Impact of road runoff in soil and groundwater.
Synthesis of Portuguese and other European case-studies

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Abstract Road circulation is capable of producing compounds that can pollute the environment. The level and type of emissions depend on several technical aspects that can be related with the road design and the vehicle engineer (size, type of fuel used), as well as with operational factors that are related with the way that the vehicle is used.
The compounds emitted come from the fuel combustion, vehicle compounds use, road accessories (like lateral crash barriers) degradation, road degradation, maintenance procedures (application of chemicals), leakage, and accidents.
In this paper a synthesis of soil and groundwater pollution by heavy metals in the vicinity of roads is presented. The results are based on data collected by LNEC as well as other data gathered in published papers, summing more than three dozens of case-studies in 10 different European countries.
The objective of this analysis was to compile as much information as possible about road pollution by heavy metals in soil and groundwater, in order to be able to have a general overview for Europe of the effective degree and extension of road pollution, independently of the different conditions specific of each study area.

Key Words: road pollution; soil; groundwater; European case-studies.

INTRODUCTION

Traffic is a source of diffuse pollution with impacts in the environment that need to be prevented or minimised. Cars, lorries, motorcycles, among other vehicles, are emitting heavy metals (Pb, Zn, Fe, Cu, Ni, Cd, Hg, Cr), hydrocarbons (PAH, oil, fuels), nutrients (N, P), particulates (clay and soil particles) and other organic matter (dust, dirt, humus) into the environment (Table 1).

Table 1 Overview of pollutants originating from roads and traffic and their main sources (adapted from Gupta *et al.*, 1981a; Luker and Montague, 1994, and Leitão *et al.*, 2000)

Type of pollutant	Source of pollution
Heavy metals	Tyres and brake pads, fuel, motor oil additives, rust, crash barriers
Cadmium	Tyres, brake pads
Chromium	Bearing, tyres, brake pads
Copper	Tyres, brake pads, radiators
Lead	Fuel, tyres, brake pads
Zinc	Lubricating oils, tyres, brake pads, crash barriers
Hydrocarbons	Oils, fuels, exhaust emission
PAHs	Fuel, plastics, pavement
Nutrients	Fertilizers, motor fuel & oils, exhaust emission
Organic matter	Vegetation, litter, animal droppings
Salts	De-icing and fertilizers
Microbe	Soil, litter, excreta, livestock movements
Particulates	Tyre, brake & pavement wear, mud & dirt accumulated on vehicles

The quantification and control of diffuse pollution sources is a requirement of the Water Framework Directive, which states that member-states should address the water policy issues in a coherent, holistic and sustainable approach. The mechanisms and pathways through which diffuse pollutants from roads move through the environment are important considerations in planning and targeting prevention and control measures.

The results presented hereinafter are a part of the information collected in case studies analysed in LNEC since 1997, in the framework of EU studies, together with other information collected in published papers. They refer to the knowledge gathered for the case of heavy metals pollution dispersion in soils and water, in more than 3 dozen of case-studies, in 10 different European countries.

IMPACTS OF HEAVY METAL ROAD POLLUTION IN THE SOIL AND WATER

The majority of studies on heavy metals in road runoff have concentrated on lead, cadmium, copper, zinc and iron. Some studies have also included nickel, chromium and manganese. The more unusual metals, such as titanium, vanadium, cobalt, arsenic, molybdenum, tin, tungsten and antimony, are occasionally mentioned as trace constituents (James, 1999).

Metals in runoff can be attached to inert sediments, or be contained in immiscible fluids, or occur as particles, soluble salts or insoluble compounds. Chemically they can be organic or inorganic, compounds or complexes, and can usually exist amongst a variety of ionic species depending primarily on the prevailing redox and pH conditions.

Soil is the media where the road pollution history is kept. Groundwater is a more hydrodynamic media, subject to higher quality fluctuations over time, depending on permeability properties of the media as well as chemical properties such as pH and CEC.

Heavy metals can be harmless in minute quantities. However, at high concentrations biological life can be threatened. The following text presents some of the results gathered for the studied heavy metals.

Cd is a very mobile element and the metal that more easily desorbs by ionic exchange processes (Harrison *et al.*, 1981; DWW, 1995; Reinirkens, 1996; Leitão *et al.*, 2000, Pagotto *et al.*, 2001 & Diamantino, 2002).

The presence of Cd in soil and groundwater close to the roads is usually low, in concentrations lower than the intervention[1] and VMA[2] defined, respectively. Nevertheless, its presence due to road effects is clear (Fig. 1). In most case-studies the Cd concentration decreases with distance to the road, and in several cases also with depth

[1] For soil, the quality values used are defined in Dutch legislation (MHSPE, 1994) as target and intervention
[2] For groundwater, the quality values used are defined in Portuguese legislation (DL 236/98, 1998) as recommended (VMR) and admissible (VMA)

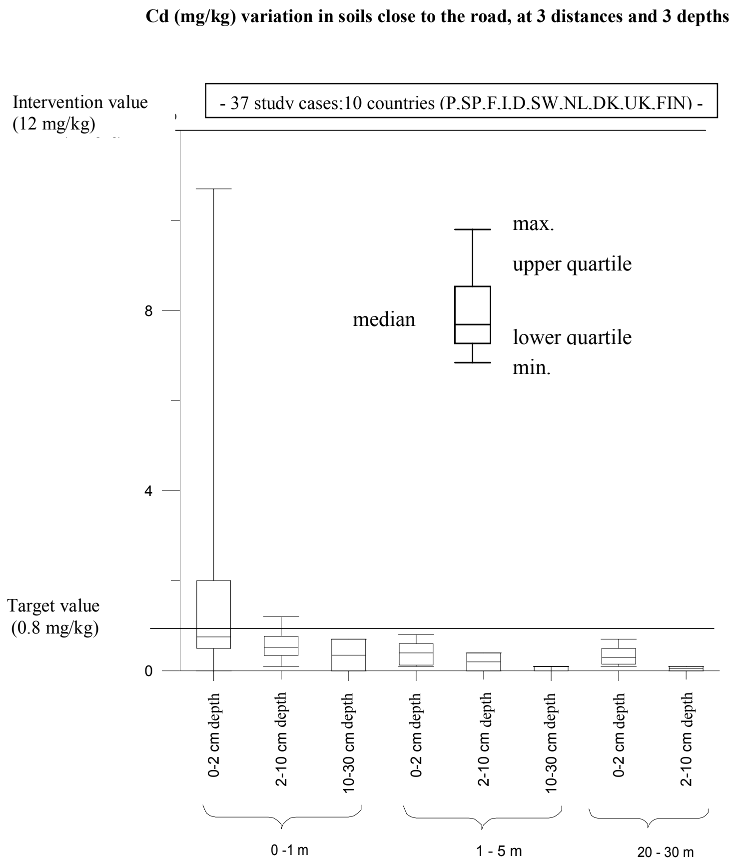

Fig. 1 Cd variation in soils close to the road, at 3 distances and 3 depths

Cd presence can also be observed in the groundwater and interstitial water in the vicinity of roads. It is possible to observe clear variations along the time and with distance to the road, due to its high mobility, with some few samples exceeding the target value (Fig. 2). It is possible to notice an increase of concentration after rain events.

Cd concentration in the road vicinity is not high once its initial amount in road dust is low. Therefore, even if there are changes in the soil conditions (*e.g.* pH decrease) that promote Cd mobility, it is not likely to find high Cd concentrations. Nevertheless, it is important to be acquainted about Cd toxicity at very low levels and about its cumulative characteristics.

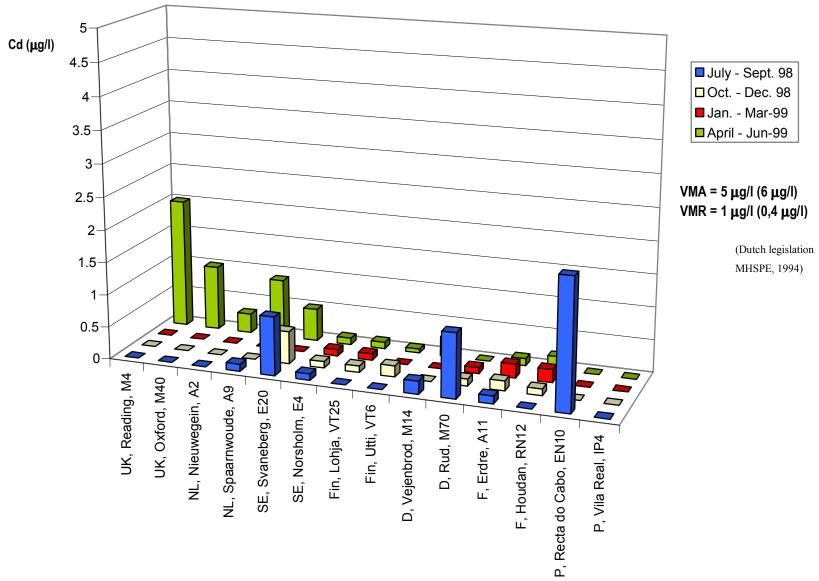

Fig. 2 Cd concentration in groundwater

Cr is a metal that tends to accumulate in the soils due to its low mobility. Its presence in areas far from the road denotes atmospheric pollution (Ward, 1990a).

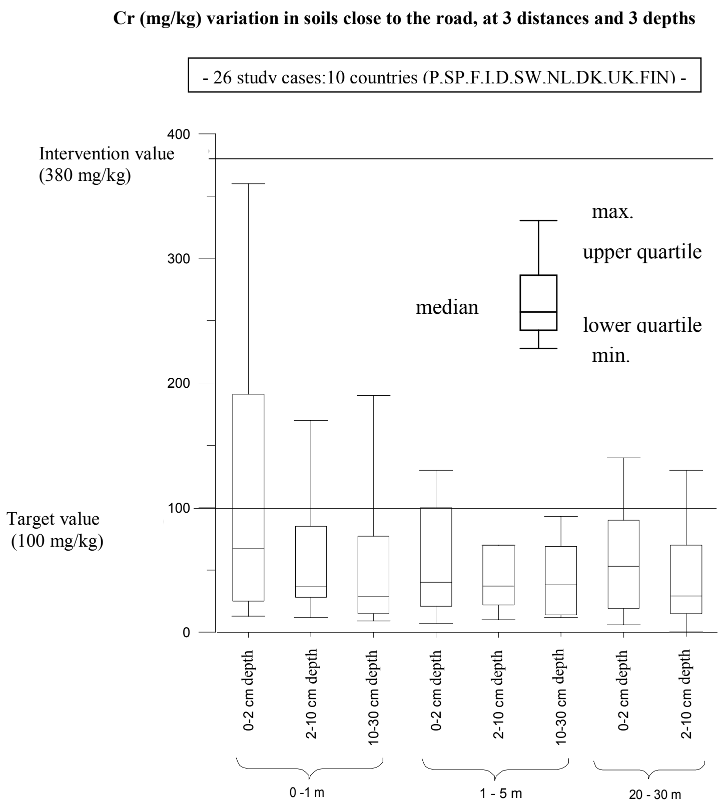

Fig. 3 Cr variation in soils close to the road, at 3 distances and 3 depths

Cr concentrations in the soils of 26 case-studies are below intervention values defined in Dutch legislation. Nevertheless, the target value is frequently overcome.

In some of the case-studies it is possible to observe the decrease in Cr concentration with the distance to the road and in depth, but other cases show the opposite pattern. Usually Cr concentration is quite constant along the depth and distance showing a low capacity for mobilization to the groundwater (cf. Fig. 3). This is also evidenced by the low concentration of Cr in water (all lower than 5 µg/l). Fig. 4 shows the concentration found in the vadose zone water. Groundwater concentration for the same studies show concentrations above detection limit in few cases.

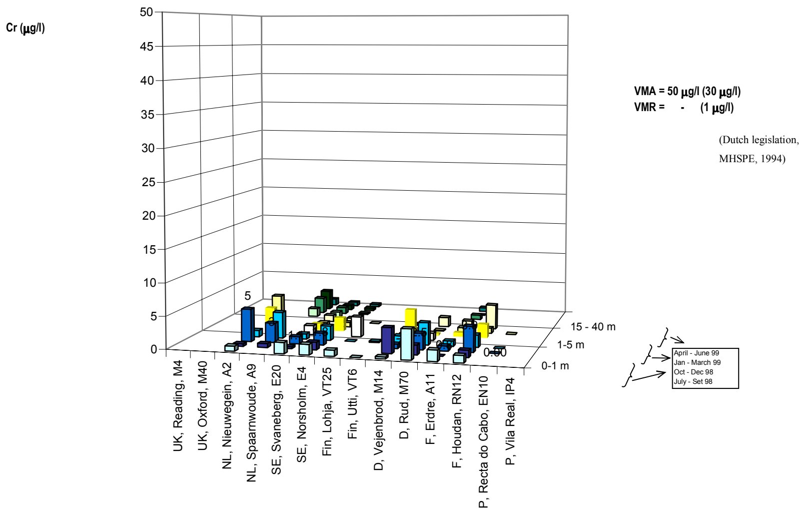

Fig. 4 Cr concentration in the vadose zone

<u>Cu</u> is a low mobility metal, especially in areas with some organic matter content, not significantly influenced by changes in pH or salt content. It is one of the metals found connected to road pollution (DWW, 1995; Reinirkens, 1996; Leitão *et al.*, 2000 & Diamantino, 2002).

Cu concentration in the soils analysed are frequently above the target value, specially in the first soil horizon and close to the road. However the intervention value is unusually overcome (cf. Fig. 5). It is also clear the decrease of Cu with distance and depth in several case-studies individually.

Cu (mg/kg) variation in soils close to the road, at 3 distances and 3 depths

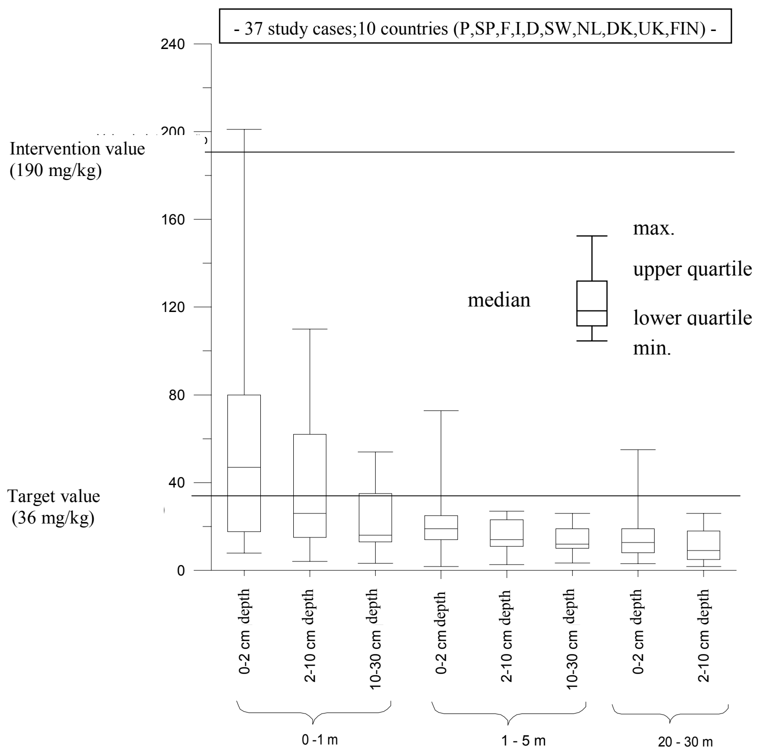

Fig. 5 Cu variation in soils close to the road, at 3 distances and 3 depths

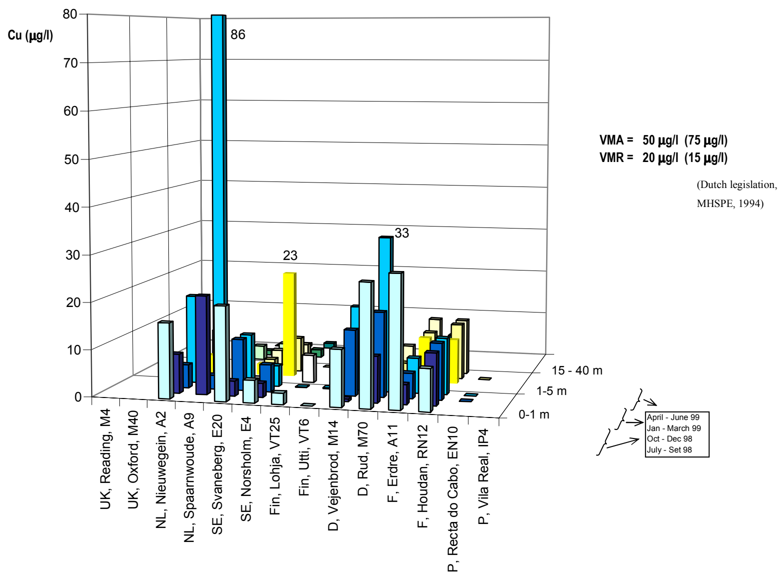

Fig. 6 Cu concentration in the vadose zone

Concerning the Cu water concentration, several values are higher than VMR, but all except one are below VMA. The higher values are closer to the road (cf. Fig. 6).

<u>Pb</u> is one of the metals more studied under road pollution. Soil analysis during the last 25 years has shown changes in the decrease of Pb due to the consumption of unleaded gasoline. Pb mobility is dependent on the presence of carbonates, Fe-Mn oxydes and to organic compounds. Their presence favours the Pb accumulation in the soil and limits its capacity to be leached (DWW, 1995).

Pb (mg/kg) variation in soils close to the road, at 3 distances and 3 depths

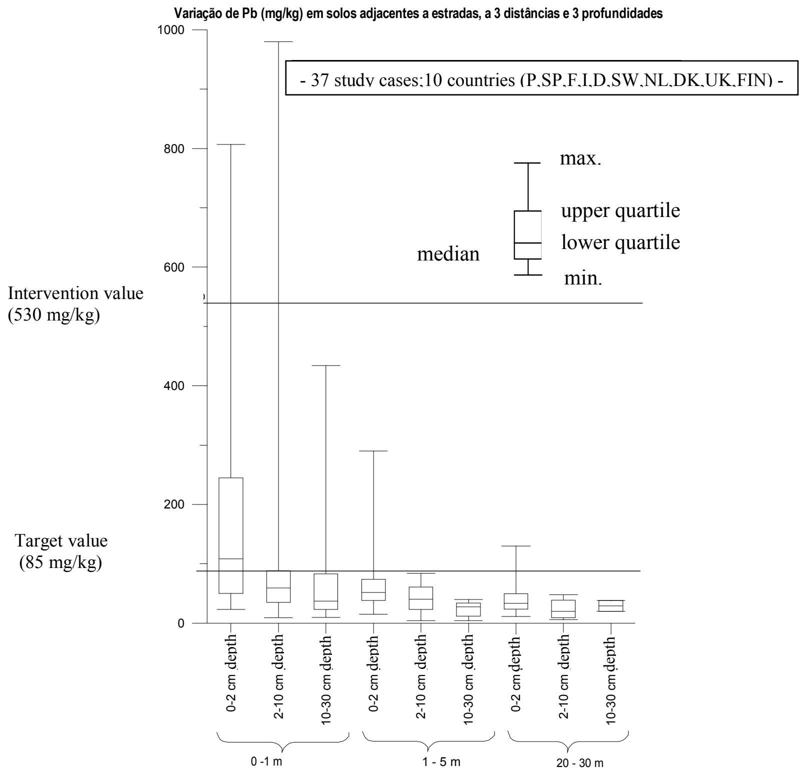

Fig. 7 Pb variation in soils close to the road, at 3 distances and 3 depths

In most case-studies, the Pb concentration in soils is quite high, several exceeding the intervention value. For waters, the presence of Pb is clear, but below VMA.

In most case-studies it is observed a diminution of Pb with the distance to the road and in depth (cf. Fig. 7).

In 10 of the 14 case-studies analysed under POLMIT project, the water in the vadose zone had concentrations below 10 µg/l. In some places there are significant changes during the year. Also groundwater has concentrations below VMA, and the pattern of concentrations is very dependent of soil conditions (cf. Fig. 8).

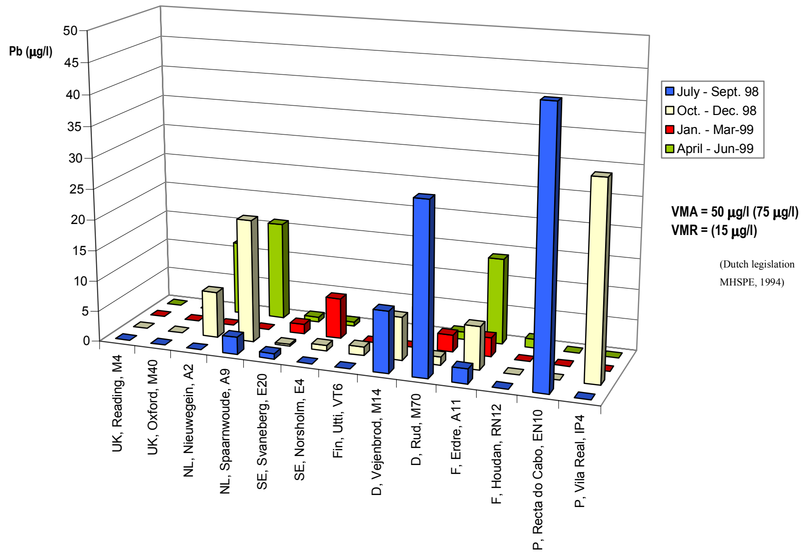

Fig. 8 Pb concentration in groundwater

<u>Zn</u> is a very mobile element especially in sandy and acid soils. Pagotto *et al.* (2001) refers to a particular sensitivity of Zn to pH decrease, with a consequent mobilization of this metal.

Zn concentration in soils is higher than the target value for the 3 depths and 3 distances analysed, in several case-studies (cf.
Fig. **9**). It is also clear a decrease in concentration with distance to the road and depth, although that is not the case in many individual case-studies.

The existence of Zn in groundwater varies from case to case, depending on the existing physico-chemical conditions. Some authors found almost no evidence of Zn pollution (Reinirkens, 1996) but most Fig. 10 found the opposite. However, values are below VMA.

Zn (mg/kg) variation in soils close to the road, at 3 distances and 3 depths

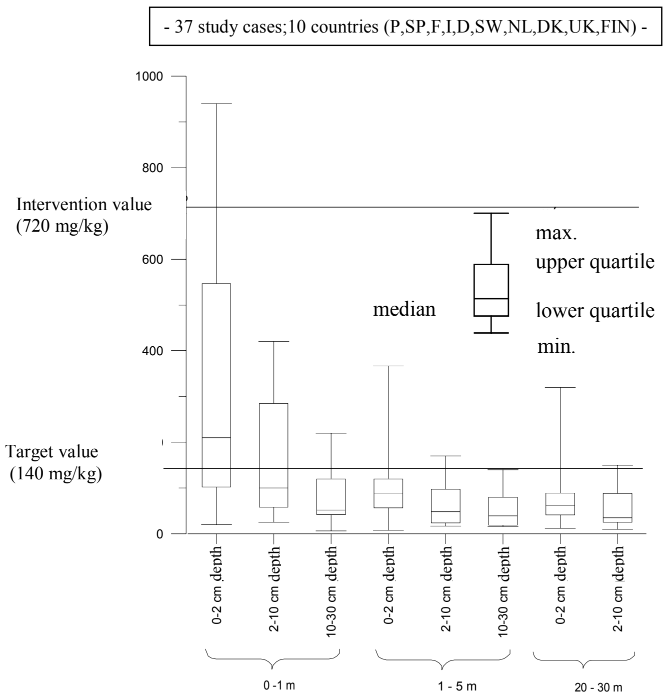

Fig. 9 Zn variation in soils close to the road, at 3 distances and 3 depths

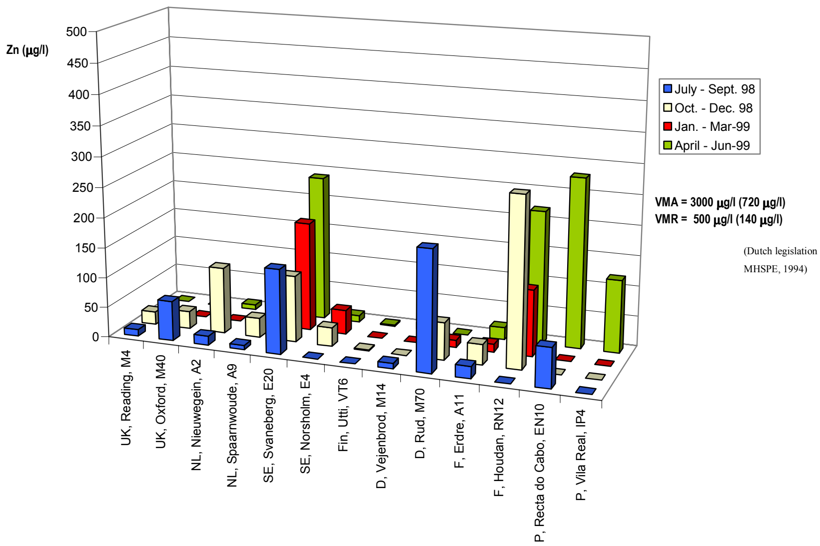

Fig. 10 Zn concentration in groundwater

SYNTHESIS AND CONCLUSIONS

Road pollution is a source of diffuse pollution that can affect the soil and water in its vicinity. The effects of runoff discharge in the environment usually do not led to acute pollution effects. The long term effects, namely of heavy metals, are the ones that can cause soil and water degradation.

The 37 case-studies analysed have shown the long term effects of heavy metals road pollution in soils. The direct effects of road pollution are spatially limited to the soils adjacent to roads, in the areas of car splash, usually influencing a strip narrower than 25 m (García e Millán, 1994; Reinirkens, 1996). However, other authors (Ward e Savage, 1994) confirm a significant increase of soil metal content up to 100 m from the road (London M25).

In most cases, heavy metal pollution decreases with the distance to the road (García e Millán, 1994). Also the first soil horizon is the more polluted one in term of heavy metals (cf. Ward, 1990a).

Road pollution is dependent of the traffic level but a direct correlation is not possible due to the influence of other factors such as wind direction, precipitation pattern, age of the road, topography, pH, CEC, soil organic matter content, etc.

Among the main heavy metals causing pollution are Pb, Zn and Cu. Ni and Cr do not influence in a relevant way the soil quality in the areas close to the roads. Several other heavy metals are under study at the present.

Cd, being a mobile element, is produced in low concentrations. Pb and Cu are produced in higher quantities but their mobilization is difficult; only for low pH conditions or as a soluble complex it is possible to mobilize them in a significant way. Zn is emitted in considerable quantities, especially when zinc crash barriers exist, and can be very mobile in acid conditions.

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