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Original Research Paper

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

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ABSTRACT

Environmental pollution of heavy metals from automobiles has attained much attention in the recent past. Plants are known to bind carbon-dioxide (CO_2) through photosynthesis, and they have become an invaluable tool in attempts to minimize air pollution. In India, some highways and national highways are covered by common plant species, but the plants (*Azadirachta indica, Bougainvillea spectabilis, Cassia fistula, Ficus religiosa* and *Polyalthia iongifolia*) are subjected to air pollution by heavy metals (Ni, Pb, Cr, Zn, Cu, Cd). These metals are released during different operations of the road transport such as combustion, component wear, fluid leakage and corrosion of metals and other activities (minerals mining, stone crusher industries). The majority of the heavy metals are toxic to the living organisms and even those considered as essential can be toxic if present in excess. The heavy metals can impair important biochemical processes affecting the plant growth and development. Traffic-related pollutants have detrimental effects on the environment. However, the effect of these heavy metals on plants is not well known. The study aimed to comparatively analyse the anatomical and morphological changes in roadside plants and heavy metal accumulation in selective roadside plants.

INTRODUCTION

Effects on plants and their relatively high concentrations in exhaust emissions, nitric oxide (NO) and nitrogen dioxide (NO_2) are the most important phytotoxic pollutants associated with road transport. However, trace amounts of other nitrogen-containing compounds such as nitrous acid (HNO_2), nitrous oxide (N_2O) and ammonia (NH_3) may also be present in vehicle emissions. During combustion, other pollutants, including sulphur dioxide (SO_2) and volatile organic compounds (VOCs), are emitted together with carbonaceous particles from incompletely burnt fuel droplets (Colvile et al. 2001).

Previous research has shown that at high concentrations, many of the pollutants present in the exhaust gases can be damaging to plants (Ackerly & Bazzaz 1995, Grantz et al. 2003, Wellburn 1990). 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 (Gil et al. 2004, Romic & Romic 2003, Zhao et al. 2008). Heavy metals are natural components of the earth's crust, and the natural concentrations of soil heavy metals tend to remain low (Rodríguez Martín et al. 2013). 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 (Facchinelli et al. 2001).

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 (Jose et al. 2009, Saeedi et al. 2009). Automobile traffic pollutes the 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 (Zehetner et al. 2009, Deska et al. 2011).

Heavy metals: Heavy metals are defined as a metallic element with a density between 4-5 g/cm^3 (Jarup 2003, Nagajyoti et al. 2010). Commonly found toxic heavy metals include lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu) (Wuana & Okieimen 2011). In toxic concentrations heavy metals can cause damage to the ecology, environmental, nutritional and evolutionary characteristics of the polluted areas (Babula et al. 2008).

Soils are heavy metals sinks, heavy metals originate from the earth's crustal rock and are released through weathering processes through its anthropogenic sources such as, fertilizers, mine tailings, pesticides, sewage sludge and smelting, causing unnaturally high contamination (Wuana & Okieimen 2011). Concentration of heavy metals persists as they are not degraded by microbial activity or chemicals, like the organic compounds, reducing soil quality (Lasat 2000). Prolonged contamination of soils severely reduces the soil quality (Oliviera & Pampulha 2006), however, changes to chemical form are possible (Wuana & Okieimen 2011).

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 (Tangahu et al. 2011). Deficient or toxic concentrations can cause disruptions to essential functions leading to poor health or death (Nagajyoti et al. 2010). The degree of toxicity or deficiency the plant has to tolerate, survival is affected by the metal form and concentration, bioavailability and species (Nagajyoti et al. 2010). 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 (Schmidt 2003, Schwartz et al. 2003).

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 (Mousavi 2011). Zinc 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 (Cakmak 2000). Zn deficiency is commonly reported in crop growth (Assuncao et al. 2010). Zn deficient plants suffer from physiological stress caused by enzyme dysfunction and other metabolic function disruptions (Mousavi 2011). Symptoms of deficiency include stunted growth, inter-venial chlorosis in younger leaves, necrotic tips and photosynthetic problems (Rout & Das 2003).

Zinc toxicity leads plants to suffer from physiological stress caused by enzyme dysfunction and other metabolic function disruptions (Mousavi 2011). Zn excess can cause: ATP synthesis (Mousavi et al. 2013), other symptoms include chlorosis, smaller leaves and necrotic leaf tips (Rout & Das 2003, Sagardoy et al. 2008) (Fig. 1).

Cadmium: 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.

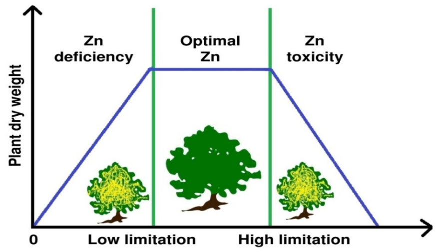

Fig. 1: Zinc concentration and its effect on the likelihood of the symptoms deficiency and toxicity being present (Lin & Aarts 2012).

Lead: Lead (Pb) 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 lead 2+ have poor solubility in water (WHO 2001). 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. Pb^{2+} was found to be acute toxic to human beings when present in high amounts. Since Pb^{2+} is not biodegradable, once soil has become contaminated, it remains as a long-term source of Pb^{2+} exposure. Metal pollution has a harmful effect on biological systems and does not undergo biodegradation (Pehlivan 2009).

Nickel: Nickel combined with other elements occur naturally in the earth's crust. It is found in all soils. In the environment, it is primarily found combined with oxygen or sulphur as oxides or sulphides. 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.

Asian comparison of heavy metals: The concentration of heavy metals (Zn, Ni, Cd, Cu and Pb) in Asian countries, is given in Table 1. In the Asian countries, Zn is in the range 13.1-3840 mg.kg^{-1}, the concentration of Pb is in the range of 11.2-1131 mg.kg^{-1}. The concentration of Ni measured at various places around Asia, which varies from 4.2-88 mg.kg^{-1}. The concentration of Cu is reported from 11.3-350 mg.kg^{-1}.

The Cd concentration, show a large range of values, i.e. from 1.17-5.0 mg.kg^{-1}.

World comparison of road side heavy metals: Jian-Hua (2009) 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 a distance of 0, 10, 20, 30, 50, 100, 200, 300 and 500 m 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 concentration of the metals was found at distance a 10-30 m from the railroad and the content of these metals was found in order of Cr > Cd >Pb > Zn > Ni > Cu.

Abechi et al. (2010) evaluated the contents of heavy metals (Pb, Zn, Mn, Cu, Ni, Cd, Co and Fe) in the roadside soils of major streets in Jos metropolis, Nigeria using an 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.

Kadi (2009) correlated the chemical composition and automobile traffic of the roadside soil of Jeddah city, Saudi Arabia. The soil samples were collected from the areas having heavy and light traffic intensity and were analysed for K, As, Co, Cr, Ni, Pb, Sb, V and Zn. The content of lead and zinc were found to be higher 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 low traffic intensity. The zinc content was found to be in the range of 56.59±0.003 to 456.93±0.06 mg/g.

Mbah et al. (2010) analysed the variations in heavy metal contents in roadside soils along a major expressway 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 analysed 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 a depth of 50cm-1m, whereas, mean values at 100 m away from the roadside were 4890, 217.86, 64.08, 87.13 and 3.05 mg/kg, respectively.

Mokokha et al. (2008) estimated the content of lead in water and soil samples around Lake Victoria, Kisumu, Kenya using atomic absorption spectrophotometer (AAS), which was found in the range of 140 to 260, 140 to 600 µL/L and 0.3 to 3.9 µg/g in tap water, surface water and soil samples, respectively. The authors correlated the presence of lead in soil and water samples to that of emissions from vehicles.

Hamurcu et al. (2010) determined the mineral and heavy metal levels of some fruits grown at the roadside in Turkey by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). The levels of Pb and Se were found

Table 1: Asian countries comparison of heavy metals Zn, Ni, Cd, Cu and Pb at roadside.

Asian Countries		Elements					Citation
Country	City	Zn	Ni	Cd	Cu	Pb	
Bangladesh	Dhaka	154	26	-	46	74	Ahmed (2006)
China	Baoji	715.1	48.83	-	123.17	408.41	Lu (2009)
China	Beijing	167	72	1.67	42	126	Han (2007)
China	Guangzhou	586	23	2.41	176	240	Duzgoren-Aydin (2006)
China	Hong Kong	168	-	2.18	24.8	93.4	Li (2001)
China	Hong Kong	3840	28.6	-	110	120	Yeung (2003)
China	Shanghai	733.8	83.98	1.23	196.8	294.9	Shi (2008)
China	Urumqi	294.47	43.28	1.17	94.54	53.53	Wei (2008)
China	Xian	421.50	-	-	94.98	230.5	Yongming (2006)
India	Calcutta	159	42	3.12	44	536	Chatterjee (1999)
Jordan	Amman	166-410	43-88	3.1-11.2	66.5-350	210-1131	Al-Khashman (2007)
Jordan	Aqaba	103-160	51-115	1.9-2.9	21-56	93-212	Al-Khashman (2007)
Jordan	Aqaba-Shuna	79	40	5	-	79	Howari (2004)
Jordan	Karak	13.1	4.2	-	11.3	11.2	Al-Khashman (2004)
Korea	Taejon	172-214	-	-	47-57	52-60	Kim (1998)
Pakistan	Islamabad	116	23	5	52	104	Tufail (2009)
Turkey	Istanbul	447-594	30-33	1.5-2.3	49-234	105-556	Han (2007)
Turkey	Kayseri	112	49.9	2.53	36.9	74.8	Tokalýoglu (2006)
Turkey	Sivas	206	68	2.6	84	197	Elik (2003)
Turkey	Tokat	60	54	1.63	38	45.1	Tûzen (2003)

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 as 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.

Malkoc (2010) studied the levels of heavy metal pollution in roadside soils of Eskisehir, Turkey. Fifteen soil samples were taken from three different lines: only - tramway lines, only - traffic lines, and both traffic and tramway lines and analysed 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 of the integrated pollution index (IPI) were found to be in the order of Pb > Zn > Cu > Fe > Mn > Ni > Cr > Cd.

Bakirdere et al. (2008) 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 Spectrophotometer (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.

Mmolawa et al. (2011) 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 sites studied 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 a high load of metal pollution as compared to GK and TS zones.

Khan et al. (2011) estimated the lead and cadmium contamination of different roadside soils and plants in Peshawar City, Pakistan. The different soil and plant (*Eucalyptus camaldulensis, Ficus elastica, Dalbergia sissoo and Alstonia scholaris*) samples were collected and analysed 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 was found to be *E. camaldulensis > F. elastic > D. sissoo > A.scholaris.*

Faiz et al. (2009) estimated the accumulation of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan from the dust and soil samples. The samples were analysed for five heavy metals using FAAS (flame atomic absorption spectrometry). The average concentration of Cd, Cu, Ni, Pb and Zn was 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.

Aslam et al. (2013) 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 analysed 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 was 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 the samples collected from the roadside having only one traffic signal was 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 was 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.

Wang (2009) 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.

Addo et al. (2012) analyzed the various heavy metals viz., As, Cr, Cu, Mn, Ni, Pb 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 Energy Dispersive X-Ray Fluorescence (EDXRF). The concentration of heavy metals studied, ranged from 0.4-18.2 μg/g for As; 284-9106 μg/g for Cr; 18.4-144.1 μg/g for Cu; 233-1240 μg/g for Mn; 12.3-493.2 for Ni; 3.1-67.8 μg/g for Pb; and 18.2-406.5 μg/g for Zn.

Naser et al. (2012) examined lead, cadmium and nickel in roadside soils and vegetables along a major highway in Gazipur, Bangladesh. The soil samples were collected at various distances viz., 0, 50, 100 and 1000 m from the road. Both soil and plant samples were analyzed for heavy metals using atomic absorption spectrometry. It was observed that there were significant differences in the concentrations of lead, cadmium and nickel for different plant species and soil sample at various distances. The order of accumulation of heavy metals was found to be nickel > lead > cadmium.

Masoudi (2012) observed the distribution of lead, cadmium, copper and zinc in roadside soil of Sari-Ghaemshahr road, Iran. The soil samples were collected at the distances of 4, 8, 16, 32, 64 and 100 m from the road edge of both sides of the road and analyzed for various heavy metals viz., Pb, Cd, Cu and Zn using flame atomic absorption. Three heavy metals excluding Cd were significantly different ($p < 0.01$) in the distance of 4 m. The concentration of Pb was found to be 2.95 mg/kg at 4 m, 1.76 mg/kg at 64 m. The concentration of Cu at 4 m of road was found to be 1.91 mg/kg which was decreased at 16 m distance (1.48 mg/kg) and then increased at 32 m (2.02 mg/kg) distance and 100 m (1.25 mg/kg). The concentration of Zn at 4, 8, 16, 32, 64 and 100 m distance from the road was found to be 3.66 mg/kg, 2.23 mg/kg, 1.37 mg/kg, 1.31 mg/kg 0.81 mg/kg and 1.13 mg/kg, respectively.

Zhang (2012) studied the influence of traffic activity on heavy metal concentrations of roadside farmland soil in mountainous areas of Trishuli city and Kathmandu, Nepal. About 342 topsoil samples from the depth of 0-5 cm were collected under dry weather and analyzed for various heavy metals viz., Pb, Cd, Cu and Zn by using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

Selection of common roadside 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 Pal et al. (2002) for the study as they were common along the roadside or on the road dividers at all the sites of the study at Lucknow, India. 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 (Neinhuis & Barthlott 1998, Meusel et al. 1999).

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. 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 roadside 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. 2 D-1, D-2) only striations could be seen under SEM. In *Cassia* (Fig. 2 B-1, B-2) epidermal cells at high polluted sites are also dust laden and disorganised as compared to the leaves of least polluted areas. In the case of trees (*Azadirachta, Ficus* and *Polyalthia*) (Fig. 2 A-1, A-2, C-1, C-2 and E-1, E-2) the epidermis shows less damage in comparison to shrubs. Araus et al. (1991) 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 (Black & Black 1979a, b). 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 (Squire & Mansfield 1972).

Stomata**:** Stomata of most of the species under study were either globosely, 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 (Lort et al. 1979). Among the gaseous pollutants, ozone is most harmful, affecting the stomata. It is generated by the action of sunlight on the vehicle exhaust gases and reaches concentrations of 200-300 ppb under appropriate weather conditions at many locations in North America (Vukorich et al. 1977), Europe (Harrison & Holman 1979) and other regions with high motor vehicle density.

Table 1: Summary of literature on heavy metals pollution in roadside soil samples.

S.No.	Heavy Metals	Location of study area	Instrument used	Results	Reference
1	Zn, Cr, Ni, Pb, Cu, and Cd	Roadside soil railroad side, Zhengzhou-Putian Section of Longxi-Haizhou Railroad, China	Pb and Cd by graphite furnace atomic absorption spectrometry (GF-AAS) while Cu, Zn, Cr and Ni by flame atomic absorption spectrometry (FAAS)	Content of metals were found in order: Cr >Cd > Pb > Zn > Ni > Cu.	Jian-Hua (2009)
2	Co, Ni, Cd, Cu, Zn, Mn, Fe, and Pb	Roadside Soils of Major streets, Jos metropolis, Nigeria	Atomic Absorption Spectrophotometer	Order of heavy metals found: Fe > Zn > Mn > Pb > Cd > Cu	Abechi (2010)
3	Sb, Ni, Zn, Cr, As, V, K, Pb, and Co	Roadside soil of Jeddah city, Saudi Arabia	Inductively coupled plasma-optical emission spectrometer (ICP-OES) and ICP-mass spectrometry (ICP-MS)	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.	Kadi (2009)
4	Pb, Cd, Zn, Fe, and Cu	Roadside soils along a major express way, south east Nigeria	Atomic Absorption spectrophotometer	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) At 100 m away from the roadside: Fe (4890), Cu (217.86mg/kg), Zn (64.08mg/kg), Pb (87.13 mg/kg) and Cd (3.05mg/kg)	Mbah (2010)
5	Pb	Tap water, Surface water, Vegetables and Soil samples, Kismu, Kenya	Shimadzu Atomic Absorption Spectrophotometer	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)	Mokokha (2008)
6	Se, Cu, Pb, Cd, Cr, and Ni	Fruits grown at the roadsides, Turkey	Inductively Coupled Plasma Atomic Emission Spectrometry	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)	Hamurcu (2010)
7	Cd, Cu, Cr, Fe, Hg, Mn, Ni, Pb, and Zn	Roadside soils of Eskisehir, Turkey	Inductively coupled plasma-optic emission spectrometer	The content of heavy metals was in order: Pb > Zn > Cu > Fe > Mn > Ni > Cr > Cd	Malkoc (2010)
8	Cd, Cu and Pb	Roadside soil and plant, Elazig, Turkey	Flame Atomic Absorption Spectrophotometer	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)	Bakirdere (2008)
9	Zn, Cd, Pb, Ni, Hg, Cu, As and Cr	Dust and soil, Kavala city, Greece	atomic absorption spectrophotometer	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)	Mmolawa (2011)

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10	Cd and Pb	Soils and plants, Peshawar City, Pakistan	Atomic Absorption Spectrophotometer	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)	Khan (2011)
11	Cu, Pb, Zn, Cd and Ni	Dust and soil, Islamabad Expressway, Pakistan	flame atomic absorption spectrometry	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)	Faiz (2009)
12	Fe, Mn, Cd, Zn, Cu, Pb and Ni	Roadside soil near different traffic signals *viz.*, near one traffic signal, near more than two traffic signal and near zero traffic signal, Dubai.	Atomic Absorption Spectroscopy (AAS)	At more than two traffic signal: Cd (0.17–1.01 mg/kg), Pb (259.66–2784.45 mg/kg), Cu (15.51–65.90 mg/kg), Ni (13.31 98.13 mg/kg), Fe (325.64–5136.37 mg/kg), Mn (57.95–166.43 mg/kg) and Zn (91.34–166.43 mg/kg) At one traffic signal: Cd (nd–0.80 mg/kg), Pb (145.95–308.09 mg/kg), Cu (0.82–18.04 mg/kg), Ni (18.29–59.36 mg/kg), Fe (88.51–3649.42 mg/kg), Mn (25.88–147.34 mg/kg) and Zn (8.97– 106.11 mg/kg) At no traffic signal: Cd (0.0–0.57 mg/kg), Pb (8.34–58.20 mg/kg), Cu (2.88–5.81 mg/kg), Ni (3.34–73.80 mg/kg), Fe (55.34–332.81 mg/kg), Mn (2.98–98.73 mg/kg) and Zn (1.23–46.6 mg/kg)	Aslam (2013)
13	Sb	Urban roadside surface soils of Xuzhou, China	Inductively Coupled Plasma Mass Spectrometry	0.96 mg/kg	Wang (2009)
14	Pb, Zn, Ni, Mn, Cu, As and Cr	Roadside soil sample, Ketu-South District, Volta Region, Ghana	Energy-dispersive. X-ray fluorescence (ED-XRF)	0.4-18.2 μg/g for As, 284-9106 μg/g for Cr, 18.4-144.1 μg/g for Cu, 233-1240 μg/g for Mn, 12.3-493.2 for Ni, 3.1-67.8 μg/g for Pb and 18.2-406.5 μg/g for Zn	Addo (2012)
15	Roadside soils and vegetables,Gazipur, Bangladesh	Cd, Ni, and Pb	Atomic Absorption Spectrophotometer (AAS)	The content of heavy metals was in order: Ni > Pb > Cd	Naser (2012)
16	Roadside soil, Sari-Ghaemshahr road in Iran	Cu, Zn, Pb and Cd	Flame Atomic Absorption	North road: Pb (2.95 ± 0.05 to 2.75 ± 0.03), Cd (0.11 ± 0.01 to 0.13 ± 0.02), Cu (1.91 ± 0.07 to 1.25 ± 0.04) and Zn (3.66 ± 0.05 to 1.13 ± 0.03) at 4 m to 100 m distance from road South road: Pb (7.83 ± 0.05 to 2.03 ± 0.01), Cd (0.16 ± 0 to 0.19 ± 0.01), Cu (3.59 ± 0.01 to 1.65 ± 0.11) and (3.55 ± 0.01 to 2.16 ± 0.01) at 4 m to 100 m distance from road	Masoudi (2012)
17	Soil, Kathmandu, Nepal	Zn, Cd, Cu and Pb	Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)	Cu (19.99 mg/kg), Zn (76.30 mg/kg), Cd (0.36 mg/kg) and Pb (22.57 mg/kg)	Zhang (2012)

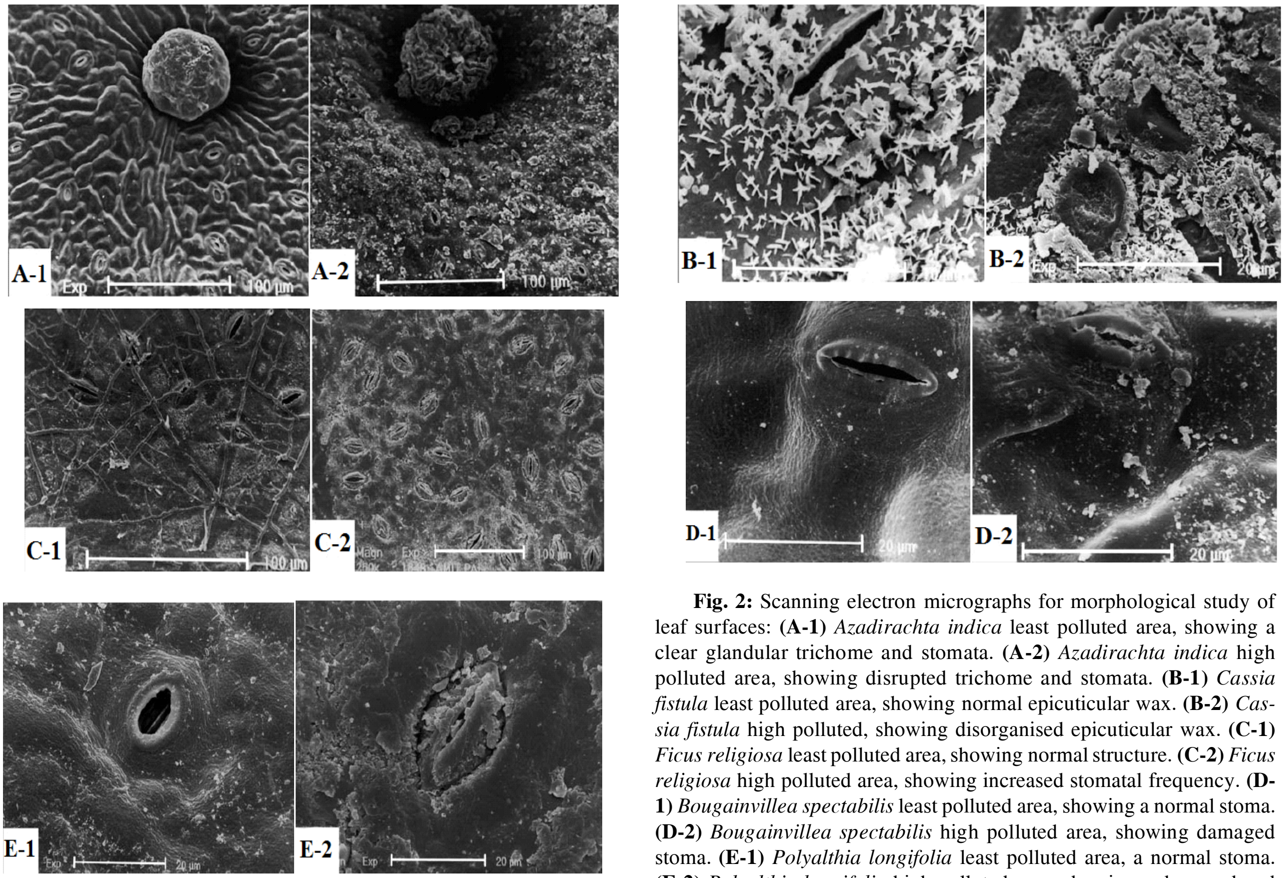

Fig. 2: Scanning electron micrographs for morphological study of leaf surfaces: **(A-1)** *Azadirachta indica* least polluted area, showing a clear glandular trichome and stomata. **(A-2)** *Azadirachta indica* high polluted area, showing disrupted trichome and stomata. **(B-1)** *Cassia fistula* least 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 (Pal et al., 2002).

***Cuticle*:** Cuticle surface structures of the studied plants are either rugose (*Cassia*) (Fig. 2 B-1, B-2), smooth or striated (*Polyalthia, Bougainvillea* and *Azadirachta*) (Fig. 2 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 (Percy et al. 1994). 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. 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. 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 in the 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 10-30 m distance from road/highways. Although the reports presented in the 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, strict guidelines should be laid and followed in order to reduce the pollution load.

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