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ENVIRONMENTAL PROBLEMS RELATED TO WINTER TRAFFIC SAFETY CONDITIONS

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Abstract. The changeable Nordic climate has added problems to road maintenance and the environment to ensure traffic safety under winter conditions. The widespread use of salt (NaCl) for snow and ice removal from roads has resulted in environmental impacts in many areas. Some of the problems associated with the use of NaCl are the corrosion of bridges, road surfaces and vehicles and damage to roadside vegetation and aquatic system that are affected by water from de-iced roads. Accumulation of hard metals (Pb, Cd, Ni, Zn, Cu, Co) hazardous to the environment in areas near the road has been determined. The growth of zinc concentration in soil was accompanied by an increase in cadmium. Negative effects of studded tyres on road surfacing have brought about a higher environmental risk. Resistance to the use of salt for de-icing is strong in many countries. This forces pertinent institutions to draft normative documents and requirements that would optimise the need of NaCl.

Keywords: traffic, road maintenance, studded tyres, chlorides, heavy metals, soil and groundwater contamination.

1. Introduction

International efforts to manage hazardous substance pollution have increased greatly over the last decade. Europe Union (EU) Directives are legally binding on member states. The main directions of the EU policy related to transport and environment are targeted to ensure air quality and to reduce environmental impacts caused by vehicle exhaust emissions. Focus has shifted from local contaminants to global hazards caused by the greenhouse gases. Among other substances, the list of common contaminants includes lead (Pb) compounds and other heavy metals (HM): cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), mercury (Hg) [1]. To realise the EU environmental policy, most importantly, it is necessary to establish quantitative environmental goals and indicators, to review and establish strict regional requirements.

According to the HELCOM (Helsinki Commission – Baltic Marine Environment Protection Commission) recommendation, the environment protection should be made an integral part of all activities in the transport sector, ie environmental goals for sustainable transport should be developed and further internalisation of external costs (environment, accidents etc) into transport costs should be applied [2].

The Estonian Road Act provides requirements for roads, the rights and obligations of road owners and users and the liability thereof for violations of traffic safety requirements, and regulates the protection of roads, humans and environment against hazards from traffic [3].

In Estonia the number of motor vehicles has quadrupled and the traffic volume has increased over six times in the last thirty years. In 2002 the total motorisation ratio (number of motor vehicles per 1000 inhabitants) exceeded 400 in Estonia and was 450 in the capital city of Tallinn [4]. However, the vigorous growth of cars, combined with the changeable Nordic climate, has not increased the accident risk in the winter period (Fig 1). One of the most important balance factors seems to be the rapid growth in the usage of winter tyres (mostly studded tyres) in Estonia.

As the studded tyres make driving easier on slippery roads under winter conditions and increase the traffic safety, their quick distribution is fully understandable. In Estonia such tyres were taken into a wide use at the beginning of the last decade. The rate of use is demonstrated in Fig 1. As it is shown, a very even increase has taken place, amounting to about 10–12 % per winter. It was only from the end of the 1990s that the increase was levelled off at 80 % [5–7].

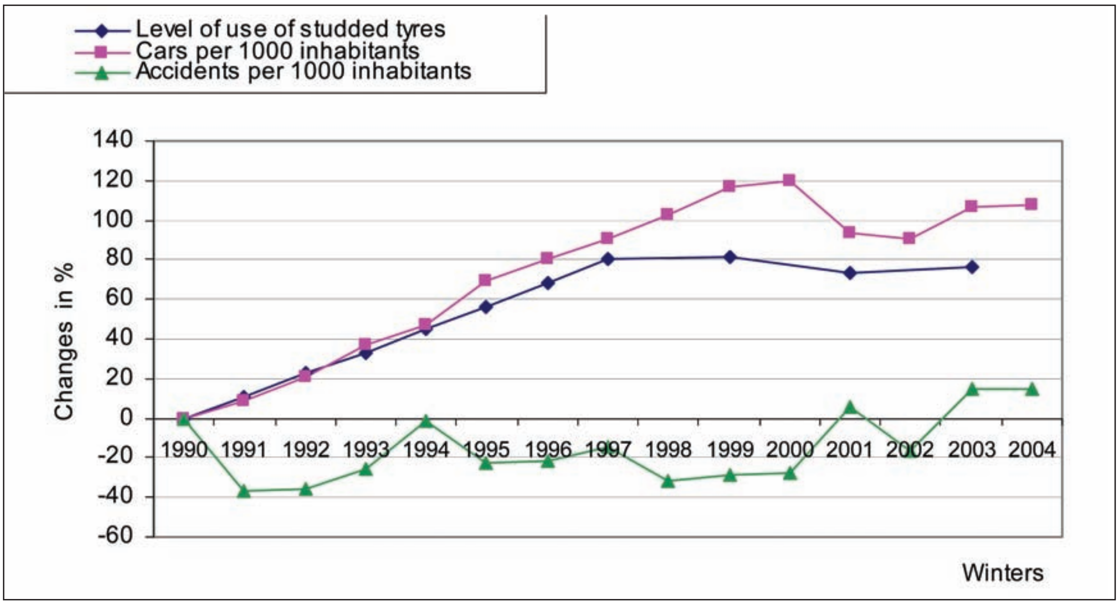

Fig 1. Change of number of cars, accidents and level of use of studded tyres in winter months (Dec, Jan, and Feb) in Estonia

At the same time, the wear of road pavements caused by studded tyres is an important road maintenance and environmental problem. A car equipped with studded tyres wears an average 3,5 kg of the pavement within a distance of 100 kilometres. The average lifetime of pavements is one half of what it would be without studded tyres [8].

Because of the problems caused by studded tyres, several countries have banned them, for instance, Germany, the Netherlands, Portugal, Luxembourg, Denmark etc. In other countries, where studded tyres are allowed, limitations and regulations have been introduced concerning the period allowed and technical parameters of tyres/studs.

Among environmental impacts caused by traffic is road dust, which in urban areas is mainly caused by pavement wear. As shown by calculations based on the data obtained in Tallinn (in 1999 the total mileage of vehicles supplied by studded tyres was approx 300 mln km, a vehicle covering 100 km tears approx 3 kg of solid particles from road surfacing), during winter, the total quantity of road dust approximated 9000 tons, exceeding about 20 times the quantity of solid particles from exhaust emissions, calculated by the transport model of contamination [9].

No studies have been conducted in Estonia to find out the proportion of mineral particles separated from road surfacing, constituting the PM_{10} particles inhaled. PM_{10} contents over 10 μg/m^3 in the air caused by transport are regarded hazardous to health by Austrian, French and Swiss researchers [10].

The literature on non-exhaust particles and their effects is quite extensive. The information about particle emissions and particle characteristics displays very large variations though, depending on investigation quality, methods and extent as well as geographic variations [11].

The rain washes and the wind takes traffic dust along a width of over 2–40 m of the roadside area. The level of pollution also depends on weather conditions and the amount of chlorides used [12].

The goal of the Baltic 21 Transport Sector emphasises the need to minimise its impact in a number of areas while retaining its ability to serve the economic and social development of the Baltic Sea region. However, indicators demonstrate that the sector□s progress toward sustainability is rather slow, and in some areas the trend is clearly unsustainable (Baltic 21) [13].

2. The study area and methods

In the pollution research carried out at Tallinn University of Technology (TUT) during 2001–2004, soil contamination and environmental risks were examined in connection with traffic and road maintenance [9, 14, 15].

Studies focused on assessing the of environmental impacts caused by traffic pollution by help of the interaction of the measured hazardous HM content in the roadside areas and the traffic volume. HMs (Pb, Zn, Cd, Cr, Ni, Cu, Fe) were selected to follow the goals set in the studies, but all the elements are contained in alloys, studs of studded tyres and tyre cords used in the automobile industry. Cd and Pb are listed as major contaminants in the EU directive of ambient air quality [16]. In addition to the selected HM concentrations, chloride content, the pH of soil and sampling sites characteristics were determined [15].

Samples were collected at distances of 4–30 m from the pavement at the depth of 3–5 cm in spring immediately after melting of the soil and at the depth of 10 cm in autumn. Sampling was made according to the ISO 11464:1994 (E).

Table 1. Comparison of average HM concentrations (mg/kg) in roadside in 2001–2004 and in 1991 and concentrations of the humus horizons of soil

Investigated samples of soil		Pb	Zn	Cd	Cu	Ni	Co
Soils in the surroundings of Tallinn, (n = 158), 1991*	median average	22 26	35 45	–	22 23	12 12	7,0 5,9
Soils in central Tallinn (an "anomaly"), (n = 24),1991*	average	73	130	–	42	17	5,6
Soils in roadside of crowded area and highway, 2001-2004 spring, **(n = 84), L = 4–30 m	average	50	149	0,70	71	23,5	5,2
Soils in roadside of Tallinn (n = 13, L < 15 m) March 2003 **	median average	44 52	134 168	0,43 1,60	55 70	16,7 17,1	5,8 5,0
Soils in roadside of Tallinn (n = 12, L = 15–30 m) March 2003**	median average	34 40	122 178	0,81 1,58	50 62	33 33	6,0 6,2
Soil in roadside of Tallinn (n = 12, L<15m) March 2004**	median average	31 40	128 134	0,44 0,51	–	9,5 9,3	–
Humus horizon of soil (Podzol) in Tallinn	average	12,5	16,0	0,23	6,2	16,4	3,8
Humus horizon of Estonian soils***	average	16,4	37,3	0,34	10,6	21,9	7,9

Remarks: n – number of soil samples, L – distance from road pavement, * Institute of Geology [17], ** TUT, Dept of Transportation, *** Geological Survey of Estonia [18].

The concentration of HM, chlorides and pH was determined in the Laboratory of Chemical Analysis of Testing Centre of TUT that has competence according to EVS-EN ISO/IEC 17025:2000 to conduct tests in the field of elements determination by help of AAS (Atomic Absorption Spectrophotometric) methods. Zn, Cu, and Ni were determined by the flame method, and Cd, Pb, and cobalt (Co) by the electro-thermal method in a graphite cuvette. Chloride was titrated amperometrically in a solution produced by digesting a mean sample of soil by diluted (1 mol/dm^3) nitric acid.

3. Results and discussion

3.1. Roadside soils pollution by heavy metals

In the studies conducted at TUT, the concentration of HM was determined at distances from 4–5 m up to ~ 30 m from road with traffic volumes in the range 500–62 100 AADT (annual average daily traffic). The maximum concentration of HMs in the soil was found at distances of 8–30 m from the pavement (the spread further from the pavement edge than 30 m was not investigated).

Table 1 presents average HM concentrations and medians.

HM content in the natural humus layer varies in different areas of Estonia, the surroundings of Tallinn are characteristic of podzol soils.

In the natural environment, average compositions of Pb, Zn and Cu in the upper soil layers had been exceeded already in 1991. Central part of Tallinn, with its increased compositions of Pb, Zn, Cu, Ag (silver), Sn (tin), was regarded to be an anomaly in 1991 [17].

As the results obtained at TUT show, HM contents in the roadside areas have increased as compared to 1991and the average concentrations of HM in soils of roadside in springs 2001–2004 exceeded the Estonians averages several times (Table 1).

3.2. In case of motor vehicles, pollution is related to mechanical wear and corrosion

Fe is the main substance in producing the body of a stud; Fe is contained in diabase, which is widely used as mineral matter in bituminous concrete. Fe is a natural soil component, the content of which has not been standardised. The study of the correlation of iron with the traffic volume gives the correlation coefficients r = 0,716 in 2001 (n = 23) and r = 0,596 in 2002 (n = 16). The coefficient of determination of R^2 distances from pavement edge L = 30 m were R^2 = 0,745 in 2001, R^2 = 0,590 in 2002, averaged R^2 = 0,686 in 2001–2002. Correlation matrices have been calculated in the Excel environment.

In addition, HM levels have been compared with the target concentration and permissible values in residential areas, established by a regulation of the Ministry of the Environment [19]. Figs 2 and 3 show the concentrations of Pb and Zn, depending on traffic volume – annual average daily traffic (AADT). In the figures, sample data are classified by sampling years.

Pb concentration has been a long-term indicator of contamination caused by motor vehicles. In the studies in 1991, Pb was the only HM, the level of which exceeded the target concentration (50 mg/kg) by Estonian regulations. At that time, in terms of environmental protection, Pb content in soil was considered a problem. Today the areas under study are still contaminated with Pb, the concentration exhibits a positive relationship with the traffic volume. It can be assumed that transfer to unleaded petrol has hampered a further increase of Pb content in roadside soils. However, a certain amount of emission from car paints still exists (Table 1, Fig 2).

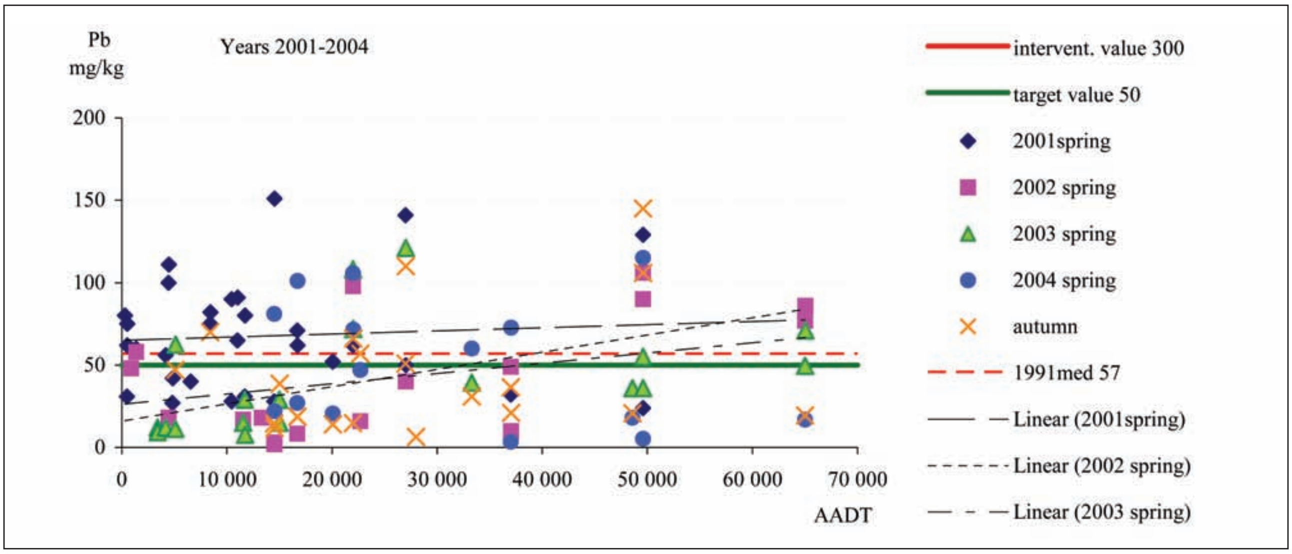

Fig 2. Pb content in roadside soils, depending on the traffic volume (an average concentration of Pb in the humus horizon of Estonian soils is 16 mg/kg, in Tallinn 12,5 mg/kg [17]

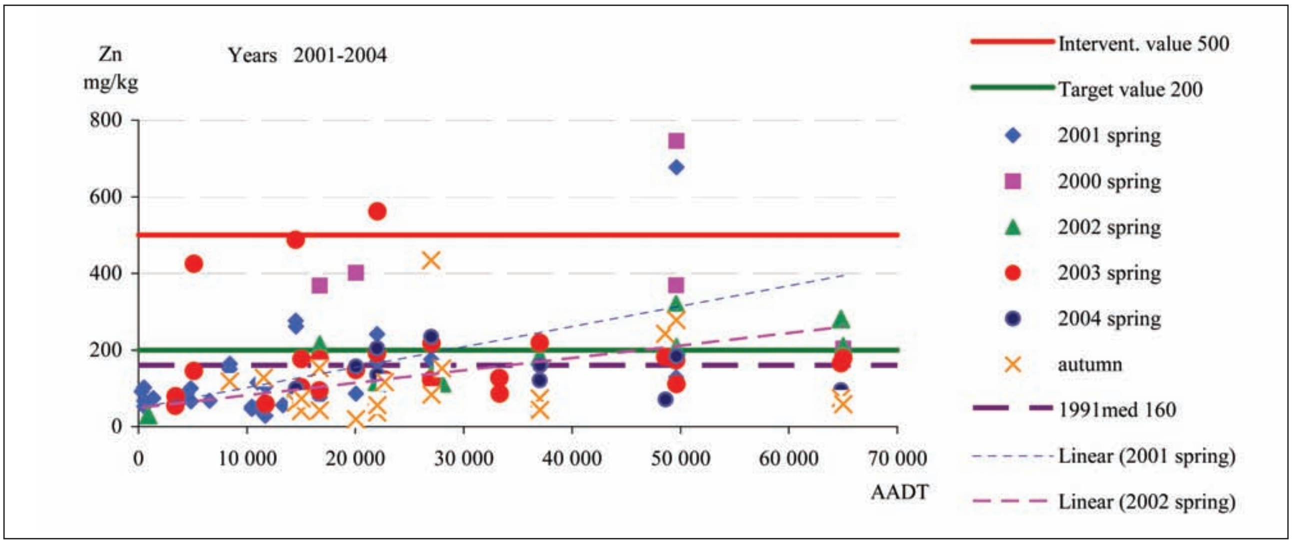

Fig 3. Zn content in roadside soils, depending on the traffic volume (an average concentration of Zn in the humus horizon of Estonian soils is 37 mg/kg, in Tallinn 16 mg/kg [17]

Zn contents were also high in the areas under study, exceeding nearly 6–8 times those of the natural environment. High Zn content in soil is suggested in case of a high concentration of chloride. On the sites with high Zn content shown in Fig 3, chloride content exceeded that of the average roadside soil several times. So Pb, used for a long time as an indicator of traffic pollution, is no longer sufficient for characterising the environmental impact of traffic any more.

Based on the increased Fe concentrations and a simultaneous increase in Zn, Pb and other HMs (Table 1, Figs 2 and 3), we can suggest that HM contents and traffic volume are related. This also provides a proof that traffic brings about the pollution of roadside areas. Figs 2 and 3 show Zn contents in 84 samples, depending on the traffic volume on roads close to sampling sites. Up to the traffic volume of 15 000 AADT, HM contents were approximately of the same magnitude, however, at the traffic volume over 15 000, HM concentrations varied significantly. In Estonia, traffic volumes over 25 000 vpd (vehicles per 24 hours) (AADT) are encountered only in Tallinn.

Soil and groundwater contamination has been found in several countries with a high traffic volume. Studies of transport pollution conducted in seven European countries (Great Britain, the Netherlands, Sweden, Finland, Denmark, France, Portugal) in 14 sites (traffic volumes 8500 and up to 150 000 AADT) in the framework of the European project POLMIT confirm that the concentrations of several polluting compounds are caused by traffic and road surfacing. It is clear that hydrocarbons are pollutants of both groundwater and soil and chloride is a pollutant of groundwater. Cd, Cu, Zn, PAH are potential pollutants, Pb and THC (hydrocar-

Table 2. Summary statistics of soil pH and concentrations of chlorides (mg/kg) in roadside soil within distances L = 3 – 15 m of road pavement in years 2003 and 2004

Statistical characteristics	March 2003 (n = 26)		March 2004 (n = 38)		September 2004 (n = 26)	
	soil pH_{KCl}	chlorides, mg/kg	soil pH_{KCl}	chlorides, mg/kg	soil pH_{KCl}	chlorides, mg/kg
Average	7,25	240	7,16	356	7,29	206
Standard deviation	0,32	231	0,48	207	0,66	124
Minimum	6,30	20	4,90	61	5,66	32
Maximum	7,90	995	7,81	944	7,92	519
Median	7,27	198	7,24	316	7,45	174

bons) are pollutants. An analysis of soil and groundwater was made according to Dutch Target and Intervention Quality Standards [20]. Target values in different countries vary slightly, for instance, in Estonia, Cd target value in soil is 1 mg/kg [19], by Dutch standards it is 0,8 mg/kg [20], in Finland 0,5 mg/kg [21].

3.3. Main factors limiting the mobility of heavy metals in soil

The accumulation of HM in roadside soil depends on the degree of the solubility of metal compounds The soluble compounds of HM usually move into deeper horizons or are washed out with rain at some distances from the roadside.

The form in which the HM is in soil depends to a great deal on the degree of the soil aeration. The main factor influencing the solubility and mobility of HMs is the pH of soil. Alkalinity is rising with the growing influence of traffic [22].

The large amount of de-icing salt used in wintertime that accumulates in the roadside soil also has a considerable influence on the solubility of most HMs. Based on the studies conducted at TUT, it is assumed that Zn and Cl contents in soil are associated. Chemical analysis of samples collected during three years indicated that correlation between chloride and zinc in soil is strong: $r_{2001} = 0{,}438$ (n = 14) > $r_{2002} = 0{,}785$ (n = 12) < $r_{2003} = 0{,}792$ (n = 25). The growth of Zn concentration in soil was accompanied by an increase in Cd. Zn can be used as an indicator element to demonstrate the traffic and winter maintenance pollution effect in spring [23].

Studies of Danish scientists confirm that in storm water flowing off roads in line have increased in line with an increase in chloride content. When chlorides are used in winter from November to April, the content of other compounds like Zn, Pb, hydrocarbon and PAH in storm water increases [24].

3.4. Effect of chlorides used as a de-icing reagent in Tallinn

The summary statistics of the soil pH and concentrations of chlorides in roadside soils of Tallinn is shown in Table 2. Larger concentrations of chlorine (Cl) were found within the distance of 3–5 m of road pavement.

Based on the regression analysis, Fig 4 shows the relationship between Cl content and the distance of the sampling site in roadside soil samples taken from different types of roads and streets in spring and autumn 2003 and 2004.

Y denotes an average Cl content in mg/kg and X the distance in metres from road pavement, respectively. The graph confirms the fact that Cl concentration is reduced as the distance from the pavement is increased, independent of road construction features. The graph shows all the results of the studies, including streets with storm water outlets as well as highway-type streets. Thus, the negative impact of chlorides on the environment cannot be excluded by storm water outlets, since even in the distance of 30 m from the road, chloride content is higher than the natural concentration of soils.

As can be seen from Fig 4, average Cl concentrations in the site under study in spring 2004 were significantly higher than in 2003. Consequently, in view of traffic safety in winter 2003/2004, the use of salts for de-icing in Tallinn was in a higher demand.

20–60 % of the salt used for de-icing is spread to the distance of 2–40 m from the road through the air [12].

Large quantities of chlorides are sprayed about 20 m

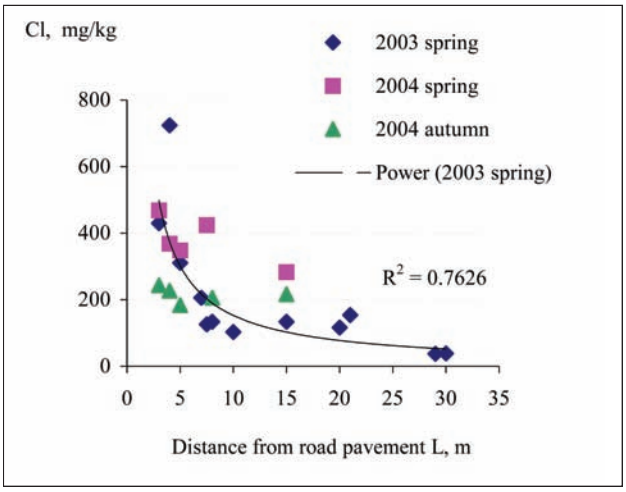

Fig 4. Average Cl contents in mg/kg in soils, depending on the distance from road pavement in 2003 and 2004

along roadside areas, thus causing damage to vegetation and groundwater, where surface groundwater is not adequately protected. Salt applied to highways runs off into streams increasing their salt content during winter and penetrates soil, resulting in elevated levels of Na and Cl within 30 m of road pavement. The salt that is most damaging to vegetation is carried onto trees and shrubs as wind-borne spray. Evergreens are particularly vulnerable but deciduous trees and shrubs are also affected [25].

3.5. Reduction of usage of studded tyres

In addition to harmful effects of chlorides on the environment, they also damage asphalt surfacing. Chlorides keep a nearly stable damp road surfacing. Unfortunately, water is the most severe enemy of asphalt surfacing. Salts destroy the protective layer of iced and snow-topped road surfacing. Studies show that the lower the temperature of the road surfacing, the higher is the wear of the asphalt surfacing by studded tyres. Studded tyres cause a ten times higher wear of damp road surfacing than that with dry surfacing [8].

In Finland, the wear of pavement, particularly in areas where salt is used for maintenance in winter, is considered the main source of road dust [26]. The wear of asphalt has been reduced by changes in the composition of asphaltic mixture and in that of hard-alloyed heads of studs. Still, it is suggested that the wear of pavement caused by studded tyres amounts to ~47 000 t/y, out of which 5–20 % or 2100–10 400 t/y is the spread into ambient air [27]. Experiments have shown that studded winter tyres produce far more PM_{10} than non-studded winter tyres, but also that a fraction of very small particles is produced (ca 20–40 nm). Different pavements produce very different amounts of PM_{10} and they have a different toxicological potential in human airway cells [28].

According to calculations, the usage of studded tyres leads to changes in cost – a decrease in traffic costs and passenger time charges allows for economy to car owners; at the same time, the total costs of road and environmental damages are to be compensated by state. The users of studded tyres bear these society costs equally with users of summer tyres and non-studded winter tyres as well as with pedestrians, although the road and environmental damages are caused mostly by them.

A possibility of decreasing this inequality would be to impose a tax on the use of studded tyres, while money, cashed in, will be used only for road maintenance and environmental needs. The annual or excise tax on studded tyres would be a certain financial tool that would encourage car owners to buy more non-studded winter tyres, the technical qualities and price class of which are nearly on the same level with studded tyres.

Another possibility is to shorten the permissible period of the usage of studded tyres: a 30-day shorter permissible period would reduce the wear of road pavements due to studded tyres by some 25 %.

3.6. The possibilities of replacing de-icing salts have been sought for a long time

In Estonia the only chemical used for de-icing is salt (NaCl), guidelines for de-icing are similar to those of Sweden [29, 30].

First studies of the impact of chlorides on groundwater were conducted at the end of the 1990s in Finland and Sweden [31–33].

Approximately 90 scientists and experts from ten countries participated in the International Symposium ”De-icing and Dust-binding – Risk to Aquifers” held in Oct, 1998 in Helsinki, Finland. The main objectives were to exchange information on the processes that affect the fate and migration of de-icing and dust-binding chemicals in different types of aquifers and the subsequent effects on groundwater quality. It was confirmed that a significant risk related to de-icing and dust-binding chemicals commonly used will affect the groundwater quality.

As an alternative to NaCl, calcium magnesium acetate (CMA) is gaining popularity in several areas around Europe and the USA. It appears that the effect of CMA on trace-metal mobility in roadside soils should have a less impact when compared to NaCl. Several tests with alternative chemical de-icers have, however, been conducted over the years. But so far they have all been rejected due to high costs and/or insufficient effect. The main drawback with CMA is its high price, which is at least 20 times of that of NaCl [34–36].

Effective solutions and possibilities of reducing salt quantities are being looked for [30, 37]. It can therefore be expected that the evaluation of the cost-efficiency types of pollution prevention measures will be increasingly required in the future [38].

3.7. Monitoring of usage of de-icing salts is needed

In most cases it is important to find useful indicators as early in the system as possible, especially when the environmental effect is delayed in time, and in that case an early warning could be reached. Chloride can be viewed as a good tracer.

In most cases it is important to find useful indicators as early in the system as possible, especially when the environmental effect is delayed in time, and in that case an early warning could be reached. Chloride can be viewed as a good tracer.

Today no methods are available in Estonia to evaluate risks to soil and groundwater related to road maintenance in winter. No target values to chloride content in groundwater have been established.

In view of experience gained in several countries, the trend of changed chloride content in surface groundwater close to the ground represents an important environmental indicator when the consequences of winter maintenance are evaluated.

In Sweden it has been concluded that de-icing salt is the principal source of the increased chloride content in the aquifer. Protection measures along the motorway are planned by the Swedish National Road Administration in order to reduce the chloride content to below 100 mg/l before 2005 and below 50 mg/l before 2025. Thereby, the risk for other contaminants from the road to reach the groundwater will decrease [39].

In view of economic considerations, the target value of chloride content in groundwater in the Netherlands and Finland is 25 mg/l; it means that if the Cl content in groundwater is ³ 25 mg/l, it is necessary to find out the reason of enhanced chloride content [20, 31]. If the reason lies in salt usage, the real situation is analysed to improve the condition, taking into account the drainage basin, location of the road in relation to the source of groundwater as well as protection of the groundwater, geology etc.

4. Generalisation

4.1. Conclusions of studies conducted at Tallinn University of Technology

- Environmental risks are enhanced along with a higher traffic volume. This correlation means that at a daily traffic volume of 15 000 cars, stricter road maintenance and winter maintenance requirements must be applied.
- The average concentrations of HM in soils of roadside in spring of 2001–2004 exceeded the Estonian averages several times: Cu ~ 7, Zn ~ 4, Pb ~ 3 and Cd ~ 2 times.
- Salts (NaCl) scattered on roads are highly soluble, dissolved by the influence of storm water and carried into the groundwater. When salt was used in winter, an increased concentration of Zn in soil was observed.
- In connection with traffic under winter conditions, additional indicators should be implemented to fix normative documents for using de-icing salt, and taking into account the carrying capacity of the ecosystem.
- An optimum solution to both traffic safety and environmental sustainability requires a precise and organised use of de-icing chemicals on roads and a more efficient control of results. Collaboration of transport and environmental professionals is needed in the management of road maintenance to decide if it is economical to replace studded tyres by non-studded winter tyres (lamella).
- It is necessary to improve the database concerning pollution caused by traffic and reporting system. Allround development of statistics will provide a basis for sustainable policy.

4.2. To take into account all the factors towards a sustainable environment, relevant political decisions are essential

In Estonian transport policy, attitudes towards environmental issues are one-sided and concrete goals have not been established. In addition, no methods are available to evaluate changes in the environment condition caused by traffic. The new requirements concerning the technology of road winter maintenance provide the quantities of recommended loose materials and salts. Limitations to permissible quantities of salt use depend on requirements for the state of road and for the weather conditions typical in winter like snow, ice and slipperiness etc [40]. These are not imposed in the requirements for the state of environment.

At the same time, the regulation provides that "measures should be taken to protect the natural environment when conducting road construction, repairs and maintenance. If a possibility of change of the geological or ecological state of the environment exists in road maintenance works, technological solutions have to be applied to avoid damages to the natural environment. If organic binding materials are used, their penetration to soil and water bodies should be avoided" [29].

Thus it is necessary to take political decisions in Estonia leading to specifying acts essential for environmental protection, since several regulations concerning implementation are ambiguous, in particular, in boundary areas of different fields – environment and transport.

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