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Development of the road network in the submountain area of the High Tatra mountains as a potential source of heavy metal pollution: a case study of the Kežmarok town

J. SOLÁR
Institute of the High Mountain Biology, Tatranská Javorina 7, 059 56-SR Slovak Republic, e-mail: solar@uniza.sk

Abstract. This study shows the landscape types, which could be threatened by heavy metals production of the road network in the model submountain area. Development of traffic and its potential impact is analyzed in the cadastral Kežmarok area during the years 1870–2008. Development of the road network shows changes in the country affecting the possibility of heavy metals dislocations and environmental quality. The most intensive increase of the road network area was recorded in 1957 because of the industrial development after the Second World War and the reconstruction of the railways originally built in 1889. Further development is characterized by the decrease of road network area because of less usage of field roads. The most threatened part of the land use by heavy metals dislocations was most likely agricultural land, but later in the development of land use structure the grasslands replaced it.

Key words: heavy metals pollution, GIS, development, road network

Introduction

According to Banásová and Hajdúk (1986) the road network can be considered as a separate anthropogenic ecosystem, which can be characterized as equally wide, flat area covered with concrete and dark resins, on the edge lined with the roadside, ditches, fences and any treatment that create border areas of the roads. This ecosystem has a significant impact on flora and fauna.

The road network with high frequency of cars represents barriers and obstacles in the movement and migration of animals (Forman and Alexander 1998). The country is so fragmented into smaller units, where particularly large animal species remain confined to small areas, and often become victims of road traffic. Spellerberg (1998) in his review of the ecological effects of roads and traffic published the summary of ecological effects of roads (Table 1). Vegetation along the roads is a dynamic phytocoenoses. The species composition depends on the macroclimatic impact, but also on human factors changing more or less from year to year. Example of these changes is also an infiltration of halophytes and other plant species tolerant to mineral rich substrate by the roadsides (Banásová and Hajdúk 1986). The effect of the traffic means that the vegetation has mechanically damaged leaves and it is intoxicated by deposition of pollutants and emissions from internal combustion engines.

Several studies show the traffic industry as a major source of introduction of heavy metals in the environment and locally reaching the highest values in the environment. Historically, the environmental contamination with lead and other heavy metals is particularly significant impact of the Industrial Revolution in the 19th Century and further development of automotive mainly after the Second World War. (Bednářová and Bednář 1978). Li *et al.* (2004) characterize car emissions as the main source of heavy metals along the roads.

To generalize the dislocation of gas and solid substances on the roads we work on a theory that each molecule of gas, particle of aerosol, a drop or a grain of salt undergoes in certain time its trajectory (Banásová and Hajdúk 1986). The result of this process is the amount of heavy metals in the surrounding structures. The microclimatic conditions above the road are influenced not only by climatic conditions of the surrounding area but also the air pressure generated by the wheel rotation and breaking the air with cars, where the higher weight and the speed of the car creates a greater air pressure. Friction of wheel, the accumulation of heat from solar radiation on the road surface and release heat from internal combustion engines are changing ambient temperature conditions. Water on the roads is a major factor in the transport of pollutants. Runoff of pollutants but also the whole dynamics of water regime on the road depends on the shape, slope and quality of road but also the shape and the manner of a ditch on the roadside. Higher concentrations of lead in soil by the older roads than the roads under the higher frequency of traffic confirmed the dependence of heavy metals in the environment from the initial time of pollutants accumulation (Bai *et al.* 2009). Deposition of metals, metal levels in surface soil, plants and gastropods decreased with increasing distance from the source of traffic (Al-Chalabi and Hawkera 1999, Viard *et al.* 2004). The highest concentrations of heavy metals in soils along traffic net occur within a distance of 5m from the edge of the carriageway. (Banásová and Hajdúk 1986, Al-Chalabi and Hawkera 1999, Li *et al.* 2004). Along the railroad this was confirmed by Ma *et al.* (2009).

The most significant factor affecting the amount of heavy metals produced by the road network usually are: age of the road network, traffic intensity, climatic characteristics, morphology of the road

Effects during construction
There is a direct loss of habitat and biota.
There are effects resulting from the infrastructure and supporting activities for construction.
The impacts may occur beyond the immediate vicinity of the road; for example changes in the hydrology. Mining for aggregates for the road may take place in a different area. It is important therefore to agree on the geographical boundary for an impact assessment.

Short term effects (of a new road)
The new linear surface creates a new microclimate and a change in other physical conditions extends varying distances from the road edge.
The newly created edge provides habitat for edge species.
Plant mortality increases along the edge; and such mortalities may extend from the road edge for varying distances.
The mortality of plants has direct and secondary effects on other organisms.
Some fauna will move from the area of the road as a result of habitat loss and physical disturbance.
Animals are killed by traffic.

Long term effects
Animals continue to be killed by traffic.
The road kills have secondary effects as carrion.
The loss of habitat and change in habitat extends beyond the edge of the road.
The changes in the biological communities may extend for varying distances from the road edge.
There is fragmentation of habitat and this in turn has implications for habitat damage and loss, for dispersal and vagility of organisms, and for isolation of populations.
The edge habitat (or ecotone) and traffic on the road may facilitate dispersal for some taxa, including pest species.
The dispersal of pest species via ecotones or traffic may have secondary effects on biological communities.
Associated structures such as bridges and tunnels may provide habitats for some taxa.
The run-off from the roads affects aquatic communities.
Emissions, litter, noise and other physical disturbances may extend into the roadside vegetation for varying distances and result in changes in species composition.

Table 1. A summary of ecological effects of roads (after Spellerberg 1998).

network, the dynamics of the surrounding water regime, the distance measurement from the road network and forms of land use along the road network.

Various researchers discuss the tolerance of plants to heavy metals (e.g. Antonovics *et al.* 1971). Some plants are able to accumulate toxic metals in tissues to the extent that they are known as hyperaccumulators. (Kaduková *et al.* 2006) These plants may be the food for some herbivorous animals, which move along the roads. Getza *et al.* (1977) measured an increase in the amount of lead in small mammals that lived at a distance of 5-10 metres from the highway. Accumulation of Pb and Cd ranged to a distance of approximately 33m. This fact led to the argument that the cultivation of food crops for human or animal consumption should be restricted within the belt on both sides of the road (Rodríguez-Floresa and Rodríguez-Castellón 1982). Atayese *et al.* (2008) draw attention to agricultural activities in the city. It should be at least 20m from the roadside. In crop production it is necessary to build barriers between the curb and the road. Romić and Romić (2003) used GIS for assessment of the overall soil pollution in the country. The content of Cd, Cr, Cu, Ni, Pb and Zn was determined in 784 soil samples from the central region of Croatia. The result of the study was the definition of the areas suitable for ecological farming. This procedure can be used to assess the suitability of agricultural land.

The main aim of this study is to suppose the threat of land use by heavy metals with the help of empirical data and GIS aplication.

Material and Methods

Study area

Area of interest is the cadastral territory of Kežmarok town. In the year 2008, it covered an area of 24.8 square kilometers. The area is located in the northeastern part of the Slovak Republic in the submountain area of the High Tatra Mountains (Fig. 1).

The city center is at altitude 626m. a.s.l. (49° 10' and 20° 25'). The study area falls within the temperate zone of the Atlantic-continental region. Area is assigned to moderately warm areas in the district, which is characterized as moderately warm, moderately humid with a number of summer days - 50 and the average air temperature in July above 16 °C (Čeman 2003). Winter is cold with average temperature -5 to -6 °C in January. The area is located in the so-called rain shadow of the High Tatras, with average annual rainfall of 600-700mm.

Modeling potencial heavy metal polution

For modelling was used simpler model. Only distances from road network with the categories 0-3, 3-8, 8-18, 18-38, 38-88 meters (Fig. 2) were taken into consideration. These categories may pose a potential threat to the vitality of living organisms.

With the use of the function multiple ring buffer, we created the layer with categories of distance around the road network. Also we created multi layer land use maps from the years 1870, 1957, 1988, 1995, 2008 and calculated the area of land

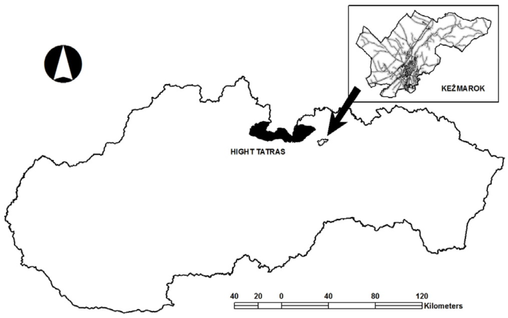

Fig. 1. Location of the study area.

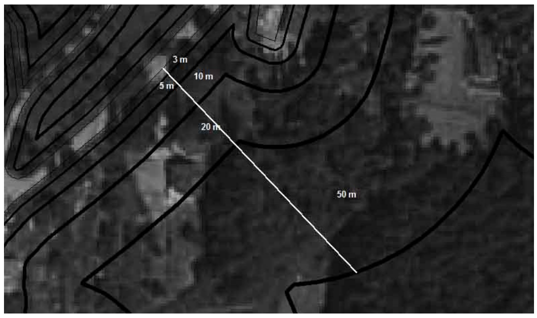

Fig. 2. Categories of potencional heavy metal pollution.

use forms in different categories and years. Multi layer land use maps were created by conducted manual vectorization in ArcView GIS 3.2 and later in ArcGIS 9.2 on the basis of available maps.

The 1870 landscape structure was created from a collection of cadastral maps of the State Regional Archives. The 1957 landscape structure was created from topographic maps 1: 25,000. For landscape structure of the year 1988 were used declassified military topographic maps 1: 25,000. For landscape structure of the year 1995 was used layer format of the AutoCad (dxf) removed in 1995 from Cadastral Portal SR. Landscape structure of the year 2002 was created on the basis of orthophoto images. The 2008 landscape structure was created on the same basis. It was supplemented by location field survey with potential changes since 2002, when the orthophotos were taken. Identified types of the land use are woodland, grassland, arable, water, urban.

Results

Development of the road network

Road network state in 1870, is joined to the development of ancient and medieval roads, remnants of previous cultures. Road network development (Fig. 3) after 1870 can be seen graphically in Fig. 4. Since 1870, the total area of the road network was extending particularly in the emergence of railroads into the direction of the Stará Ľubovňa. Also new roads within the city and roads to new industrial and agricultural buildings were built after Second World War. In the year 1988 we have registered decrease of the road network, because of the reduction of many field roads. Agricultural road were replaced by new roads along large-block fields, formed during the agricultural development in 1959. The decrease is only 0.08%, whereas arose new roads in the city due to urban development. Significant change could be seen in the city centre, declared in 1950 as a conservation area and partial traffic was diverted into its present form. After the change of political orientation in 1989 and transition to market economy, there is a decline of agriculture large-block fields. Thereby also increase in the number of field roads, permanent not in nature, in subsequent periods frequently altered. They cannot be regarded as roads. Traffic net in 2008 consists of railways (Poprad-Tatry-Plaveč), main roads, roads in the urban area, paved and unpaved roads such as forest and field roads. Major roads have three lines: Poprad-Kežmarok with transport

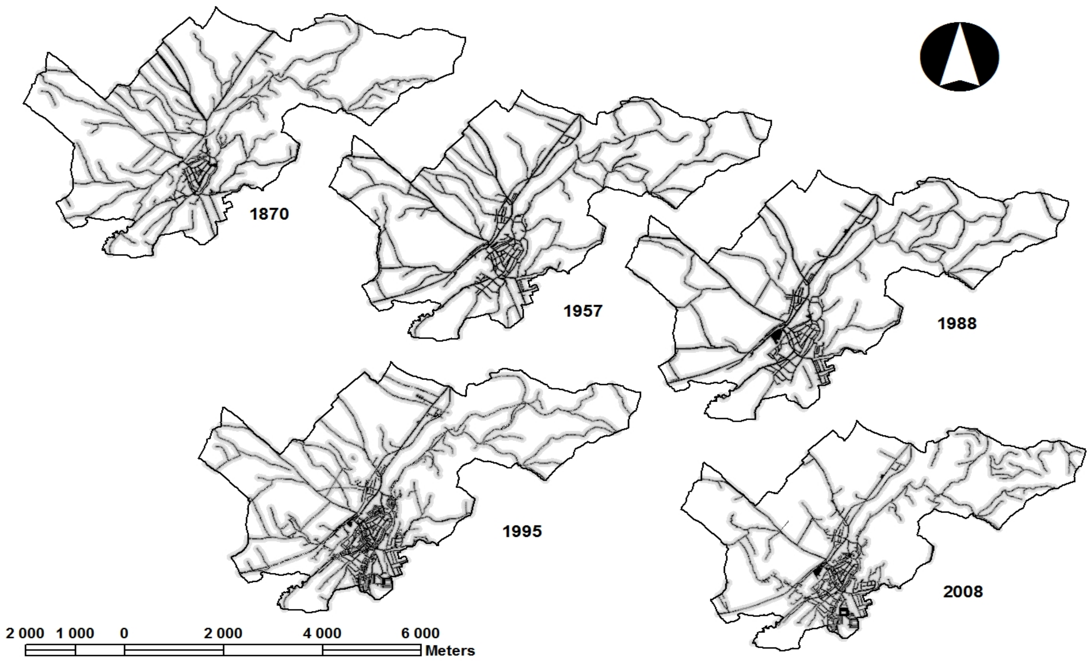

Fig. 3. Develoment of the road network.

frequency of 12,061 cars / day, Kežmarok - Ľubica with transport frequency of 7,290 cars/day and Kežmarok - Stará Ľubovňa with transport frequency of 11,927 cars/day. Paved traffic areas are represented by bus stations, gas stations and parking areas diffused in the urban area around technical and residential buildings. Most burdened form of land use was arable land (Fig. 5). It was localized mostly along the roads and they are generally the mostly represented forms of land use in the study area. In 1995, we recorded changes and the most burdened form of land use by the roadsides up to 8m was grassland, but with increasing distance was agricultural land again the most endangered by pollutants from the traffic. This change is connected with the decline of agriculture after 1989. But it also means reducing amount of heavy metals in the human food chain via agricultural products. In 1957 with 22.88% and in 2008 with 45.82% were grassland obtaining greater representation, from the viewpoint of land use structure. The increase of roads closely relates to increase of the urban structures (1957). The impact on urban structure decreases with the increasing distance.

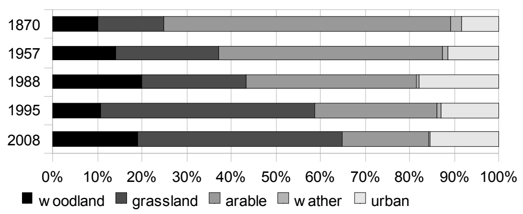

Fig. 4. Land use into distance to 3m from road network from 1870 to 2008.

Discussion

According to Baratová (1989, 1996) we know that there was a road (via magma) stretching alongside the Poprad river. Thanks to the fort in Kežmarok town and it's surrounding area we know the road connected the northern part of Europe with Orient. The medieval military trade route use to cross Kežmarok town. The historical development of the town developed the road network as well. The road networks represent the shortest ways of networking the surrounding of the town. Some of the road communications no longer exist, most of them became local streets, some of them became sporadically used farm-tracts. The road network was a lot denser in mediaval times because of the dense networks between the fields.

The development of the road network in the studied period was influenced by three factors:

- the construction of a railway 1889,
- the growth of automobile industry and the industrialization of agricultural production after the Second World War,
- decline of the agricultural production after 1989.

The situation till 1870 was satisfying, the automobile industry wasn't very developed, the land was hand-cultivated or with the help of farm animals. The situation has changed since 1957. Because of the industrialization of agricultural production, the machines with internal-combustion engine started to be used. The agricultural mechanization affected the amount of metal in the farm land. Positive affect after 1957 was that grass strips were formed occasionally alongside the agricultural roads. The decline of the agriculture after 1989 made the situation most probably better.

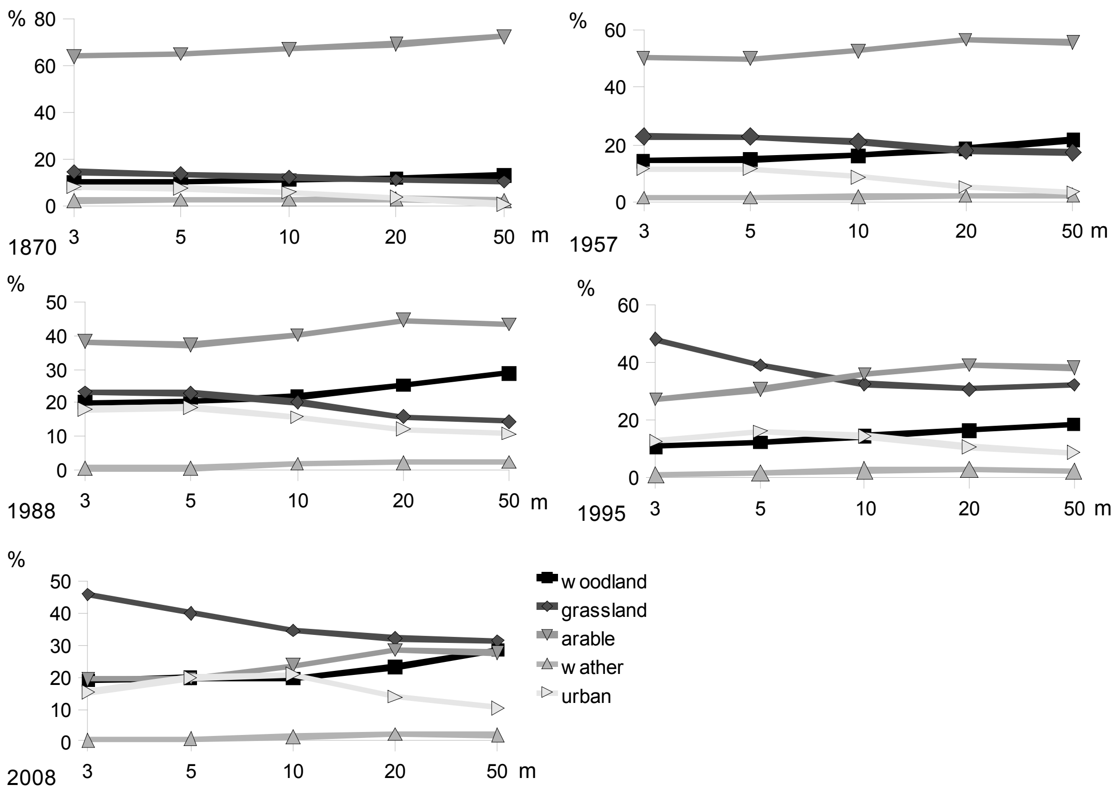

Fig. 5. Land use in dependence on distance from the traffic in the years 1870-2008.

Form Land Use	Distance	1870	1957	1988	1995	2008	Average
woodland	3	10.18	14.23	20.07	10.89	18.93	14.86
grassland	3	14.74	22.88	23.20	47.94	45.81	30.91
arable	3	64.28	50.26	38.15	27.16	19.40	39.85
wather	3	2.43	1.26	0.54	1.16	0.34	1.14
urban	3	8.30	11,35	18.01	12,82	15.29	13.16
woodland	5	10.55	14.70	20.54	12,36	19.74	15.58
grassland	5	13.74	22.67	22.91	38,95	40.00	27.65
arable	5	65.30	49.96	37.24	30,67	19.63	40.56
wather	5	2.67	1,25	0.64	1.86	0.65	1.42
urban	5	7.67	11.39	18.65	16.14	19.81	14.73
woodland	10	11.31	16.10	21.87	14.53	19.57	16.68
grassland	10	12.51	20.87	20.26	32.48	34.59	24.14
arable	10	67.34	52.71	40.08	35.87	19.63	43.13
wather	10	2.84	1.64	1.96	2.64	1.36	2.09
urban	10	5.92	8.66	15.80	14.45	20.78	13.12
woodland	20	12.18	18.38	25.30	16.48	23.11	19.09
grassland	20	11.37	17.88	15.84	30.77	32.08	21.59
arable	20	69.53	56.54	44.52	39.01	28.57	47.63
wather	20	3.12	2.02	2.23	3.03	2.25	2.53
urban	20	3.76	5.15	12.09	10.69	13.87	9.11
woodland	50	13.27	21.60	28.82	18.44	28.51	22.13
grassland	50	10.66	17.15	14.47	32.31	31.37	21.19
arable	50	72.79	55.69	43.36	38.19	27.66	47.54
wather	50	2.35	2.19	2.41	2.29	1.94	2.24
urban	50	0.85	3.34	10.91	8.74	10.42	6.85

Table 2. Land use forms in distance categories and their proportion during the years 1870 - 2008 in m^2 in the Kežmarok town area.

The traffic in the area of Kežmarok is twice as heavy as on the nearby road in High Tatras (cesta Slobody). Bednářová and Bednář (1978) evaluated the intensity of the traffic from 5 to 6 thousand cars daily. Measured values of lead in washed off plants in the vertical transect showed: 0-4m 14.96 ppm Pb, 4-8m 7.39 ppm Pb, 8-15m 5.97 ppm Pb, 15-50m 6.38 ppm Pb, 50-150m 6.87 ppm Pb, 150 and more 5.62 ppm Pb. The results show that the roadsides up to 4m are mostly exposed to the pollution, while in the area 4 to 8m the figures are half of it. We can assume a certain similarity in the amount of lead in the plants along the roads also in our area of interest. Banásová and Hajdúk (1986) show that the amount of chlorides as well as heavy metals along the roads increase in time even though the vegetation is regularly cut and helps to reduce this condition. After six years, in 1983, two times increase of lead was recorded in plants growing along the roads and tree times increase of cadmium. The concentration of these metals could be even higher these days because of present way of accumulation.

It is well known that the amount of heavy metals in the over ground parts of plants rises with its concentration in the soil. We can simulate the amount of lead in the soil from the gained reports from Al-Chalabi and Hawkera (1996), who analyzed the soil along Logan Road in Brisbane in Australia with the intensity 28,000 cars per day, which is two times more than on the road from Kežmarok to Stara Lubovna. In 5m distance from the road they measured 280 ppm and in the depth 5-10 cm 200 ppm. Bai *et al.* (2009) measured the amount of lead in soil in 200m distance from Dali Road, which was 20 years in operation and Road 320, which was 13 years in operation with the intensity 15,000 cars a day. On Dali Road it was measured 34,87 ppm of lead. If these figures were applied to the lead rate in the soil to the amount of lead in plants from the soil, most probably the same amount of lead would be found as Bednářová and Bednář (1978) reported. Czarnowska and Milewska (2000) measured 6, 6-13 ppm of lead in Warsaw in 1998 in *Taraxatum officinale* on grass strips close to roads and one hundred metres from the road 4,2 – 8,7 ppm.

If we look at certain factors we won't get exact figures but we can get an idea from the previous results in similar conditions as Kežmarok cadastre is.

With the increasing motoring trend and prerequisite for growth of traffic is needed to be planned with consideration of the results to avoid heavy metal pollution. The most important is to localize such forms of use along the roads that minimally come under trophic structure. Also plan the road networks so that we can count emerged microclimatic conditions on roads which have the greatest influence in dislocating heavy metals to a wider distance. We should also think about using new technologies and look for alternative fuels. New technologies used in means of transport lower the amount of heavy metals in emissions and together with new rules improve the quality of the environment. Positive changes are thanks to the improved quality of fuels in February 1995 when the biggest producer and seller of automotive petrol in SR stopped supplying automotive petrol containing lead. At present the petrol is produced with 0,003 g/l of lead and motor oil contains no lead. According to the report of environment conditions in SR, the greatest part of heavy metal emissions in the atmosphere in 2000 took copper - 19.65%, nickel - 11.66% and zinc - 9.19% and other heavy metals in comparison to the previous year dropped (Fabricius 2002).

Inevitable to improve the situation is:

- not to use the agricultural soil up to 50m from the roads,
- around the roads up to 5m use the grass strips with plants called hyperaccumulators heavy metal,
- to build the roads in flume or to plant scrubland plants to reduce the air flow on the roads,
- we also shouldn't forget to build so called green bridges for animal to give them a possibility to migrate.

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