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Heavy Metal Contamination of Soil Due to Road Traffic

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ABSTRACT: *Particles coming from the pavement's maintenance or from the traffic on it enter the soil carried by water. More pollutants transferred by air are dispersed in different distances, also polluting the soil. Precautionary and remedial measures are suggested for urban, peri-urban, and rural zones crossed by roadways, as a function of the plants' species and the level of the road. The proposed measures are based on the soil's chemical composition and draining conditions. Iron and the non-volatile heavy metals, copper, zinc, cadmium, lead, chromium, nickel, are often found in roadside topsoil, as well as in roots and leafage of vegetables and trees. Manganese is found in combination with iron in many minerals and not as free element. The reasons and frequency of existence of metals have to be examined so as to take measures against contamination and possible health hazards. Heavy metal concentrations of soils have been seldom studied in Greece and there is a lack of data sources for the environmental impact of these elements in soil and dust from the pavements and the traffic. The impacts of road construction and service on the surrounding soil masses are studied and analyzed in view of their quality as nutrient materials.*

Keywords: *environmental impact, heavy metal, pollution, road traffic, soil contamination*

I. INTRODUCTION

Modern demands for mobility of both freight and people, especially in urban areas, are fulfilled by transport activities which in turn have yielded growing levels of motorization and congestion. The most serious impacts of transport on the environment are associated to climate change, air quality, noise, water quality, biodiversity, land take, and soil quality. Soil erosion and soil contamination are the main forms of environmental impact of transportation on soil. When earth's surface material is removed for the advance of road building projects or at the cases of lowering of grades of the existing soil material for airport or harbour construction, there is an essential loss of productive and fertile soils. The use of toxic materials by the transport industry can result to soil contamination. Leaking out of oil or fuel from cars, trucks, buses, and motorcycles enter the soil since they are washed on the road sides [1-3].

Appraising total soil resistance to transport threats is necessary to take into account soil's resistance to every separate threat, as well as connections between its properties. The change of ground water conditions is considered as the relatively highest threat. The subsoil water level lowering is usually followed by negative effects appearing gradually and on the other hand soil flooding results in gley formatting that destroys soil irreversibly. The accumulation of heavy metals, especially cadmium compounds, is a large threat also. These pollutants are of significant environmental concern, because they do not biodegrade while their half-lives in the soil are long. This behaviour predicates extensive effects on biological systems which include soil micro-organisms and other soil biota. However, zones of elevated concentrations of heavy metals compounds are not very wide (~50 m from the roadway's edge). Therefore, it is safe to use grass for feeding animals or to eat vegetables grown at distances more than 50 metres from the edge of roadways.

It is a usual practice to take samples from depths varying from 0-5 cm through 10-15 cm to 15-20 cm in order to assess the effects that could be brought about by heavy metal accumulation in soils due to traffic flow and other vehicle activities related pollution. The ratio between mean concentration of a selected heavy metal in surface and depth 15–20 cm samples is called enrichment ratio. Its mean value has been found to be 2.34 for soils and 2.0 for sediments. The higher enrichment ratio in soil samples than in sediment samples is attributed to the action of organic matter in heavy metal absorption beside clay minerals. Abundance of clay minerals and medium to alkaline pH causes low mobility of heavy metals in soils in the region [4].

Plants usually accumulate automobile-emitted heavy metals through foliar absorption or root uptake. Soil, especially around the heavy traffic areas, can also accumulate emitted compounds in the atmosphere. Both surface and underground waters are receivers of heavy metals. In the first case, water sources are the runoff from the city streets and highways as well as collected snow from cities and highways dumped into lakes and rivers. Underground waters are contaminated by leaching of soluble metal compounds.

Heavy metal compounds reaching the soil surface could trigger various chemical reactions, thus achieving equilibrium of different forms [5]. Accumulation of heavy metal compounds around the roadways is dependent on several factors including:

- average daily traffic (ADT) or traffic volume [6-10],
- distance from the road [11-13],
- depth of the soil profile [14-16],
- prevailing wind speed and direction [17, 18],
- length of exposure time or age of the road [19, 20],
- type of driving, whether freeway or city [21, 22], and
- vehicle age and speed [21]

Several other factors also affect the heavy metal contents of soil and plants along roads:

- the method of soil engineering applied during the road construction,
- the use of metal-containing pesticides to protect roadside grasses and trees, and
- the presence of local industries that discharge metals into the air as fumes or dust [23, 24].

Some impacted species of vegetation and fauna near highways by heavy metals are shown in Table I.

Table I: Heavy metal concentration impacting vegetation and fauna near highways

Impacted item	***Distance (m)***	***Overall mean levels (mg/kg)***						***Ref.***
		Cr/Mn	***Pb***	***Cd***	***Ni***	***Cu***	***Zn***	
Vegetation								
Grass, low-growing weeds, leaves: pumpkin, tuber (cassava) and grain	1.5	2.6±0.13	243±13.6	1.7±0.09	3.3±0.15	18.7±0.8	47.8±2.7	[25]
	1.5 washed	0.92±0.06	86±3.6	<0.2	1.6±0.08	7.7±0.33	34.2±1.3	
	50	0.73±0.03	4.1±0.2	<0.4	1.1±0.12	9.1±0.51	11.7±0.6	
Loliurn .sp.	1.0	/ 23.2-37.2	0.9-13.2	0.02-0.52		7.3-13.7	13.7-19.2	[26]
Loliurn .sp.	1.0	/ 14.6-60	1.6-11.7	0.12-0.64		8.8-15.5	18-130	
Loliurn .sp.	4.0	/ 29.7-197.2	1-3.8	0.04-0.17		4.7-19.0	17.4-29.2	
Loliurn .sp.	4.0	/ 20.8-212.6	1.6-4	0.13-0.25		5.4-19.3	16.2-54.9	
Trifolium repens roots/ leaves/ stolons		3.9				60.6		[27]
		3.8				50.4		
		3.4				43.9		
Lolium perenne Roots/ leaves		5.8				28.8		
		2.3				20.8		
Poa annua L. Roots/leaves		1.1				22.0		
		3.9				31.2		
Holcus lanatus L Roots/leaves.		2.9				25.6		
		2.3				27.3		
Plantago, Bellis, Crepis Roots/leaves		2.2				27.0		
		1.7				22.6		
Bellis perennis L. Roots/leaves		0.9				9.2		
		1.6				18.3		
Paspalum dilatatum L.		1.7				18.0		
		1.0				18.3		
Dactylis glomerata L. roots/leaves		2.2				28.8		
		1.9				15.6		
Grass	8		68.2	0.95	5.00		32.00	[5]
	16		47.5	0.73	3.80		28.50	
	32		26.3	0.50	2.80		27.30	
Olea europaea	1	/ 26±2	148±13	0.7	4±0.9	11±1	41±3	[28]
	20	/ 15±3	38±6	0.6±0.1	2±0.1	5±1	16±3	
	50	/ 16±1	24±3	0.5±0.1	0.92	5±0.7	12±1	
Citrus limon	1	/ 8±0.1	23±2	0.6	2±0.2	7±0.3	25±3	
	20	/ 10±0.5	15±2	0.6	1.2	6±0.4	20±0.4	
	50	/ 11±0.1	10±0.6	0.7	1.5±0.1	6±0.5	26±1	
Lagenaria siceraria	0-1,000		3.43-1.71	0.18-0.13	49.0-21.9			[29]
Cucurbita moschata	0-1,000		4.76-1.65	0.20-0.15	30.7-22.9			
Cynodon dactylon		/22-174	14-463	0.09-1.46		3-47	43-276	[30]
Amaranthus dubius			3.85-13.0	0.50-1.60			23.8-74.3	[31]
Lycopersicon esculenta			0.19-15	0.06-1.00				
Phaseolus vulgaris			2.0-7.8					
I95	6-48		286.97-84.92	0.98-0.93	2.55-3.03		219.08-63	[32]
Fairfax US 240	6-48		147.36-57.39	0.48-0.19	1.66-1.86		81.20-52.15	
Va 114	3-48		33.26-10.57	0.26-0.62	1.99-1.13		55.05-38.95	
Va 42	3-48		13.91-6.6	0.50-0.25	1.42-1.43		45.20-32.93	
Ioannina, GR		0.027-0.36	0.002-0.41	0.001-0.052	0.02-1.68	0.11-4.12	0.21-8.42	[33]
Preveza, GR		0.030-0.88	0.002-0.33	0.001-0.073	0.02-1.05	0.13-4.34	0.34-9.30	

Table I: (cont.)

Impacted item	*Distance (m)*	*Overall mean levels (mg/kg)*						*Ref.*
		Cr/Mn	*Pb*	*Cd*	*Ni*	*Cu*	*Zn*	
Mammals								
I95			21.96-72.56	0.16-1.71	1.00-2.47		99.26-139.20	[32]
US 460			13.38-35.13	0.06-0.54	0.45-1.63		84.98-135.06	
Va 114			5.24-12.03	0.11-1.09	0.23-2.16		50.84-146.18	
Va 42			1.85-4.40	0.15-0.29	1.34-1.53		97.52-109.08	
Nematodes								
Shen Ha Highway	5-320		44.73-82.12			20.42-27.41	92.27-150.18	[34]

II. ROADSIDE SOIL POLLUTION BY SOURCES OF HEAVY METALS

The main processes through which vehicles spread heavy metals (Pb, Zn, Cu, Cd, Ni) into the environment are combustion processes, the wear of cars (tires, brakes, engine), leaking of oil and corrosion. Tyre wear has been reported as a source of manganese (Mn) from road traffic [35, 36]. Manganese and copper are contained in different components of vehicle engines, chassis and piping system while chromium and nickel (also coming from combustion of lubricating oils) are used in chrome plating. Nickel is also emitted from the nickel added to gasoline and Ni-containing parts of automobiles [37].

Most of the added lead is released in combustion of leaded petrol, zinc is derived from tire dust, galvanized parts of vehicles, or lubricating motor oils, copper is derived from brake abrasion and corrosion of radiators, and the other heavy metals have mixed origins [28, 38].

In order to investigate the effect of heavy metals ending up to adjacent land from a highway facility in Northern China (Shen-Ha highway) on soil nematode guilds, Han and his colleagues [34] collected soil samples at distances of 5, 20, 40, 80, 160, and 320 m from the highway. Thirty six genera of soil nematodes belonging to 23 families were identified and classified to four types based on their response to soil heavy metals. Soil nematode guilds may operate as a major indicator to heavy metal pollution of road construction and operation origin. The analysis had shown that the contents of total and available Pb, Cu, and Zn varied significantly with the distance from the road edge, with Pb being the main pollutant. The most polluted area was the zone between 20 and 40 m away from the highway.

Particles originating from pavement construction and maintenance or from the traffic enter the ground transferred by the water. Other types of particles are transferred by the wind and spread in various distances, polluting the soil [11]. Heavy metals like lead, zinc, nickel or cadmium are among elements for which special caution is required. According to data presented in a transport experts meeting [2], engine oil has a large share (83%) in Cd found in roadside soils and is responsible for the 33%, 28% and 25% of Cr, Zn and Ni, respectively. Chromium (12%) and Ni (11%) are prevailing species in emissions caused by pavement abrasion. Most important emissions from tyre wear had been recorded for Se (58%), Zn (33%) and Ni (15%). Brake wear is the most important source of emissions [39] and values found for Cu, Pb, As, Ni, Zn, Cr, and Se were 100%, 96%, 82%, 46%, 39%, 37%, and 40%, respectively.

The traffic on highways and the road maintenance works induce heavy metal pollution in roadside soil and grass as well as in the runoff water. Due to wind dispersion, these pollutants could be deposited onto soils or be dispersed into the atmosphere as has been shown by investigations alongside rural highways, especially zinc, since galvanized crash barriers constitute a source of zinc pollution, followed by Pb which is characterized by high bioavailability in polluted soils and Cu. Pollutant concentrations in soils decrease rapidly with distance from the roadway. Pb concentrations in the soil in different distances from the pavement depend on the particle size; hence, the wind can carry them in large distances. Nevertheless, except the case of prevalence of vigorous winds or local atmospheric inversions, significant concentrations are presented in distances between 0.5 and 50.0 meters from the pavement and heavy metal concentrations in the ground beyond 10 meters are negligible [40, 41]. In Table II, international reference values for soils are presented referring to heavy metals (Cd, Cr, Cu, Ni, Pb, Zn, As).

Heavy metal accumulation and distribution patterns in farmland soil due to traffic activity could be different on mountainous roadways, from those on plain roads, as Zhang et al. [21] have shown. A study on a mountain roadway around Kathmandu, Nepal, was based on miscellaneous design factors (altitude, roadside distance, terrain, and tree protection) and focused on the influence of Cu, Zn, Cd, and Pb concentrations in farmland soils along a mountain roadway. The findings showed no serious roadside pollution due to traffic emissions. However, some spots had high concentrations of Zn, Cd, and Pb, close to or higher than the tolerable level. Pb concentration in the downgrade roadside soil was lower than that in the upgrade soil, while the Zn concentration soil was marginally lower in the upgrade soil. The concentrations of Cu and Pb in the roadside soils with tree protection were lower than those in soils without tree protection. Within a range of 100 m, the attenuation pattern of heavy metal concentrations -as a function of roadside distance- couldn't be identified consistently.

Table II: Normal range of heavy metals in natural soil and Dutch value for good soil quality [42]

	Range in natural soil (mg/kg)	*Normal level in good soil (Dutch standard) (mg/kg)*	*B value (maximum allowable level) (mg/kg)*	*C value (needs soil decontamination measures)*
Cd	0.01-0.70	0.8	5	20
Cr	1-1000	100	250	800
Cu	2-100	36	100	500
Ni	7-4.280	35	100	500
Pb	2-200	85	150	600
Zn	10-300	140	500	3000

III. HEAVY METALS EVALUATION IN SOIL THROUGH DIFFERENT METHODS

Criterion for the choice of a procedure for the evaluation of heavy metals in the roadside soils is the effectiveness of different methods. There are various methods mostly known by their abbreviations: PW -heavy metals in pore water, DGT- diffusive gradients in thin films, DTPA -diethylene triamine pentaacetic acid extraction, THM- and total heavy metals in soil. The assessment of heavy metal bioavailability from soils having various properties and heavy metal contents could also be made with other practical methods [43].

DTPA has been used in order to evaluate heavy metal availability in different kinds of soil and grass. Lindsay and Norvell [44] working with neutral and calcareous soils deficient in trace metals proposed DTPA soil test. Then, the use has been broadening to other types of soils, even those contaminated by different sources [33, 45, 46]. With the use of atomic absorption spectroscopy, the total (soil and grass) and DTPA-extractable (soil) contents of Cd, Cu, Fe, Mn, Pb and Zn can be determined. The metal contents in road soils and grasses confirm the effect of traffic as a source of pollution. The most remarkable influence has been shown in soil, since it accumulates metals on a relatively long-term period [26].

The determination of the speciation of trace elements in dusts is hardly achieved and various problems arise during the procedure, such as the relatively low concentration of the elements, as well as the interpretation of the results from selective sequential extractions [47-49]. The most common method to approach the trace metal content in dust has been the comparison of individual element concentration against some known source. If the concentration decreases with distance, then the proposed source is evidenced. Another approach is based on the use of statistical techniques and source-receptor models to analyze multi-element data. Four main types of sources are recognized: weathered materials, industrial, road traffic, and specific intermittent episodes [50]. When trends in concentrations of individual trace elements in street dust are studied in order to establish their sources, the main focus are pollution elements. Automobiles are considered as the principal polluting source of many trace elements, mainly Pb, Cd, Cu, Zn, Fe, Cr, and Ni.

Lead comes from the lead in petrol, whereas the other elements come from wear and tear on the car, such as Zn and Cd from tyre wear. Evidence for the source derives from trends in concentrations with traffic density [31, 51-53] distance from roads [54, 55], urban and suburban differences [56, 57] and the mode of traffic movement [58]. The primary methods of analyzing lead in environmental samples are AAS (atomic absorption spectrometry), GFAAS (graphite furnace atomic absorption spectroscopy), ASV (anode stripping voltammetry), ICP/AES (inductively coupled plasma/atomic emission spectrometry) and XRFS (X-ray fluorescence spectrometry).

Usually, cadmium in environmental samples is analysed by AAS or AES techniques. Samples are prepared by digestion with nitric acid. Since cadmium in air is usually associated with particulate matter, standard methods involve collection of air samples on glass fiber or membrane filters, acid extraction of the filters, and analysis by AAS. ETV-ICP-MS (electrothermal inductively coupled plasma mass spectrometry) is also been used to analyse atmospheric particles for cadmium. The accuracy of the analysis of cadmium in acid digested atmospheric samples, measured by ACSV, was evaluated and compared with graphite furnace atomic absorption spectrometry (GFAAS) and inductively coupled plasma mass spectrometry (ICP-MS) [59, 60].

Methods used to detect nickel in environmental samples are AAS, either flame or graphite furnace, ICP-AES, or ICP-MS [61], while total chromium concentration can be analyzed by flame AAS and or AAS/ETA techniques.

Additives in unleaded petrol, as methyltertiobuthylether, ethyltertiobuthylether, and methyltertioamylether (MTBE, ETBE and TAME), or platinum of catalytic silencers are candidate substances for soil contamination with road transport origin. At the same time, lead levels tend to decrease, because unleaded petrol is increasingly used. Therefore, scientists have to seek for tracers in order to assess the size of the contamination. Heavy metals are also released due to weathering of road surface asphalt and corrosion of crash barriers and road signs [62]. Studies on heavy metals have shown that the concentrations in the soil are closely related to vehicle's traffic in road's vicinity, as well as to the distance from the road. The way pollutants are spread is highly dependent on the quantity and time distribution of rainwater and on the other hand on the quality of road surface material (dense asphalt concrete or porous asphalt). When porous asphalt is used, some contaminants fill the pores. Heavy metals are attached to particles and for the most part remain in the pavement's surface.

In Dubai, United Arab Emirates, samples from 11 sites near traffic signals and 11 sites without any traffic signal were collected and analyzed for seven heavy metals by Atomic Absorption Spectroscopy (AAS) following the acid digestion of the soil samples [63]. Lead, the origin of which had been attributed to vehicular exhaust, was in high concentration, while the other six metals (Cd, Cu, Ni, Fe, Mn and Zn) were present at normal levels. Three monitoring sites yielded values which suggest that automobiles are a major source of heavy metals for the roadside environment.

Metals such as Fe, Cu and Zn are essential components of many alloys, pipes, wires and tyres in motor vehicles and are released into the roadside environment as a result of mechanical abrasion and normal wear and tear. Bermuda grass (*Cynodon dactylon*) grown alongside roads in Hong Kong was chosen for study [30]. Elevation in the levels of Pb, Cu, Zn, Fe, Mn and Cd in roadside soil and grass were found and the amounts of metal contamination were positively related to traffic volume. The levels of metals found in both soil and grass may be used to reflect the extent of aerial deposition of metals in the roadside environment.

Routes through which heavy metals enter plant, animal and human tissues are air inhalation, diet, and manual handling. Pollutants can be transferred to plants from the ground. The concentrations are increasing and ultimately pass to the food chain, accumulating to animals meat sometimes in dangerous for human health levels. Motor vehicle emissions are a major source of airborne contaminants including arsenic, cadmium, cobalt, nickel, lead, antimony, vanadium, zinc, platinum, palladium and rhodium [64]. Groundwater and other water sources can be polluted by heavy metals leaching from roadway structures. Acid rain can release heavy metals trapped in roadside soils, thus exacerbating the contamination process. Taking water, plants are exposed to heavy metals; plants are eaten by animals. Ingestion of plant- and animal-based foods brings heavy metals to human tissues.

Since metals are elements, they do not degrade. Organisms exposed to high levels of metals have mechanisms to sequester and excrete metals [65], unless the concentrations are higher than usual and metals cannot be excreted quite rapidly in order for damage to be prevented.

There are certain relationships between contaminants which can be revealed if multivariate statistical analysis is performed. In such an effort, Odat [66] determined the heavy metal accumulation in twenty one soil samples from sediments. Odat used atomic absorption spectrophotometric method as well as multivariate statistical techniques to identify the origin of Fe, K, Mg, Mn, Na, Cu, Pb, and Zn. It was concluded that the level of contamination was low and it was found that significant correlation existed only between Cu, Mn and Zn.

Cadmium and zinc come from lubricating motor oils (as antioxidant, Zn, and Cd dithiophosphate), tyres (as Zn and Cd oxide and Zn and Cd diethyl and dimethyl carbonate in vulcanization), and galvanized parts of vehicles such as galvanized tanks. Although the wear-and-tear of tyres is recognized as a major source of cadmium alongside roadways, a study by Akan et al. [67] suggested that the combustion of fuel (especially diesel) and oil/lubricants, which are known to contain trace levels of cadmium, may be a significant source of Cd as found in roadside soil. Cadmium is a cumulative poison posing problems for humans and preferably accumulates in the kidneys. In urban environments, serious health risk could arise by the highest levels of Cd in the roadside soil closer to the highways, because the small particles have the potential to be taken up by the lungs. The Pb/Cd ratio in plants, taking it from the ground, is reduced as the concentration in them increases. That is, plants prefer the cadmium concentrations [31]. The ratio is even smaller for humans. So, in extreme cases, it is possible to cause poisoning (the deathly dose to humans is about 400 mg).

Chromium is a heavy metal (microtrace element) required for sugar metabolism of human. Although chromium in elemental form occurs in nature very rarely, many minerals contain chromium in chromite form or in complex with other elements. That is why the element chromium is ranked seventh in abundance on Earth [68]. Lead's isotopic composition in grasses has been shown to be similar to that of the surface soil alongside roadways [5], indicating that grasses derive their lead from the surface soil and not from layers below.

The quality guidelines for plant and soil heavy metal concentrations developed in various countries indicate wide variations. The natural heavy metal content of soil is strongly related to the composition of the parent rock. The mean lead concentration for surface soil on the world scale is estimated as 25 parts per million (ppm) with the upper limit at 70 ppm. Mean total zinc and copper contents in surface soils of different countries range from 17 to 125 ppm and 6 to 60 ppm, respectively. Soils throughout the world contain nickel within a broad range (1 to about 200 ppm). The background cadmium levels in soils do not exceed 0.5 ppm, while the calculated mean of nickel for world soils is 20 ppm [69]. Because of the severe adverse environmental and/or ecological and health effects of heavy metals, there have been many studies on heavy metal contamination in soils along major roads. The results of various researchers are comparable, as shown in Table III.

In Greece, heavy metals and toxic trace elements have been investigated (a) in soils of selected areas of the Kavala prefecture [72] and in Ermoupolis, the Capital of Syros Island [45] and (b) in street dusts from two of the Greece's busiest cities, namely Thessaloniki [73, 74] and Athens [75-78].

Table III: Heavy metal concentrations in roadside soils and dusts

	Distance	Depth	Overall mean levels (mg/kg)					Ref.
	(m)	(cm)	Pb	Cd	Ni	Cu	Zn	
Gazipur, Bangladesh	0-1,000		20.8-13.0	0.29-0.23	36.3-25.9			[29]
	0-1,000		23.3-11.6	0.32-0.20	39.1-25.2			
I95	6-48		735.82-81.42	0.71-0.30	4.53-1.76		151.70-18.91	[32]
Fairfax US 240	6-48		140.44-55.84	0.40-1.10	4.83-2.47		72.38-24.78	
Va 114	3-48		307.62-15.00	0.32-0.47	9.22-1.37		56.94-14.82	
Va 42	3-48		30.58-19.77	0.73-0.33	4.03-3.74		36.48-29.82	
Ioannina, GR			5.2-25.3	0.10-0.16	0.20-0.81	1.1-17.8	7.8-19.0	[33]
Preveza, GR			6.1-15.2	0.04-0.36	0.05-0.47	1.9-18.2	2.8-24.4	
Kathmandu, Nepal	0-100		10.4-34.75	0.25-0.54		17.08-24.66	38.78-97.63	[21]
Istanbul E-5 Highway	0-1,000		61.40-555.40	0,80-6.70	10.43-65.7	47.3-1358.5	190.9-1,852.0	[70]
Hong Kong	3	0-2	50-2,215	0.23-2.31		8-285	84-1,445	[30]
Toronto								
Highway 400	0-3		118.3-205	0.47-0.50	34-80	53.9-286.1	39.3-1,367	[47]
Highway 401			32.5-378.7	0.46-0.95	32-327	113.6-392.1	81.3-366.8	
Highway 404			124.7-212.2	0.48-0.56	16-62	76.2-230.3	56.8-290.9	
Don Valley PW			105.2-321.8	0.48-0.54	33-110	106.1-249.5	85.3-342.7	
Dubai, UAE Roadside	5	0-5	6.92-113.26	0.39-0.93	3.34-73.80	0.94-5.81	1.23-46.6	[63]
Dubai, UAE One signal	5	0-5	145.95–308.09	0.00–0.80	18.29–59.36	0.82–18.04	8.97–106.11	
Dubai, UAE >2 signals	5	0-5	259.66–2784.45	0.17–1.01	13.31–98.13	15.51–65.9	91.34–166.43	
Thrace Region	>50	0-10	4.8-968	0.03-0.17	2.6-249	1.8-167	6-165	[71]

IV. PROTECTIVE MEASURES AGAINST SOIL POLLUTION RELATED TO TRAFFIC AND ROADSIDE CONDITION

Adequate protection and restoration of soil ecosystems contaminated by heavy metals poses a requirement for a comprehensive soil characterization and the implementation of improved remediation strategies. Remediation of heavy metal contaminated soils would be based on data referring to the source of contamination, the basic chemistry, and environmental and associated health risks of the heavy metals [79]. The protective measures against soil contamination may be distinguished in preventive and curative [80]. The control of the number of vehicles has to be a goal for the near future. Since contamination induced by traffic is a main source of metals in urban areas, restricting the number of vehicles will be an effective measure for the decrease of pollutant metal discharge.

Plants in the roadside area can help reduce heavy metal pollution. This intervention is often called phytoremediation [81] and has relatively low cost (less than excavation or in situ fixation) while widely accepted [82]. It can be less than a quarter of the cost of excavation or in situ fixation. Phytoremediation, chemical remediation and physical remediation are technologies that could be adopted, but further work is needed to distinguish which method is effective for the soils in a given area.

As a protective measure, olericulture cultivations should be avoided within a distance less than 10 metres from the road, when this is in embankment or in the same grade with the natural soil. The use of plants growing within a distance smaller than 10 meters from a heavily trafficked road should strictly be avoided for animal feeding. This holds true for pastures or meadows, as well as for forage from slope production or road's central islands. Curative measures could be described as follows:

- In the case of exceptionally sensitive zone and for its protection the creation of a coppice type (silvicolous) hedge, with a height equal to the slope's height, when the road is on an embankment, with a minimum height of 2 meters.
- For the creation of the abovementioned hedges in urban or suburban zones, the planting of plants bearing up the pollution is preferred, avoiding plants with continuous leafage as well as plants with smooth and spoil leaves, more sensitive in the accumulation of dust.
- Phytoremediation has been considered as a promising new countermeasure for in situ cleanup of heavy-metal contaminated soils [83, 84]. Some of the possibilities for phytoremediation are via phytoextraction, rhizofiltration, phytodegradation, phytostabilization, and phytovolatilisation, that is, detoxification of soils by plants able to produce volatile compounds.

High priority must be given to legislation work on metal contamination control in an effort to strengthen the prevention of the emission of heavy metals in the environment. The analysis of data measured by Zhang et al. [21] indicated that trees planted along roadways can reduce the concentration of heavy metals in the roadside farmland in a very effective way. Therefore, planting trees close to roadways is an effective countermeasure. In the previously mentioned study it was also verified that heavy-metal concentrations in the rural farmland soils consistently decrease with the distance from the roadside. Normally, the heavy metal content in roadside soils has a belt-shaped distribution in terms of distance to road edge, decreasing exponentially with the distance from the road [85]. These two findings differ due to lower traffic volume on the Highway in the 2012 study. To more realistically describe the distribution of heavy metals in roadside farmlands, the sampling must be more exhaustive sampling in the first 10 m from road edge.

At the construction site any toxic material must be properly stored and disposed. When leaving a construction site, vehicles and machinery have to be washed to remove excess mud. Temporary auxiliary exit and entry roads to plants and worksites with a coarse rock surface should be chosen, in order to prevent the transfer of soil offsite where it can clog drainage channels. In order to prevent soil and water bodies to be contaminated by fuel and lubricants, the operation, maintenance and refuelling of equipment and vehicles must follow some official guidelines. Such provisions could include the location of fuel storage areas at least 300 meters from all structures used for drainage purposes, or the disposal of any collected petroleum products as it is specified.

V. CONCLUSION

Due to large number of motor vehicles on Greek roads, and as a consequence of commercial and industrial activities, considerable amounts of some heavy metals are likely to be emitted regularly as long as the nearby sources remain active. Because very limited information is available in Greece on the level of heavy metal accumulation in roadside soil and vegetable crops due to highway traffic, there is a need for research in this domain. The concentration of soil pollution is dangerous both for the agricultural products, directly taken by humans, and for fodder ending up again to man via animals meat.

Pollutants, particularly lead and zinc, accumulate in the roadside soils and are absorbed by invertebrate macro-fauna and vegetation. The general decrease in concentrations of heavy metals with distance from the road, with depth in the soil profile, and the general increase in concentrations with traffic density indicates their relation to traffic. With the increasing use of unleaded petrol, the lead levels tend to decrease regularly and therefore another tracer should be identified in order to assess the road transport contamination. Lead seems to be the most adapted tracer of highway contamination. The plant bioaccumulation results enable researchers to understand the metal bioavailability in the environment.

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