases in the atmosphere (United States Environmental Protection Agency, 2021).

Air pollution is a serious worldwide issue and is one of the key factor that reducing the standard of the life in urban environment, rendering people more prone to diseases (Makhelouf, 2009; Esfahani *et al.*, 2013). It is the complicated composition of air borne particulate particles and gaseous pollutants like, nitrogen dioxide (NO₂), ozone (O₃), Sulphur dioxide (SO₂), volatile organic compounds (VOCs) like benzene, carbon monoxide (CO), water vapor, heavy metals (Ter *et al.*, 2020). Air is the crucial component for the sustenance of life, has now polluted by rapid unmanaged industrialization and urbanization and by naturally and human activities (WHO/UNEP, 1992). In a developing country like Nepal, the adverse consequences of industrialization manifest prominently, with air pollution emerging as a critical issue (Odilara *et al.*, 2006). This environmental challenge poses a substantial threat to both public health and the ecosystem. Vehicular emissions, industrial activities, brick kilns, open burning of waste and biomass, and traditional cooking stoves are identified as the primary culprits behind the escalating air pollution levels in Nepal. The country's

unique topography, characterized by towering mountains and deep valleys, exacerbates the situation by trapping pollutants and intensifying the impact of air pollution. Notably, urban city like Dang also bear the burnt of decreasing air quality due to local and transported pollutants (Lamichhane *et al.*, 2021).

The repercussions of air pollution on public health in Nepal are profound, contributing to an estimated 27,000 premature deaths annually. Respiratory ailments, especially chronic obstructive pulmonary disease (COPD) and lung cancer, stand out as the leading causes of mortality attributable to air pollution in the country. Addressing these issues becomes imperative to safeguard the well-being of the population and preserve the environment. In 2016, Nepal's air quality, as measured by the Environmental Performance Index (EPI), ranked 177th among 180 countries (Hsu *et al.*, 2017). The World Health Organization (WHO) revealed that fine Particulate Matter (PM 2.5) in Nepal's metropolitan regions reached a maximum of 140 $\mu\text{g}/\text{m}^3$, which is 10 times higher than the recommended range. Currently, Nepal's (PM 2.5) concentration exceeds the WHO 24-hour air quality guidelines by 10.3 times (World Health Organization, 2016). This alarming situation underscores the pervasive issue of air pollution in the 21st century, affecting both developed and developing nations.

In Nepal, the pollution controlling measures in the industrial sectors are mostly not adequately addressed. Hence some of the industries are contributing to air pollution. There are many unmanageable industries in Nepal in which cement industry is one of them. In Nepal 53 cement industries are operating, they produce 160 million sacks of cement annually (Prasain, 2018). In most of areas Cement dust from cement industry is a localized air pollution problem. Cement industry is polluting industry among other industries and is a source of air pollution (Shukla *et al.*, 2008). Particles of dust are released into the surrounding air by mining operations, coals yards, and cementing clinkers, as well as diverse operations such as crushers and clinkerization (Chapagain and Dhakal, 2011). The cement industry is characterized by its high-energy, high-carbon production process, making it a significant contributor to global anthropogenic CO_2 emissions (Bakhtyar *et al.*, 2017). This sector has long held a prominent position among the largest CO_2 emitters, releasing 900kg of CO_2 per production tonne of cement (Bakhtyar *et al.*, 2017). Dust contains various gaseous compounds like NO , NO_2 , SO_2 and CO (Abida and Harikrishna, 2010). Limestone and cement dusts, characterized by pH values exceeding 9, have the potential to inflict harm on leaf tissues

either directly or indirectly by influencing pH of the soil (Vardaka *et al.*, 1995; Auerbach *et al.*, 1997). Particulate particles deposited on a leaf's outer layer alters its structure and function (Agbaire and Esiefarienrhe, 2009). In cement polluted area heavy accumulation of cement dust is formed on the plants so this dust coating limits the growth of the plants and brings physiological disorder to plant species (Oblisami *et al.*, 1978). Long-term exposure to cement particles may cause sensitive plants to disappear from the area, and if such species are rare and endangered, this might be a severe loss to biodiversity (Chapagain and Dhakal, 2011). On a global scale, cement ranks as the second most consumed material, trailing only behind water (Elawa *et al.*, 2022). The cement industry has given rise to environmental pollution concerns, with its pollutants adversely affecting the air, water, and land. The cement industry is identified by the central pollution control board as one of the top 17 industries contributing to pollution. Over the past few decades, the emission of dust from cement factories has surged significantly, driven by the expansion of more plants to meet the growing demand for construction materials. The escalating concentration of cement dust pollutants is associated with discernible harm, including a gradual decrease in vital processes like photosynthesis and leaf respiration rate (Senthil *et al.*, 2015). The obtained effect can serve the purpose of monitoring suspended particulate matter within the cement industry by assessing SPM (Suspended Particulate Matter) concentrations. This allows for the observation of air quality in the vicinity. The plants surrounding the cement industry exhibit elevated pollution exposure levels, similar to the findings observed in control plants (Radhapriya *et al.*, 2012). Cement dust has a substantial influence on plant height, leaf area and number, chlorophyll fluorescence, leaf mass per area, fresh and dry weight of shoot and root systems, decreases in photosynthesis as well as carotenoid compounds including total sugars, proteins, along with entire lipids (Salama *et al.*, 2011). As a result, plants that are exposed to high levels of pollution around the cement industry (Radhapriya *et al.*, 2012) can be employed as effective biomonitoring plant species in addition to being advised to tolerate dust. Deposition of pollutants takes place via either wet or dry mechanisms. Both gaseous and particulate air pollutants have been identified as sources of detrimental impacts on plants (Singh, 2005).

Plants are highly significant components of the nature, since they assist to purify the atmosphere, soil, and water of industrial environments as well as beautifies cities (Ghafari *et al.*, 2021). Planting fast growing as well as resistant plant species helps to

reduce air pollution. As plants have stationary nature, they are continuously exposed to the air pollutants. The main receptor of air pollutants are leaves of the plants (Ter *et al.*, 2020). Plants exhibit such a high level of efficiency in absorbing pollutants that they have the capability to generate areas of purified air (Gilbert, 1968). Airborne contaminants can affect plants directly through their leaves or indirectly through soil acidity (Abida and Harikrishna, 2010). By different factors, such as the response of plants to pollutants at the biological or chemical level within trees, tolerance as well as sensitivity nature of plant may be understood (Ter *et al.*, 2020). Vegetation serves as a reservoir for air pollutants, playing a crucial role in mitigating pollution levels in the atmosphere (Hamraz *et al.*, 2014). The interaction between trees and the surrounding air is evident, with variations in atmospheric conditions directly influencing the physiological and biochemical aspects of trees. Depending on their responsiveness to environmental conditions, trees possess the ability to actively take in, collect, retain, and assimilate pollutants within their biological frameworks (Elawa *et al.*, 2022). However, it's important to note that pollution poses a human-induced stress on trees (Fusaro *et al.*, 2019), and certain substances have the potential to negatively impact photosynthetic activity, pigment concentration, and plant growth (Leghari *et al.*, 2014; Bharti *et al.*, 2018). The response of different types of plants to air pollution can be determined by measuring the APTI value. It is grading index which represents the capacity of a plant to combat against air pollution (Singh and Rao, 1983). APTI index is the value which indicate the normal health stress condition of plants and help to evaluate plants respond to air pollution through biochemical and physiological means (Singh and Verma, 2007). The connection between trees and the surrounding air is evident, and changes in atmospheric conditions can directly impact the physiological and biochemical aspects of trees. Vegetation serves as a reservoir for air pollutants, playing a crucial role in mitigating pollution levels in the atmosphere (Hamraz *et al.*, 2014). The interaction between trees and the surrounding air is evident, with variations in atmospheric conditions directly influencing the physiological and biochemical aspects of trees. The air pollution tolerance index is calculated using four physiological parameters: leaf extract pH, relative water content, ascorbic acid, and total chlorophyll concentration (Singh and Rao, 1983). The plant's sensitivity and resistance vary with changes in these characteristics (Liu and Ding, 2008). Plant species which are sensitive, used as filters for reducing air pollution and indicators of the pollution (Brandt and Heck, 1968; LeBlanc and Rao, 1975). Tolerant plants can significantly contribute to

enhancing air quality by diminishing pollutant concentrations in the atmosphere. They serve as natural filters, absorbing harmful gases and pollutants, thus aiding in the mitigation of air pollution through gas exchange processes (Prajapati and Tripathi 2008). Generally, the leaf surface acts as a site for the accumulation of dust and hence it causes stress on the surface of leaf. The stress in the surface of leaves may contribute to the development and growth of plants. Leaf size and Specific leaf area (SLA) are some of the measures to understand the stress on the leaf.

1.2 Rationale of the study

Dang district of Nepal is situated in the mid-western region, Lumbini Province. It is Asia's second largest valley, flanked by Shivalik Hills in the south and the Mahabharat Range in the north. All together seven cement factories are located in Dang Valley. Among them Ghorahi cement industry Private Limited is the largest cement plant in private sector of Nepal, located in Ghorahi Sub-4 Metropolitan, Laxmipur, Gogli Dang. It was established in the year 2009, and produces 1900 metric tones per day (MTPD) clinkers and 2200 MTPD cement. The vicinity of the factory encompasses a highway, an educational institution, and a human settlement within one kilometer radius. These areas face exposure to dust pollution, adversely impacting the well-being of all living organisms within them. The primary focus of this study is to investigate the impact of air pollutants on tree species that are commonly found and dominant in the areas surrounding cement industries. Cement dusts are detrimental to both humans and plants lives (Chapagain and Dhakal, 2011). Plants play a vital role in mitigating air pollution in the vicinity of cement plants. That is why tolerant and sensitive plants need to be identified near polluted areas, because tolerant plants may serve as screen to reduce air pollutants, whilst sensitive plants may act as the indicator of air pollution (Ter *et al.*, 2020). In Ghorahi, there are several villages surrounding the cement factory. To the east lies Rampur, to the west is Belvar, to the north is Lachhinpur, and to the south is Jhingni. The trees species like (*Magnifera indica*, *Litchi chinensis*, *Artocarpus heterophyllus*, *Psidium guajava* and *Syzygium cumini*) are mostly available in these villages, these all are fruit species. It is unclear which fruit trees are more resistant or vulnerable to air pollution. It is also unknown if the cement dust from cement industry causes any biological harm to these fruit trees species. To better understand this, the APTI of some commonly available trees has been proposed for the current investigations. This research helps to unfold the impact of air pollutants on fruit trees

around the industry, as they are source of food for human are directly related with human health and economy. Present study has also helped in selecting the tolerant and sensitive fruit tree species so that planting of different tolerant fruit trees can be done for future plan as well as it also helps to reduce air pollution in the polluted area and assist in maintaining greenery. Most of the APTI work in Nepal are confined to roadside trees (Kanwar *et al.*, 2016, Hamal and Chhetri 2017, Ter *et al.*, 2020 etc.). But very few works on APTI have been conducted outside the Kathmandu valley. APTI related research is very important in the areas around the cement factory, to identify the tolerant and sensitive trees. Problems associated with dust of cement on fruit trees in Dang valley have not been investigated for their APTI value. It is not known that, fruit trees can contribute to control and mitigate air pollution problem around the cement factory.

1.3 Research questions

- i. Does different trees species able to withstand air pollution equally?
- ii. Which tree species are more sensitive?
- iii. Which tree species are more tolerant?

1.4 Research Objectives

General objectives:

- i. To evaluate the Air Pollution Tolerance Index of some selected trees around a Ghorahi cement industry.

Specific objectives:

- i. To evaluate the biochemical characteristics such as effects of dust pollutants on Leaf extract pH, Total chlorophyll concentration, relative water content and ascorbic acid content of plant species.
- ii. To analyze leaf area and Specific Leaf Area.

1.5 Limitations

- i. APTI was conducted for the winter season only.
- ii. Due to frequent rains, the dust impose on leaves was not measurable.
- iii. Because of limitations in time and resources, only five tree species were chosen for the research.

CHAPTER 2: LITERATURE REVIEW

The Air Pollution Tolerance Index (APTI) serves as a metric for assessing the capacity of plants to withstand the effects of air pollution. It was first proposed by Singh and Rao in 1983 and has since been widely used in various studies. APTI is a useful tool for evaluating the ability of plants to tolerate air pollution. The technique is straightforward and easy to use, and it has been used effectively to identify resistant plants species (Singh *et al.*, 1991). The APTI assesses a plant's ability to measure the effects of airborne pollutants (Girish *et al.*, 2017). The evaluation of pollutants' effects on plants employs the Air Pollution Tolerance Index (APTI), which relies on biochemical indicators. The calculation of APTI depends on specific biochemical markers that suffer negative impacts from air pollutants. These markers encompass factors like the levels of ascorbic acid, total chlorophyll, relative water content, and the pH of leaf extract (Karmakar *et al.*, 2019). Numerous investigations have been carried out to explore the APTI of plants in the vicinity of cement factories, which are one of the major sources of air pollution. Studies have shown that different plant species have different levels of APTI, and this information can be used to select suitable plant species for planting in areas with high levels of air pollution. Air pollution from industrial activities such as cement factories can have adverse effects on the environment, including plant life. An extensively employed method for evaluating the resilience of various plant species to dust pollution in the vicinity of cement industries is the use of the APTI. Study of APTI in different plant species reveals diverse APTI levels. This information is valuable for choosing appropriate plant species in areas with high air pollution. Some plants adapt to environmental changes through biochemical adaptations in chlorophyll levels, ascorbic acid concentration, leaf extract (pH), and relative water content (Flowers *et al.*, 2007; Kuddus *et al.*, 2011). Combining these parameters helps determine the APTI of specific plant species. APTI serves as a tool to classify plants as sensitive, intermediate, or tolerant to air pollutants in a broader context (Liu and Ding, 2008; Das and Prasad, 2010; Leghari *et al.*, 2011; Nayak *et al.*, 2015). A comparative analysis was conducted to assess the Air Pollution Tolerance Index of six common roadside plants collected from industrial (Rourkela) and non-industrial (Aizawl) areas. Notably, *Mangifera indica* and *Bougainvillea spectabilis* exhibited minimal disparity in their APTI values, suggesting a similar level of tolerance for both

species (Rai *et al.*, 2013). The APTI of ten plant species in urban environments were evaluated by Mondal *et al.* (2011). They indicated that *Psidium guajava*, *Swietenia mahagoni*, *Magnifera indica*, *Ficus benghalensis*, and *Polyanthia longifolia* exhibited the highest APTI values among the species studied.

APTI on higher plants on urban area was studied by (Esfahani *et al.*, 2013). They found that *Morus alba* exhibited the highest dust deposition rate, while *Cercis siliquastrum* showed the lowest and APTI value is also maximum in *Morus alba* so they suggested about its higher tolerance capacity. Air pollution tolerance index (APTI) of some tree species was evaluated around an industrial area by (Bakiyaraj and Ayyappan, 2014). They found that *Eucalyptus* spp., *Lawsonia inermis*, *Citrus limon*, *Sesbania sesban* and *Morinda tinctoria* can be used as bio monitors of pollution stress and bio monitoring of plants is an important tool to evaluate the impact of air pollution. Similarly, Dwivedi and Tripathi (2007) calculated the Air Pollution Tolerance Index for 99 plants near coal-fired (bricks) operations in India. Plants were classified as either susceptible or resistant. Notably, *Ricinus communis* emerged as the most resistant species, maintaining a uniform presence across all polluted sites. On the other hand, *Lepidium sativum* stood out as the most sensitive species and was exclusively found in less polluted areas. Air pollution tolerance index of plant species around industrial site was analyzed by (Agbaire and Esiefarienrhe, 2009) and found that *Emilia santifolia*, *Manihot esculenta* and *Elaeisis guineensis* exhibited greater tolerance as evidenced by the percentage increase in APTI values. They reached the conclusion that examining APTI values holds significance, given the rising threat of deforestation stemming from escalating air pollution accompanying industrialization. Similarly, Chouhan *et al.* (2012) analyzed the APTI of plants developing in the Pithampur manufacturing region and concluded that planting *Calotropis gigantea* , *Dalbergia sissoo* , *Eugenia Jambolana* and *Mangifera indica* were beneficial to the development of green belts including the reduction of industrial air pollution. The APTI values were calculated for a total of 69 plant species, comprising various types such as herbs, shrubs, and trees, thriving within the urban-industrial environment of the Lahartara region in Varanasi were evaluated by Singh *et al.* (1991). They determined that the sensitivity of plants to air pollution, categorized as sensitive, intermediate, or moderately tolerant based on their index values, aligned closely with the observed reactions of plants in both laboratory and field experiments. When

screening sensitive or tolerant plants in an environment where the air-shed is contaminated by many contaminants, the APTI determination offers a dependable method. The comparative investigation of the air pollution tolerance index of a few fruit trees species thrive within in the industrial zone investigated by Zouari *et al.*(2018). They offered helpful information for the selection of (i) sensitive species (*Ficus carica* and *Morus alba*) that aid in identifying air pollution, and (ii) tolerant species (*Olea europaea* and *Phoenix dactylifera*) in order to restore degraded environments and landscapes as well as future planning. Enete *et al.* (2013) examined the APTI of plants and ornamental shrubs within Enugu City, with potential implications concerning the urban heat island phenomenon. Their study showed the varying levels of tolerance among species, with plants as *Anacardium occidentale* and *Psidium guajava* exhibiting higher APTI values compared to ornamental shrubs like Yellow bush and Ixora red. They found that the use of APTI as a valuable tool for selecting vegetation in urban heat island mitigation efforts and emphasized that plants generally showed greater tolerance to air pollution than ornamental shrubs. Hamal and Chettri (2017) investigated air pollution tolerance index of certain gymnosperm species along the roadsides within Kathmandu Valley, Nepal. Their observations highlighted that *Pinus roxburghii*, *Thuja orientalis*, *Cedrus deodara*, and *Araucaria bidwillii* exhibited notably high APTI values, suggesting their potential suitability for urban area plantation initiatives. (Chapagain and Dhakal, 2011) conducted vegetation study in the vicinity of a cement industry, examining the impact of dust pollution on agricultural output in Kathmandu. They determined that wheat, maize, and mustard crops are severely impacted, and the land surrounding the facility is completely unsuited for vegetable production. Crop productivity of wheat, maize, and mustard was considerably lower in field 1.5 km from the industrial site than in areas 3-4 km away, whereas rice productivity was least affected. Ter *et al.* (2020) also focused in Air pollution tolerance index of some tree species in Pasupati area Kathmandu. They found that two sensitive tree species that can be utilized as bioindicators in pollution monitoring are *Phyllanthus emblica* and *Schima wallichii*. They concluded that tolerant plant species such as *Cinnamomum camphora*, *Ficus elastica*, *Ficus religiosa*, *Ficus benghalensis* and *Grevillea robusta* were identified as suitable for planting alongside. These plants were found to effectively mitigate and diminish air pollution levels. Air pollution tolerance index of plant species around industrial site was analyzed by (Agbaire and Esiefarienrhe, 2009) and found that *Emilia santifolia*,

Manihot esculenta and *Elaeagnus guineensis* exhibited higher tolerance, as evidenced by the percentage increase in APTI values. A study in Allahabad city, India, examining the tolerance of selected plant species to air pollution was investigated by Kuddus *et al.* (2011). Among the plant species studied, *Magnifera indica* demonstrated the highest tolerance to pollution, as evidenced by its elevated APTI value. Conversely, *Artocarpus chaplasi* exhibited the lowest APTI, suggesting its vulnerability and potential utility as a bioindicator plant for assessing pollution levels. Similarly, Thawale *et al.* (2011) investigated the alterations in biochemistry in *Azadirachta indica*, *Mangifera indica*, *Delonix regia*, and *Cassia fistula* across the Nagpur area of India, specifically across the commercial, industrial, and residential sectors, to determine the Air Pollution Tolerance Index. They revealed significant variations in four key biochemical properties of the chosen plant species, demonstrating their responsiveness to air pollution. Similarly, Gour *et al.* (2016) conducted a study in a Delhi educational institute to assess the APTI of 21 plant species. They found that *Magnifera indica*, *Ficus religiosa*, and *Ficus benghalensis* exhibited the highest tolerance levels, attributed to their elevated concentrations of ascorbic acid, which aid in the preservation of chlorophyll levels. Moreover, it was observed that plant species characterized by broad leaves and substantial canopy coverage demonstrated a higher APTI when contrasted with those featuring small, compound leaves, and limited canopy coverage. Manjunath and Reddy (2019) conducted on six plant species within both highly polluted and control areas of Bengaluru. They found that *Ocimum sanctum* exhibited the lowest value of APTI in both regions, suggesting its potential for bio-monitoring applications. On the other hand, *Vicia rosea* and *Baugainvillea spectabilis* displayed higher APTI values, indicating their suitability for use in heavily polluted urban environments. These plants could play a crucial role in revitalizing and restoring the green urban ecosystem. Gupta *et al.* (2016) conducted a study in Delhi, India, evaluating the APTI value and API of four plant species (i.e. *Terminalia arjuna*, *Morus alba*, *Dalbergia sissoo*, and *Polyalthia longifolia*) were used to determine their resistance to air pollutants and suitability for fostering green belt. The study focused on physiological and biochemical factors to determine the APTI values, concluding that these values are sensitive indicators of plant biology for the selected species. Achakzai *et al.* (2017) investigated tolerance of plants to air pollution in close proximity to brick kilns in Rawalpindi, Pakistan. They discovered that *Calotropis procera* and *Alternanthera pungens* were very tolerant, whereas *Malva neglecta* was

the most susceptible. Krishnaveni *et al.* (2014) conducted a comparative study for air pollution tolerance index, focusing on locations near a railway junction and its adjacent residential area. They found that *Syzygium cumini* near the railway junction and *Ficus benghalensis* in the residential area exhibited a high air pollution tolerance index. However, overall, plants in both locations were observed to be sensitive to pollution, with no species identified as tolerant to air pollution. An investigation was carried out by Nuthan and Hina (2015) on APTI of *Artocarpus heterophyllus*, *Mangifera indica*, *Psidium guajava*, *Ficus benghalensis*, and *Polyalthia longifolia* plants by several biochemical characteristics in Bhadravathi, an industrial town in Karnataka, India. Among these species, *Artocarpus heterophyllus*, *Psidium guajava*, and *Ficus benghalensis* were identified as having higher tolerance to air pollution, based on the calculated APTI values. They suggested that APTI can serve as a valuable tool for the selection and cultivation of pollution-resistant trees in landscaping initiatives. Rai *et al.* (2013) A comparison between the APTI in industrial and non-industrial areas reveals distinct disparities in air quality resilience, the study highlighted the site-specific nature of plant tolerance to air pollution. The research revealed that the APTI values were higher in the industrial region in contrast to the non-industrial region. An assessment of the Anticipated Performance and Air Pollution Tolerance Indices to determine the feasibility of establishing a green belt development in an industrial area was evaluated by Gopammal *et al.* (2022). Their study provided data on 17 of the most common tree species found in Visakhapatnam's industrial and urban vegetation. Furthermore, the research discovered that 11 plant species (i.e. *Ficus benghalensis*, *Bauhinia purpurea*, *Syzygium cumini*, *Artocarpus heterophyllus*, *Terminalia catappa*, *Eucalyptus citriodora*, *Mangifera indica*, *Tamarindus indica*, *Azadirachta indica*, *Acacia auriculiformis*, and *Polyalthia longifolia*) exhibited relatively higher tolerance levels, they could potentially be utilized to establish a green belt. These particular species might aid in effectively scavenging elevated concentrations of airborne pollutants compared to other species currently present in Visakhapatnam. In the examination conducted by Viradiya *et al.* (2020), the comparative assessment of APTI was investigated for certain plants originating from two distinct industrial locations in Rajkot. The research encompassed two diverse industrial sites within the city of Rajkot, evaluating 20 plants for their Air Pollution Tolerance Index. They revealed that all the assessed plants exhibited sensitivity to air pollutants. Notably, *Delonix regia* displayed the highest APTI value

among the 20 plants screened at Site 1, while *Cassia fistula* demonstrated the highest APTI value at Site 2. This underscores the potential suitability of these plants for plantation in areas subjected to industrial pollution stress. The derived Air Pollution Tolerance Index not only identifies these plants as sensitive to air pollution but also positions them as potential bioindicators, reflecting the environmental condition of the studied areas. Assessment of air pollution tolerance levels of certain plants to air pollution in the vicinity of a cement industry, Coimbatore, India was conducted by (Radhapriya *et al.*, 2012). They found that *Mangifera indica*, *Psidium guajava*, *Bougainvillea* species were highly tolerant, appropriate for the development of an effective "green belt" surrounding cement manufacturing, and their cultivation might be encouraged in large numbers to alleviate the problem of particle pollution. Babu *et al.* (2013) investigated the Air Pollution Tolerance Indices of plant species thriving near a Cement Industry and within the vicinity of Yogi Vemana University Campus. They discovered that trees like *Aegle marmelos* and shrubs like *Cassia auriculata* and *Bougainvillea spectabilis* can be utilized as sinks for air pollution. Similarly, (Nawaz *et al.*, 2019) described the impact of dust from cement on the physiological processes of selected trees in cement nagger, India and found that the value of APTI exhibited elevated levels within *Ficus benghalensis*, *F. religiosa*, *Terminilia catappa*, *L. leucocephala* and *Mangifera indica* are widely recommended for developing green belts and raising water tables near cement factories. Elawa *et al.* (2022) investigated the possible usage of four plant species in Egyptian greenbelts to decrease cement dust pollution. Their findings indicated that the cement industry, being a high-energy and high-carbon process, significantly contributes to global anthropogenic CO₂ emissions. Radhapriya *et al.* (2012) assessed the APTI of plant species near a cement industry in Coimbatore, India. Their findings suggested that plants in proximity to the cement industry exhibit significantly higher exposure to air pollution compared to those in control areas. Among the *Phyllanthus emblica*, *Cercocarpus ledifolius*, *Thevetia nerifolia*, and *Saraca indica* demonstrated low APTI values, suggesting greater susceptibility to air pollution indicating. Conversely, species like *Mangifera indica*, *Psidium guajava*, and *Bougainvillea spp.* exhibited high APTI values, indicating higher tolerance to pollution. Sahu *et al.* (2015) investigated the APTI of certain plant species including on *Tectona grandis*, *Ficus religiosa*, *Mangifera indica*, *Tamarandis indica*, *Azadirachta indica* and investigated the explored their expected tolerance levels, capacity for carbon sequestration, and effectiveness in collecting dust

particles, and suggested that selecting suitable species is essential for combating air pollution issues. Assessing the influence of dust emissions from cement plants on surrounding vegetation growth was evaluated by Shukla *et al.* (2008). They discovered that the cement industry is a major source of pollution, particularly impacting the air. The dust from cement contains harmful heavy metals such as nickel, cobalt, lead, and chromium, posing risks to the environment, including vegetation, human and animal health, and ecosystems. They highlighted that *Azadirachta indica* and *Eucalyptus globulus* were particularly effective for dust as well as, with *Madhuca indica* also showing good dust holding capacity. Additionally, *Eucalyptus globulus* and *Madhuca indica* were found to be the least affected by chlorosis and necrosis. As a result, they suggested that *Eucalyptus globulus* and *Madhuca indica* could be valuable for creating green belts around cement plants to mitigate the impact of dust emissions. An assessment comparing the APTI of various plant species at two distinct locations in close proximity to the CCI-Rajban cement factory in Sirmaur was investigated by Amin *et al.* (2021). They reported a range of plant species, such as Teak, Sal, Mango, Mallotus, and Guava, demonstrated low tolerance and heightened sensitivity to air pollution. Peepal plant species were characterized as moderately tolerant, and *Eucalyptus* spp. displayed a high level of tolerance to air pollution. Hazarika *et al.* (2023) reviewed “Air pollution tolerance index and anticipatory performance index of horticultural plants as a tool for assessing air quality” Their review inferred that plants with higher APTI and API values are ideal for green belt development, while those with lower values can serve as bio-indicators for areas with poor air quality. Overall, the literature suggests that the Air Pollution Tolerance Index (APTI) of tree species near cement industries fluctuates based on the species and the intensity of air pollution. Additional studies are required to deepen our comprehension of tree species' resilience to air pollution and to pinpoint the most appropriate species for cultivation in proximity to cement industries.

2.1 Reviews on different parameters of APTI

2.1.1 Relative Water Content (RWC)

Plant weight is influenced by water content, as plants store significant amounts of water for growth. Water plays a crucial role in regulating plant metabolism, growth, production, and photosynthesis (Lohe *et al.*, 2015). Plants exhibiting reduced tolerance

levels could lead to a decrease in transpiration rates, which may detrimentally affect the leaf's ability to draw water from the roots (Seyyednjad *et al.*, 2011; Chouhan *et al.*, 2012). Plants exhibiting elevated RWC in polluted environments may demonstrate increased tolerance to pollutants. Water is crucial for plants to survive. Adequate water levels within the plant are essential to maintain its physiological balance, particularly in challenging conditions such as air pollution, which can increase transpiration rates (Swami *et al.*, 2004). The presence of pollutants adversely affects transpiration rate of leaves, resulting in a reduction of the RWC in various plant species (Swami *et al.*, 2015). Plants rich in water content prove beneficial in mitigating the detrimental impacts of air pollutants, as highlighted by Kuddus *et al.* (2011) and play a crucial role in upholding ecological equilibrium. Hence, plants exhibiting elevated relative water content in polluted environments could potentially display a higher degree of tolerance towards pollutants, as suggested by Radhapriya *et al.* (2012). A leaf's relative water content (RWC) helps with transpiration, keeping plants cool and restoring vitality in droughts. The water in leaves acts like an engine, drawing minerals from the soil are transported via the plant roots (Sahu *et al.*, 2020). When leaves experience pollution stress, raising the Relative Water Content (RWC) is beneficial for trees. This helps in preserving physiological equilibrium of plants (Tanee and Albert, 2013; Nadgórska-Socha *et al.*, 2017). In stressful situations, such as exposure to air pollution, plants may exhibit an increase in transpiration rates. This heightened transpiration can be associated with a higher Relative Water Content (RWC), which, in turn, enhances the plants' ability to tolerate and adapt to air pollution. A higher RWC is indicative of improved water retention and can contribute to the overall resilience of plants in the face of environmental challenges like air pollution (Singh *et al.*, 1991). The RWC is essential for regulating cell protoplasm permeability, managing water loss, and upholding physiological equilibrium within plants. Additionally, the vapor pressure deficit a key factor in air quality, has a significant impact on controlling the RWC in leaves. Plants with a higher RWC capacity exhibit increased tolerance to air pollution, highlighting the importance of water content regulation in plant responses to environmental stressors (Jigyasu *et al.*, 2023). Numerous investigations have demonstrated that the Relative Water Content (RWC) undergoes changes corresponding to the level of air pollution, and an escalation in pollution levels is associated with a heightened relative content of plants (Sharma *et al.*, 2019). Plants with high relative water content (RWC) are more drought-resistant, but air pollution can

reduce transpiration rates and damage the leaf's water-pulling engine. This leads to a decrease in RWC, impacting the plant's ability to transport minerals and cool its leaves, as observed in studies such as Swami *et al.* (2004).

2.1.2 Ascorbic acid (AA)

Vitamin C, or ascorbic acid, is super important for both plants and animals. It helps plants grow and stay healthy by protecting them from different challenges, like dust pollution. Ascorbic acid is like a stress superhero for plants. It fights against stress, acts like an antioxidant, and is usually higher in plants that can handle stress better, as mentioned by Radhapriya *et al.* (2012). This superhero vitamin is also a signal for how well plants can handle air pollution. Gopamma *et al.* (2022) found that the amount of ascorbic acid in plants tells us how well they can tolerate air pollution because it has antioxidant powers. When we look at how plants respond to air pollution, we see that those with more ascorbic acid handle it better. Air pollution can affect the amount of ascorbic acid in plant leaves and even mess with the process plants use to make it, called photosynthesis. In a study by Sumangala (2018), they checked 46 plant species and found that those with more ascorbic acid were usually better at handling pollution. The difference in ascorbic acid levels is one reason some plant are better at handling different air pollutants. Other studies, like (Aguiar-Silva *et al.*, 2016) and (Aghajanzadeh *et al.*, 2016), also found that AA levels are linked to how well plants can deal with air pollution. One interesting thing is that during the summer, when air pollution is usually worse, plants with higher ascorbic acid content seem to do better. This suggests that the plant's ability to make this antioxidant is crucial for handling stress from air pollution, as found in studies measuring APTI scores. Sumangala (2018) observed substantial variations in the levels of Ascorbic acid among the 46 plant species examined. Jigyasu *et al.* (2023) investigated the Air Pollution Tolerance Index of *Persea bombycina*, and discovered that higher levels of sulfur compounds and nitrogen oxides in the vicinity of the polluted area exhibited a correlation with increased levels of ascorbic acid and decreased total chlorophyll content in the foliage. Nonetheless, there were no significant differences in extractable pH and relative water content across contaminated and non-polluted locations, or between seasons Zouri *et al.* (2018) reported decrease in the amount of ascorbic acid levels in polluted regions compared to unpolluted areas. However, the industrial site exhibited higher concentrations of ascorbic acid than the control sites. Esfahani *et al.* (2013) noted that the tolerance of

plants to pollution is associated with their ability to maintain elevated levels of ascorbic acid. The concentration of ascorbic acid directly influences its reducing power, indicating that plants with consistently high levels of this compound are deemed tolerant even in polluted environments. Similarly, dust pollution, its elimination, and its impact on the physiological aspects of foliage in urban trees was studied by Chaudhary and Rathore (2019) and they revealed a noteworthy increase in the ascorbic acid concentration of the contaminated site's leaves throughout all seasons.

2.1.3 Total chlorophyll content (TChl)

The assessment of air pollutants' impact on photosynthesis in plant leaves often involves measuring the total chlorophyll content, as highlighted by Sharma *et al.* (2019). This parameter is crucial for evaluating the physiological health and photosynthetic activity of plants, acting as a key indicator of their capacity to generate energy through photosynthesis. Giri *et al.* (2013) studied impact of air pollution on chlorophyll levels in leaves. Chlorophyll, a crucial photoreceptor in photosynthesis, plays a key role in converting carbon dioxide into carbohydrates and oxygen through light-driven processes. The study focused on plant species including *Azadirachta indica*, *Nerium oleander*, *Mangifera indica*, and *Dalbergia sissoo*, with leaf samples collected from areas with varying levels of air pollution. The research revealed that decrease in the levels of photosynthetic pigments including chlorophyll a, chlorophyll b, and carotenoids, within the foliage of plants from sites with higher pollution levels compared to those in less polluted or non-polluted areas. The primary contributors to gaseous and particulate emissions from industries and automobiles are oxides of nitrogen sulphur, and fly-ash. These pollutants, when exposed to leaves, Leads to a decrease in the level of essential pigments for photosynthesis like chloroplast and carotene. This reduction adversely impacts plant productivity, seed germination pedicle length, and the number of flowers in inflorescence (Nithamathi and Indira, 2005). Dust and air pollutants adversely affect plants by reducing photosynthetic pigments and yield (Farmer, 1993). Sandelius *et al.* (1995) demonstrated that these pollutants also decrease chlorophyll synthesis and accelerate chlorophyll degradation. Singh *et al.* (2018) also found, decline in the overall chlorophyll content in trees affected by atmospheric dust deposition. This decrease was evident in chlorophyll a, chlorophyll b, and the total chlorophyll levels found in the leaves of both tree species throughout all seasons, as opposed to the leaves in the control group. Viradiya *et al.* (2020) found that chlorophyll

content in plants varied based on pollution levels in the area. Higher pollutant levels were associated with lower chlorophyll content, as specific pollutants significantly reduced overall chlorophyll levels. Senthil *et al.* (2015) investigated the effect of cement dust on *Sesamum indicum* plants, revealed that reduction of total chlorophyll concentration in the polluted area compared to the non-polluted area.

2.1.4 Leaf extract pH

The pH of plants functions as a delicate gauge for detecting air pollution. Elevated pH level can enhance the transformation of hexose sugar into ascorbic acid, consequently bolstering the plants' resilience to air pollution in regions with heightened pollution levels (Chen *et al.*, 2015; Pandit and Sharma, 2020). In addition to the findings of Pandey *et al.* (2016), it was observed that the pH of leaf extract decreases when exposed to acidic pollutants. Kaur and Nagpal (2017) observed that when exposed to acidic pollutants, there is a reduction in leaf pH. This reduction occurs more rapidly in sensitive plant species compared to tolerant ones. An increased pH level of leaf extract in plants corresponds to an elevated tolerance to an acidic contaminants (Go-vindaraju *et al.*, 2012; Sharma *et al.*, 2019). *Ficus bengalensis* displayed a higher leaf pH level, suggesting an alkaline environment likely caused by increased dust deposition. In contrast, *Artocarpus heterophyllus* exhibited a lower leaf pH level (Rai and Panda, 2014). Similarly, plants with a lower pH level exhibit greater susceptibility, whereas those with a pH close to 7 demonstrate higher tolerance (Nadgórska-Socha *et al.*, 2017; Achakzai *et al.*, 2017).

2.2 Specific leaf area (SLA)

Chhetri *et al.* (2018) studied the impact of polluted air on micromorphological structure of various broad leaf trees species. They identified 11 notable alterations in the morphological characteristics of plants in contaminated areas compared to control areas. Additionally, they highlighted a reduction in stomatal size in polluted regions, along with decreased thickness in the epidermal layer, cuticle, and specific leaf area. Chaturvedi *et al.* (2013) investigated how the accumulation of dust impacted the leaf characteristics of tree species located alongside roads and revealed a noteworthy reduction in the specific leaf area (SLA) values within polluted sites. Wuytack *et al.* (2011) suggested that the impact of air pollution on Specific Leaf Area (SLA) varies among plant species and is linked to the protective or adaptive mechanisms exhibited

by these plants. Plants are consistently subjected to the impact of air pollution, leading them to assimilate, absorb, accumulate, and incorporate encountered pollutants. The observable alterations in leaves or foliar surfaces serve as indicators reflecting the prevailing air pollution levels (Karthiyayini *et al.*, 2001). They observed that the effect of Particulate Matter (PM) on the SLA of various plant species differed. Eslamdoust *et al.*, 2023, studied Reactions to cement dust pollution in the leaf water status of *Quercus castaneifolia* and *Carpinus betulus* in Northern Iran, they revealed that the Specific Leaf Area (SLA) of these two species exhibited minimal responsiveness to cement dust pollution. Meziane and Shipley (2001) investigated the relationship among exchange of gases of leaf, specific leaf area, and foliage nitrogen content. They observed that the amount of nitrogen in the leaves as well as the net photosynthetic activity are directly influenced by the SLA. Yang *et al.* (2023) studied the responsiveness of common garden plant leaf traits to air pollution in Suzhou City's urban parks (China) focused on discerning the fluctuations in Specific Leaf Area (SLA) across various plant life forms amidst varying levels of air pollution. Air pollution levels were inversely associated with Specific Leaf Area (SLA) values across all plant types. When subjected to atmospheric pollution stress, plants demonstrated a proclivity for reduced SLA and increased leaf dry matter content (Zhu, 2020).

2.3 Research gap

Based on the preceding literature survey, it is clear that the majority of Air pollution tolerance index research is focused on roadside trees and other commonly available plants. A few studies on the *Magnifera indica* and *Psidium guajava* have been conducted but the impact on these plants with distance and different directions from the factories have been ignored. Therefore, it is proposed to study the impact of cement dust pollution on different trees at different distance and directions from the Ghorahi cement industry. This literature review presents a summary of recent studies on APTI.

Most of the APTI work in Nepal are confined to roadside trees (Kanwar *et al.*, 2016, Hamal and Chhetri, 2017, Ter *et al.*, 2020) and no work has been conducted on fruit trees. But very few works on APTI have been conducted outside the Kathmandu valley. APTI related research is very important in the areas around the cement factory, to identify the tolerant and sensitive trees. Problems associated with dust of cement on fruit trees in Dang valley have not been investigated for their APTI value. It is not

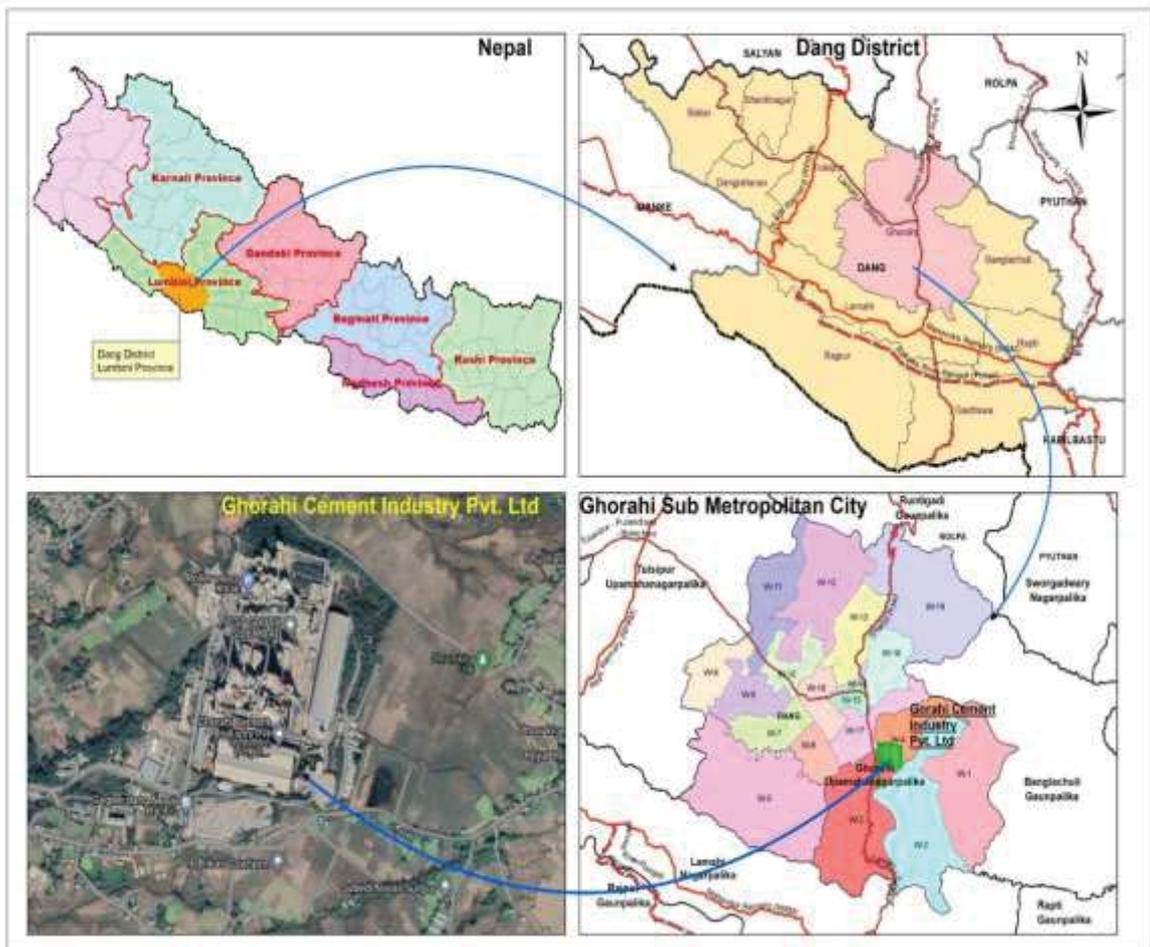
known if fruit trees can contribute to controlling and mitigating the air pollution problem near the cement industry.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area

The Dang district is situated within the Lumbini Province, nestled in the inner Terai of Nepal's Mid-Western region. It stands at a distance of around 453 kilometers from Kathmandu, the nation's capital. Covering an area of 2,955 square kilometers, the district comprises both lowland Terai regions and hilly areas. Elevations range from around 200 meters above sea level in the plains to over 2,000 meters in some hilly areas, with a population of 548,141 (as per the 2011 census). Notably, it stands as the second-largest valley in Asia, nestled within the Churiya hills in the Southern part and the Mahabharat range in the north. The study area's geographical location is 676 meters above sea level, positioned at Latitude: 28° 02' 25.20" N and Longitude: 82° 29' 9.59" E. Ghorahi Cement Industry Limited (GCIL), located in the largest sub-metropolitan city (Ghorahi Sub-Metropolitan City-4, Laxmipur, Gogli, Dang), is the largest clinker manufacturer in the country (Figure.1). According to data from 2021, the facility boasts an aggregate capacity of over 2 million metric tonnes annually and occupies approximately 52.73 hectares of land, with a total green area inside the factory spanning 23.196814 hectares. Established in 2009, the manufacturing unit has the capacity to produce 1900 metric tons per day (MTPD) of clinker and 2200 MTPD of cement which is 45000 Bags per day. To mitigate pollution, the cement factory employs bag filters, Electrostatic Precipitators (ESC), and two chimneys. Situated strategically in Ghorahi, Dang Nepal, along the Lamahi-Tulsipur Highway about 18 kilometers distant from Lamahi City in the direction of Ghorahi City, it rests a mere 5 kilometers from the factory site, the company holds a prime location ensuring easy access to high-grade limestone. In March 2021, the company transitioned into a public limited company and was renamed Ghorahi Cement Industry Limited (GCIL). The landscape around the Ghorahi Cement Industry varies significantly. A mud road in the north (within 500 m) from the factory is in use for transportation of various raw materials (limestone, clinker etc.). Adjacent to this road, apartments are constructed for the factory employees. Behind the cement industry, dense plantation primarily of fruit trees are present. Residential areas scatter in all four directions, with the eastern direction housing the raw material deposition site for cement production near the factory. In the western

direction, there's grazing land for local livestock, while in the north, a gravel road connects to the main highway. A dispersed residential neighborhood and a water reservoir linked to the industry can be found to the east. In the south-west, within 200 meters of the factory, lies the main highway (Lamahi -Tulsipur Highway) amidst a dense residential area. This highway has been under reconstruction for the past five years, resulting in a significant amount of dust particles due to vehicular movement. Additionally, dense residential areas encircle the cement industry in this direction.



Source: Department of Survey and Google Earth

Figure 1. Map of Study area around the Ghorahi cement Industry Limited, Ghorahi Dang

3.2. Climate and Hydrology

The designated climate zone for the research area is tropical. Analyzing the data reveals that the highest average temperature ranged from (34.25°C) in May to (20.98°C) in January. Similarly, the highest average minimum temperature ranged from (23.6°C) in July to (6.63°C) in January.

In terms of rainfall, the highest average was registered in August at (99.55 mm), whereas the lowest occurred in November with a mere (0.405 mm) (Figure. 2).

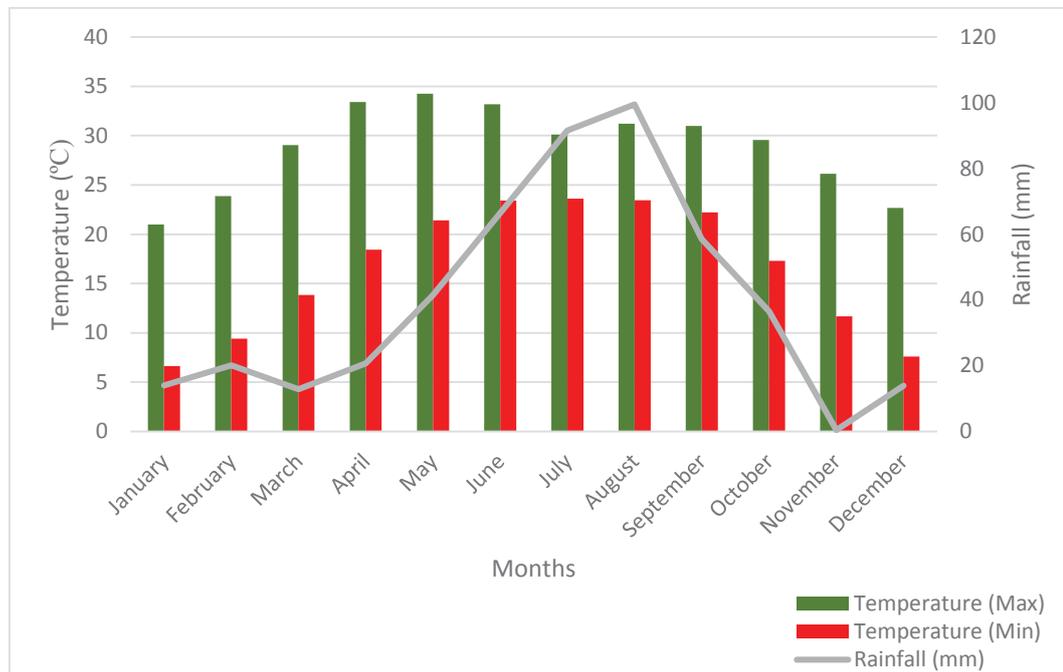


Figure 2. Meteorological graph of average monthly temperature and precipitation of last ten years (2012-2022) in Dang, Nepal (Source: Department of Hydrology and Meterology, Babarmahal, Government of Nepal).

3.3 Study species

Leaves of five plants species (commonly available) in the vicinity of the Ghorahi cement Industry were collected, chosen from various distances and directions. These plants were collected from locations spanning 200-500m, 500-800m, and beyond 800m, in addition to being collected from east, west, north and south directions. Plant species were selected on the basis of their prevalence across all sites. Identification of these plants was facilitated through literature and experts. Table 1 provides the scientific and local names of the identified plant species.

Table 1. List of the studied five Plant species.

S.N.	Scientific Name	Family	Local Name
1	<i>Magnifera indica</i>	Anacardiaceae	Aap
2	<i>Psidium guajava</i>	Myrtaceae	Amba
3	<i>Litchi chinensis</i>	Sapindaceae	Litchi
4	<i>Artocarpus heterophyllus</i>	Moraceae	Rukh Katahar
5	<i>Syzygium cumini</i>	Myrtaceae	Jamun

3.4 Methods

3.4.1 Sample collections and designs

The current research was performed during winter, 25th November, 2021 and 2nd February, 2022. Initially, the area around factory was vividly divided into three sectors: (200-500) m, (500-800) m, and beyond 800 m, from the factory, covering four directions (east, west, north, and south) around the Ghorahi Cement Industry (Figure 3). Well-developed leaf samples from fruit tree species taller than five feet were collected in the morning from each distance and direction, then stored in Ziplock bags and transported to the laboratory. To ensure precision, three duplicates were acquired for each sample. The parameters like ascorbic acid content, total chlorophyll, pH of the leaf extract and relative water content were tested at laboratory of Mahendra Multiple Campus, Dang, for APTI. Specific leaf area and leaf area were also measured. Dust particles adhered to the leaf surface were cleaned carefully using soft tissues papers. After cleaning fresh weight of leaf was taken using three digital scale balance. Digital images of the fresh leaf samples along with scale were captured for subsequent analysis.

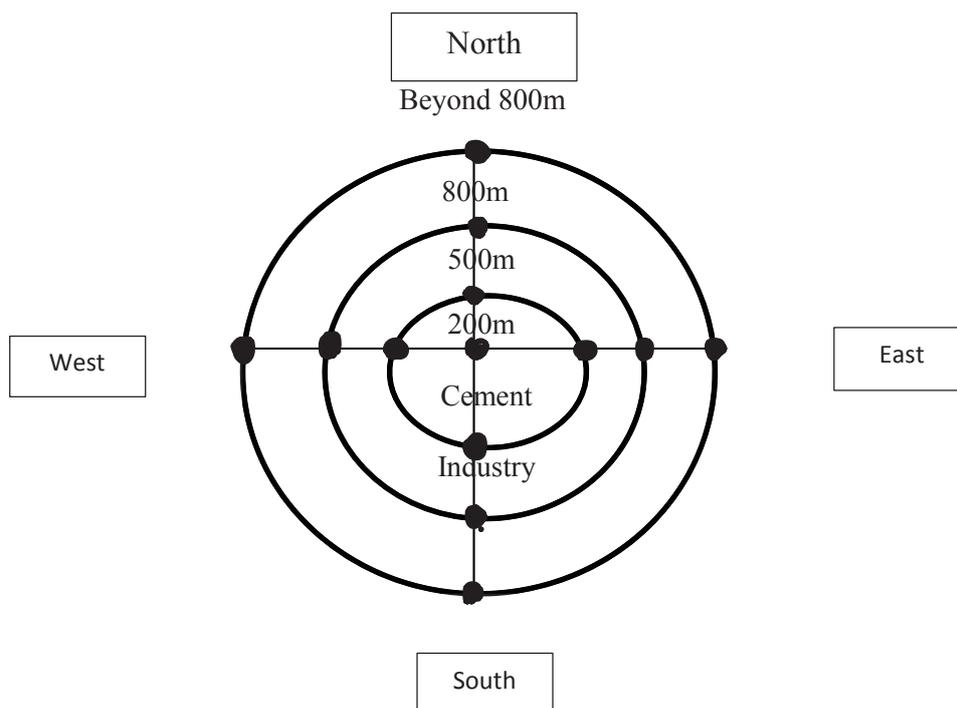


Figure 3. A diagram representing the study area, displaying various distances (200-500 m, 500-800 m, and beyond 800 m) and directions (east, west, north and south).

3.4.2 Biochemical analysis for Air Pollution Tolerance Index (APTI)

The APTI value for studied plant species was assessed by analyzing various biochemical factors (relative water content, total chlorophyll content, leaf extract pH, and Ascorbic Acid) of each plant sample.

3.4.2.1 Relative leaf water content (RWC)

Initially fresh weight of leaves was measured, followed by immersion in water overnight to determine their hydrated weight. Subsequently, the hydrated leaves were allowed to dry at 70°C for 24 hours in oven and ultimately dry weight was recorded. Using these measurements, the leaf relative water content was calculated, using the formula given by Turner (1981).

$$RWC(\%) = \frac{F - D}{T - D} \times 100$$

Where, F represents the fresh weight (g), D represents the dry weight (g), and T represents the turgid weight (g).

3.4.2.2 Ascorbic acid (AA)

The levels of AA (mg/g) were determined following the spectrophotometric method outlined by Bajaj and Kaur (1981). Initially, fresh leaf samples weighing 1 g were placed in a test tube. Subsequently, oxalic acid-EDTA (4 ml), orthophosphoric acid (1 ml), sulfuric acid (1 ml), ammonium molybdate solution (2 ml), and distilled water (3 ml) were added sequentially. The mixture was left to stand for 15 minutes at room temperature. After this incubation period, the absorbance at 760 nm was measured using a spectrophotometer. A solution of the same mixture without leaves was used as a blank.

To quantify the ascorbic acid concentration, a standard curve was prepared using known concentrations of ascorbic acid. By correlating the absorbance readings with the weight of the leaf samples, the concentration of ascorbic acid in the leaves was determined.

3.4.2.3 Chlorophyll estimation

Chlorophyll content in leaves was extracted according to Barnes *et al.* (1992) using Dimethyl sulfoxide (DMSO). A quantity of 0.5 grams of leaves was taken in test tube and 5 ml of DMSO was added. It was then placed in a hot water bath (60-65°C) for one hour, till complete extraction of chlorophyll. Then the samples were allowed to cool till room temperature. The cooled samples were filtrated, and the absorbance of the filtrate was taken at 665 nm and 648 nm using a spectrophotometer. Pure DMSO solution with no leaf samples was used as a blank.

Here are the equations of Chlorophyll a, chlorophyll b and Total Chlorophyll content:

$$\text{Chlorophyll a (mg/g F.W)} = (14.85 \times A_{665} - 5.14 \times A_{648}) \dots \dots \dots (1)$$

$$\text{Chlorophyll b (mg/g F.W)} = (25.48 \times A_{665} - 7.36 \times A_{648}) \dots \dots \dots (2)$$

$$\text{Total chlorophyll (mg/g F.W)} = (7.49 \times A_{665} + 20.34 \times A_{648}) \dots \dots \dots (3)$$

3.4.2.4 Leaf extract pH

Datta and Sinha-Ray (1995), conducted an experiment to ascertain the pH level of leaves. They processed 5 grams of fresh leaves by washing and homogenizing them with 25 ml of distilled water. Subsequently, the pH of the resulting leaf extract was determined by filtration and measured using a pH meter.

3.4.2.5 Air pollution tolerance index (APTI)

APTI was determined employing the following formula:

$$\text{APTI} = \frac{A(T+P)+R}{10} \quad (\text{Singh and Rao, 1983}),$$

Where A represents the Ascorbic acid content (mg/g), T represents total chlorophyll (mg/g), P represents pH of leaf extract and R represents relative water content of leaf.

3.4.3 Categorization of plants

Padmavathi *et al.* (2013) classified the plant species into various categories based on their APTI scores: Sensitive (APTI less than 11), Intermediate (APTI between 12 and 16) and Tolerant (APTI above 17).

Lohe *et al.* (2015) categorized various terrestrial plant species based on their air pollution tolerance index in a comparative study: Tolerant (APTI 30-100), Intermediate (APTI 17-29), Sensitive (APTI 1-16) and very sensitive (APTI <1).

3.4.4 Leaf area

To calculate leaf area, images of fully developed, healthy, and mature leaves were taken along with a reference scale. Using image-J software (Kovaic and Nicolic, 2005), then computed the area of each leaf.

3.4.5 Specific leaf area (SLA)

To determine specific leaf area, images of fully developed healthy and mature leaves were captured alongside a reference scale, and their area was computed using image-J software (Kovaic and Nicolic, 2005). Then the leaf samples were subjected to air drying in an oven at 70°C-75°C for more than 24 hours until they reached their consistent dry weight. The dry weight of the leaves was then measured. The calculation of SLA was conducted according to the formula outlined by Zobel *et al.* (1987).

$$\text{SLA} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry mass (g)}}$$

3.4.6 Data analysis

The obtained data were computed using Microsoft Excel 2016, and subsequently were transferred to SPSS for normality testing. The normality of the data was assessed via box plots generated in SPSS, with attention paid to Skewness and Kurtosis values falling within the range of -2 to +2 (George and Mallery, 2010). Since the biochemical parameters exhibited a normal distribution in all instances, further statistical analyses, including one-way ANOVA followed by Duncan's Multiple Range Test, were carried out using SPSS version 27 to investigate significant differences at a significance level of $p=0.05$ among various distances from the factory. Additionally, correlation coefficient analysis between the biochemical parameters (RWC, Tchl, pH, AA, and APTI) and SLA was performed using SPSS version 27.

CHAPTER 4: RESULT

4.1 Air pollution tolerance index (APTI)

4.1.1 Relative water content (RWC)

In the vicinity of the cement industry, tree species generally exhibited elevated mean value of RWC. RWC values varied from 70.77±1.93% to 97.00±0.47%. *Litchi chinensis* recorded the highest RWC (97.00±0.47%) within the distance range of 200-500 m, while the lowest RWC was also observed in *Litchi chinensis* (70.77±1.93%) beyond 800 m range (Table 2).

Table 2. Mean value and standard error of Relative water content (%) in leaves of various tree species at various distance and directions from Ghorahi Cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangifera indica</i>	2-500	94.77±0.691 B	93.87± 0.70 A	94.74±1.40 A	94.76±1.53 B
	500-800	89.22±1.79A	92.10±1.90A	92.66±0.77A	92.30±3.65AB
	Beyond 800	88.34±3.87A	91.47±1.94 A	93.22±1.02 A	89.49±0.79A
<i>Psidium guajava</i>	2-500	90.55±0.62 B	94.51±1.65 B	93.31±2.00 B	89.73±0.91 B
	500-800	87.14±0.69 A	92.96±0.68 B	90.78± 2.71 AB	85.11±1.00 AB
	Beyond 800	86.16±1.79 A	84.14±3.16 A	88.05± 1.90 A	79.19±8.30 A
<i>Litchi chinensis</i>	2-500	86.51±2.53 A	82.71±1.91 B	92.20± 2.07 B	97.00±0.47C
	500-800	83.87±2.29 A	80.27±0.49 B	90.63± 1.31 B	90.46± 1.30 B
	Beyond 800	83.71±2.11A	70.77± 1.93 A	87.67±1.31 A	84.99± 0.93 A
<i>Artocarpus heterophyllus</i>	2-500	83.81±4.85 A	80.86±5.35 C	88.27±3.06 B	88.67±5.31 B
	500-800	80.61±3.83 A	71.36±1.44 B	80.21±5.44 A	82.47± 0.77AB
	Beyond 800	78.69±6.80 A	59.56±3.49 A	75.61±2.56A	74.85±4.41A
<i>Syzygium cumini</i>	2-500	95.00±2.37 B	87.10 ±0.89 B	92.01±1.54 A	94.94±4.45A
	500-800	90.38±1.25 A	80.07± 1.17 AB	91.75± 4.18 A	93.47±7.65A
	Beyond 800	90.41±0.76 A	76.52± 8.65 A	89.02± 0.78A	88.25±1.77A

Same alphabet followed after mean value \pm standard deviation for a particular species in a column indicates insignificant difference (at $p=0.05$) according to Duncan's multiple range test followed after one-way ANOVA ($n=9$).

Here, while moving away from the industry i.e. (200- 500 m) to (500-800m) and beyond 800, the mean value of RWC of plant species was showed significant ($p=0.05$) decrease. The mean value of *Syzygium cumini* was high in east and south direction and *Magnifera indica* in west and north direction. Among the studied, species like *Magnifera indica* showed a significant increase in the north direction and a significant decrease in the east direction. *Psidium guajava* exhibited a significant increase in RWC in the west direction and a decrease in the south direction. *Litchi chinensis* and *Artocarpus heterophyllus* showed a significant increase in the north direction and a decrease in the west direction. Similarly, *Syzygium cumini* demonstrated a significant increase in the east direction and a decrease in the west direction (200-500 m).

4.1.2 Ascorbic Acid Content (AA)

The average value of AA in the leaves of studied plants ranged from 0.10 ± 0.06 to 14.08 ± 4.23 mg/g (Table 3). The value of ascorbic acid was highest in *P. guajava* (14.08 ± 4.23 mg/g) at (2-500 m) distance and lowest in *L. chinensis* (0.10 ± 0.06 mg/g) beyond 800 m. Plants species like *M. indica* was showed high ascorbic acid in west direction and low in south direction than other two directions at same range. *P. guajava* was showed high ascorbic acid in west direction and low in east direction than other two directions at (200-500 m) distance. *L. chinensis* statistically demonstrated significant increase in east and south direction nearer to industry and insignificant in west and north direction. At same range (200-500 m) *A. heterophyllus* showed significant ($p=0.05$) increase ascorbic acid mean value in west direction. Similarly, *S. cumini* exhibited significant ($p=0.05$) increase in ascorbic at west direction. In western direction, all fruit plant species studied exhibited significantly higher value of total ascorbic acid content around the industry within similar range. While moving away (200-500) m to beyond 800 m from the factory most of the plant species showed significant ($p=0.05$) reduction in ascorbic acid at all directions but *L. chinensis* showed insignificant ascorbic acid mean value.

Table 3. Mean value and standard error of Ascorbic acid content (mg/g) in leaves of various tree species at various directions and distance from the Ghorahi Cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera ndica</i>	2-500	1.11±0.15 A	2.05±0.16 A	1.58±0.08 A	1.38±0.05 A
	500-800	4.03±0.16 B	3.05±0.33 B	1.90±0.12 B	1.65±0.10 B
	Beyond 800	5.05±0.28 C	3.19±0.66 B	2.21±0.04 C	1.88±0.13 C
<i>Psidium guajava</i>	2-500	1.30 ±0.08 A	1.98±0.46 A	1.89±0.12 A	1.50±0.07 A
	500-800	2.61±0.24 B	3.04±0.62 AB	3.51±0.02 B	2.461±0.48 B
	Beyond 800	5.06±0.24 C	3.64±0.78 B	3.60 ±0.05 B	2.52±0.17 B
<i>Litchi chinensis</i>	2-500	0.56±0.08 A	1.16±0.27 A	1.17±0.03 A	0.90±0.08 A
	500-800	0.77±0.036 B	1.38±0.08 AB	1.78±0.06 B	1.02±0.21 A
	Beyond 800	1.96 ±0.09 C	1.76±0.59 A	1.77±0.09B	1.32±0.08 B
<i>Artocarpus heterophyllus</i>	2-500	1.07±0.002 A	1.25±0.06 A	1.69±0.34 A	1.35±0.11 A
	500-800	2.12±0.07 B	3.04± 0.68 A	2.60±0.05 B	1.97±0.16 B
	Beyond 800	2.30±0.02 C	4.17 ±1.13 B	3.52±0.41 C	1.88±0.12 B
<i>Syzygium cumini</i>	2-500	1.09±0.06 A	1.81 ±0.12 A	1.38±0.08 A	1.35±0.11 A
	500-800	1.30±0.06 B	2.49 ±0.27 B	2.44±0.03 B	1.69± 0.09 B
	Beyond 800	4.13±0.10 C	4.77±0.40 C	3.05±0.12 C	2.06±0.17 C

Same alphabet followed after mean value ± standard deviation for a particular species in a column indicates insignificant difference (at p=0.05) according to Duncan's multiple range test followed after one-way ANOVA (n=9).

4.1.3 Total Chlorophyll content (TChl)

All tree species had a low mean value of total chlorophyll content near the factory at a distance of (200-500) meters. Total chlorophyll concentration ranged from 0.56±0.08 to 5.06±0.24 mg/g (Table 4).

Table 4. Mean value and standard error of chlorophyll content (mg/g) in leaves of various tree species at various directions and distance from the Ghorahi Cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera indica</i>	2-500	4.92±1.11 C	5.74±0.45 A	5.31± 1.03 B	4.41± 1.51 A
	500-800	2.94±0.14 B	5.20 ± 1.18 A	2.10 ± 0.29 A	3.65± 0.25 A
	Beyond 800	0.83± 0.03 A	5.061±2.13 A	1.87± 0.34 A	2.77± 0.46 A
<i>Psidium guajava</i>	2-500	2.69± 0.90 A	14.08± 4.23 B	3.43± 0.14 A	5.83± 0.276 A
	500-800	2.46± 0.20 A	4.30± 3.81 A	2.70± 0.37 A	5.49± 3.32 A
	Beyond 800	1.64± 0.37 A	2.79± 2.57 A	2.61± 1.06 A	4.54± 1.28 A
<i>Litchi chinensis</i>	2-500	1.87± 2.59 A	2.56± 0.76 B	2.03± 0.12 B	1.31± 0.77 B
	500-800	1.46± 0.32 A	0.85± 0.54 A	0.38± 0.13 A	0.57± 0.40 AB
	Beyond 800	0.14± 0.10 A	0.91± 0.43 A	0.40± 0.24 A	0.10± 0.06 A
<i>Artocarpus heterophyllus</i>	2-500	2.35± 0.71B	4.35± 1.27 B	2.84± 0.39 B	1.73± 0.167A
	500-800	2.16± 0.42 B	1.23± 0.78 A	1.59± 0.07 A	1.37± 0.48A
	Beyond 800	0.66± 0.50 A	0.27± 0.29A	1.26± 0.77 A	1.25± 0.044 A
<i>Syzygium cumini</i>	2-500	3.97± 0.60 C	10.73± 1.88 B	3.9± 0.28 C	2.45±0.230 A
	500-800	2.36± 0.08 B	2.42± 1.63 A	2.90± 0.27B	2.45± 0.11 A
	Beyond 800	1.48± 0.18 A	0.79± 1.17 A	2.29± 0.15 A	2.28± 1.15 A

Same alphabet followed after mean value ± standard deviation for a particular species in a column indicates insignificant difference (at p=0.05) according to Duncan's multiple range test followed after one-way ANOVA (n=9).

The mean value of total chlorophyll content was highest in *P. guajava* (5.06±0.24 mg/g) beyond 800 m and lowest in *L. chinensis* (0.56±0.08 mg/g) at distances ranging from 200 to 500 m. All of the plant species exhibited the lowest mean chlorophyll content value within the 200-500 m range. As the distance from the factory increased from 200-

500 m to beyond 800 meters, most of the plant species showed a significantly higher total chlorophyll concentration value in all directions (east, west, north, and south), except for *L. chinensis* and *S. cumini* which showed insignificant total chlorophyll values in the north and south directions. In the eastern direction, a majority of the examined species displayed notably increased levels of total chlorophyll content as they moved beyond the industry (i.e., beyond 800 meters). Conversely, in the southern direction, all the plant species investigated exhibited notably decreased levels of total chlorophyll. *M. indica* showed a significant ($p=0.05$) increase in chlorophyll content beyond 800 m in all directions. In the east direction within the 800 m range, *M. indica* exhibited a high mean value of chlorophyll content, while in the north direction at the same range, it showed a low value. *P. guajava* displayed elevated levels in the eastern direction and decreased levels in the southern direction beyond 800 m. Notably, *L. chinensis* showed high chlorophyll content in the east direction and low content in the south direction beyond 800 m. It also showed a significant ($p=0.05$) increase in the mean value of overall chlorophyll concentration as the distance from the industry increased within the same range in the east, west, and north directions, but not in the south direction. Similarly, *S. cumini* demonstrated a significant increase in the west direction and a decrease in the south direction. This species also showed a significant ($p=0.05$) increase in the mean value of overall chlorophyll concentration as the distance from the industry increased in all directions.

4.1.4 Leaf extract pH

The findings derived from leaf pH analysis indicated a consistent upward trend as distance from the factory increased across various tree species. Leaf extract pH ranged from (4.17 ± 0.15) to (6.97 ± 0.35). *L. chinensis* exhibited the highest pH value (6.97 ± 0.35), while *S. cumini* displayed the lowest (4.17 ± 0.15) (Table 5). Within the (200-500) m range, all plants exhibited low pH values regardless of direction. Notably, *L. Chinensis* and *A. heterophyllus* displayed less degradation of pH near the industry, with values of (6.1 ± 0.1) and (6.1 ± 0.2) respectively. However, as distance increased (from 200-500 m to beyond 800 m), *M. indica* and *P. guajava* demonstrated significantly ($p=0.05$) higher pH values in the east direction and lower values in the west and south directions beyond 800m. Conversely, *L. chinensis* and *S. cumini* displayed significantly ($p=0.05$) higher pH values in the north and west directions beyond 800m, with lower values in the south and east directions. *A. heterophyllus* exhibited a notable increase in

pH mean value in the east, west, and south directions, and insignificant change in the north direction, yet significantly higher pH value in the west direction and lower in the east direction beyond 800m. Across all species, pH mean values were lower in proximity to the industry area (200-500m).

Table 5. Mean value and standard error of Leaf extract pH in leaves of various tree species at various directions and distance from the Ghorahi cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera indica</i>	2-500	4.9±0.17 A	5.17± 0.15 A	5.2± 0.2 A	5.3± 0.17 A
	500-800	5.73± 0.15B	5.27± 0.06 A	5.27± 0.15 A	5.37± 0.06 A
	Beyond 800	5.97± 0.25 B	5.4± 0.2 A	5.43± 0.15 A	5.7± 0.1 B
<i>Psidium guajava</i>	2-500	5.83± 0.12 A	4.83± 0.12 A	4.97± 0.25 A	5.6± 0.26 A
	500-800	6.47± 0.15 B	5.43± 5.43 B	6.03± 0.15 B	5.73± 0.15 A
	Beyond 800	6.5± 0.1 B	6.33± 0.12 C	6.33± 0.06 B	5.97± 0.15 A
<i>Litchi chinensis</i>	2-500	6.1± 0.1 A	5.9± 0.1 A	5.97± 0.15 A	5.6± 0.26 A
	500-800	6.33± 0.15 AB	5.93± 0.15 A	6.3± 0.1 A	5.97± 0.15 A
	Beyond 800	6.47± 0.15 B	6.9±0 B	6.97± 0.35 B	6.37± 0.15 B
<i>Artocarpus heterophyllus</i>	2-500	5.73± 0.21 A	5.67± 0.15 A	5.63± 0.15 A	6.1± 0.2 A
	500-800	6.13± 0.23 B	5.83± 0.23 A	6.57± 0.127 C	6.23± 0.15 A
	Beyond 800	6.17± 0.06 B	6.53± 0.06 B	6.3± 0.1 B	6.4± 0.17 A
<i>Syzygium cumini</i>	2-500	4.17± 0.15 A	4.4± 0.1 A	4.43± 0.25 A	4.27± 0.15 A
	500-800	4.57± 0.06B	4.93± 0.21 B	4.57± 0.12 A	4.27± 0.06 A
	Beyond 800	4.6± 0.1 B	5.07± 0.12 B	4.43± 0.25A	4.67± 0.15 B

Same alphabet followed after mean value ± standard deviation for a particular species in a column indicates insignificant difference (at p=0.05) according to Duncan's multiple range test followed after one-way ANOVA (n=9).

4.1.5 Air pollution tolerance index (APTI)

The average APTI values for tree species showed an increase in proximity to the industry. APTI values ranged from (6.23 ± 0.34) to (18.97 ± 2.50) (Table 6). Highest APTI mean value was in *P. guajava* (18.97 ± 2.50) and lowest APTI value in *A. heterophyllus* (6.23 ± 0.34) in non-polluted site. The APTI value in *L. chinensis* and *A. heterophyllus* in both polluted (200-500 m) as well as control site (beyond 800 m) had minimal mean value of APTI in east and west direction. Among studied five tree species studied, four plant species showed significantly ($p=0.05$) higher APTI mean value in west direction in comparison to remaining three directions at (200-500) m. Remaining one *L. chinensis* showed significantly higher APTI value in north direction at same range. Plants species like *M. indica* showed significant increased APTI value in west direction than remaining three directions in nearer to the industry (200-500 m) and significant decreased APTI value at controlled site (i.e. beyond 800 m range) in east direction. *P. guajava* showed significant higher value in west direction nearer to the industry and significantly lower APTI value in south direction than remaining three directions in controlled site. Others remaining three species like *L. chinensis* showed higher APTI value in north direction at (200-500 m) range and lower value in west direction beyond 800 m. *A. heterophyllus* and *S. cumini* showed significant higher APTI mean value at west direction than remaining three directions in nearer to industry (200-500 m) and also lower APTI value in away from the industry (beyond 800 m) in same direction. In this context, the APTI value of the plants examined significantly decreased ($p=0.05$) as the distance from the industry increased from 200-500 meters to beyond 800 meters.

Table 6. Mean value and standard error of APTI of various tree species at various directions and distance from the Ghorahi cement industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera indica</i>	2-500	12.45±0.67B	13.53± 0.32 A	13.06± 0.52 B	12.44± 1.01A
	500-800	11.80 ±0.04 B	13.51± 1.00 A	10.77± 0.16 A	11.79± 0.49 A
	Beyond 800	9.75±0.41 A	13.38± 1.63 A	10.75± 0.34 A	11.05±0.37 A
<i>Psidium guajava</i>	2-500	10.96±0.63 A	18.97 ± 2.50 B	11.68± 0.26 A	13.12±0.38 A
	500-800	10.94±0.23 A	12.80± 2.83A	11.66± 0.14 A	12.97± 2.71 A
	Beyond 800	10.51±0.33 A	11.34± 2.98 A	11.39± 1.10 A	10.27±1.98 A
<i>Litchi chinensis</i>	2-500	9.89± 1.51A	10.08± 0.39 C	10.67± 0.28 B	10.56±0.53 C
	500-800	9.42± 0.178 A	8.64± 0.40 B	9.37± 0.22 A	9.44± 0.22 B
	Beyond 800	8.49± 0.14 A	7.87± 0.20 A	9.11 ± 0.24 A	8.57± 0.05 A
<i>Artocarpus heterophyllus</i>	2-500	9.98±0.45 B	11.09± 0.41 C	10.90± 0.43 B	10.16± 0.59 B
	500-800	9.85±0.59 B	8.19± 0.46 B	9.48± 0.50 A	9.37± 0.31 AB
	Beyond 800	8.42±0.34 A	6.23± 0.34 A	8.78± 0.68 A	8.52± 0.47 A
<i>Syzygium cumini</i>	2-500	11.58±0.062 B	15.37± 1.26 B	11.49± 0.05 B	10.87±0.54 A
	500-800	10.43±0.09 A	9.81 ± 1.21A	11.20± 0.41 B	10.80± 0.82 A
	Beyond 800	10.33±0.19 A	8.43± 1.03A	10.61±0.07 A	10.35± 0.80 A

Same alphabet followed after mean value ± standard deviation for a particular species in a column indicates insignificant difference (at p=0.05) according to Duncan's multiple range test followed after one-way ANOVA (n=9).

4.2 Leaf Area

The average leaf area of few examined species was notably reduced in close proximity to the cement (within 200m) in all directions. Leaf area values varied between (14.93± 0.85 cm²) and (59.88± 3.93 cm²). The value of leaf area was lowest in *L. chinensis* 14.93± 0.85 cm²) and highest in *M. indica* (59.88± 3.93 cm²) (Table 7). Species like *M. indica* showed significant increased (p=0.05) in the east, west and south directions beyond 800 m range but insignificant mean value of leaf area of fruit plant species at

north direction. *P. guajava* showed significant increased ($p=0.05$) mean value of leaf area in west direction at same range (i.e. beyond 800 m) but insignificant in remaining three directions. *Litchi chinensis* showed insignificant mean value in all four directions and all ranges. *A. heterophyllus* showed significant ($p=0.05$) increased mean value in east away from the industry and north direction but insignificant in east and south direction. Similarly, *S. cumini* exhibited significantly high value of leaf area at east, north and south directions at same range (i.e. beyond 800 m) but insignificant value in west direction. The average leaf area varies significantly across different directions and distances. However, there is generally no significant correlation observed between the variation in leaf area values near the cement industry and those farther away, across various distances and directions.

Table 7. Mean value and standard error of Leaf area (cm^2) of various tree species at various directions and distance from the Ghorahi cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera indica</i>	2-500	31.58± 0.66 A	30.06± 2.89 A	32.09± 3.18 A	25.08± 1.93 A
	500-800	42.37± 2.17 B	38.55± 1.64 B	58.28± 5.64 B	32.61± 3.49 B
	Beyond 800	58.35± 1.24 C	59.88± 3.93 C	28.65± 1.33 A	39.04± 2.92 C
<i>Psidium guajava</i>	2-500	40.40± 2.05 B	24.83± 1.22 A	32.54± 0.87 C	29.43± 2.45 B
	500-800	42.38± 3.38 B	25.17± 0.48 A	22.94 ± 0.82 A	24.22± 1.02 A
	Beyond 800	32.15± 2.65 A	38.26± 1.67 B	27.89± 1.50 B	30.37± 2.09 B
<i>Litchi chinensis</i>	2-500	16.91± 1.68 A	16.35± 1.48 A	23.72± 1.48 B	18.70 ± 0.52 A
	500-800	24.01± 2.27 B	14.93± 0.85 A	23.19 ± 1.43 B	20.82± 1.14 A
	Beyond 800	23.24± 1.99 B	19.70 ± 0.93 B	18.54± 0.613	20.68± 1.49 A
<i>Artocarpus heterophyllus</i>	2-500	27.40 ± 1.17 A	49.96± 1.81 B	31.73± 0.65 A	33.19± 1.41 B
	500-800	31.50± 1.78 B	29.37± 2.18 A	37.75 ± 1.53 B	30.36± 1.04 A
	Beyond 800	48.01± 2.09 C	46.62± 2.20 B	40.29± 0.723 C	32.76± 1.17 AB
<i>Syzygium cumini</i>	2-500	30.62± 4.01 A	49.09± 3.66 C	30.57± 3.45 A	33.31± 2.00 B
	500-800	46.67± 4.51 B	27.15± 3.85 A	35.18± 0.78 B	23.62± 1.65 A
	Beyond 800	48.31± 2.09 B	34.91± 3.67 B	37.32± 0.07 B	42.28± 3.83 C

Same alphabet followed after mean value ± standard deviation for a particular species in a column indicates insignificant difference (at $p=0.05$) according to Duncan's multiple range test followed after one-way ANOVA ($n=9$).

4.3 Specific leaf area (SLA)

The average SLA of the species examined was relatively low in close proximity to the factory within a range of 200-500 m in all directions. SLA values varied from (23.33± 1.38 cm²/g) to (64.62± 6.74 cm²/g). Among the species, *M. indica* exhibited the lowest SLA value (23.33± 1.38 cm²/g), while *P. guajava* demonstrated the highest (64.62± 6.74 cm²/g) (Table 8). Species like *M. indica* mean value of SLA showed significantly (p=0.05) high in north direction beyond 800 m range than remaining three directions. *P. guajava* and *L. chinensis* showed high SLA value in south direction in comparison to others three directions at same range.

Table 8. Mean value and standard error of Specific leaf area (cm²/g) of various tree species at various directions and distance from the Ghorahi Cement Industry.

Name of tree species	Distance (meters)	East	West	North	South
<i>Mangnifera indica</i>	2-500	23.33± 1.38 A	23.93±8.21 A	33.31±2.30 A	29.04± 3.82A
	500-800	36.16 ± 3.56 B	38.77± 8.21 B	45.96± 6.11 B	31.86± 3.14 AB
	Beyond 800	37.39± 2.75 B	45.06±4.76 B	46.95 ± 6.25 B	38.60 ± 3.44 B
<i>Psidium guajava</i>	2-500	35.09± 2.24 A	31.68± 1.98 A	41.78± 3.65 A	45.97± 4.77 A
	500-800	44.46± 2.92 B	35.24± 2.63 A	43.42± 7.79 A	57.30± 4.73 B
	Beyond 800	57.50± 1.90 C	58.26± 6.86 B	42.56± 2.93 A	64.62± 6.74 B
<i>Litchi chinensis</i>	2-500	38.24± 4.40 A	32.26±5.40 A	39.05± 3.82 A	45.98± 4.35A
	500-800	41.91± 2.07 A	51.95±7.43 B	42.42± 6.76 A	57.33± 3.12 B
	Beyond 800	57.25± 2.77 B	58.06± 3.51 B	56.06± 2.65 B	59.37± 6.56 B
<i>Artocarpus heterophyllus</i>	2-500	33.51± 1.66 A	50.71± 4.64 A	48.13± 2.48 A	31.67± 1.69 A
	500-800	39.61± 7.31 A	56.80±5.23 A	48.50± 0.91 A	44.65± 3.54 B
	Beyond 800	46.10 ± 9.11 A	56.48± 0.77 A	54.13± 3.81B	43.34± 5.00 B
<i>Syzygium cumini</i>	2-500	33.43± 2.89A	35.50± 4.72 A	26.87± 5.83 A	30.91± 1.63 A
	500-800	40.79±1.58 B	42.80 ± 2.69 A	32.48± 4.375AB	32.86± 1.46A
	Beyond 800	48.38 ± 48.38 C	45.08 ± 10.30 A	40.23 ± 7.43 B	38.39 ± 7.76 A

A. heterophyllus showed significantly high at west direction and *S. cumini* showed significant (p=0.05) high SLA mean value at east direction in comparison to remaining three directions at same range (i.e. beyond 800 m) but *P. guajava* and *A. heterophyllus*

species showed insignificant SLA mean value at north and south directions. As the distance from the factory increases, ranging from 200 to 500 m to beyond 800 m, there was a notable rise in the SLA values across various plant species and directions.

Same alphabet followed after mean value \pm standard deviation for a particular species in a column indicates insignificant difference (at $p=0.05$) according to Duncan's multiple range test followed after one-way ANOVA ($n=9$).

4.4 Correlation of RWC with APTI in four directions (East, West, North and South)

The correlation between RWC and APTI was found to be positive in all directions (Table 9). Species like *M. indica* and *P. guajava* showed an insignificant positive correlation between RWC and APTI in the east, west and north directions while a positive significant ($p<0.05$) correlation in the south direction. For *L. chinensis*, positively insignificant correlation between RWC and APTI was displayed in the east direction, but a positively significant correlation was observed in remaining three directions. Similarly, correlation for *A. heterophyllus* was an insignificantly positive in the east direction and positively significant ($p<0.01$) towards west, north and south directions. *S. cumini* exhibited positive significant correlation between RWC and APTI in all studied directions.

Table 9. Correlation of RWC with APTI in Four directions ($n=9$)

S.N.	Name of tree species	RWC- APTI (East Direction)	RWC- APTI (West Direction)	RWC- APTI (North Directions)	RWC- APTI (South Directions)
1	<i>Magnifera indica</i>	0.655	0.629	0.628	0.670*
2	<i>Psidium guajava</i>	0.312	0.563	0.341	0.733*
3	<i>Litchi chinensis</i>	0.008	0.780*	0.827**	0.934**
4	<i>Artocarpus heterophyllus</i>	0.592	0.902**	0.904**	0.966**
5	<i>Syzygium cumini</i>	0.848**	0.726*	0.759*	0.822**

Note: Significant at * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

4.5 Correlation of AA with APTI in four directions (East, West, North and South)

The correlation between AA and APTI of studied tree species (*Magnifera indica*, *Psidium guajava*, *Litchi chinensis*, *Artocarpus heterophyllus* and *Syzygium cumini*)

showed positive correlation in all four directions (Table 10). *M. indica* showed positively significant ($p < 0.01$) correlation in all studied directions. For *P. guajava*, positively significant ($p < 0.01$) correlation was found between AA and APTI in three (east, west and north) directions but positively insignificant correlation was observed in the south direction. *L. chinensis* displayed positively significant ($p < 0.01$) correlations between AA and APTI in all studied directions. Similarly, correlation for *A. heterophyllum* and *S. cumini* exhibited positively significant between AA and APTI in all directions.

Table 10. Correlation of AA with APTI in Four directions (n=9)

S.N.	Name of tree species	AA- APTI (East Direction)	AA- APTI (West Direction)	AA- APTI (North Directions)	AA- APTI (South Directions)
1	<i>Magnifera indica</i>	0.950**	0.971**	0.991**	0.975**
2	<i>Psidium guajava</i>	0.941**	0.985**	0.831**	0.696
3	<i>Litchi chinensis</i>	0.976**	0.903**	0.976**	0.925**
4	<i>Artocarpus heterophyllum</i>	0.816**	0.947**	0.929**	0.747*
5	<i>Syzygium cumini</i>	0.930**	0.992**	0.809**	0.685*

Note: Significant at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4.6 Correlation of TChl with APTI in four directions (East, West, North and South)

The correlation between TChl and APTI was found to be negative in all directions (Table 11). Species like *M. indica* showed significant ($p < 0.05$) negative correlation in the east and south directions and also significant ($p < 0.01$) in north direction but an insignificant negative correlation between TChl and APTI in the west direction. For *P. guajava*, an insignificant negative correlation was found between TChl and APTI in all the studied directions. *L. chinensis* displayed an insignificant negative correlation in the east and west direction but significant ($p < 0.01$) negative correlation between TChl and APTI was observed in the north and south directions, Similarly, correlation for *A. heterophyllum* and *S. cumini* showed an insignificantly negative in the east and south directions but significantly negative correlation between TChl and APTI was observed in the west and north directions.

Table 11. Correlation of TChl with APTI in Four directions (n=9)

S.N	Name of tree species	TChl- APTI (East Direction)	TChl- APTI (West Direction)	TChl- APTI (North Directions)	TChl- APTI (South Directions)
1	<i>Magnifera indica</i>	-0.782*	-0.498	-0.817**	-0.748*
2	<i>Psidium guajava</i>	-0.477	-0.649	-0.178	-0.348
3	<i>Litchi chinensis</i>	-0.629	-0.568	-0.937**	-0.842**
4	<i>Artocarpus heterophyllus</i>	-0.566	-0.932**	-0.927**	-0.558
5	<i>Syzygium cumini</i>	-0.597	-0.756*	-0.807**	-0.423

Note: Significant at *p<0.05, **p<0.01, ***p< 0.001.

4.7 Correlation of leaf extract pH with APTI in four directions (East, West, North and South)

The correlation between pH and APTI of most of the plant species was found to be negative (Table 12). Species like *M. indica* showed a significant (p<0.05) negative correlation in the east direction but an insignificant negative correlation was observed between leaf extract pH and APTI in the west, north and south directions. For *P. guajava*, an insignificant negative correlation was found between leaf extract pH and APTI in the east, north and south directions but a significant (p<0.05) negative correlation was observed in the west direction. *L. chinensis* displayed an insignificant negative correlation between leaf extract pH and APTI in the east direction but significant negative correlation was observed in the remaining three directions. Similarly, correlations for *A. heterophyllus* showed an insignificant negative correlation in the east and north directions but significant negative correlation in the west and south directions. *S. cumini* exhibited significant (p<0.01) negative correlation between leaf extract pH and APTI in the east and west directions, while the south direction exhibited an insignificant negative correlation and the north direction exhibited positively insignificant correlation.

Table 12. Correlation of leaf extract pH with APTI in Four directions (n=9)

S.N.	Name of tree species	pH- APTI (East Direction)	pH- APTI (West Direction)	pH- APTI (North Directions)	pH- APTI (South Directions)
1	<i>Magnifera indica</i>	-0.687*	-0.486	-0.453	-0.468
2	<i>Psidium guajava</i>	-0.336	-0.697*	-0.132	-0.369
3	<i>Litchi chinensis</i>	-0.48	-0.749*	-0.803**	-0.722*
4	<i>Artocarpus heterophyllus</i>	-0.247	-0.851**	-0.652	-0.771*
5	<i>Syzygium cumini</i>	-0.925**	-0.893**	0.221	-0.026

Note: Significant at *p<0.05, **p<0.01, ***p<0.001.

4.8 Correlation of SLA with APTI in four directions (East, West, North and South)

The correlation between SLA and APTI was found to be negative in all directions (Table 13). Species like *M. indica* showed an insignificant negative correlation between SLA and APTI in both the east and west directions, while a significant ($p<0.05$) negative correlation was observed in the north and south directions. For *P. guajava*, an insignificant negative correlation was found between SLA and APTI in all directions. *L. chinensis* displayed significant negative correlation between SLA and APTI in the east, west, and south directions, but an insignificant negative correlation was observed in the north direction. Similarly, correlation for *A. heterophyllus* showed an insignificant negative correlation in all studied directions. *S. cumini* exhibited significant ($p<0.05$) negative correlation between SLA and APTI in the east, west, and north directions, while the south direction exhibited an insignificant negative correlation.

Table 13. Correlation of SLA with APTI in Four directions (n=9)

S.N.	Name of tree species	SLA- APTI (East Direction)	SLA- APTI (West Direction)	SLA- APTI (North Directions)	SLA- APTI (South Directions)
1	<i>Magnifera indica</i>	-0.613	-0.199	-0.758*	-0.760*
2	<i>Psidium guajava</i>	-0.454	-0.632	-0.052	-0.343
3	<i>Litchi chinensis</i>	-0.749*	-0.844**	-0.629	-0.694*
4	<i>Artocarpus heterophyllus</i>	-0.522	-0.537	-0.599	-0.646
5	<i>Syzygium cumini</i>	-0.779*	-0.702*	-0.731*	-0.549

Note: Significant at *p<0.05, **p<0.01, ***p<0.001.

CHAPTER 5. DISCUSSION

5.1 Air pollution tolerance index

The Air pollution tolerance index determination offers a dependable approach for evaluating the susceptibility of a substantial number of plants to air pollutants, making it an effective method for screening (Lohe *et al.*, 2015). APTI has emerged as an innovative ecological strategy for the purpose of selecting plant species that can effectively mitigate air pollution. The (APTI) represents a fundamental characteristic of plants, enabling them to withstand the challenges posed by air pollution, particularly in areas marked by both industrial and non-industrial zones (Enitan *et al.*, 2022). Stress Tolerant tree species exhibit elevated APTI values, whereas sensitive tree species, acting as possible indicators for air pollution and exhibit reduced APTI scores (Bharti *et al.*, 2018). Plant species are chosen based on their tolerance to air pollution when considering Air Pollution Tolerance (Das and Prasad, 2010) as plant species continually interact with their surroundings and are significantly impacted by air pollution due to their enduring nature, they actively take in, accumulate, and amalgamate contaminants on their leaves. Plants with elevated APTI scores are ideal candidates for enhancing green belts and implementing effective, long-term air pollution control measures in urban and developed regions. Plants exhibit observable harm and alterations in their physiological metrics, serve as criterion to define the APTI for plants (Khureshi, 2013). Examining the suitability of plant species for cultivation based on the specific environmental needs of an area can effectively address and mitigate air quality challenges in that particular region (Das *et al.*, 2018). Plants with elevated APTI for enhancing green belts and implementing effective, long-term air pollution control measures in urban and developed regions (Hazarika *et al.*, 2023). The results of the analysis of the APTI parameters are explained:

5.1.1 Relative Water Content

Relative Water Content in a leaf refers to the water level compared to its full turgidity. The RWC is connected to the permeability of cell protoplasm, affecting water loss and nutrient dissolution in plants. This process contributes to leaf senescence (Sharma *et al.*, 2017). In the current study, the Relative Water Content of most of the tree species were elevated significantly at polluted sites (around the cement industry) i.e. (200-500

m) range, it might be the reason of plants tolerance capacity to pollutants (Das and Prasad, 2010). A higher RWC value in proximity to the industry is likely crucial for maintaining the normal operation of biological processes in plants (Meerabai *et al.*, 2012). A higher water content within the plant body is advantageous for combating stress and maintaining physiological balance, enhancing the plant's drought tolerance capacity. Therefore, monitoring and maintaining adequate RWC is crucial in air pollution management as it directly influences the plants' relative tolerance to air pollutants (Rai *et al.*, 2013). The highest RWC was found in *L. chinensis* (97.00%) at (200-500 m) range at south direction followed by *S. cumini* (95.00±2.37 B) in east direction and (94.94%) in south direction and *M. indica* (94.77%) in east direction, nearer to the industry at (200-500 m) same range. *P. guajava* showed high RWC mean value near to the industry in west direction and *A. heterophyllus* showed high RWC at (200-500 m) in south direction. The lowest RWC was also found in *Litchi chinensis* (70.77%) in west direction beyond 800 m range (i.e. control site). The high water content acts as an indicator of a plant's resistance to drought. However, air pollution can lead to reduced transpiration rates, causing damage to the leaf's water-pulling mechanism. Consequently, plants are unable to transport minerals efficiently or cool the leaf, impacting their overall health (Lohe *et al.*, 2015). Plant survival under stress conditions is closely linked to Relative Water Content (RWC). When exposed to air pollution during periods of increased transpiration, there is a risk of desiccation (Enitan *et al.*, 2022). The variation in RWC is attributed to differences in plant species, potentially stemming from variations in their ability to withstand stress conditions (Elawa *et al.*, 2022). It has been observed that the RWC of plant species tends to rise in environments with higher pollution levels compared to non-polluted sites (Radhapriya *et al.*, 2012; Amulya *et al.*, 2015; Sharma, 2019; Yadav and Pandey, 2020). Plants with low RWC may suffer reduced transpiration, leading to potential damage to the leaf's water transport system, which is responsible for moving water from the roots to the rest of the plant (Chouhan *et al.*, 2012). A high water content in plants is essential for maintaining physiological balance during stress, like exposure to air pollution, where transpiration rates are typically elevated (Lohe *et al.*, 2015). The increased relative water content detected in trees situated in industrial areas is probable to support the regular operation of plant physiological functions (Rai *et al.*, 2013; Roy *et al.*, 2020). Therefore, the restoration of Relative Water Content by plants plays a vital role in assessing their resilience to air pollution (Verma 2003). All the trees species in this

study around the industry (i.e. 200 -500 m) had higher RWC, which might be due to the plants' inherent reaction to stress as a protective measure against water loss (Bui *et al.*, 2022) and conversely, RWC decreased as distance from the industry increased (500-800 m to beyond 800 m), indicating lower values in less polluted or controlled sites. Pollutant effects on the rate of transpiration in leaves may be caused by a decrease in the relative water content of some plant species (Swami *et al.*, 2004).

5.1.2 Ascorbic Acid (AA)

Ascorbic acid, known as an antioxidant, enhances plant resistance to air pollutants by contributing to cell wall synthesis, defense mechanisms, and cell division (Deepalakshmi *et al.*, 2013). Its inherent detoxifying properties help mitigate the adverse effects of air pollutants on plant tissues (Conklin, 2001). Plant species can be categorized into tolerant and sensitive types based on their levels of ascorbic acid (Rai, 2016). Ascorbic acid safeguards chloroplasts from SO₂ -induced damage, protecting the functionality of enzymes involved in the CO₂ fixation cycle and preserving chlorophyll activity by neutralizing the effects of H₂ O₂ , O₂ , and OH deposits (Tiwari *et al.*, 2006). The current study findings indicated that the levels of ascorbic acid (AA) in the designated fruit tree species were elevated in the polluted areas in contrast to the control area. All the studied five fruit tree species showed significant (p=0.05) increase in Ascorbic Acid mean value in all four directions nearer to the cement industry (i.e. 200-500 m). The value of ascorbic acid was highest in *P. guajava* (14.08 mg/g) followed by *S. cumini* (10.7 mg/g) around the industry (i.e. 200-500 m). The results are also supported by the findings of Katiyar and Dubey (2001). The results of the study align with previous research, indicating that plants maintaining high levels of ascorbic acid in polluted environments exhibit tolerance to air pollution (Begum and Harikrishna, 2010). All the tree species showed high AA mean value in west direction in comparison of other three direction at (200-500 m) range. It may be due to the Increased levels of ascorbic acid may help plants battle air contaminants that enter their system (Sabri *et al.*, 2015). Plants that can sustain high levels of ascorbic acid in the presence of pollutants are deemed tolerant to air pollution, as the acid's decline typically accompanies exposure to pollutants (Keller and Schwager, 1977). In polluted sites, the concentration of ascorbic acid is higher compared to control sites. Ascorbic acid, known for its strong reducing properties, plays a role in activating various physiological mechanisms (Agbarie and Esiefarienne, 2009). Ascorbic acid functions as an

antioxidant, enhancing plants' resistance to stress. In the face of rising pollution levels, the ascorbic acid content in plants increases as a protective response to counteract stress (Bharti *et al.*, 2018). Increased pollution load leads to higher levels of ascorbic acid in various plant species. The increase in reactive oxygen species (ROS) production is linked to the photooxidation process converting sulfur dioxide (SO₂) into sulfur trioxide (SO₃). Sulfites, originating from absorbed SO₂, play a role in facilitating this reaction (Bakiyaraj *et al.*, 2014). The value of ascorbic acid decreased dramatically as the distance from the industry increased (from 500-800 m to beyond 800 m) in four species (*M. indica*, *P. guajava*, *A. heterophyllus* and *S. cumini*) but the AA of *Litchi chinensis* was significantly decrease *L. chinensis* in all directions but insignificantly decrease in west and north direction. The plant species like *L. chinensis* exhibited the least amount of ascorbic acid (0.10 mg/g and 0.14 mg/g) in east and south direction. Variation in amino acid (A.A.) content plays a role in the differing tolerance capacities of plants species to different air pollutants at various locations (Aguiar-Silva *et al.*, 2016; Aghajanzadeh *et al.*, 2016). The reducing power of a plant is directly linked to the concentration of ascorbic acid (Raza and Murthy 1988). So, plants with lower levels of ascorbic acid are more sensitive and higher level of ascorbic acid are tolerant species (Rai, 2016).

5.1.3 Total Chlorophyll Content

Chlorophyll, a green pigment present in the leaves and stems of plants, is responsible for imparting the green coloration to foliage which absorbs light, crucial for photosynthesis (Singh *et al.*, 2018). Chlorophyll within plants is indicative of their photosynthetic function, growth, biomass accumulation, and overall plant well-being (Joshi and Chauhan, 2008). Assessing chlorophyll levels is crucial for gauging the impact of air pollutants on plant health since chlorophyll is integral to plant metabolism. While specific pollutants can elevate overall chlorophyll levels (Allen *et al.*, 1987), others can lead to a reduction. This study clearly demonstrated that the amount of chlorophyll exhibited different reactions to dust pollution. According to this study, the *P. guajava* species exhibited the highest total chlorophyll content (5.06 mg/g) and lowest in *L. chinensis* (0.56±0.08 mg/g). All of the plant species showed lowest chlorophyll content mean value at (200-500) m range. The greater the sensitivity of the plant species, the lesser the chlorophyll content it tends to have (Agrawal and Tiwari, 1997). It might be due to the total chlorophyll Content exhibits a notable inverse

relationship with the amount of dust present (Singh *et al.*, 2018). Among all the plants studied, *M. indica* showed lower degradation of chlorophyll content (2.05 mg/g) near the industry. This indicates that *M. indica* can be considered a tolerant plant species because it maintains its chlorophyll content even under stress conditions. The concentrations of chlorophyll in plants fluctuate based on factors such as species, leaf maturity, environmental pollution, and various biological and environmental influences (Katiyar and Dubey, 2001). The chlorophyll levels in plants decrease under stress conditions (Speeding and Thomas, 1973). Plants growing in polluted environments exhibit higher sensitivity and lower chlorophyll content (Rai and Panda 2014). Generally, the total chlorophyll content tends to decrease as air pollution levels rise (Allen *et al.*, 1987). Cement dust accumulation on plant surfaces led to decreased height, productivity, and chlorophyll content (Darweesh and Sayed, 2014). This reduction in chlorophyll content is attributed to the accumulation of pollutants, such as dust, in polluted areas, where plants absorb and incorporate such contaminants into their systems (Mir *et al.*, 2008; Achakzai *et al.*, 2017). Reduced chlorophyll content leads to lower plant productivity (Hazarika *et al.*, 2023). In this study, *L. chinensis* and *S. cumini* species exhibited insignificant changes in total chlorophyll values when moving from industrial areas located 200-500 meters away to areas 500-800 meters away, both in the North and South directions. The total chlorophyll content decreased near a factory and increased as distance from the factory increased (within ranges of 200-500, 500-800, and beyond 800 meters). Specifically, *L. chinensis* had lower chlorophyll content (1.35 mg/g) compared to other fruit species beyond 800 meters. This suggests *L. chinensis* is sensitive to environmental factors, potentially due to its higher rate of chlorophyll degradation compared to other species at control sites. Chlorophyll levels in plants were influenced by considering the contamination levels in the area and the tolerance/sensitivity of the plant type (Chandawat *et al.*, 2011). Current study observed that the target species exhibited significantly higher chlorophyll levels in areas with lower pollution levels (control sites) compared to areas with higher pollution levels. Rai *et al.* (2013) and Karmakar *et al.* (2019) observed similar results for trees in polluted industrial zones. The chlorophyll content of plants fluctuates depending on pollution levels in the area. Plants with higher tolerance to pollution experience lower degradation of chlorophyll content, while those with lower tolerance experience higher degradation (Ter *et al.*, 2021).

5.1.4 Leaf extract pH

Leaf extract pH indicates hydrogen ion activity, mainly affected by the amounts of adsorbed hydrogen and metallic ions, serving as a measure of suspension acidity and alkalinity (Verweji *et al.*, 2008). The pH levels significantly affect plant physiology and biochemical activities, crucial for overall plant health and functioning. Hexose sugar production of ascorbic acid is pH-dependent, enhancing its resilience against harsh environments (Liu and Ding 2008). Researchers have found that pH levels significantly affect how efficiently plants utilize light for photosynthesis. From this present study, comparing pH levels in different plant species across various sites, it was found that the highest pH value (6.97) was recorded in *L. chinensis* at a non-polluted site located in the North direction (beyond 800 m). Conversely, the lowest pH value (4.17) was observed in *S. cumini* at a polluted site situated in the east direction (between 200-500 meters). All the examined plants had low pH values within a range of 200-500 meters in all directions. The pH values decreased along the polluted site compared to the controlled site, indicating higher acidity in the polluted area. Lower pH levels result in reduced light usage for photosynthesis. This insight suggests that higher pH levels in leaf extracts can enhance plants' tolerance to pollution (Liu *et al.*, 2008). The effectiveness of ascorbic acid in plants is influenced by pH levels, with higher pH levels increasing its activity and lower pH levels reducing it. Research suggests that plants with higher leaf extract pH levels are more tolerant to air pollution (Singh *et al.*, 1991), while those with lower pH levels may experience reduced chlorophyll content and thus lower tolerance to air pollution (Shrestha *et al.*, 2021). Among five studied Plants species, the degradation of pH extract values in five plant species, noting that *L. Chinensis* and *A. heterophyllus* exhibited lower degradation (6.1) near industrial areas in the east and south directions. This suggests that these species are tolerant to stress conditions, as they maintain pH levels despite exposure to acidic pollutants like SO₂ and NO₂ or metabolic changes induced by specific pollutants (Ahmad, 2019). Air pollutants like sulfur oxides (SO_x), nitrogen oxides (NO_x), and carbon oxides (CO_x) enter plant leaves and interact with the stomatal and cellular water. This interaction leads to a decrease in pH levels within the plant (Dwivedi *et al.*, 2008; Patel and Kousar, 2011). Plants in polluted sites of the city exhibit acidic nature also found in previous findings of (Rawal *et al.*, 2001; Bharti *et al.*, 2018). The effectiveness of converting hexose sugar to ascorbic acid can be affected by pH. High pH has been found to

potentially increase this conversion efficiency (Pasqualini *et al.*, 2001; Escobedo *et al.*, 2008;). Conversely, exposure to acidic pollutants might shift cell sap pH towards acidity, potentially decreasing the efficiency of this conversion process (Hamal and Chettri, 2017). In plants, low leaf pH reduces photosynthesis (Turk and Wirth, 1975). Conversely, plants with higher leaf extract pH demonstrate improved absorption of SO₂ and NO₂ (Zou, 2007). In this study, among five plant species (*M. indica*, *P. guajava*, *L. chinensis*, *A. heterophyllus*, and *S. cumini*). The *M. indica*, *P. guajava*, and *L. chinensis* showed a significant increase in pH value as distance from the industry increased, regardless of the direction (200-500 meters to beyond 800 meters). However, *A. heterophyllus* and *S. cumini* showed insignificant increase of pH value in North direction at same range. The activity of ascorbic acid in reducing pollution in plants depends in pH, with higher pH levels increasing its effectiveness and lower pH levels reducing it. Tree species with a pH around 7 are more tolerant to pollution, while those with lower pH are more susceptible (Bakiyaraj and Ayyappan 2014). Based on this, *L. chinensis* is identified as a more susceptible species compared to others, which are relatively more tolerant.

5.1.5 Air pollution tolerance index (APTI)

The Air Pollution Tolerance Index is a measure of a tree species' ability to withstand and respond to the effects of air pollutants. It helps in assessing the impact of air pollution on trees. (Girish *et al.*, 2017). Singh and Rao (1983) suggested using the Air Pollution Tolerance Index (APTI) as a method to distinguish between plant species that can tolerate air pollution and those that are susceptible to it. Plants display visible damage and changes in their physiological traits, which serve as criteria for determining their tolerance to air pollution (Khureshi, 2013). Assessing the tolerance and sensitivity of tree species plays a pivotal role in mitigating pollution in industrial areas (Marfaviyorahmadi and Gholami, 2014; Gholami *et al.*, 2016). In this current investigation, the average APTI values of fruit plant species exhibited an elevation in proximity to the cement industry, mirroring findings observed by Rai *et al.* (2013) at an industrial site. Similarly, Prasai (2021) noted heightened APTI values across all plant species found in polluted sites exhibit differences when compared to those in control sites. The value of APTI ranged from (6.23± 0.34 to 18.97 ± 2.50). The APTI values fluctuate within the same species depending on the environment, whether it's polluted or not. A greater APTI value observed in polluted sites enables the plant to better sustain

its physiological equilibrium compared to plant species with lower APTI values (Agbaire and Esiefarienrhe, 2009). Among five plant species the Higher APTI value is highest in *P. guajava* (18.97) followed by *S. cumini* (15.37) and *M. indica* (13.53) in west direction. *A. heterophyllus* exhibited notably higher mean APTI values when situated to the west of the industrial area compared to the other three directions within a proximity of 200-500 meters. This might potentially be attributed to the substantial dust emissions stemming from the Lamahi-Tulsipur Highway construction and vehicular traffic, primarily concentrated in the southwest direction, located within 200 meters of the industrial site. Conversely, other species such as *L. chinensis* displayed elevated APTI values in the northern direction within the same distance range, likely due to the significant dust accumulation from the road construction and industrial activities occurring in that vicinity. While moving from industry (200-500 m) to (beyond 800 m) there was a notable decrease in the APTI value across all species studied ($p=0.05$). Variances in APTI among plant species reflect their differing capacities to withstand pollutants without evident external harm (Elawa *et al.*, 2022). Species with higher APTI values, classified as tolerant, may serve as repositories for pollutants in industrial zones (Kuddus *et al.*, 2011), potentially aiding in mitigating air pollution issues. Conversely, plants with lower APTI values could serve as indicators of the level of air pollution in their environment (Singh and Rao, 1983). Different geographical regions exhibit varying behaviors among plant species in terms of sensitivity and tolerance (Karmark and Padhay, 2019). Urban greening initiatives should prioritize the cultivation of plant species identified as tolerant and intermediate. This approach offers a promising avenue for fostering economic progress and promoting sustainable urban development, particularly in areas grappling with industrial air pollution (Chaudhary and Rathore, 2018; Zhu *et al.*, 2019; Tahmasbi *et al.*, 2019; Chaudhary and Rathore, 2019). Conversely, plant species identified as sensitive can play a crucial role as effective bio-indicators for air pollution (Singh and Rao, 1983; Seyyednjad *et al.*, 2011). Environmental effects arise throughout the entire production process of cement and lime, encompassing emissions of air pollutants like dust, gases, noise, and vibrations during machinery operation and quarry blasting, leading to damage to the surrounding landscape due to quarrying activities (Dubey and Bhopal, 2013). Several researchers have utilized the APTI to classify plant species into three groups: sensitive, intermediate, and tolerant (Agrwal *et al.*, 1991; Padmavathi *et al.*, 2013). Plants with an APTI value of ≤ 11 are regarded as sensitive, while those with

values ranging from 12 to 16 are categorized as intermediate, and those with a value of ≥ 17 are identified as tolerant (Sivakumaran *et al.*, 1978). According to the findings of the current study, out of the five species examined, only *P. guajava* demonstrated tolerance, with an Air Pollution Tolerance Index (APTI) value exceeding seventeen (18.97) and *M. indica* and *S. cumini* were categorized as moderately tolerant, with APTI values falling between twelve and sixteen. These three plant species could be recommended for the establishment of green spaces either within or surrounding the industry. On the other hand, *L. chinensis* and *A. heterophyllum* were identified as sensitive species, given their APTI values below eleven. These fruit plants species could serve as indicators of air pollution. Plant species possessing higher APTI values play a crucial role in mitigating air pollution, whereas those with lower APTI values serve as indicators of the level of air pollution (Singh and Rao, 1983). Sensitive species are utilized as indicators of air pollution levels, whereas tolerant species play a role in mitigating air pollution effects (Subrahmanyam *et al.*, 1985). Tolerant plant species serve as absorbers of pollution and offer various environmental advantages when cultivated in polluted regions. Therefore, assessing plants based on their tolerance to air pollution is deemed essential for this purpose (Lakshmi *et al.*, 2009). Thus, the APTI values assigned to the target species indicate their resistance to cement dust pollution. It is recommended that these species be widely planted near cement industries and other polluted areas to fight dust pollution. As a result, species categorized as highly, moderately, and intermediately tolerant can be considered ideal candidates for establishing an efficient “green belt” encircling cement plant. Their cultivation should be actively encouraged as a means to mitigate particulate pollution (Radhapriya *et al.*, 2012).

5.2 Leaf area

The leaf plays a pivotal role in plant photosynthesis, significantly influencing crop growth and overall productivity (Li *et al.*, 2008). Leaf area is a crucial factor in various aspects of plant research such as plant nutrition, protection, soil-water dynamics, and crop ecosystems (Mohsenin, 1970). Precise and rapid non-destructive assessment of leaf area holds significant importance in plant research aimed at comprehending and modeling ecosystem dynamics (Li *et al.*, 2008). In the current research, it was found that the mean value of Leaf Area of certain species examined was notably reduced in close proximity to the factory (within 200-500 m) across all directions. Similar findings

were found in the study by Chukwu and Adams, 2016. Diminished leaf area resulting from air pollution can hinder a plant's ability to undergo photosynthesis effectively and diminish its resilience in coping with the strains posed by air pollutant stressors (Tiwari *et al.*, 2006). The value leaf area ranged from (14.93 ± 0.85 to 59.88 ± 3.93 cm²). The value of leaf area was lowest in *L. chinensis* (14.93 ± 0.85 cm²) and highest in *M. indica* (59.88 ± 3.93 cm²). Leaf area's mean value was varied significantly across different directions and distances. However, there wasn't significant relation between the leaf area values near the cement industry and those farther away, across various distances and directions. The characteristics of leaf surfaces are impacted by various elements, including competition for light (exposure within the canopy), divergent conditions among sites, and soil attributes such as soil composition, nutrient presence, and interactions between plants and soil nutrients (Jarvardi *et al.*, 2023). The extension of both the leaf and its petiole indicates the plant's ability to withstand stress (Xu *et al.*, 2009). Several research works have noted a decrease in leaf dimensions, including length, width, and area, across various plant species in polluted environments (Lima *et al.*, 2000; Verma and Singh, 2006; Balasooriya *et al.*, 2009; Kardel *et al.*, 2010; Arriaga *et al.*, 2014). Reducing it decreases water loss and transpiration, while also retarding leaf growth and enhancing species' resistance to tension. Species resilient to tension typically exhibit elevated relative water content (Mahecha *et al.*, 2013). The leaf area within polluted environments stands out as a critical biological indicator for monitoring contamination levels (Verma and Singh, 2006; Balasooriya *et al.*, 2009).

5.3 Specific leaf area (SLA)

Specific leaf area serves as a combined measure of leaf area and dry mass, both of which are crucial factors in agronomic and ecological functions such as photosynthesis, transpiration, and field energy balance. However, the assessment of leaf area and specific leaf area can pose challenges in terms of cost and complexity (Payhe *et al.*, 1991). The significance of specific leaf area lies in its influence on growth rate. In the current study, the mean value of SLA of all analyzed species was low near the factory (200-500 m) in all four directions near the industry than those present away from the factory. This finding aligns with previous studies by Kayode and Otoide (2007), Seyyednejad *et al.* (2009), and Chhetri *et al.* (2018), which also noted a significant decrease in SLA in areas affected by pollution. In the contaminated areas of Azadi and Gisha Bridge, a decrease in SLA was noted, which serves as a tactic to enhance

resistance to stress conditions (Xu *et al.*, 2009). Plant species thriving in environments characterized by limited nutrients, water scarcity, and minimal light exhibit low SLA values (Cornelissen *et al.*, 2003). SLA value ranged from $(23.33 \pm 1.38$ to 64.62 ± 6.74 cm^2/g). SLA's value was lowest in *M. indica* 23.33 ± 1.38 cm^2/g) and highest in *P. guajava* (64.62 ± 6.74 cm^2/g). SLA may fluctuate due to environmental elements such as light and temperature (Awal *et al.*, 2004). Prolonged exposure of leaves to dust results in the accumulation of a thick layer of dust on their surface, diminishing the plants' ability to capture light and impeding their photosynthetic processes (Pourkhabbaz *et al.*, 2010). A greater SLA implies a larger surface area available for light absorption relative to the previously accumulated mass. SLA shows an inverse relationship with leaf lifespan and a direct relationship with nitrogen content, photosynthetic capacity, transpiration rate, and respiration rate (Reich *et al.*, 1997; Wright *et al.*, 2004). SLA is also closely linked to stomatal conductance, the rate of photosynthesis, and the growth of plants (Meziane and Shipley, 1999). Species such as *M. indica* exhibited significantly higher SLA values towards the northern direction, particularly beyond 800 meters from the industrial site, compared to the other three directions. *P. guajava* and *L. chinensis* demonstrated elevated SLA values towards the southern direction within the same range, outperforming the other directions. *Artocarpus heterophyllus* exhibited notably higher SLA values towards the west direction, while *S. cumini* displayed significantly higher SLA values towards the east direction, both compared to the other directions within the same range (i.e., beyond 800 m), but *P. guajava* and *A. heterophyllus* species showed insignificant SLA mean value at north and south directions. So, while moving away from the industry, specifically from 200-500 meters to 500-800 meters and beyond 800 meters, there is a notable rise in SLA values across various directions in nearly all plant species examined. This trend mirrors findings in previous studies, where SLA and stomatal density showed significant increments transitioning from suburban to more urbanized environments, whereas stomatal pore surface exhibited the opposite trend (Kardel *et al.*, 2010). The concentration of particulate matter impacts the SLA, though variations were observed between exposure and control sites due to the correlation between particulate matter and plant age (Borowia and Filder, 2014). Plant species residing in environments characterized by limited nutrients, water, and sunlight tend to possess lower SLA values (Cornelissen *et al.*, 2003). Decreasing the specific leaf area results in an increase in the concentration of chloroplasts per unit area in plants (Abbasi *et al.*, 2018). Plants

characterized by lower specific leaf area (SLA) values are adept at conserving nutrients efficiently, whereas those with higher SLA values excel in light capture and typically experience comparatively higher growth rates (Yang *et al.*, 2023). Thicker leaves exhibit greater photosynthetic capacity. The reduction in leaf size serves as an adaptive mechanism for these plants, aimed at minimizing the infiltration of harmful substances into their leaves under polluted conditions (Zarinkamar *et al.*, 2013). Conversely, increased Water content in leaves and thinner leaf blades contribute to higher SLA values (Witkowski and Lamont, 1991; Cunningham *et al.*, 1999) and thicker leaves correspond to lower SLA values.

5.4 Correlation of biochemical parameters (RWC, AA, TChl and leaf extract pH) with APTI in four directions (East, West, North and South)

The APTI of five tree species in four directions showed mostly a positive correlation with RWC and AA but showed mostly a negative correlation with TChl and leaf extract pH. This result is consistent with the findings of (Satpute and Bhalerao, 2017). The variability in plant responses to pollution stress, suggesting that different species may exhibit distinct physiological responses (Tak and Kakde, 2020) highlights the variability in plant responses to pollution stress, indicating that different species may exhibit distinct physiological responses. From the observation, high positive significant correlation was found between APTI and ascorbic acid of all five plant species in all four directions. This suggests that AA may play a role in air pollution tolerance. It may be due to the higher accumulation of particulate matter-associated heavy metals inducing stress, leading to an increased production of ascorbic acid in plants (Gupta *et al.*, 2011). Bharti *et al.* (2018) also observed a high positive correlation between APTI and AA. These findings support the idea that AA may play a significant role in mechanisms of air pollution tolerance, as indicated by consistent patterns of correlations between APTI and physiological parameters across different tree species and directions.

5.5 Correlation of SLA with APTI in four directions (East, West, North and South)

The specific leaf area of all five plants species in four directions exhibited a negative correlation with APTI. Similarly, SLA exhibited a negative correlation with the biochemical parameters of roadside plants. It is noteworthy that the physiological

functions of APTI parameters within leaves often do not significantly correlate with Specific Leaf Area (SLA), potentially due to the diverse strategies plants employ for physiological adaptation under stress conditions (Hamal and Chettri, 2022). Exploring the connection between leaf variables, such as leaf area and SLA, and air pollutants, a notable negative correlation was found, specifically between leaf area and O₃ levels (Javardi *et al.*, 2023). Furthermore, Yang *et al.* (2023) also documented that the SLA value of various plant types exhibited a negative correlation with air pollution levels in relation to common garden plant leaf traits.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, the findings of this current study, it is evident that APTI serves as a valuable tool for assessing plant tolerance to air pollution, particularly in areas surrounding cement industries. The findings illustrate the effect of cement dust pollution on fruit plant species, as shown by changes in Biochemical indicators like relative water content, levels of ascorbic acid, total chlorophyll content, and pH of leaf extracts. The industrial vicinity led to a rise in biochemical indicators such as relative water content and ascorbic acid levels, while there was a corresponding decline in total chlorophyll levels and leaf extract pH. Additionally, this study aids in the identification of sensitive and tolerant fruit species in proximity to cement industries based on their APTI values. Notably, *Psidium guajava* exhibited significant tolerance with a high APTI value above seventeen, while *Mangifera indica* and *Syzygium cumini* were categorized as intermediate species, and *Litchi chinensis* and *Artocarpus heterophyllus* were deemed sensitive. Moreover, the study revealed a correlation between APTI values and the direction of air pollution, with higher APTI values observed in the west direction of the cement industry. The APTI of five tree species in four directions showed mostly a positive correlation with RWC and AA but showed mostly a negative correlation with TChl and leaf extract pH and revealed that ascorbic acid showed highly significant correlation with APTI. Additionally, changes in leaf area and specific leaf area (SLA) distribution further highlighted the influence of air pollutants on plant morphology and physiology, with decreases in SLA observed near the cement factory and variations in leaf area across different directions. The SLA of plants species examined mostly exhibited significant negative correlation in all directions with APTI. Overall, the biochemical investigations conducted in this study underscored the significant impact of air pollutants on plant health, particularly in close proximity to industrial activities. These findings emphasize the importance of implementing measures to mitigate air pollution and protect plant biodiversity in areas affected by industrial emissions. Further research in this field is crucial for developing effective strategies to safeguard both plant species and environmental quality against the detrimental effects of air pollution.

6.2 Recommendations

- Considering the effectiveness of certain species in acting as sinks to control air pollution, it is recommended to prioritize the plantation of *Psidium guajava*, *Mangnifera indica*, and *Syzygium cumini* for establishing greenbelts around or within industrial areas. These species have demonstrated significant tolerance to pollutants and can contribute effectively to air purification efforts.
- In particularly polluted areas such as the vicinity of the Ghorahi Cement Industry, where pollution levels are notably high, *Psidium guajava* stands out with its high APTI value. Hence, it is strongly recommended for plantation, especially on the western side where pollution is more concentrated. Plantation efforts should be strategically focused on mitigating pollution in the most affected areas.
- There is a clear need for additional research to expand the selection of plant species tolerant to dust pollutants found around industrial zones. Future studies should aim to identify and evaluate the suitability of various plant species in effectively combating air pollution.
- Future research endeavors should not only concentrate on the capacity of plants to absorb pollutants but also assess the impact of dust pollution on the quality of fruits produced by these plants. Understanding this aspect is crucial for ensuring the sustainability of fruit cultivation in polluted environments and for safeguarding public health.

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APPENDICES

Appendix I. Photos of studied plant species



a. *Magnifera indica*



b. *Psidium guajava*



c. *Litchi chinensis*



d. *Artocarpus heterophyllus*



e. *Syzygium cumini*,

Appendix II. Photos of leaf samples with reference scale for leaf area and SLA measurement



a. *Magnifera indica*



b. *Psidium guajava*



c. *Litchi chinensis*



d. *Artocarpus heterophyllus*



e. *Syzygium cumini*,

Appendix III. Photos of Ghorahi cement industry



a. Ghorahi Cement Industry and surrounding vegetation



b. Dust emission from the industry

Appendix IV. Photos of Lab Work



a. Preparation for chemical analysis



b. Taking readings from Spectrophotometer

Appendix V. Certificate of Appreciation from Ghorahi Sub-Metropolitan City



Ghorahi Sub-Metropolitan City
Office of the Municipal Executive

Ghorahi, Dang, Lumbini Province, Nepal

Phone & Fax : 082-560162
082-560243, 561268, 560700
Fire brigade : 082-560499
www.ghorahimun.gov.np



Date: 2078-12-13

CERTIFICATE OF APPRECIATION

M/s Anu Sharma,
Amrit Science Campus,
Reg. No.5-2-54-123-2014

We appreciate your thesis work on the topic "Air Pollution Tolerance Index (APTI) of some fruit trees around Ghorahi Cement Industry in Dang". You have done a praiseworthy job while completing the research; and hereby we are very thankful for your laborious research findings. We hope your study will help us while working in the area the environment protection; maintaining air quality and greenery in our city.

Chief Administrative Officer

Rishiram K.C.
Chief Administrative Officer

Mayor
Naru Lal Chaudhary
Mayor