Vol.2, Issue 2, April-June 2026, Page: 100-109 ISSN: 3107-4863

Global Journal of Science and Technology (GJST)

Native Plants as Bioindicators of Air Pollution: A Systematic Review of Pollution Syndrome Traits and Their Applications in Environmental Monitoring

[1]kritika Mishra, [2]Avshesh Kumar

[1,2]Department Of Botany T.D.P.G.College, Jaunpur Affliated To VBSP University, Jaunpur(222002).

ABSTRACT

One of the most significant environmental issues affecting terrestrial ecosystems, biodiversity, and human health globally is air pollution. Because native plant species react strongly to atmospheric pollutants through a variety of visual, physiological, biochemical, and anatomical alterations together referred to be pollution syndrome features, they are becoming more widely acknowledged as trustworthy bioindicators. Chlorosis, necrosis, leaf damage, early senescence, stomatal changes, decreases in chlorophyll content, shifts in relative water content, fluctuations in the pH of leaf extract, ascorbic acid buildup, and dust collection on leaf surfaces are some of these characteristics. An efficient, cost-effective, and environmentally sustainable method for tracking air quality and assessing ecosystem health is provided by the evaluation of these reactions in conjunction with indices like the Air Pollution Tolerance Index (APTI).

By combining research from various urban, industrial, roadside, agricultural, and forest environments, this review summarizes the state of the art regarding the use of native plants as bioindicators of air pollution. It looks at the physiological and biochemical processes that underlie stress reactions brought on by pollution, contrasts the characteristics of pollution syndrome in various native plant species, and talks about how they might be used in environmental assessment and biomonitoring. The review also identifies significant research gaps, highlights current developments in pollution monitoring, and stresses the significance of integrating native plant-based biomonitoring into conservation planning and air quality management. This review offers a thorough framework for comprehending the importance of native plants as natural indicators of environmental pollution and promotes their broader application in sustainable ecosystem management by fusing pollution ecology, plant physiology, and conservation science.

KEYWORDS
Native plants; Air pollution; Bioindicators; Pollution syndrome; Air Pollution Tolerance Index (APTI); Biomonitoring; Chlorosis; Necrosis; Leaf injury; Chlorophyll degradation; Ascorbic acid; Relative water content; Stomatal characteristics; Oxidative stress; Atmospheric pollutants; Environmental monitoring; Urban ecology; Ecosystem health; Plant physiology; Biodiversity conservation.

ARTICLE HISTORY
Received: 27 April 2026
Accepted: 15 May 2026
Published: 30 June 2026

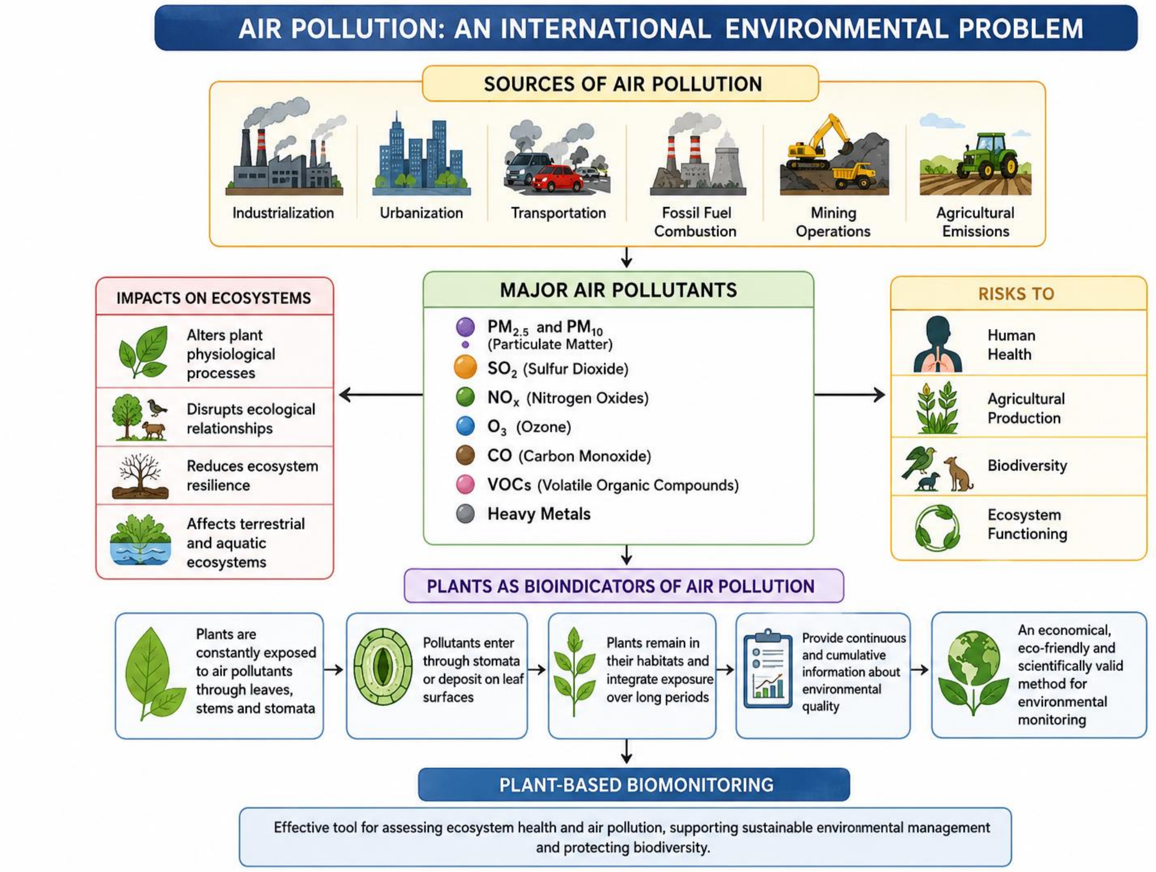
CITATION
Mishra, K., (2026). Native Plants as Bioindicators of Air Pollution: A Systematic Review of Pollution Syndrome Traits and Their Applications in Environmental Monitoring, *Journal of Science and Technology (GJST)*, 2(2), 100-109. https://doi.org/10.65523/gjst.2026.v2.i2.14

1. Introduction

1. Air Pollution: An International Environmental Problem

One of the biggest environmental issues of the twenty-first century is air pollution, which poses major risks to human health, agricultural production, biodiversity, and ecosystem functioning. The concentration of air pollutants, such as particulate matter ($PM_{2}.^{1}$ and PM_{1}^{1}), sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOCs), and heavy metals, has significantly increased due to rapid industrialization, urbanization, transportation, fossil fuel combustion, mining operations, and agricultural emissions (WHO, 2022; IPCC, 2023). By changing plant physiological processes, upsetting ecological relationships, and decreasing ecosystem resilience, these pollutants have a negative impact on both terrestrial and aquatic ecosystems (Cape, 2003; Tiwari et al., 2006).

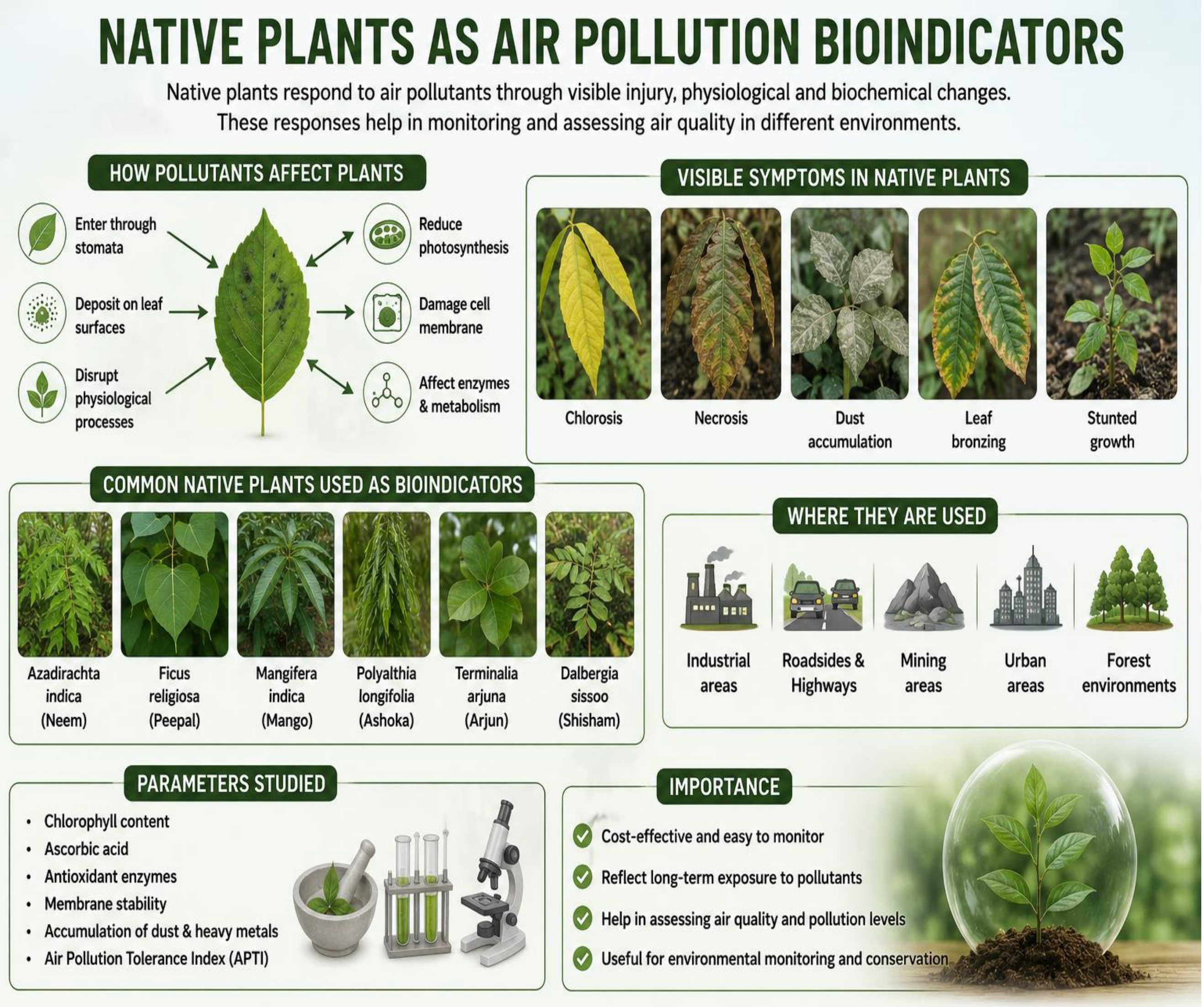
Because they stay in their habitats and interact directly with the environment through their leaves, stems, and stomata, plants are constantly exposed to air contaminants. Plants are useful biological indicators of atmospheric pollution because, in contrast to many animal-based monitoring methods, they provide continuous and cumulative information about environmental quality over extended periods of time (Singh & Rao, 1983; Rai, Panda, Chutia, & Singh, 2013). As a result, plant-based biomonitoring has become an economical, eco-friendly, and scientifically valid method of evaluating ecosystem health and air pollution.



2. Native Plants as Air Pollution Bioindicators

Because native plant species have adapted to the local environment and show distinctive reactions to variations in air quality, they are becoming more widely acknowledged as useful bioindicators. Compared to many introduced or ornamental species, they are better able to reflect environmental stress due to their long-term adaptation to local climate conditions (Markert, Breure, & Zechmeister, 2003; Bargagli, 2016). Native plants are useful for tracking both acute and chronic air pollution because they integrate exposure to pollutants over time.

According to Markert et al. (2003), bioindicators are living things whose physiological, biochemical, anatomical, or ecological reactions reveal quantifiable details about their surroundings. Air pollutants affect photosynthesis, respiration, membrane integrity, nutrient metabolism, enzyme activity, and antioxidant defense systems in plants. They mainly enter leaf tissues through stomata or build up on leaf surfaces (Manning & Tiedemann, 1995; Agrawal & Agrawal, 1999). The intensity and distribution of air pollution in various settings can be assessed by measuring these stress-induced changes.



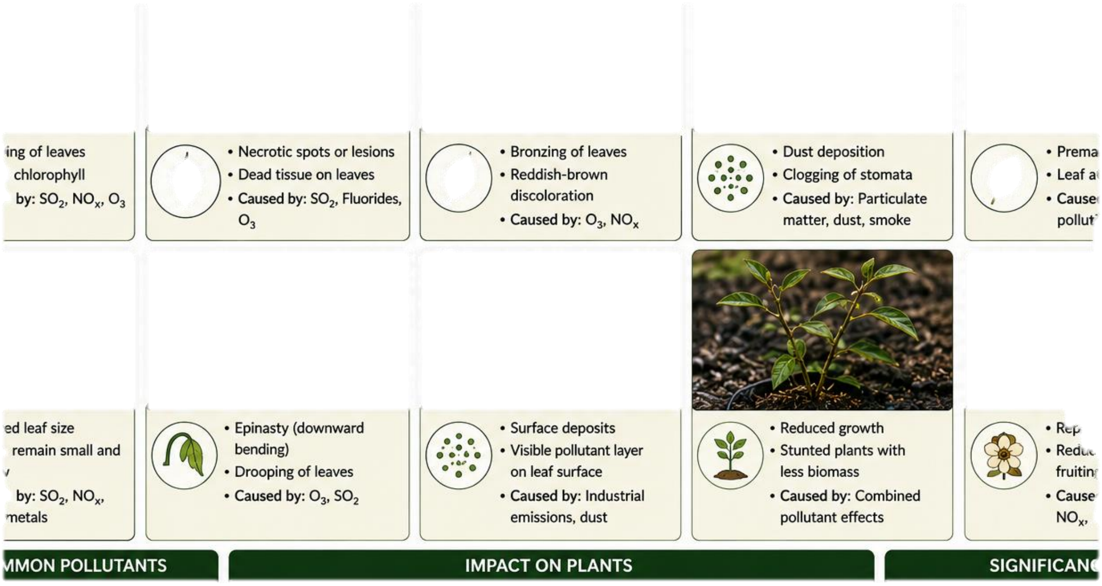
Many studies have shown that native trees, shrubs, herbs, grasses, mosses, and lichens react strongly to air pollutants in urban, industrial, roadside, mining, and forest habitats (Rai et al., 2013; Bargagli, 2016). Due to their extensive distribution and quantifiable physiological reactions to air pollutants, species like Azadirachta indica, Ficus religiosa, Mangifera indica, Polyalthia longifolia, Terminalia arjuna, and Dalbergia sissoo have often been assessed as bioindicators (Singh & Rao, 1983; Tiwari et al., 2006).

2. Characteristics of Pollution Syndrome in Native Plants

Pollution syndrome features are a collection of distinctive morphological, physiological, biochemical, and anatomical abnormalities brought on by exposure to air pollutants. These reactions arise as a result of pollutants producing excessive amounts of reactive oxygen species (ROS), such as hydrogen peroxide, superoxide radicals, and hydroxyl radicals, which produce oxidative stress (Gill & Tuteja, 2010). Oxidative damage to chloroplasts, cellular membranes, proteins, lipids, and nucleic acids results in observable symptoms and physiological malfunction when antioxidant defense mechanisms are compromised.

Chlorosis, necrosis, bronzing, leaf bending, early senescence, decreased leaf area, aberrant flowering, and early leaf abscission are examples of morphological symptoms (Manning & Tiedemann, 1995; Rai et al., 2013). Reduced growth, changed transpiration rates, impaired stomatal conductance, decreased photosynthetic efficiency, and decreased chlorophyll concentration are common physiological alterations

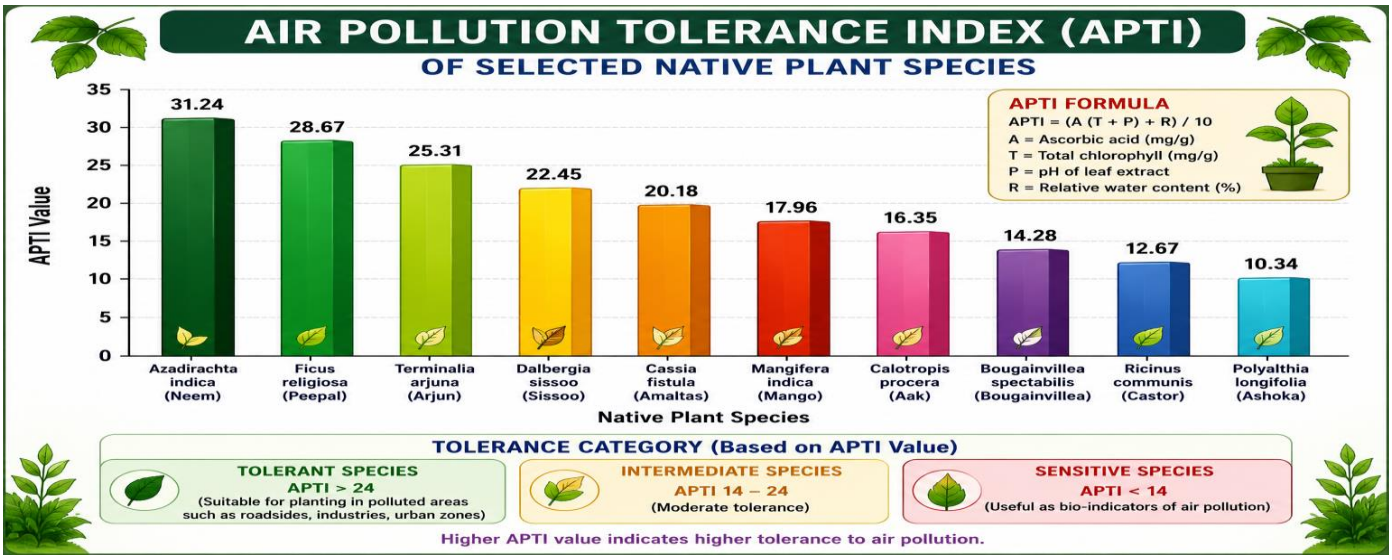
(Agrawal & Agrawal, 1999). Increased production of antioxidants like ascorbic acid, changes in the relative water content, variations in the pH of leaf extract, proline accumulation, increased activity of antioxidant enzymes, and changes in the synthesis of secondary metabolites are examples of biochemical reactions (Tripathi & Gautam, 2007; Gill & Tuteja, 2010). Long-term exposure to air pollution is also reflected in anatomical changes such as cuticular thickening, stomatal deformation, and changes in the structure of epidermal cells.



4. The Air Pollution Tolerance Index (APTI): A Trustworthy Biomonitoring Instrument

The Air Pollution Tolerance Index (APTI) has emerged as one of the most popular biomonitoring instruments among the different techniques used to assess plant responses to atmospheric pollution. APTI was developed by Singh and Rao (1983) to evaluate the pollution tolerance of plant species by integrating four biochemical parameters: ascorbic acid concentration, leaf extract pH, relative water content, and total chlorophyll content. While species with lower APTI values are seen to be sensitive bioindicators that can identify early environmental degradation, species with higher APTI values are typically thought to be pollution tolerant and are advised for green belt development (Singh & Rao, 1983; Rai et al., 2013). Many studies carried out in Asia, Europe, Africa, and North America over the past few decades have effectively used APTI to identify native plant species in urban and industrial settings that are both pollution-tolerant and pollution-sensitive (Tripathi & Gautam, 2007; Rai et al., 2013; Bargagli, 2016). Sustainable urban planning, roadside plantation initiatives, biodiversity protection, and environmental impact assessment have all benefited from the combination of APTI with pollution syndrome features, which has greatly improved the accuracy of biomonitoring programs.

Thus, it has become more crucial to comprehend how native plants react to air pollution for ecological monitoring, conservation planning, and the creation of natural remedies for enhancing environmental quality. Native plant-based biomonitoring provides an efficient and sustainable method for assessing ecosystem health and enabling evidence-based environmental management as urbanization and climate change continue to worsen air pollution globally.



5. The Biochemical and Physiological Mechanisms of Pollution Syndrome

A number of interrelated physiological and biochemical processes control how native plants react to air pollutants and define how sensitive or tolerant they are to environmental stress. During gaseous exchange, air contaminants mostly enter plant tissues through stomata or build up as particulate matter on leaf surfaces. Pollutants like sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), and heavy metals disrupt photosynthesis, respiration, membrane stability, enzyme function, and nutrient transport once they are inside the leaf (Manning & Tiedemann, 1995; Agrawal & Agrawal, 1999). Pollutant concentration, exposure time, environmental factors, and the genetic makeup of the plant species all affect how much harm is done.

The decrease in photosynthetic efficiency is one of the first physiological reactions to air pollution. Chlorosis and decreased carbon absorption are caused by pollutants' damage to chloroplast membranes, inhibition of chlorophyll production, and acceleration of pigment breakdown (Cape, 2003; Rai et al., 2013). In particular, ozone reduces net photosynthetic rates, stomatal conductance, and oxidative damage to photosystem II, all of which affect plant productivity (Fiscus, Booker, & Burkey, 2005). Similar to this, sulfur dioxide dissolves in leaf wetness to produce sulfite and bisulfite ions, which impair enzyme activity and harm cellular structures (Manning & Tiedemann, 1995).

It is commonly known that oxidative stress is the primary mechanism causing damage to plants caused by pollution. Reactive oxygen species (ROS), such as superoxide radicals ($O_2{\bullet}^-$), hydroxyl radicals (•OH), singlet oxygen ($^1O_2$), and hydrogen peroxide (H_2O_2), are produced excessively when air pollution is present (Gill & Tuteja, 2010). ROS are involved in cellular signaling under normal physiological settings, but an excessive build-up impairs membrane integrity, oxidizes proteins, degrades nucleic acids, and causes lipid peroxidation, which results in cellular dysfunction and early senescence (Apel & Hirt, 2004). Thus, in native plants, oxidative stress is a trustworthy biochemical marker of pollution syndrome.

In order to combat oxidative damage, plants activate a complex antioxidant defense system that includes non-enzymatic antioxidants like ascorbic acid, glutathione, carotenoids, flavonoids, and phenolic compounds in addition to enzymatic antioxidants like superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX) (Gill & Tuteja, 2010; Sharma et al., 2012). Because it stabilizes cellular membranes, detoxifies reactive oxygen species, and directly contributes to the Air Pollution Tolerance Index (APTI), ascorbic acid has drawn a lot of attention. Greater resistance to air pollution is typically indicated by higher ascorbic acid concentrations (Singh & Rao, 1983; Tripathi & Gautam, 2007).

6. Anatomical and Morphological Signs of Air Pollution

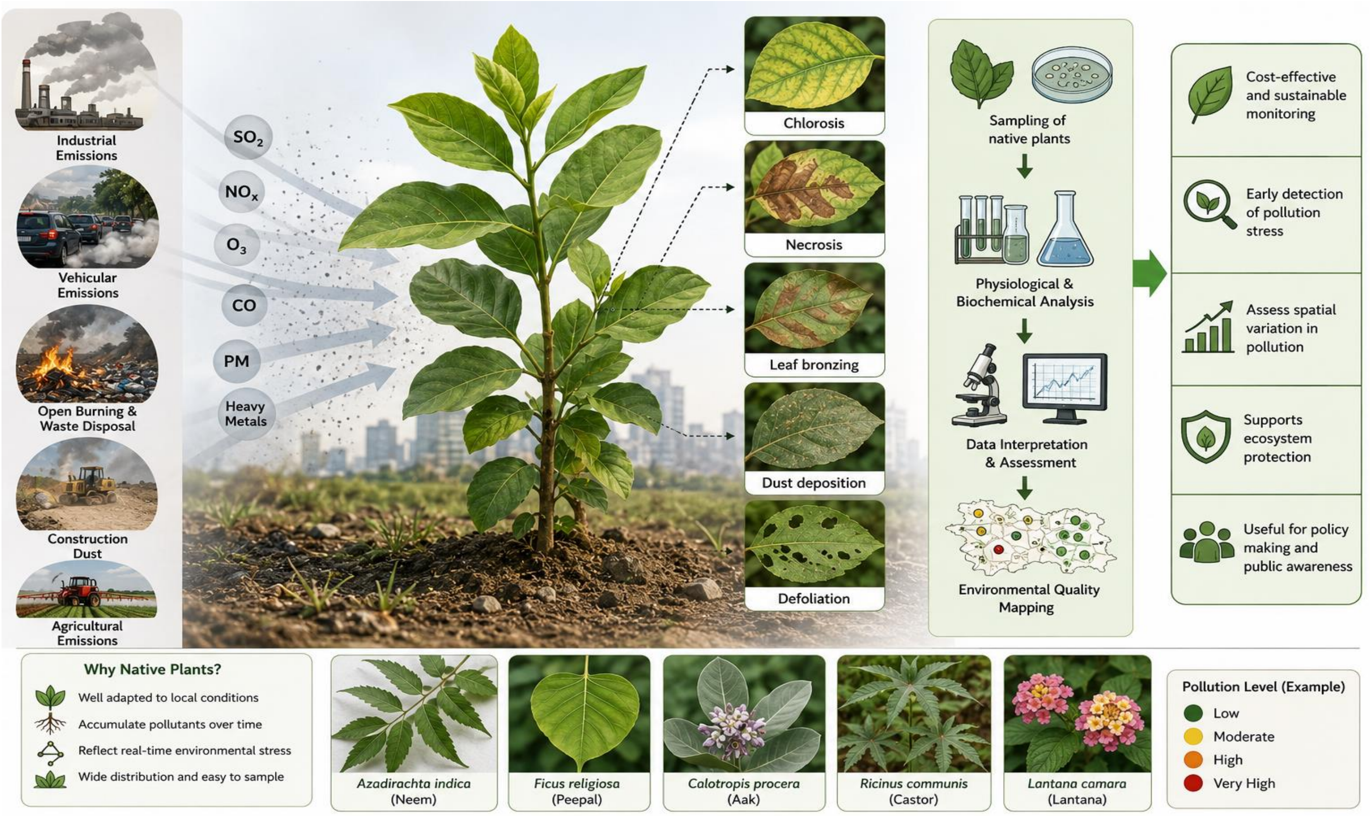
Some of the first signs of pollution stress in native plants are visible morphological abnormalities. Chlorosis, necrotic lesions, bronzing, leaf curling, marginal scorching, early leaf fall, smaller leaves, delayed blooming, and aberrant fruit development are typical symptoms (Rai et al., 2013; Bargagli, 2016). These symptoms frequently have a high correlation with pollutant concentration and exposure length, albeit they may differ between species.

Microscopic anatomical alterations offer more proof of damage caused by pollutants. Stomatal density, stomatal aperture, epidermal cell arrangement, cuticle thickness, mesophyll organization, and vascular tissue structure are all commonly affected by air pollution (Gostin, 2009). In addition to restricting carbon dioxide intake for photosynthesis, fine particulate matter can obstruct stomatal pores, decreasing gaseous exchange and transpiration (Saebø et al., 2012). Epidermal tissue thickening may also result from prolonged exposure as an adaptive mechanism that reduces pollutant penetration. These structural alterations enhance knowledge of plant adaptability and offer useful markers for sustained environmental observation.

7. Using Native Plants for Environmental Biomonitoring

Because native plants integrate pollutant exposure over long periods of time and respond through quantifiable physiological and biochemical changes, they have grown in importance as components of environmental biomonitoring programs (Markert et al., 2003). Plants reflect cumulative pollution exposure and biological consequences, providing complementary information about ecosystem health, in contrast to traditional air-monitoring devices that provide instantaneous observations (Bargagli, 2016).

In urban and industrial settings throughout India, a number of native tree species, such as Azadirachta indica, Ficus religiosa, Terminalia arjuna, Mangifera indica, Polyalthia longifolia, and Dalbergia sissoo, have been extensively studied for their capacity to withstand pollution and serve as biomonitors (Tripathi & Gautam, 2007; Rai et al., 2013). According to Markert et al. (2003) and Bargagli (2016), mosses and lichens are also known as very sensitive bioindicators because they immediately absorb air pollutants without a protective cuticle, allowing for the early detection of gaseous contaminants and heavy metals.



By combining biochemical studies with geographic information systems (GIS), remote sensing, spectral reflectance, chlorophyll fluorescence imaging, and machine-learning techniques, recent technical developments have reinforced plant-based biomonitoring.

These interdisciplinary approaches support evidence-based environmental management, enable long-term ecological monitoring, and enhance the spatial assessment of pollution stress (Richardson et al., 2013; Rai et al., 2013).

Conclusion

Ecosystem health and biodiversity are still seriously threatened by air pollution. This review emphasizes that because native plants show quantifiable morphological, physiological, biochemical, and anatomical reactions to air pollution, they are trustworthy bioindicators. The Air Pollution Tolerance Index (APTI) and pollution syndrome features are useful instruments for evaluating environmental quality, identifying species that can withstand pollution, and promoting biomonitoring and ecological restoration. Environmental monitoring can be enhanced by combining these strategies with cutting-edge technology like GIS, remote sensing, and molecular biomarkers. To improve sustainable air quality management and biodiversity protection, future research should concentrate on long-term studies, standardized assessment techniques, and climate–pollution interactions.

References

1. Agrawal, M., & Agrawal, S. B. (1999). Effects of air pollution on physiological and biochemical characteristics of plants. *Environmental Pollution, 106*(3), 305–313.
2. Apel, K., & Hirt, H. (2004). Reactive oxygen species: Metabolism, oxidative stress, and signal transduction. *Annual Review of Plant Biology, 55*, 373–399. https://doi.org/10.1146/annurev.arplant.55.031903.141701
3. Bargagli, R. (2016). *Moss and lichen biomonitoring of atmospheric pollution: A review*. Springer.

4. Beckett, K. P., Freer-Smith, P., & Taylor, G. (2000). Effective tree species for local air-quality management. *Journal of Arboriculture, 26*(1), 12–19.
5. Berg, L. R., & Hager, M. C. (2009). *Environmental science*. McGraw-Hill.
6. Cape, J. N. (2003). Effects of airborne volatile organic compounds on plants. *Environmental Pollution, 122*(1), 145–157.
7. Chaurasia, S., & Rao, D. N. (2013). Air pollution tolerance index of selected roadside plants. *International Journal of Environmental Sciences, 3*(2), 670–681.
8. Chaudhary, C. S., Rao, D. N., & Kumar, V. (2018). Air pollution tolerance index of selected urban tree species. *Environmental Monitoring and Assessment, 190*, 1–12.
9. Fiscus, E. L., Booker, F. L., & Burkey, K. O. (2005). Crop responses to ozone: Uptake, modes of action, carbon assimilation and partitioning. *Plant, Cell & Environment, 28*(8), 997–1011.
10. Gill, S. S., & Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry, 48*(12), 909–930.
11. Gostin, I. N. (2009). Air pollution effects on the leaf structure of some Fabaceae species. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 37*(2), 57–63.
12. Gupta, G. P., Kumar, B., & Kulshrestha, U. C. (2016). Impact of particulate matter on plants. *Environmental Skeptics and Critics, 5*(1), 7–15.
13. Hoagland, L., et al. (2012). Plant responses to atmospheric pollution. *Plant Science, 190*, 1–9.
14. IPCC. (2023). *Climate Change 2023: Synthesis Report*. Intergovernmental Panel on Climate Change.
15. Joshi, N., & Swami, A. (2009). Air pollution induced changes in selected plant species. *Journal of Environmental Biology, 30*(2), 295–298.
16. Katiyar, V., & Dubey, P. S. (2001). Sulfur dioxide sensitivity on plant species. *Environmental Monitoring and Assessment, 71*, 1–13.
17. Klumpp, A., Ansel, W., & Klumpp, G. (2006). Urban air pollution and vegetation. *Environmental Pollution, 144*(1), 68–74.
18. Lichtenthaler, H. K. (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. *Methods in Enzymology, 148*, 350–382.
19. Manning, W. J., & Tiedemann, A. V. (1995). Climate change: Potential effects of increased atmospheric carbon dioxide, ozone, and ultraviolet-B radiation on plant diseases. *Environmental Pollution, 88*(2), 219–245.
20. Markert, B. A. (1993). *Plants as biomonitors: Indicators for heavy metals in the terrestrial environment*. VCH Publishers.
21. Markert, B. A., Breure, A. M., & Zechmeister, H. G. (2003). *Bioindicators and biomonitors: Principles, concepts and applications*. Elsevier.
22. Mishra, A., & Pandey, J. (2012). Air pollution tolerance index of plants. *Environmental Monitoring and Assessment, 184*, 713–721.
23. Nadgórska-Socha, A., et al. (2017). Plant antioxidant responses under pollution stress. *Environmental Science and Pollution Research, 24*, 21899–21910.
24. Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees. *Urban Forestry & Urban Greening, 4*(3–4), 115–123.
25. Pandey, A. K., Pandey, M., Mishra, A., Tiwary, S. M., & Tripathi, B. D. (2015). Air pollution tolerance index and anticipated performance index of some plant species. *Ecological Indicators, 52*, 531–538.
26. Pathak, V., et al. (2011). Assessment of air pollution tolerance index of trees. *Journal of Environmental Biology, 32*, 521–526.

27. Rai, P. K. (2016). Impacts of particulate matter pollution on plants. *Environmental Skeptics and Critics, 5*(1), 7–15.
28. Rai, P. K., Panda, L. L. S., Chutia, B. M., & Singh, M. M. (2013). Comparative assessment of air pollution tolerance index in urban plants. *Ecotoxicology and Environmental Safety, 95*, 119–127.
29. Richardson, A. D., et al. (2013). Climate change, phenology and ecosystem productivity. *Agricultural and Forest Meteorology, 169*, 156–173.
30. Saebø, A., Popek, R., Nawrot, B., Hanslin, H. M., Gawrońska, H., & Gawroński, S. W. (2012). Plant species differences in particulate matter accumulation. *Science of the Total Environment, 427–428*, 347–354.
31. Sahu, C., & Sahu, S. K. (2015). Biomonitoring of air pollution using plants. *International Journal of Environmental Sciences, 5*(6), 1085–1094.
32. Sandermann, H. (1996). Ozone and plant health. *Annual Review of Phytopathology, 34*, 347–366.
33. Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2012). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants. *Journal of Botany, 2012*, 217037.
34. Singh, A., & Verma, P. (2007). Air pollution tolerance index of plants. *Journal of Environmental Biology, 28*(2), 327–330.
35. Singh, S. K., & Rao, D. N. (1983). Evaluation of plants for their tolerance to air pollution. *Proceedings of the Symposium on Air Pollution Control*, 218–224.
36. Singh, S. N. (Ed.). (2006). *Trace elements in the environment: Biogeochemistry, biotechnology, and bioremediation*. Springer.
37. Tiwari, S., Agrawal, M., & Marshall, F. M. (2006). Evaluation of ambient air pollution impact using plants. *Environmental Monitoring and Assessment, 120*, 269–281.
38. Tripathi, A. K., & Gautam, M. (2007). Biochemical parameters of plants as indicators of air pollution. *Journal of Environmental Biology, 28*(1), 127–132.
39. Uka, U. N., et al. (2019). Plant bioindicators in environmental pollution assessment. *Environmental Monitoring and Assessment, 191*, 1–20.
40. U.S. Environmental Protection Agency. (2023). *Integrated Science Assessment for Particulate Matter*. U.S. EPA.
41. Vardaka, E., et al. (1995). Heavy metal accumulation by plants in polluted environments. *Environmental Pollution, 90*, 283–291.
42. Verma, A., & Singh, S. N. (2006). Biochemical and physiological responses of plants to air pollution. *Environmental Monitoring and Assessment, 120*, 179–194.
43. WHO. (2022). *WHO global air quality guidelines*. World Health Organization.
44. Winner, W. E., & Atkinson, C. J. (1986). Absorption of air pollutants by plants. *Environmental Pollution Series A, 42*(3), 195–206.
45. Woo, S. Y., et al. (2007). Physiological responses of urban trees to air pollution. *Environmental Pollution, 146*, 745–753.
46. Yadav, S., & Pandey, J. (2018). Assessment of pollution tolerance of roadside plant species. *Environmental Science and Pollution Research, 25*, 11245–11256.
47. Youssef, N. A., et al. (2013). Anatomical responses of plants exposed to atmospheric pollutants. *Flora, 208*(2), 95–103.
48. Zhang, W., et al. (2016). Plant physiological responses to atmospheric particulate pollution. *Environmental Pollution, 218*, 131–140.
49. Zhao, D., et al. (2018). Urban vegetation and air quality improvement: A review. *Atmospheric Environment, 183*, 301–309.

50. Zvereva, E. L., Kozlov, M. V., & Haukioja, E. (2010). Stress responses of plants under air pollution. *Environmental Pollution, 158*(4), 1072–1080.