Effect of Heavy Metals on Some Selected Roadside Plants and its Morphological Study: A Review

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Abstract: The effect of heavy metals on some selected roadside plants and its morphological structure a detailed literature survey was carried out. Total five plant species, namely Bougainvillea spectabilis Willd., Azadirachta indica A. Juss., Polyalthia longifolia Benth. & Hook., Cassia fistula L. and Ficus religiosa L., were selected. The results of the anatomical study reported in literature showed that these plants appeared some surface structural abnormalities; in some cases major structural changes were also recorded. With constant exposure of a leaf surface to auto-exhaust emissions, the epidermal cells collapsed and the cell boundaries which are originally clear changed to irregularly fused cells in most of the cases. In the plants from high polluted areas, the stomata were smaller in size, their frequency was higher and in almost all cases they were in level with epidermal cells. Cuticle surface structures of the studied plants are either rugose (Cassia), smooth or striated (Polyalthia, Bougainvillea and Azadirachta). Present paper tries to summaries effect of heavy metals (Zn, Ni, Cd, Cu and Pb) on five selected road side plants through detailed literature review in their anatomical, morphological and cell properties.

Key words: Anatomical Study • Heavy Metals • Highways • Morphology • Roadside Plants

INTRODUCTION

Effects on plants and their relatively high concentrations in exhaust emissions, nitric oxide (NO) and nitrogen dioxide (NO₂) are the most important phytotoxic pollutants associated with road transport. However, trace amounts of other nitrogen-containing compounds such as nitrous acid (HONO), nitrous oxide (N₂O) and ammonia (NH₃) may also be present in vehicle emissions. During combustion, other pollutants, including sulphur dioxide (SO₂) and volatile organic compounds (VOCs), are emitted, together with carbonaceous particles from incompletely burnt fuel droplets [1].

Previous research has shown that at high concentrations, many of the pollutants present in exhaust gases can be damaging to plants [2-4]. Much of this research has, however, looked solely at the individual components of exhaust emissions and there is very little information on the impacts of the particular mix of pollutants characteristic of urban areas.

In soils, heavy metals mainly originate from the weathering of soil parent material and from external inputs resulting from human activities, such as industrial activities, the application of agricultural chemicals and the improper disposal of waste [5-7]. Heavy metals are natural components of the Earth's crust and the natural concentrations of soil heavy metals tend to remain low [8]. However, over the last few decades, the anthropogenic inputs of several heavy metals into soils have exceeded the natural heavy metal inputs from pedogenesis, even at a regional scale [9].

Roadside soils are the “recipients” of large amounts of heavy metals from a variety of sources, including vehicle emissions, coal burning waste and other activities [10,11]. Automobile traffic pollutes roadside environments with a range of contaminants. Heavy metals are found in fuels, in the walls of fuel tanks, in engines and other vehicle components and in catalytic converters, tires and brake pads, as well as in road surface materials [12,13].
Heavy Metals: Heavy Metals are defined as a metallic element with a density between 4-5g/cm³ [14,15]. Commonly found heavy metals include Lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu) [16]. In toxic concentrations heavy metals can cause damage to the ecology, environmental, nutritional and evolutionary characteristics of the polluted area [17].

Soils are heavy metals sinks heavy metals originate from the earth’s crustal rock and are released through weathering processes although its anthropogenic sources such as; fertilisers, mine tailings, pesticides, sewage sludge and smelting have caused unnaturally high contamination [16]. Concentration of heavy metals persists as they are not degraded from microbial or chemicals like organics, reducing soil quality [18]. Prolonged contamination of soils severely reduces the soil quality [19] However, changes to chemical form are possible [16].

Heavy Metals and Plants: Heavy metals and plants have complex relationships. Heavy metals are essential nutrients in trace concentrations for healthy growth as Plants require the nutrients for essential physiological functions [20]. Deficient or toxic concentrations can cause disruptions to essential functions leading to poor health or death. [15] The degree of toxicity or deficiency the plant has to tolerate surviving is affected by Metal Form and concentration, bioavailability and species [15]. High and low concentrations of heavy metal in soil can negatively affect crop growth, as these metals interfere with metabolic functions in plants, including inhibition of photosynthesis and respiration and degeneration of main cell organelles, even leading to death of plants [21,22].

Zinc: Zn is an essential micro-nutrient for physiological functions. Zn is a building block for enzymes; in addition, many enzymatic reactions are activated by zinc [23]. Zn exerts a great influence on many plant life processes, such as; Nitrogen metabolism and uptake of nitrogen and protein quality; photosynthesis and chlorophyll synthesis, carbon anhydrase activity; resistance to abiotic and biotic stresses and protection against oxidative damage [24]. Zn deficiency is commonly reported in crop growth [25] Zn deficient plants suffer from physiological stress caused by enzyme dysfunction and other metabolic function disruptions [23] Symptoms of deficiency include stunted growth, inter-venial chlorosis in younger leaves, necrotic tips and photosynthetic problems [26]. Zn toxicity leads plants to suffer from physiological stress caused by enzyme dysfunction and other metabolic function disruptions [23]. Pb toxicity can cause; ATP synthesis [27], other symptoms include chlorosis, smaller leaves and necrotic leaf tips [26, 28].

Cd: Cadmium is a relatively rare heavy metal, which occurs naturally in combination with other metals. Cadmium has been observed in road dust due to its presence in automobile fuel and in soil. Therefore inhalation exposure to Cd can occur from road dust. After inhalation, the absorption of Cd compounds may vary greatly depending upon the particle sizes and their solubility. Cadmium is a metal, which can cause severe toxicity in humans. Prolonged exposure to Cd can affect a variety of organs with the kidney being the principal target. The following observations were made regarding the concentration of Cd in road dust samples collected along Islamabad Expressway [29].

Pb: Lead (Pb), with atomic number 82, atomic weight 207.19 and a specific gravity of 11.34, is a bluish or silvery-grey metal with a melting point of 327.5°C and a boiling point at atmospheric pressure of 1740°C. It has four naturally occurring isotopes with atomic weights 208, 206, 207 and 204 (in decreasing order of abundance). Despite the fact that lead has four electrons on its valence shell, its typical oxidation state is +2 rather than +4, since only two of the four electrons ionize easily. Apart from nitrate, chlorate and chloride, most of the inorganic salts of lead2+ have poor solubility in water [30]. Lead (Pb) exists in many forms in the natural sources throughout the world and is now one of the most widely and evenly distributed trace metals. Soil and plants can be contaminated by lead from car exhaust, dust and gases from various industrial sources. Pb2+ was found to be acute toxic to human beings when present in high amounts. Since Pb2+ is not biodegradable, once soil has become contaminated, it remains a long-term source of Pb2+ exposure. Metal pollution has a harmful effect on biological systems and does not undergo biodegradation [31].

Nickel: Nickel combined with other elements occurs naturally in the earth's crust. It is found in all soils. In the environment, it is primarily found combined with oxygen or sulfur as oxides or sulfides. Nickel is also released into the atmosphere by Oil and coal burning power plants and trash incinerators. Health hazards associated with exposure to Ni in the occupational environment have resulted primarily from inhalation.
Table 1: Asian countries comparison of heavy metals Zn, Ni, Cd, Cu and Pb in roadside

<table>
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<td>Country</td>
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Asian Comparison of Heavy Metals: The concentration of heavy metals (Zn, Ni, Cd, Cu and Pb) in Asian country, as given in Table 1. The Asian countries of Zn is in the range 13.1-3840 mg kg$^{-1}$, the concentration of Pb is in the range 11.2-1131 mg kg$^{-1}$. The concentration of Ni measured at various places around the Asia, which various from 4.2-88 mg kg$^{-1}$. The Asian concentration of Cu as reported from 11.3-350 mg kg$^{-1}$. The Asian Cd concentration, as in show a large range of values; i.e. from 1, 17-5.0 mg kg$^{-1}$.

World Comparison Road Side Heavy Metals: [50] Studied the distribution of heavy metals such as Ni, Pb, Cr, Zn, Cu and Cd from the roadside soil of Zhengzhou-Putian Section of Longxi-Haizhou Railroad, China. The soil samples were collected at distance of 0, 10, 20, 30, 50, 100, 200, 300 and 500m from the railroad edge. The contents of Pb and Cd were estimated by graphite furnace atomic absorption spectrometry (GF-AAS) while contents of Cu, Zn, Cr and Ni were estimated by flame atomic absorption spectrometry (F-AAS). The maximum concentrations of the metals were found at distance 10–30m from the railroad and the content of these metals was found in order of Cr > Cd > Pb > Zn > Ni > Cu.

[51] Evaluated the contents of heavy metals (Pb, Zn, Mn, Cu, Ni, Cd, Co and Fe) in roadside soils of major streets in Jos metropolis, Nigeria using Atomic Absorption Spectrophotometer (AAS). The order of the total metal content for the studied samples was Fe > Zn > Mn > Pb > Cd > Cu. Correlation analysis between metals and the traffic volume was found to be significantly positive at $p < 0.05$. The study also emphasized that metal pollution in soil was mostly originated from vehicular emissions.

[52] Correlated the chemical composition and automobiles traffic of roadside soil of Jeddah city, Saudi Arabia. The soil samples were collected from the areas having heavy and light traffic intensity and were analyzed for K, As, Co, Cr, Ni, Pb, Sb, V and Zn. The content of lead and zinc were found to be high in the samples that were collected from the areas of heavy traffic intensity. The content of lead ranged from 0.3 - 104.8±0.003 mg/kg for the samples of high traffic intensity while the content of lead was 0.3±0.00 for the samples of no traffic intensity. The zinc content was found to be in range of 56.59±0.003 to 456.93±0.06 mg/g.

[53] analyzed variations in heavy metal contents on roadside soils along a major express way in south east Nigeria. 15 surface soil samples were collected at the distance of 50 cm–1 m and 15 samples from 100 m away from the roadside. The soil samples were analyzed using Atomic Absorption spectrophotometer. The mean values of Fe, Cu, Zn, Pb and Cd were 5205.11, 247.97, 74.11, 100.19 and 18.8 mg/kg, respectively at depth of 50 cm – 1 m whereas means values at 100 m away from the roadside were 4890, 217.86, 64.08, 87.13 and 3.05 mg/kg, respectively.
The content of lead was estimated in water and were divided into five zones as FN (Francistown- Nata), NM (Nata-Maun), MG (Maun-Ghanzi), GK (Ghanzi-Kang) and TS (Tshabong-Sekoma). The zones FN, NM and MG showed high load of metal pollution as compared to GK and TS zones.

Determined the mineral and heavy metal levels of some fruits grown at the road sides in Turkey by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). The levels of Pb and Se were found to be very high in the fruit samples. The results showed that the average level of Cu ranged between 0.27 mg/kg and 0.05 mg/kg, Cr as 0.32 mg/kg and 0.18 mg/kg, Ni as 0.68 mg/kg and 0.26 mg/kg, Pb as 2.86 mg/kg and 1.54 mg/kg and Se 12.96 mg/kg and 5.42 mg/kg. The levels of Cu, Cd and Cr in samples were found to be below pollution levels.

Studied the levels of heavy metal pollution in roadside soils of Eskisehir, Turkey. 15 soil samples were taken from three different lines: only – tramway lines, only – traffic lines and both tramway and traffic lines and analyzed for different heavy metals viz., Cd, Cu, Cr, Fe, Hg, Mn, Ni, Pb and Zn. The level of pollution in soil was estimated based on the geoaccumulation index (Igeo), enrichment factor (EF), pollution index and integrated pollution index (IPI). The values for the integrated pollution index (IPI) were found to be in the order of Pb > Zn > Cu > Fe > Mn > Ni > Cr > Cd.

Determined the lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. The soil samples were collected at distances of 0, 25 and 50 m from the roadside soil and the concentrations of lead, cadmium and copper were measured using Flame Atomic Absorption Spectrophotometry (FAAS). To increase the sensitivity of Pb, Cd and Cu, the Slotted Tube Atom Trap (STAT) was used. Lead concentrations in soil samples varied from 1.3 to 45 mg/kg while mean lead levels in plants ranged from 120 mg/g to 866 mg/g. The level of Cd in soil samples ranged from 78 to 527 mg/g while Cd concentration in different vegetation samples varied from 1.3 to 45 mg/kg. Concentrations of Cu in soil and plant samples were found to be in the range of 11.1 – 27.9 mg/kg for soil and 0.8 – 5.6 mg/kg for plants.

assessed heavy metals viz., Al, Co, Cu, Fe, Pb, Mn, Ni and Zn along the major roadside soils of Botswana, using enrichment factor ratios (EF), contamination factor (CF), pollution load index (PLI) and geoaccumulation index (Igeo) methods. The studied sites were divided into five zones as FN (Francistown- Nata), NM (Nata-Maun), MG (Maun-Ghanzi), GK (Ghanzi-Kang) and TS (Tshabong-Sekoma). The zones FN, NM and MG showed high load of metal pollution as compared to GK and TS zones.

Estimated lead and cadmium contamination of different roadside soils and plants in Peshawar City, Pakistan. The different soil and plants (Eucalyptus camaldulensis, Ficus elastica, Dalbergia sissoo and Alstonia scholaris) samples were collected and analyzed for Pb and Cd metals by Atomic Absorption Spectrophotometer. The mean content of Pb and Cd was 53.9 and 6.0 mg/kg, respectively in soils and 49.1 and 10.9 mg/kg, respectively in plants. The order of metal accumulation index (MAI) in different plant species were found to be E. camaldulensis > F. elastic > D. sissoo > A.scholaris.

Estimated accumulation of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan from the dust and soil samples. The samples were analyzed for five heavy metals using FAAS (flame atomic absorption spectrometry). The average concentration of Cd, Cu, Ni, Pb and Zn were found to be 5, 52, 23, 104 and 116 mg/kg, respectively. The pollution level was estimated based on the geoaccumulation index (Igeo), the pollution index (PI) and the integrated pollution index (IPI). The values of IPI were in the order of Cu > Pb > Zn > Cd > Ni.

Studied the heavy metals contamination in roadside soil near different traffic signals in Dubai. The roadside soil samples were collected from three different locations viz. roads having more than two traffic signals, roads having only one traffic signal and roads having no traffic signals. They analyzed Cd, Pb, Cu, Ni, Fe, Mn and Zn by Atomic Absorption Spectroscopy (AAS). The range of the metals observed in soil having more than two traffic signals were Cd (0.17 – 1.01), Pb (259.66 – 2784.45), Cu (15.51 – 65.90), Ni (13.31 – 98.13), Fe (325.64 – 5136.37), Mn (57.95 – 166.43) and Zn (91.34 – 166.43) mg/kg while the range of metals analyzed in samples collected from the roadside having only one traffic signal were Cd (nd – 0.80), Pb (145.95 – 308.09), Cu (0.82 – 18.04), Ni (18.29 – 59.36), Fe (88.51 – 3649.42), Mn (25.88 – 147.34) and Zn (8.97 – 106.11 mg/kg). However, the range of metals at roads having no traffic signals were Cd (0.0 – 0.57), Pb (8.34 – 58.20), Cu (2.88 – 5.81), Ni (3.34 – 73.80), Fe (55.34 – 332.81), Mn (2.98 – 98.73) and Zn (1.23 – 46.6 mg/kg). Cd, Cu, Ni, Fe, Mn and Zn in soil were present within the normal range of background levels whereas lead was reported in high concentration.
[62] Analyzed the antimony in urban roadside surface soils of Xuzhou (China). In order to assess the magnitude of contamination and to identify the possible contamination sources, 21 top soils samples were collected. It was observed that Sb in urban surface soils was 0.96 mg/kg. The Sb in the Xuzhou top soils was mainly due to the inputs of coal combustion.

[63] Analyzed the various heavy metals viz., Pb, Cd, Cu and Zn from the dust deposited roadside soil samples collected from the Ketu-South District, Volta Region in Ghana. About 50 samples were analyzed for various heavy metals using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Table 2.

Selection of Common Road Side Plant Species: Five plant species, namely Bougainvillea spectabilis Willd., Azadirachta indica A. Juss., Polyalthia longifolia Benth. & Hook., Cassia fistula L. and Ficus religiosa L., were selected by [67] for the study as they were common along the road side or on the road dividers at all the sites of the study. Lucknow, the capital of the North Indian state of Uttar Pradesh is situated between 26°52’N latitude and 80°52’E longitude, 120 m above sea level in the plains of the Indian sub-continent. Plant species differ significantly in their ability to mitigate traffic pollution due to differences in their leaf surface characteristics such as epicuticular wax, cuticle, epidermis, stomata and the trichomes [68,69].

Micro-morphological leaf surface characters of plants, the following plant species growing along roadsides in low and high traffic density areas have been selected: Azadirachta indica, Bougainvillea spectabilis, Cassia fistula, Ficus religiosa and Polyalthia longifolia.

Anatomical Characteristics of Leaf Surface: Leaf surface characteristics were studied with light and scanning electron microscopes (JEOL JSM 35C, Japan and Philips XL-20, The Netherlands). For light microscopy, epidermal peels and leaf transverse sections were prepared with razor blades. Ten slides were prepared for each reading. The SEM studies were conducted by using the standard techniques viz. washing, fixation, air drying, stub preparation followed by gold coating (thickness 2000 Å) and then examining under the microscope. Details of the leaf surface characteristics obtained from normal, healthy and fully mature leaves (5 leaves each) photomicrographs are presented in Fig. 2. Plants selected for this work always were growing directly on the road side or on the road dividers. These plants showed some surface structural abnormalities; in some cases major structural changes were also recorded.

Epidermis: With constant exposure of a leaf surface to auto-exhaust emissions, the epidermal cells collapsed and the cell boundaries which are originally clear changed to irregularly fused cells in most of the cases. In Bougainvillea (Fig. 1 D-1, D-2) only striations could be seen under SEM. In Cassia (Fig. 1 B-1, B-2) epidermal cells at high polluted sites are also dust laden and...
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<th>S.No.</th>
<th>Heavy Metals</th>
<th>Location of study area</th>
<th>Instrument used</th>
<th>Results</th>
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<td>Zn, Cr, Ni, Pb, Cu and Cd</td>
<td>Roadside soil railroad side, Zhengzhou-Putian Section of Longxi-Haizhou Railroad, China</td>
<td>Pb and Cd by graphite furnace atomic absorption spectrometry (GF-AAS) while Cu, Zn, Cr and Ni by flame atomic absorption spectrometry (FAAS)</td>
<td>Content of metals were found in order: Cr &gt; Cd &gt; Pb &gt; Zn &gt; Ni &gt; Cu.</td>
<td>[50]</td>
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<tr>
<td>2</td>
<td>Co, Ni, Cd, Cu, Zn, Mn, Fe and Pb</td>
<td>Roadside Soils of Major streets, Jos metropolis, Nigeria</td>
<td>Atomic Absorption Spectrophotometer</td>
<td>Order of heavy metals found: Fe &gt; Zn &gt; Mn &gt; Pb &gt; Cd &gt; Cu</td>
<td>[51]</td>
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<tr>
<td>3</td>
<td>Sh, Ni, Zn, Cr, As, V, K, Pb and Co</td>
<td>Roadside soil of Jeddah city, Saudi Arabia</td>
<td>Inductively coupled plasma-optical emission spectrometer (ICP-OES) and ICP-mass spectrometry (ICP-MS)</td>
<td>Lead and Zinc was found in high contents and ranged from 0.3 104.8±0.003mg/kg of 56.59±0.003 to 456.93±0.06mg/g, respectively.</td>
<td>[52]</td>
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<td>4</td>
<td>Pb, Cd, Zn, Fe and Cu</td>
<td>Roadside soils along a major express way, south east Nigeria</td>
<td>Atomic Absorption spectrophotometer</td>
<td>At distance 50cm - 1m away from roadside: Fe (5205.11mg/kg), Cu (247.97mg/kg), Zn (74.11mg/kg), Pb (100.19mg/kg) and Cd (18.8 mg/kg)</td>
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<td>At 100m away from the roadside: Fe (4890), Cu (217.86mg/kg), Zn (64.08mg/kg), Pb (87.13 mg/kg) and Cd (3.05mg/kg)</td>
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<td>5</td>
<td>Pb</td>
<td>Tap water, Surface water, Vegetables and Soil samples, Kismu, Kenya</td>
<td>Shimadzu Atomic Absorption Spectrophotometer</td>
<td>Tap water (140 to 260µl/L), surface water (140 to 600µl/L), Vegetables (0.0-3.3µg/g) and soil (0.2-3.9µg/g)</td>
<td>[54]</td>
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<td>6</td>
<td>Se, Cu, Pb, Cd, Cr and Ni</td>
<td>Fruits grown at the roadsides, Turkey</td>
<td>Inductively Coupled Plasma Atomic Emission Spectrometry</td>
<td>Cu (0.27mg/kg and 0.05mg/kg), Cr(0.32 mg/kg and 0.18 mg/kg), Ni (0.68 mg/kg and 0.26 mg/kg), Pb (2.86 mg/kg and 1.54 mg/kg) and (Se 12.96 mg/kg and 5.42 mg/kg)</td>
<td>[55]</td>
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<td>7</td>
<td>Cd, Cu, Cr, Fe, Hg, Mn, Ni, Pb and Zn</td>
<td>Roadside soils of Eskisehir, Turkey</td>
<td>Inductively coupled plasma-optic emission spectrometer</td>
<td>The content of heavy metals was in order: Pb &gt; Zn &gt; Cu &gt; Fe &gt; Mn &gt; Ni &gt; Cr &gt; Cd</td>
<td>[56]</td>
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<td>8</td>
<td>Cd, Cu and Pb</td>
<td>Roadside soil and plant, Elazig, Turkey</td>
<td>Flame Atomic Absorption Spectrophotometer</td>
<td>In soil: Pb (1.3 to 45 mg/kg ), Cd (1.3 to 45 mg/kg), Cu (11.1-27.9 mg/kg) In vegetation: Pb (120 ng/g to 866 ng/g), Cd (1.3 to 45 mg/kg) and Cu (0.8-5.6 mg/kg)</td>
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<td>9</td>
<td>Zn, Cd, Pb, Ni, Hg, Cu, As and Cr</td>
<td>Dust and soil, Kavala city, Greece</td>
<td>Atomic absorption spectrophotometer</td>
<td>In street dust: Pb (300.9 µg/g), Cu (123.9 µg/g), Zn (271.6 µg/g), Ni (57.5 µg/g), Cr (196.0 µg/g), Cd (0.2 µg/g), As (16.7 µg/g) and Hg (0.1 µg/g) In roadside soil: Pb (359.4 µg/g), Cu (42.7 µg/g), Zn (137.8 µg/g), Ni (58.2 µg/g), Cr (193.2 µg/g), Cd (0.2 µg/g), As (62.3 µg/g) and As (0, µg/g)</td>
<td>[58]</td>
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<td>10</td>
<td>Cd and Pb</td>
<td>Soils and plants, Peshawar City, Pakistan</td>
<td>Atomic Absorption Spectrophotometer</td>
<td>In soils: Pb (53.9 mg/kg) and Cd (6.0 mg/kg) In plants: Pb (49.1 mg/kg) and (10.9 mg/kg)</td>
<td>[59]</td>
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<tr>
<td>11</td>
<td>Cu, Pb, Zn, Cd and Ni</td>
<td>Dust and soil, Islamabad Expressway, Pakistan</td>
<td>Flame atomic absorption spectrometry</td>
<td>Cd (5 ± 1 mg/kg), Cu (52 ± 18 mg/kg), Ni (23 ± 6 mg/kg), Pb (104 ± 29 mg/kg) and Zn (116 ± 35 mg/kg)</td>
<td>[60]</td>
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disorganised as compared to the leaves of least polluted areas. In the case of trees (*Azadirachta*, *Ficus* and *Polyalthia* (Fig. 1 A-1, A-2, C-1, C-2 and E-1, E-2) the epidermis shows less damage in comparison to shrubs. [70] Reported that, due to fused epidermal cells under detrimental conditions, wheat leaves attained a glazed appearance followed by patches of lesions which further reduced their photosynthetic area. Epidermal cells may be attacked earlier by the pollutants than guard cells by virtue of their greater exposure to pollutants [71,72]. Since guard cells are usually protected by a well developed cuticle, the pollutant has to reach them by entering the stomatal pore and by transfer through adjacent epidermal cells [73].
Fig. 1: Scanning electron micrographs for morphological study of leaf surfaces: (A-1) *Azadirachta indica* least polluted area, showing a clear glandular trichome and stomata. (A-2) *Azadirachta indica* high polluted area, showing disrupted trichome and stomata. (B-1) *Cassia fistula* least polluted area, showing normal epicuticular wax. (B-2) *Cassia fistula* high polluted, showing disorganised epicuticular wax. (C-1) *Ficus religiosa* least polluted area, showing normal structure. (C-2) *Ficus religiosa* high polluted area, showing increased stomatal frequency. (D-1) *Bougainvillea spectabilis* least polluted area, showing a normal stoma. (D-2) *Bougainvillea spectabilis* high polluted area, showing damaged stoma. (E-1) *Polyalthia longifolia* least polluted area, a normal stoma. (E-2) *Polyalthia longifolia* high polluted area, showing a damaged and almost closed stoma [67]

**Stomata:** Stomata of most of the species under study were either globose, elevated or slightly sunken if harvested from least polluted sites. In the plants from high polluted areas, the stomata were smaller in size, their frequency was higher and in almost all cases they were in level with epidermal cells. Only in *Ficus* they were slightly raised as compared with the least polluted sites situation. The outer stomatal ledge and peristomatal rim were damaged at high polluted sites. The structural changes were most probably direct effects of traffic pollutants. Entry of Pb into the plant system is reported to occur mostly through stomatal pores and may affect themselves immediately [74]. Among the gaseous pollutants ozone is most harmful affecting the stomata. It is generated by the action of sunlight on vehicle exhaust gases and reaches concentrations of 200–300 ppb under appropriate weather conditions at many locations in North America [75], Europe [76] and other regions with high motor vehicle density.
Cuticle: Cuticle surface structures of the studied plants are either rugose (*Cassia*) (Fig. 1 B-1, B-2), smooth or striated (*Polyalthia, Bougainvillea* and *Azadirachta*) (Fig. 1 E-1, E-2, D-1, D-2 and A-1, A-2). While patterned striations occurred in least polluted area plants, characteristic wrinkles appeared on the cuticle of high polluted area plants, which resulted in a changed contact angle of the surface. The particular cuticle roughness plays a critical role in making a plant resistant to pollution. Cuticles with heterogeneous lipid structures can be effective barriers against harmful factors, e.g. pollutants [77]. Of primary importance is the microstructure of the cuticular surface where the initial interaction with air-borne pollutants occurs. This interface has a considerable influence on leaf wet ability and, consequently, on gaseous and particulate depositions and retention of moisture [78]. It has been observed that the degree of mitigation of negative influences on a leaf increased with the effective surface area. This effective surface is determined by the extent of roughness of the epicuticular wax structures. Various naturally occurring and anthropogenic organic compounds (including alcohols, organic pollutants and surfactants) have been shown to increase the presence of plant cuticles [79]. Loss in cuticular resistance allows pollutants to enter inside the leaf, resulting in the collapse of epidermal cells followed by glazing of the surface.

CONCLUSIONS

Road dust is an increasing problem for developed and developing countries and is a source of various diseases. Samples of road dust collected along National Highways were analyzed for Cd, Cu, Ni, Pb and Zn and its impact on road side plants. The concentrations of these elements were generally on the lower side when compared with those available in the literature. Several studies on the pollution of soils along the highways indicated the presence of carcinogenic heavy metals and polycyclic aromatic hydrocarbons. The maximum concentration of both heavy metals and polycyclic aromatic hydrocarbons were found to be at 10–30m distance from road/highways. Although the reports presented in present review article discloses the load of heavy metals and polycyclic aromatic hydrocarbons on soil ecosystems via vehicular emissions, yet, the literature is scanty from many parts of the world. Considering the harmful consequences of pollutants released from vehicular emissions, the strict guidelines should be laid and followed in order to reduce the pollution load.

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