Water in Celtic Countries: Quantity, Quality and Climate Variability (Proceedings of the Fourth InterCeltic Colloquium on Hydrology and Management of Water Resources, Guimarães, Portugal, July 2005).
IAHS Publ. 310, 2007.

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

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Abstract Road traffic circulation produces compounds that pollute the environment. The level and type of emissions depend on several technical aspects related to road design and vehicle engine (size, type of fuel used), as well as to operational factors that are related to the way that the vehicle is used. The compounds emitted come from fuel combustion, corrosion of vehicle compartments, road accessories (e.g. 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 dozen 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 provide a general overview for Europe of the effective degree and extension of road pollution, independent of the different conditions specific to each study area.

Key words European case-studies; groundwater; road pollution; soil

INTRODUCTION

Traffic is a source of diffuse pollution with impacts on the environment that need to be prevented or minimized. Cars, lorries, motorcycles and 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).

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 via 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 at 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 three dozen case studies, in 10 different European countries.

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

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. Some of the results gathered for the studied heavy metals are presented.

Cadmium

Cadmium (Cd) is a very mobile element and a metal that is more easily desorbed 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 (for soil, the quality values used are defined in Dutch legislation (MHSPE, 1994) as target and intervention) and VMA (for ground-water, the quality values used are defined in Portuguese legislation (DL 236/98, 1998) as

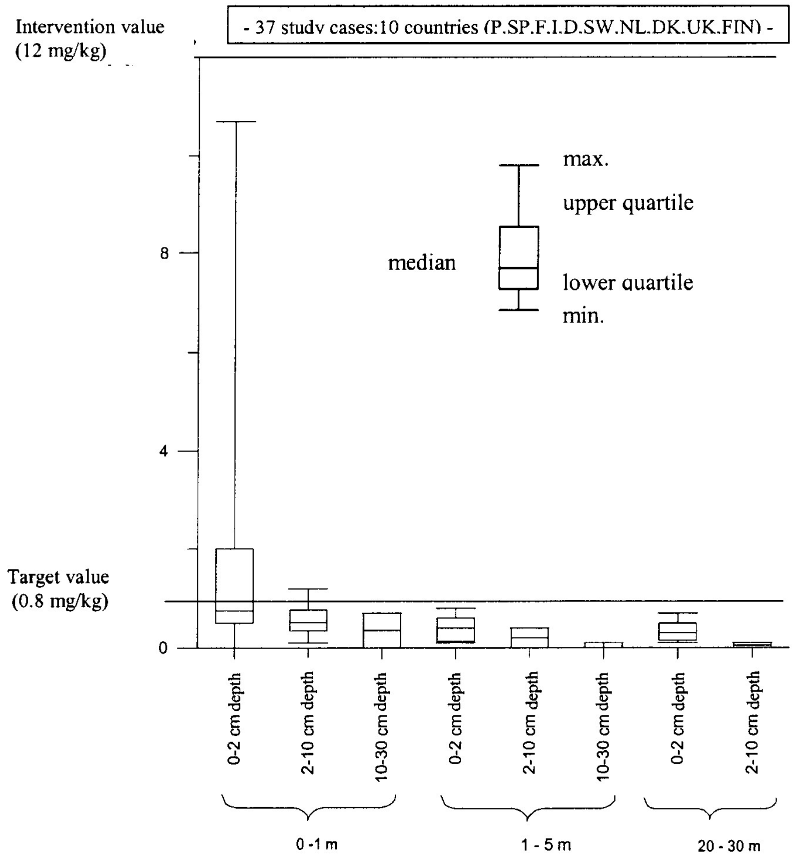

Fig. 1 Cd variation in soils close to the road, at three distances and three depths.

recommended (VMR) and admissible (VMA)) 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.

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 reduced. 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 with Cd toxicity at very low levels and with its cumulative characteristics.

Cromium

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, 1990).

Cr concentrations in the soils of 26 case studies are below intervention values defined in Dutch legislation. Nevertheless, the target value is frequently overcome (Fig. 3).

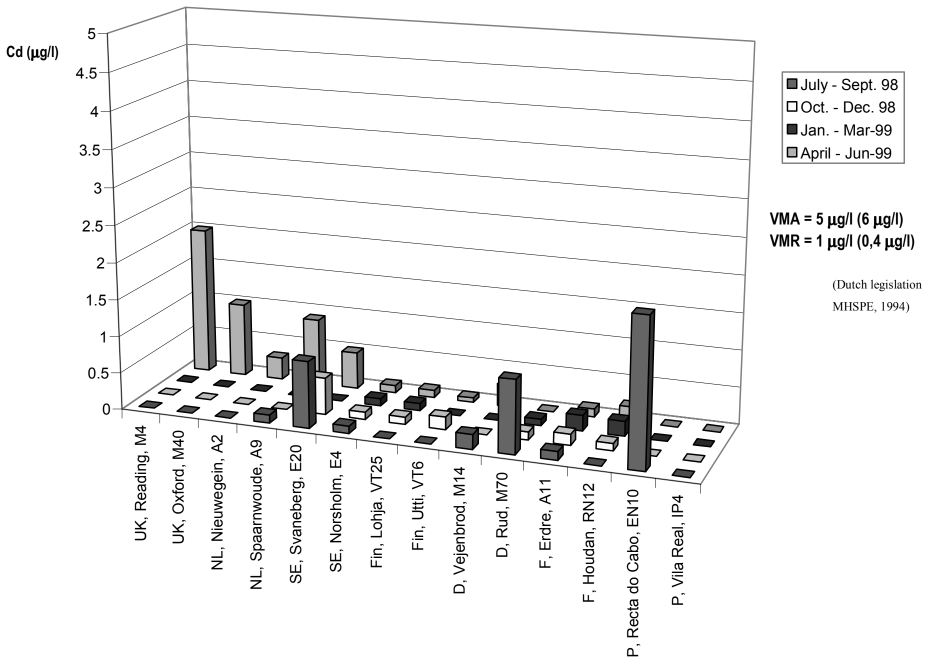

Fig. 2 Cd concentration in groundwater.

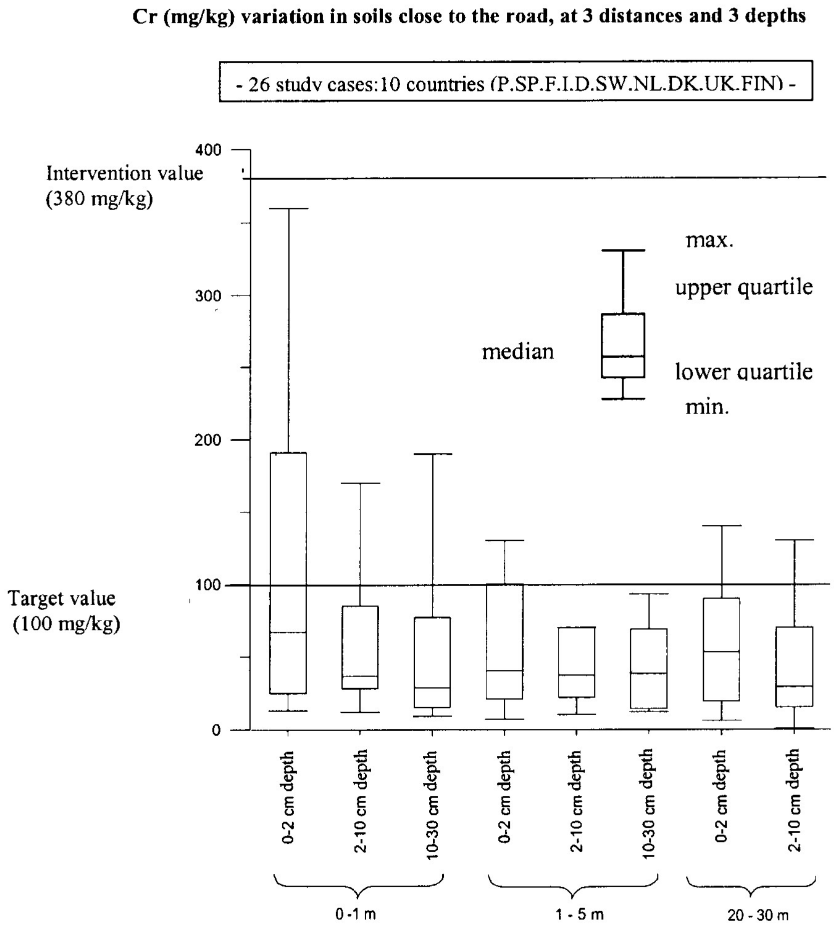

Fig. 3 Cr variation in soils close to the road, at three distances and three depths.

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^{-1}). Figure 4 shows the concentration found in the vadose zone water. Groundwater concentration for the same studies show concentrations above the detection limit in a few cases.

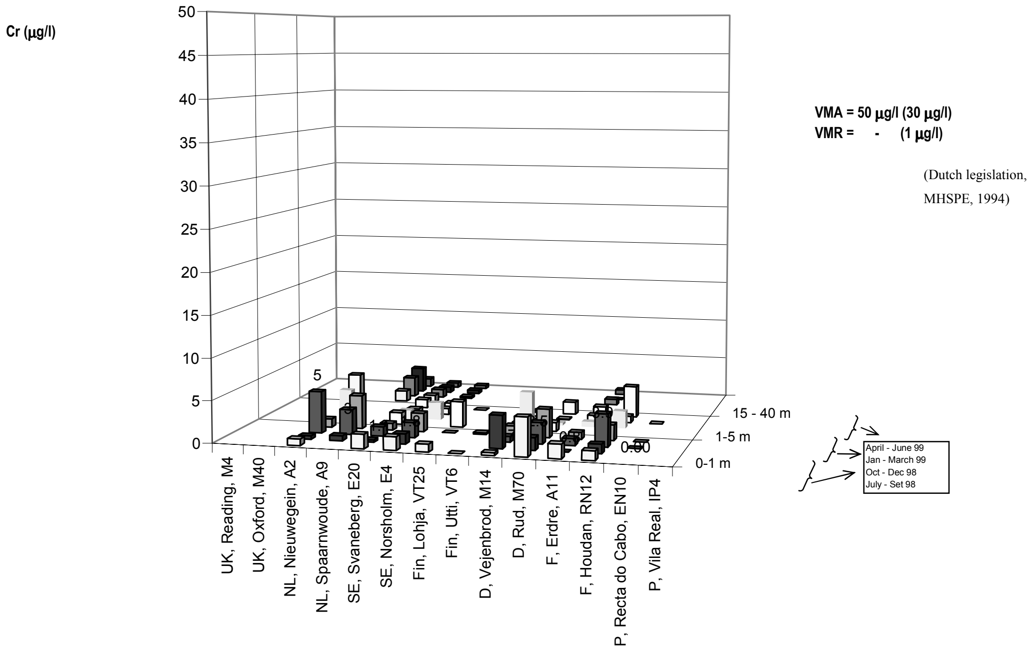

Fig. 4 Cr concentration in the vadose zone.

Copper

Cu 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 linked 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, especially in the first soil horizon and close to the road. However, the intervention value is unusually overcome (cf. Fig. 5). The decrease of Cu with distance and depth is also clear in several individual case studies.

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).

Lead

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

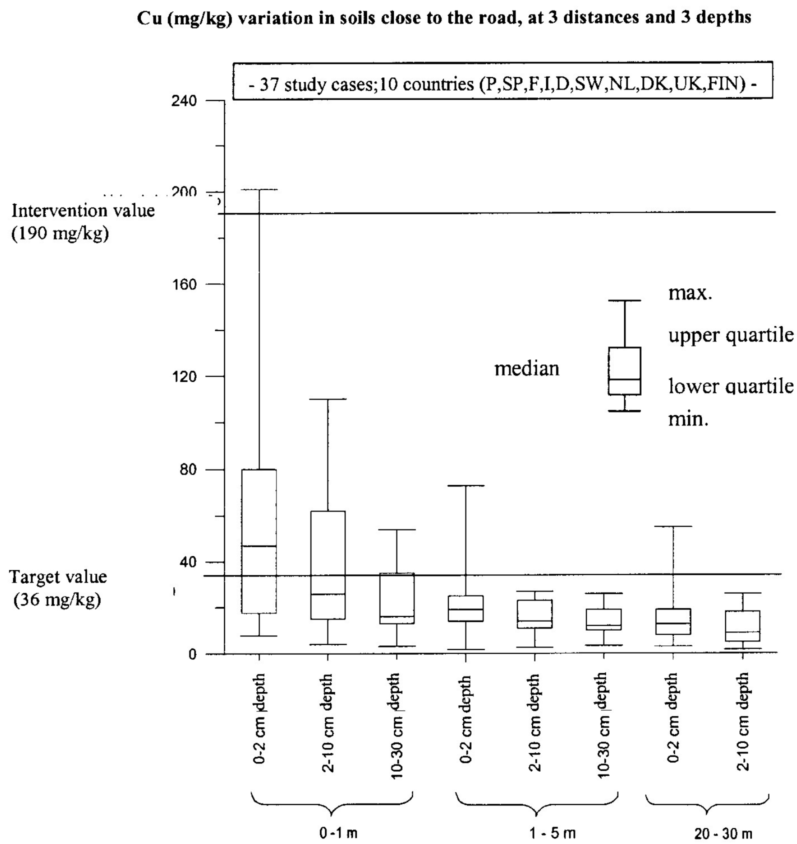

Fig. 5 Cu variation in soils close to the road, at three distances and three depths.

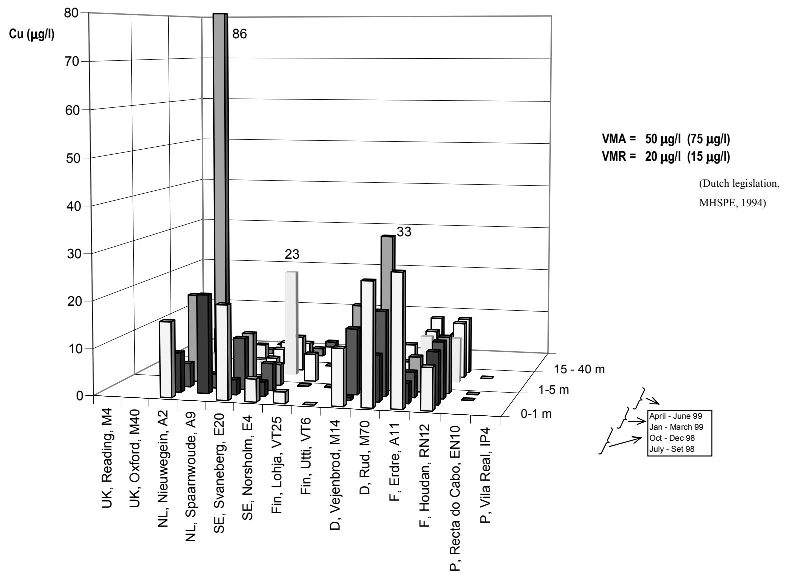

Fig. 6 Cu concentration in the vadose zone.

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

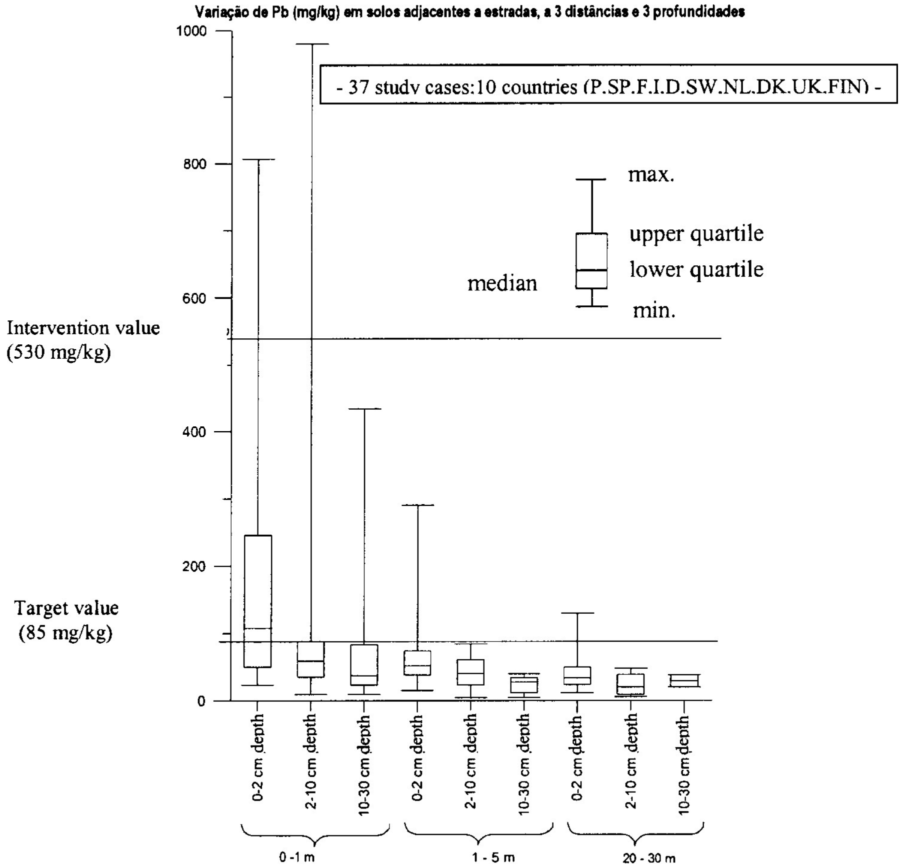

Fig. 7 Pb variation in soils close to the road, at three distances and three depths.

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 a diminution of Pb with the distance to the road and in depth is observed (cf. Fig. 7).

In 10 of the 14 case-studies analysed under the POLMIT project, the water in the vadose zone had concentrations below 10 $\mu g\ L^{-1}$. In some places there are significant changes during the year. Also groundwater has concentrations below VMA, and the pattern of concentrations is very dependent on soil conditions (cf. Fig. 8).

Zinc

Zn 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 three depths and three distances analysed in several case-studies (cf. Fig. 9). It is also clear that there is a decrease in concentration with distance to the road and depth, although that is not the case in many individual case-studies.

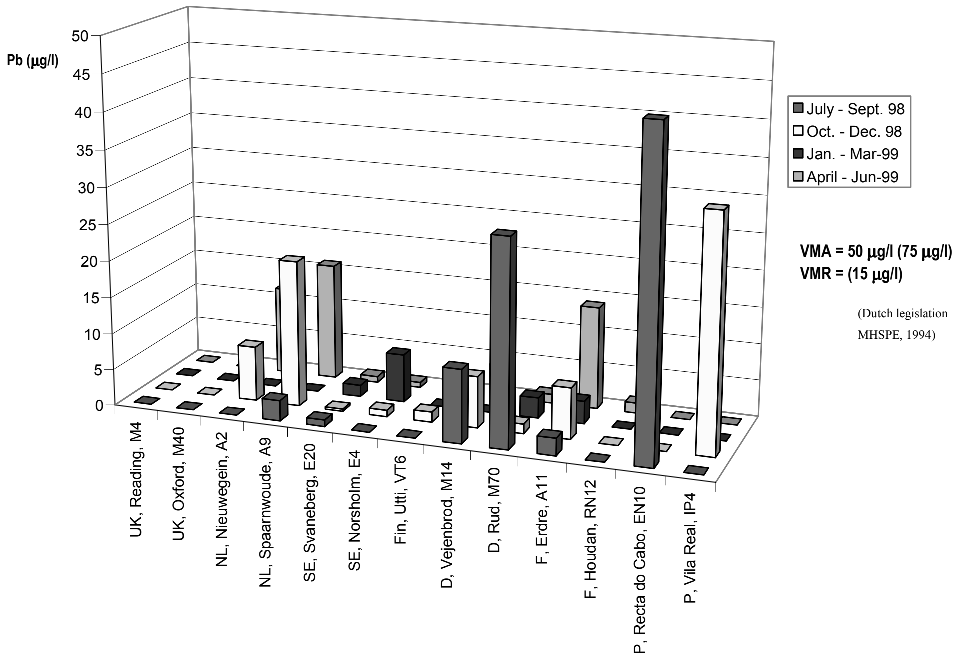

Fig. 8 Pb concentration in groundwater.

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

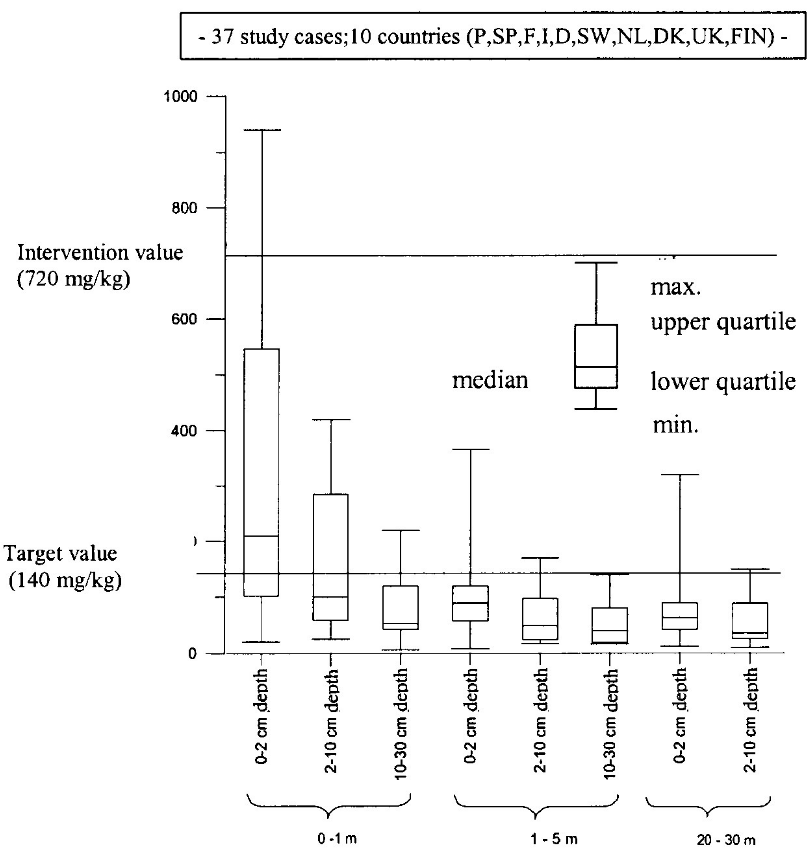

Fig. 9 Zn variation in soils close to the road, at three distances and three depths.

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.

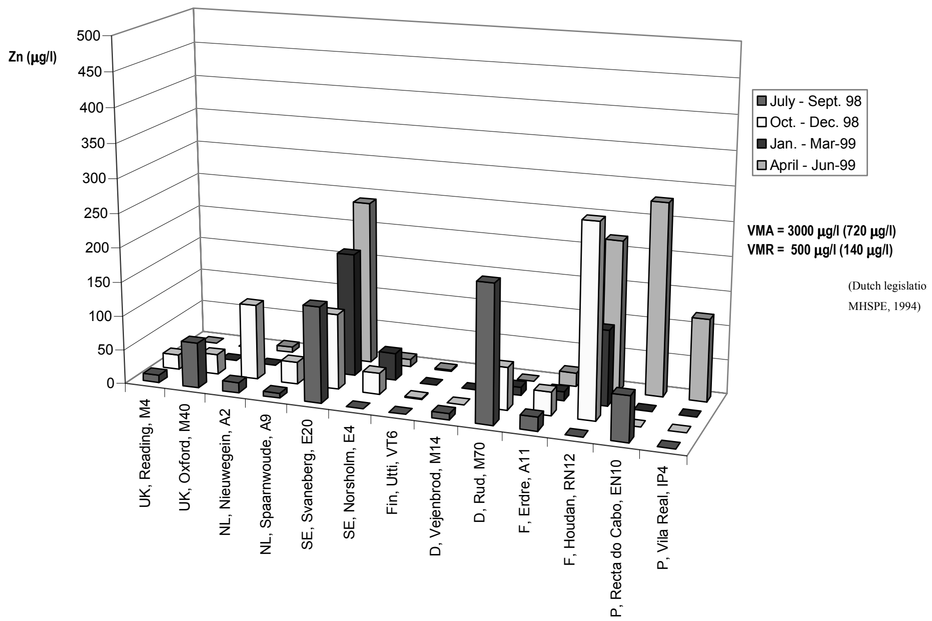

Fig. 10 Zn concentration in groundwater.

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 lead 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 & Millán, 1994; Reinirkens, 1996). However, other authors (Ward & 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 & Millán, 1994). Also the first soil horizon is the more polluted one in terms of heavy metals (cf. Ward, 1990).

Road pollution is dependent on 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 being studied at 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 is it 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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