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IMPACTS OF ROAD TRAFFIC ON WATER QUALITY

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Abstract

Industrialized countries having a large number of vehicles were suffering even in the 70's because of the undetected and non-point emissions of traffic. Emitted pollutants affected not only the quality of air, but also of surface and ground waters. The relative importance of this impact grew as waste waters had been treated. Detailed studies were carried out to identify the most important contaminants and processes influencing their fate. Hungary is facing a situation like the West was two decades ago: the road traffic causes inadmissible environmental impacts. This issue should be handled simultaneously with point source pollution control having an incomparably lower level than in industrialized countries. This paper deals with the characterization of traffic related pollutants and possibilities to evaluate their impact on the quality of surface water runoff.

Keywords: non-point pollution, heavy metals, surface runoff.

Introduction

Environmental impacts originated from non-point and traffic related pollution sources were realized in the developed Western countries 20 years ago. As far as the water quality control is concerned, the importance of these emissions became increasing parallel with the spreading of application of advanced waste water treatment technologies, i.e., phosphorus and nitrogen removal.

In Hungary, although the non-point pollution sources have been studied since the early 80's, the traffic related water quality impacts have hardly been investigated. This problem has become as timely as the road traffic has increased. This paper aims at a description of the state-of-the-art situation by summarizing Western countries' experiences. Hungary will also be forced to treat similar environmental deterioration in the near future.

1. Emission of Road Traffic

Among other sources such as industrial plants and household heating, the emissions of road traffic and activities related determine the contaminants accumulated on the surface of urban areas. These contaminants are mostly inorganic. Exhaust fumes and their soot particles could be mentioned on the first place, which represent only about 5% of total traffic related emissions. However, they are decisively potential poisons. The other 95% comes from contaminated tires and car bodies, their abrasion and corrosion, scattering of transported materials and spills of oils and oil derivatives. The latter are organic but non biodegradable.

From a pollution point of view traffic is characterized by its density, ratio of passenger cars and trucks, and their technical conditions, respectively. Road constructions and conditions affect also heavily the pollution processes. For example, contaminant discharge from asphalt roads can be estimated by some 80% higher than from concrete covered surface. Generally, accumulation of contaminants on roads of poor quality was found 2.5 times higher than on good ones (SARTOR – BOYD, 1972; PITT, 1979). Compounds of contamination originated from highways and main roads and reaching receiving waters and sewers as non-point sources are summarized in *Table 1* (SHAHEEN, 1975). The traffic forced, direct and specific solid pollution emission was found 0.7 g/km as average, while the US EPA (1977) published 0.2 g/km as specific average vehicle engine emission and 0.125 g/km tire crumbs produced by a vehicle.

Table 1
Emitted solid particles of road traffic (Per cent of total weight)

Contaminant	Per cent of total weight
Volatile compounds	5.1
Biochemical oxygen demans (BOD_5)	0.23
Chemical oxygen demand (COD)	5.4
Grease	0.64
Total phosphorus	0.06
Total Kjeldahl nitrogen	0.016
Nitrate	0.008
Asbestos	$3.6 \cdot 10^5$ asbestos fibre/g
Lead	1.2
Chromium	0.008
Copper	0.012
Nickel	0.019
Zinc	0.15
Ratio of emission in the total solid phase	0.671 g/road km

Table 2
Traffic related specific emissions

Contaminant	Specific emission (g/vehicle, km)
Solid, $d < 3.35$ mm	$6.71 \cdot 10^{-1}$
Organic solid matter, $d < 3.35$ mm	$3.41 \cdot 10^{-2}$
BOD_5	$1.53 \cdot 10^{-3}$
COD	$3.61 \cdot 10^{-2}$
Grease – oil	$4.29 \cdot 10^{-3}$
Total phosphorus, P	$4.06 \cdot 10^{-4}$
Orthophosphate	$1.22 \cdot 10^{-5}$
Nitrate, NO_3–N	$5.33 \cdot 10^{-5}$
Nitrite, NO_2–N	$6.37 \cdot 10^{-6}$
NH_4–N, organic nitrogen	$1.05 \cdot 10^{-4}$
Tire	$3.50 \cdot 10^{-3}$
Lead	$7.87 \cdot 10^{-3}$
Chromium	$5.22 \cdot 10^{-5}$
Copper	$8.01 \cdot 10^{-5}$
Nickel	$1.24 \cdot 10^{-4}$
Zinc	$9.87 \cdot 10^{-4}$
Cadmium	$8.77 \cdot 10^{-6}$

Data listed in *Table 2* represent the specific traffic related emissions sampled in USA. However, their validity is limited in Hungarian conditions.

Solid particles come from abrasion of street cover and tire, road maintenance and atmospheric dry deposition. Tire abrasion contains zinc, cadmium, and PCBs, while exhaust fumes discharge into the environment lead, nickel. The latter could be detected in spilling fuel and lubricants, as well. Corrosion and abrasion of car body and parts results in chromium, nickel, copper and asbestos contamination. Animals transported can produce pathogen microorganisms pollution by spread excreta. Plant nutrients, i.e., nitrogen and phosphorus detected in surface runoff is a consequence of overfertilization of plants located along roads. As far as the gas phase contaminants are concerned, NO_x, CO and CO_2 should be pointed out.

Organic nutrients serve as foodstuffs for aerobic bacteria and cause proliferation of natural populations of aquatic bacteria. Bacterial decomposition of these materials results in a drop in dissolved oxygen, with dire effects on other oxygen-requiring organisms. Inorganic plant nutrients, nitrogen and phosphorus cause excessive plant growth. Bacterial decay in the fall results in a drop in dissolved oxygen, which may suffocate fish and other organisms. The harmful effects of oil spills are many. Oil kills plants and animals of the aquatic life. Oil settles on beaches of lakes and river banks and kills organisms that live there. Oil poisons algae and may disrupt major food chains and decrease the yield of edible fish. Heavy metals are inorganic toxic pollutants. Entering into the food chain they could be accumulated in species.

To evaluate the importance of road traffic emissions, a comparison was made between the point discharge (municipal waste water) transported by the sewer system into the receiver and the non-point, traffic related pollution emission of an urban area characterized by 1 million PE (population equivalent). Number of cars in traffic was estimated as 150,000. Each of them runs 30 km daily. The estimated values of the emissions are summarized in *Table 3.*

Table 3
Estimated daily emission of municipal waste water and road traffic$^{(*)}$

Source	BOD_5	COD	Total P	NH_4–N**	NO_3–N	Lead	Oil***
Point	60,000.00	180,000.00	3000.00	12,000.00	–	–	–
Non-point	6.00	162.00	1.83	0.47	0.24	35.40	19.30

Remarks: $^{(*)}$ – values are expressed in kg/day, $^{(**)}$ – organic N, $^{(***)}$ – mineral oil

It can be stated that the potential impact of road traffic emissions on receiving water bodies is negligible, as far as the discharge of organic, biodegradable matters and nutrients are concerned. However, heavy metal and mineral oil load is related mainly to this source.

Pollutants emitted, except gases, are linked to the particles accumulated on roads and their surroundings. Information about the profile of solids (distribution profile of particle sizes) is essential, because the smaller the particle the larger is its relative surface, and the amount of contaminants fixed on the surface. Moreover, the smaller the particle the easier and quicker is the washing down process forced by rain water runoff. Regarding some typical contaminants, a result of sampling analyses is summarized in *Table 4*.

As it can be seen, more than 30% – 50% of important contaminants are linked to the particles being smaller than 0.25 mm by diameter. Taking into account the removal efficiency of traditional street sweeping technology (*Fig. 1*), it can be stated that these pollutants decisively discharge natural receiving water bodies by the transport of surface runoff. In addition, the cross-sectional accumulation of wastes on street surface is not uniform (*Fig. 2*). This fact together with parking cars makes the systematic street cleaning not efficient or impossible. (It should be underlined that artificial

Table 4
Ratio of contaminants in road waste, depending upon the size of particles (BRUNNER, 1977)

Size of particle	Organic solid matters	BOD_5	COD	Oil, grease	Tire	Lead	Zinc
mm	mg/g						
3.35 – 0.85	76.1	3.64	67.5	9.0	0.7	0.81	0.24
0.85 – 0.42	43.2	2.98	55.7	6.4	1.0	3.20	1.02
0.42 – 0.25	34.1	3.11	51.2	6.4	1.5	3.44	1.60
0.25 – 0.075	59.3	3.80	106.4	14.5	4.5	5.89	1.81
< 0.075	25.6	6.91	211.2	29.2	17.8	6.43	1.50

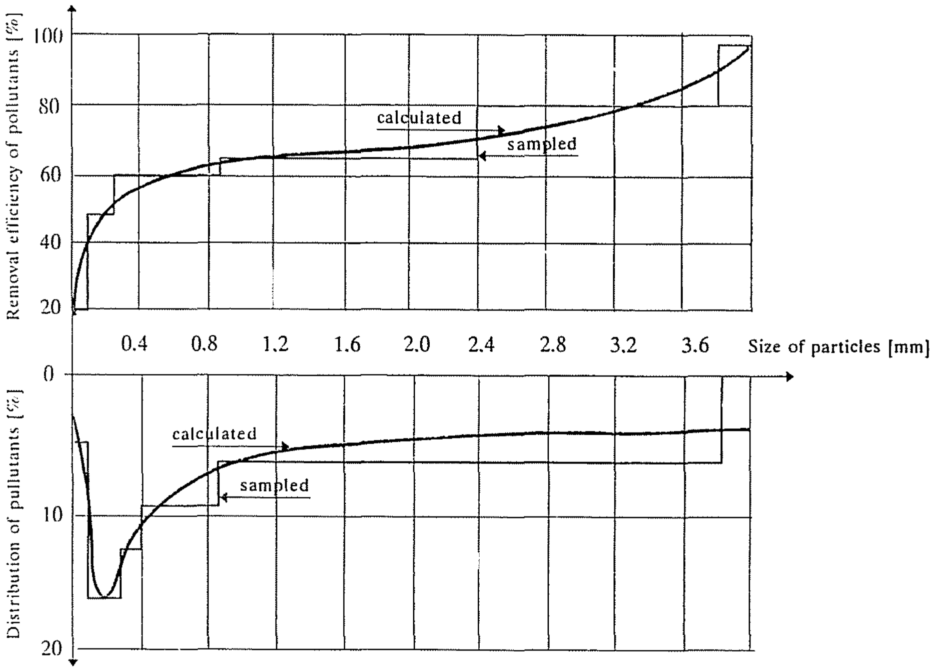

Fig. 1. Distribution of pollutants by size of particles and their removal efficiency by traditional street sweeping technology

washing down of pollutants into sewers is inadmissible from point of view of water quality protection if they are not treated.)

Calculation of pollution originated from urban areas and transported by rainwater surface runoff is a new requirement of effective water quality

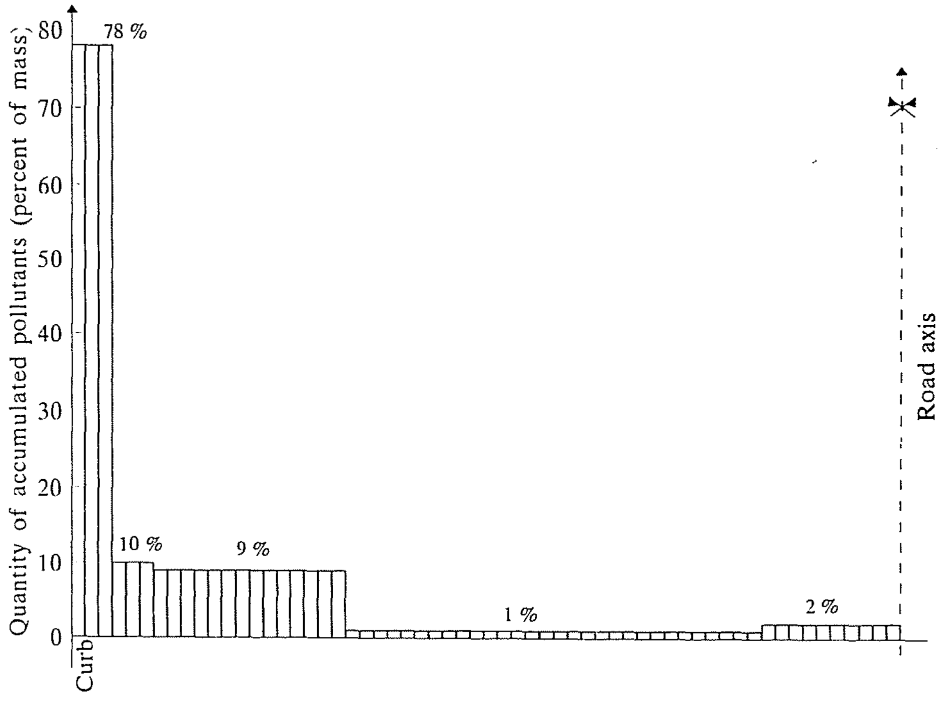

Fig. 2. Cross-sectional accumulation of pollutants on street surface

control in all of regions where the treatment of municipal waste water has been treated on an advanced level.

Rain water, before reaching the receiving water body could be contaminated (1) during the falling down in the atmosphere, (2) in the process of surface runoff and (3) by the pipe flow in the drainage system. As it was discussed before, traffic affects the second process by diffuse pollution related to surface runoff. This process results in some orders of magnitude higher contamination than the first one. From practical point of view that is why analyses of impact on natural waters of urban areas are focusing on runoff contamination (HAHN, 1990). It is noted that pipe flow pollution could have the greatest importance if the sewer system is a combined sewer system. The reasons are twofold:
a) the overflows of these systems contain municipal wastewater as well as
b) sewer pipe sedimentation mobilized by the rain water waves. Both of them cause additional pollution of the rain water pipe flow (BUZÁS, 1983). However, this impact is not related directly to traffic.

2. Calculation of Pollution Accumulation

The amount of accumulated pollution along the street curb can be described by a simple balance equation. The change is equal to the difference between waste production and losses:

$$\frac{\mathrm{d}P}{\mathrm{d}t} = I - \alpha P\,, \tag{1}$$

where
P – accumulated pollutants, (g),
I – intensity of waste production, (gd^{-1}),
t – time, (d) and
α – removal factor, (d^{-1}).

Application of this equation needs information about the removal factor. NOVOTNY et al. (1985) gave a calculation method:

$$\alpha = 0.0116 e^{-0.08H}(TS + WS)\,, \tag{2}$$

where
H – height of curb, (cm),
TS – characteristic speed of vehicles, (km/h),
WS – main value of wind speed perpendicular to road axis, (km/h).

(The removal factor was found altering between $0.2 - 0.4\ d^{-1}$ at USA conditions.)

Eq. (2) is not valid during wintertime when the surface is covered by snow, because contaminants are fixed in snowflakes. Accumulation is just linear in this period. This is why P can reach 3 – 6 times higher value during wintertime than in other seasons.

To illustrate the extent of accumulation, a highway characterized by the following parameters was analysed:

– traffic intensity:	40 000 vehicle unit/day,
– characteristic speed, TS:	85 km/h,
– main speed of wind during the period, WS:	25 km/h,
– height of curb:	15 cm.

Taking into account 0.125 g/km specific emission of engines and 0.2 g/km abrasion of tires, the daily accumulation along one kilometre is:

$$I = 40000 \cdot (0.125 + 0.2) = 13000 \qquad \mathrm{g/km \cdot d}\,, \tag{3}$$

while the removal factor is :

$$\alpha = 0.0116 \cdot e^{-0.08 \cdot 15} \cdot (85 + 25) = 0.38 \qquad \mathrm{d}^{-1}\,. \tag{4}$$

Then the intensity of accumulation

$$\frac{\mathrm{d}P}{\mathrm{d}t} = 13000 - 0.38 \cdot P \qquad \mathrm{g/d}\,, \tag{5}$$

At the initial values $t = 0$, and $P = 0$, the amount of accumulated contamination is as follows:

$$P = \frac{I}{\alpha}\left(1 - e^{-\alpha t}\right) = 34210 \cdot \left(1 - e^{-0.38t}\right)\,. \tag{6}$$

Supposing a realistic, two-week long dry period, the time dependence of accumulation process can be seen in *Fig. 3.* The result is 3.4 kg/km accumulated pollution. Accumulation profile is asymptotic to a theoretical condition, when waste production and removal are in equilibrium.

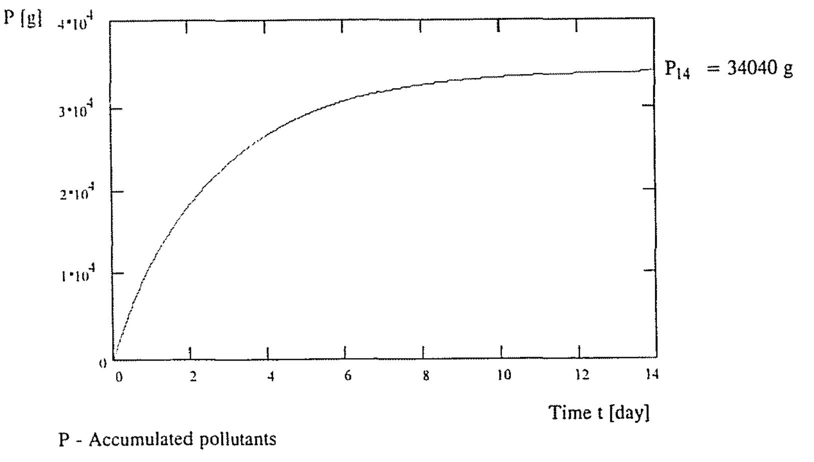

Fig. 3. Accumulation of pollutants along one-kilometre of highway

The range of emitted pollutants can be illustrated by the example of the Hungarian highway M7 which has the same average traffic density as was supposed previously. Taking into account its 98 km length, about 3.3 tons of pollutants could be accumulated during a two-week long period.

3. Assessment of Washing Down Process

Washing down involves mechanical and chemical processes. The mechanical process is twofold: raindrops break up the pollutants meanwhile the runoff carries it to the manholes of sewers. The most simple and widely used empirical equation was formed by SARTOR (1972):

$$\frac{\mathrm{d}P}{\mathrm{d}t} = -K_u r P, \tag{7}$$

where

r – rain intensity, (mm/h),
K_u – washing down factor, (its value depends on street surface characteristics), (mm^{-1}),
P – accumulated contaminants on the surface, (g),
t – time, (h).

Value of K_u does not depend on the size of particles in the domain of size 10 μm – 1 mm. Its suggested value is 0.19, if the rain intensity is given in mm/h dimension. (It is noted that even a low intensity rain ($r \approx 3 - 5$ mm/h) is able to produce washing down effect.) This equation is not valid for evaluation of snow melting.

To demonstrate the impact of the process, the example before discussed was chosen. A one-hour long and 9.0 mm/h intensity rain was supposed in the fifth day of evaluated period. Then

$r = 9.0$ mm/h,
$t = 1.0$ h,
$K_u = 0.19\ \mathrm{mm}^{-1}$, and
$P_5 = 29090$ g (calculated by *Eq.(6)*).

By the initial condition $t = 0$ and $P = P_5$, the contamination remained at the end of the rain event is:

$$P = P_5 \cdot e^{-rK_u t} = 29090 \cdot e^{-9.0 \cdot 0.19 \cdot 1} = 5191 \qquad (\mathrm{g}), \tag{8}$$

while 23899 g is removed. *Fig. 4* shows the effect of washing down. It should be pointed out, that – although the rain removes more than 80% of accumulated contaminants at the end of two-week long period – the traffic forced pollution is near to the one of the dry period.

Taking into account the previous Hungarian example, in case of M7 highway this rain event would discharge the environment by the contaminated surface runoff with 2.3 tons of pollutants.

4. Contamination of Surface Runoff

As a consequence of polluted watershed area, the surface runoff is heavily contaminated. The characteristic pollutants are mostly toxic (KOBRIGER,

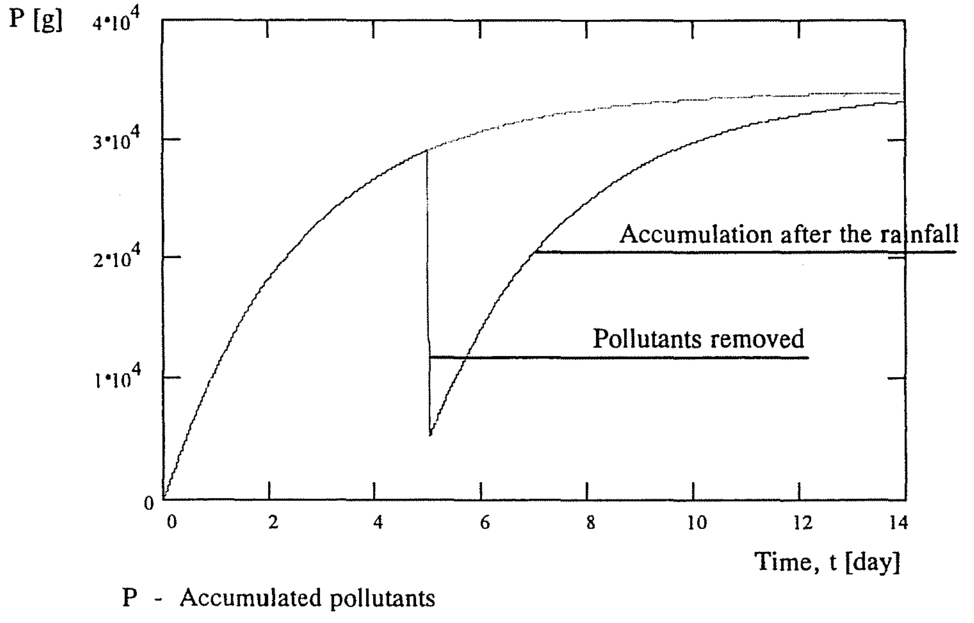

Fig. 4. Washing down effect on accumulation of pollutants

1984). In the frame of the National Urban Runoff Project (USA; EPA, 1983) some 14 kinds of toxic inorganic pollutants were detected. Namely 13 heavy metals and asbestos. The most frequently observed metals were copper, lead and zinc. All of them were represented in 91% of samples. Arsenic, chromium, cadmium, nickel and cianides formed another characteristic group of contaminants.

Most of the contaminants are related to oils and oil derivatives. Asbestos comes from break-shoes, clutch and tire abrasion, while some volatile matters like Trichloromethane from salt, reaction of fuel and asphalt and Toluene from asphalt.

Statistical analyses of runoff samples showed a strong correlation between the contamination and land use or density of traffic. Fish was used as indicator of toxicity. Runoff of high density traffic proved to be toxic because of lead (73% of samples) and silver, copper and zinc (over 90% of samples). Concentration of lead over the toxic limit detected only in 4% of samples of the areas with low intensity traffic. As far as the copper and zinc is concerned, this ratio was below 30%, while silver never proved to be toxic. Organic pollutants were detected rarely and with lower concentration than inorganic ones. Correlation between heavy metals content and density of traffic is illustrated in *Fig. 5.* As it can be seen, the relationship between them is nearly linear (AquaNova International Ltd, 1993).

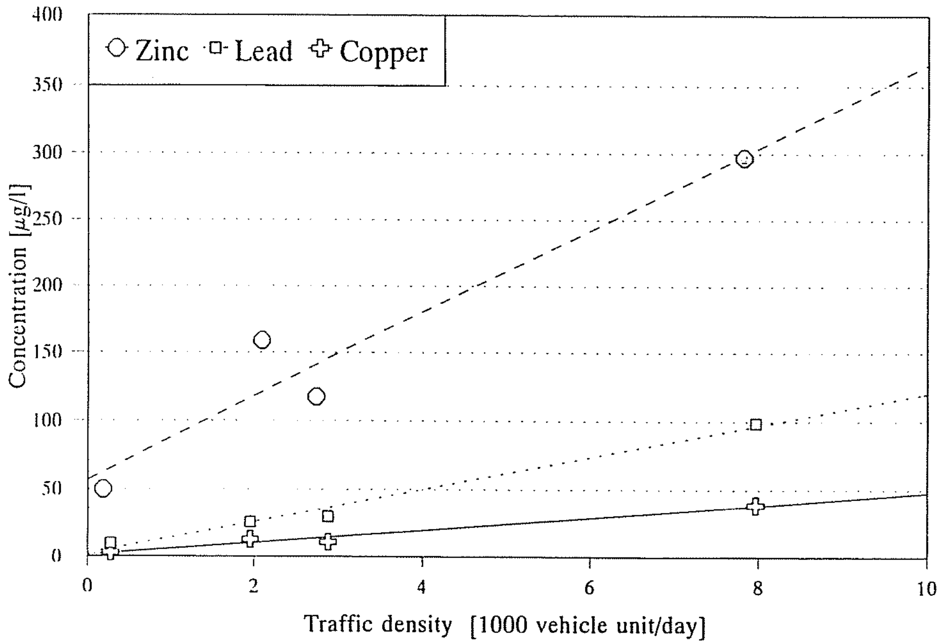

Fig. 5. Correlation between heavy metal concentration and density of traffic

Discharges of these contaminated surface runoffs can often seriously impair the quality of receiving waters. Mitigation of impacts are practicable by source control, i.e., reduction of traffic related emissions and improvement of street cleaning technology or by control of surface runoff. The latter includes retention and detention basins, and/or artificial overland flow (wetlands) for pollutant removal from traffic road runoff (DORMAN et al., 1988; KRAMME, 1985).

5. Summary

Traffic related contamination was discussed on the basis of extended studies performed in USA and Germany, which countries were forced to face a serious deterioration of water quality. Contaminants accumulated on and near to the traffic areas are responsible for the pollution. It was found that the source of these is mainly the traffic. The amount of contaminants depends on the duration of dry weather period, while the intensity of accumulation is affected by traffic conditions. Rain events wash down a significant part of wastes. A simple method of calculation of these processes was discussed. Important findings were as follows: the dry atmospheric deposition is linked to the solid particles; the smaller the characteristic particle size, the higher its specific pollutant content is, and at the same time the easier and quicker the washing down process; the most characteristic group of pollutants is the one of potentially toxic heavy metals.

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