ISSN 2644-0814

Ecology, Pollution and Environmental science: Open Access (EEO)

Researchview Article

Yakutsk is A Captive of Lead

VN Makarov[1*]

[1]Melnikov Permafrost Institute SB RAS, Yakutsk, Russia.

Lead (Pb) is a heavy metal of Group IV (carbon group) in the Mendeleev periodic table characterized by low abundance and high toxicity. Lead has been extensively used by humans for centuries and is known to accumulate in various ecosystems.

Environmental pollution with Pb and its compounds is a major problem around the world. Due to the widespread use of Pb compounds, lead concentrations in humans have increased 100 times over the last 5000 years, reaching the level only 5 times lower than the exposure considered poisoning [1]. Unfortunately, Yakutsk, like many other Russian cities, suffers from Pb pollution.

Yakutsk is one of the largest cities located in the cryolithozone, founded in 1632. German engraving gives an idea of the city in the XVIII century (Figure 1).

Atmosphere. Atmospheric Pb level at the South Pole is estimated to be 0.5 ng/m^3; the average concentrations above the oceans are an order of magnitude higher [2]. In Central Yakutia, the Pb concentration in atmospheric air is 2.2 ng/m^3, which is within the range of 1.5 to 4.4 ng/m^3 reported for Siberian regions [3].

The major sources of Pb in urban air are emissions from vehicles (approximately 1 kg/yr per vehicle), printing industry, and burning of solid waste, coal and oil. In Yakutsk, where the total number of vehicles (automobiles, trucks, and buses) is 112,000 (2018), the total Pb emission rate into the atmosphere is estimated to be about 112 t/yr.

Pb contents in atmospheric aerosols in Yakutsk vary between 40 and 580 ng/m^3, which are close to the values for suburban areas and almost an order of magnitude lower than the maximum values observed in the atmosphere of Russian cities (Table 1).

Aerosol Pb concentrations are 15-20 ng/m^3 in the suburbs of Yakutsk, exceeding background by about an order of magnitude.

Figure 1: General view of the city of Yakutsk on an engraving of the XVIII century.

Table 1: Pb content in atmospheric air and aerosols.

Atmospheric air [2]		Aerosols, ng/m^3			
		Russia [4]		Yakutsk	
Ocean	South Pole	Suburbs	Cities	Mean	Max.
2.8	0.5	300	3 000	223	580

Mean concentrations within the city are approximately 223 ng/m^3, reaching 400-580 ng/m^3 in the air above major streets. These levels exceed the background values by two orders of magnitude and are 1.5-2.0 times above the maximum permissible level (MPL) of 300 ng/m^3 set for lead in Russia (Figure 2).

Aerosol Pb concentrations in Yakutsk are two orders of magnitude higher than in the arctic town of Tiksi with low air pollution and significantly higher than in Norilsk, another northern city which has a similar population size but is better planned (Table 2).

Lead is deposited on the Earth's surface in two main forms, water soluble and solid. Its content in rainfall and snowfall varies over a wide range in Yakutsk. Background precipitation concentrations of Pb in Yakutia are lower than in any other region of Russia (0.05-0.3 μg/L). In the city of Yakutsk, Pb levels in the liquid phase of snowcover are an order of magnitude higher than background concentrations (mean = 7.1, max = 70 μg/L) and approximately close to the values for Chita,

Figure 2: Distribution of Pb in atmospheric aerosols, units sanitary standards.

Table 2: Pb content in atmospheric aerosols of northern cities, ng/m^3 [5].

City	Mean	Min.	Max.	MPL
Tiksi	1.2	0.17	3.0	
Norilsk	35.0	6.4	90.0	300
Yakutsk	223	23	580	

***Corresponding author:** VN Makarov, Melnikov Permafrost Institute SB RAS, Yakutsk, Russia, Tel: 7-4112-390-883; Fax: 7-4112-390-883; E-mail: vnmakarov@mpi.ysn.ru

Received: July 30, 2019; **Accepted:** August 10, 2019; **Published:** August 13, 2019.

a city with similar population but more industrial (Table 3).

The typical dust Pb level in polluted air of the Russian cities is assumed to be 0.1 mg/kg [4]. In Yakutsk, the highest Pb content in the solid phase of snow (atmospheric dust) for the period of 1989–2016 was 500 mg/kg, and the mean was 125 mg/kg which is four times the MPL_{soil}, close to the mean for Blagoveshchensk, and an order of magnitude higher than in Chita (see Table 3).

The extremely high background Pb content in the dust phase of snow in Blagoveshchensk draws attention. This might be due to the transfer of atmospheric pollution from the Chinese city of Heihe which is located only 500 meters across the Amur River.

Most of the pollutants accumulated in the liquid phase of snow cover are transferred into natural waters, while the solid phase pollutants settle on the lake and soil surface, with the Pb concentration in Yakutsk atmospheric dust significantly exceeding the contents in soils and alluvium. In the centre of anthropogenic anomalies, Pb concentration in the solid phase of snow (dust deposition) is tens of times higher than the permissible contaminant level for soil (see Table 3). The deposition of dust particles leads to increased Pb levels in the urban soils.

There is a distinct relationship between the Pb levels in precipitation and the intensity of anthropogenic impact. The highest concentrations, up to 70 μg/L in the liquid phase of snow and 500 mg/kg in the solid phase, are observed in the downtown area of Yakutsk with dense vehicular traffic (Figure 3).

Much higher Pb concentrations, up to 2000 mg/kg, in the solid phase of snow occur in the airport area, where heavy pollution is produced by exhaust from aircraft and vehicle engines during aircraft landing, take-off, engine starting and taxiing, as well as airside vehicle operations. Increased lead pollution is observed near the aircraft ground running area and along the runway (Figure 4).

The accumulation of gaseous, aerosol and dust emissions in the air and subsequent deposition on the surface results in contamination of streams, lakes and soils with Pb.

Natural waters. Few data available for Pb concentrations in Yakutsk natural waters are presented in Table 4.

Table 3: Pb levels in snowcover in selected cities of the Russian Far East.

Snow (liquid phase), μg/L				MPL_{AL}
City	Background	Mean	Max.	
Yakutsk	0.1	7.1	70	10
Chita [6]	1.0	3.1	69.5	
Snow (solid phase), mg/kg				MPL_{soil}
Yakutsk	0.5	125	500	32
Yakutsk (airport)		500	2000	
Chita [6]	-	10.4	30.5	
Blagoveshchensk [7]	29.8	91	-	

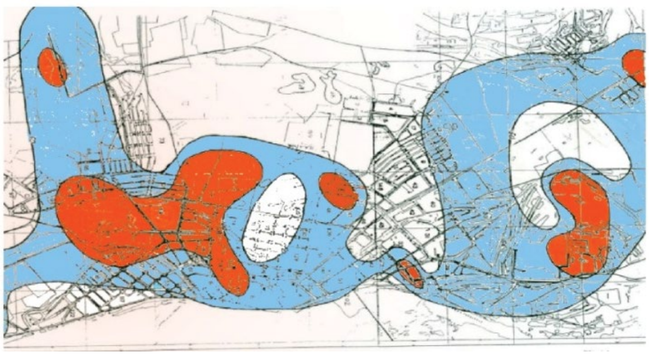

Figure 3: Pb distribution in the solid phase of snow cover, mg/kg.

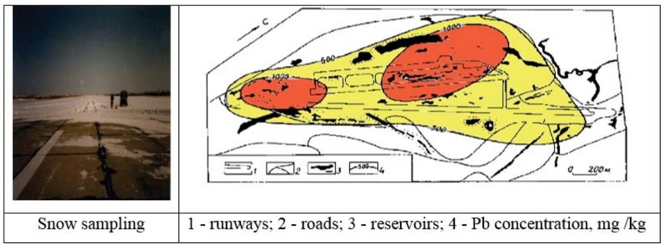

Figure 4: Pb anomalies in the solid phase (dust) of snow cover, Yakutsk airport.

Table 4: Pb levels in natural waters, μg/L.

Natural waters	Pb	MPL_{AL}/MPL_{H}	Reference
Groundwater in the permafrost province	1.5	10/30	[8]
River water	1.0		[9]
Yakutsk			
Groundwater (J_1 aquifer system)	0.020 - 0.10	10/30	
Cryopegs	7.1-81.4		[10]
Lakes	0.5-20		
Lena River (near Yakutsk)	0.05-0.3		

Note: MPL_{AL} - maximum permissible level for aquatic life protection; MPL_{H} - maximum permissible level for human health protection.

Pb concentrations both in surface water and groundwater in the vicinity of Yakutsk are two to three orders of magnitude lower than the global averages for stream water and permafrost groundwater. This is consistent with the low background levels in the region outside the zone of anthropogenic influence. The situation is drastically different within the city where waters have elevated concentrations of lead.

Atmospheric Pb is deposited on soils and subsequently carried to lakes by runoff. Lake water Pb concentrations in Yakutsk vary over a wide range, from 0.05 to 20 μg/L, with an average of 2.26 μg/L for ten major lakes (Figure 5).

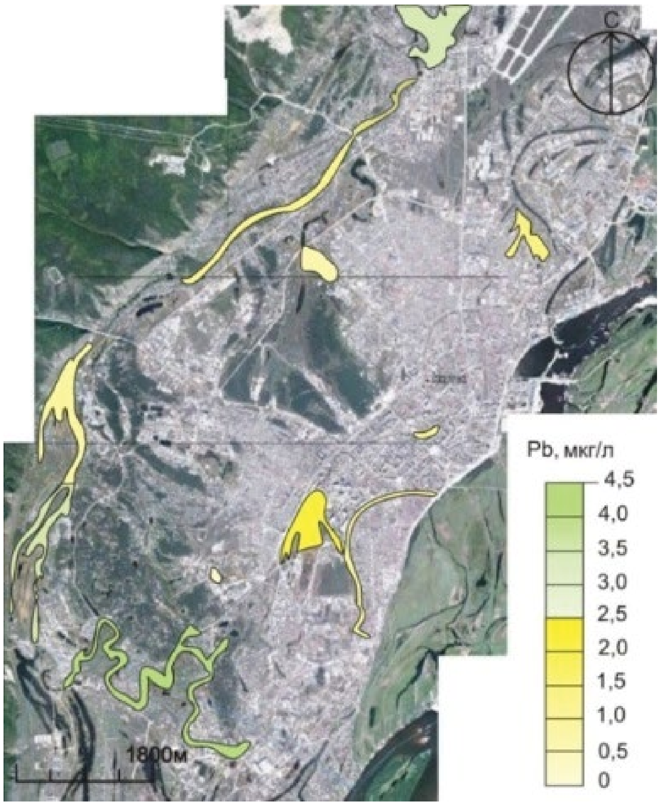

Figure 5: Average Pb concentrations in major lakes, Yakutsk [11].

Anomalously high Pb levels between 4 and 8.7 µg/L are observed in lakes located in close proximity to motorways. "Hurricane" concentrations were measured near the Modular Building Combine (20 µg/L, Sergelyakh Lake) and the poultry factory (10 µg/L, Ytyk-Kuel Lake).

Pb levels in soils and major lakes show similar temporal trends (Figure 6).

Pavlova [10] reports elevated concentrations of Pb and other heavy metals in cryopegs occurring above and within permafrost. Cryopegs enriched with heavy metals migrate downwards, extending from the cultural layer into the alluvial deposits. Where cryopegs have dissolved-solids contents of 10 to 22 g/L, Pb concentrations are as high as in 81.4 µg/L at depth of 2.4-4.5 in the cultural layer and 15.3 µg/L at depths of 17-18 m in the alluvial deposits.

Biosphere. Lead belongs to the group of weak and very weak biological uptake. However, there are Pb accumulator plants which include mosses, lichens, bilberry, ferns, horsetail, sedge, and oxalis. At the toxic level of 30 mg/kg or more, 0.003–0.005% of the total Pb is taken up by plants.

A study of common reed (*Phragmites communis*) growing in lakes and drainage canals was undertaken to define the distribution of Pb in Yakutsk plants. The measured Pb concentrations in reed are shown in Table 5 together with mean concentrations (clarkes) in terrestrial plants.

Compared to the clarke concentrations in terrestrial plants, lead is enriched from 2- to 10-fold in Yakutsk reeds. The anomalous Pb levels are caused by anthropogenic pollution of lake water and bottom sediments, as well as by atmospheric deposition.

Most Pb is accumulated in the root system of reed, where its content is 4-9 times higher than in the stems. Reeds growing along the canals (more contaminated than lakes) exhibit higher root Pb concentrations compared to the lake reeds.

An important question is how much Pb aquatic plants can absorb from heavily contaminated water and wastewater. Data on the maximum metal contents accumulated by aquatic plants were collected

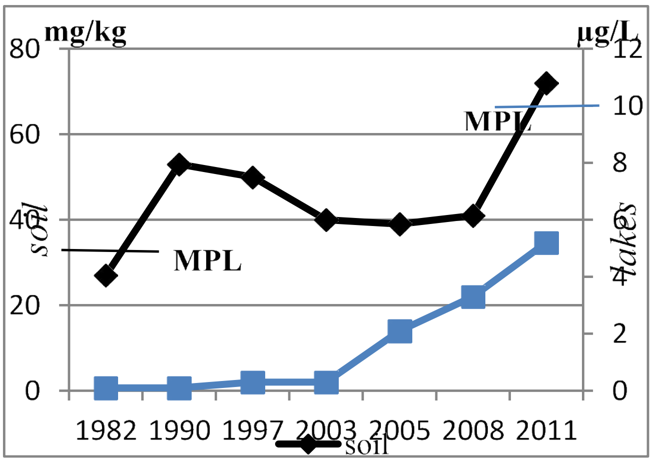

Figure 6: Dynamics of Pb concentrations in lakes and soils, Yakutsk.

Table 5: Lead concentrations in terrestrial plants and Yakutsk reed, mg/kg.

Clarkes in terrestrial plants [4,12,13]			Terrestrial plants [8,14]		Reed, Yakutsk [15]
2.7			2.7		26.3
Pb content in reed roots and stems					
Roots (n=19)			Stems (n=18)		
Mean	Min.	Max.	Mean	Min.	Max.
35	7	150	5.2	2	20

by Jackson et al. [16]. Their findings are consistent with the Pb levels obtained for reed roots in Yakutsk, while higher concentrations in the plant species studied by Jackson et al. are due to their confinement to an ore deposit (Table 6).*Sediments, rocks, and artificial ground*. The geochemical spectrum of sediments and sedimentary rocks in the Yakutsk area was analysed by Pod'yachev [17]. Table 7 presents the distribution of a large group of trace elements and Pb in the main geological units.

The Cambrian formations, Innikan and Tympin, comprised of limestones, dolomites and marls are characterized by the accumulation of siderophile and chalcophile elements with a limited amount of excess elements and Pb concentrations below the crustal average.

The Mesozoic and Cenozoic rocks, as well as the Holocene alluvial deposits have a significantly wider spectrum of lithophile and chalcophile elements that are in excess of crustal abundances. Pb levels in these materials are up to 1.5-2.0 times the crustal average. In the alluvium, Pb concentrations increase with decreasing grain size, from 10 mg/kg in medium-grained sands to 30 mg/kg in silts and silty clays.

Anthropogenic ground (the cultural layer) within the city of Yakutsk shows differences in Pb content depending on its thermal condition and length of anthropogenic impact [18]. In areas of relatively recent development (<100 years), Pb values are similar for the thawed and frozen layers, while in the areas of longer land use,

Table 6: Maximum concentration of Pb accumulated by aquatic plants during the growing season.

Vegetation	Pb, mg/kg dry wt.	Reference
Aquatic plants	580	[16]
Yakutsk		
Reed, roots	150	[15]
Reed, stems	20	

Table 7: Pb and trace element concentrations in the main geological units relative to crustal abundance [17].

Formation and dominant rocks	Concentration ratio				
	0.7-1.0		1.0 – 1.5	1.5 – 2.0	>2.0-5.0
Innikan Formation - €1 in *limestone, dolomites*	Ti, Cr,P, Zn	Yb Li, Mn, Co, Ga, Ge, Sn, W, **Pb,** Ag, Sn	Be, Sc, Ag, Cu, As, Y, Nb, La, Yb, Bi, Sb, B, V, Ni, Tl	-	Mo, Au
Tympin Formation - €2 tm *limestone, dolomites, marls*	Zn, **Pb**	Mn, Yb Li, Ti, Cr, V, Co, Ni, Cu, Ga, Y, Nb, W, Mo, Ge	Be, B, Sc, Mn, As, La, Yb, Sb, Bi, Tl, Sb, Au, Mo	W	-
Ukugut Formation - J1 uk *sandstones, conglomerates*	-	Mo, W	Li, Be, B, Sc, Cu, Au As, Nb, Yb, Sb, Bi, Tl, Zn V, Mn, Ni, Ge, Ag, Sn	P, Ti, Co, **Pb**, Au	Cr, Zn, Ga
Tyung Formation - J1 tn *sandstone, clay, sands*	-	Ag, Mo, B, Cu, Ge, W	Be, B, Zn, **Pb**, Ni, La, Yb, Tl, Sc, Mn, V, Co, Nb, Sn	P, Li, Cr, Zn, Ga, Y	Ti
Yakut Formation - J2 jak *sandstones, sands*	-	B, Ni, Mo	Li, Be, Sc, Mn, Cu, Ge, Nb, La, Yb, Au, Co, Ag	P, Ga, Sn, W, **Pb**	Cr, Zn
Mavrinskaya suite-laQII-III mv *sands*	Li, V	B, P, Mn, Co, Ni, Zn, Ag	Be, Sc, Ti, Cu, Ge, Mo, La, Yb, Tl, Cr, Ga, Y, Nb, Sn, **Pb**		W
II river terrace *sands*	Li	B, V, Co, Cu, La, Ag,Yb	Be, Mn, Ni, Ge, Au, P, Ti	Mo Sn, **Pb** Zn, Nb, W	Cr, Ga
I river terrace *sands*	Li, B Cr, Mn	Yb V, Ni, Cu, W Mo	Be, Ge, Sn, **Pb**, Sc, Co, Zn, Y, Ag La, Au	P, Ti, Ga,	-

Pb concentrations tend to be higher in the seasonally thawed layer (Figure 7).

Anomalous Pb concentrations in the older (>100 years) cultural layer are 1.4 to 1.7-fold higher than in the undisturbed alluvial deposits. Anomalies extend throughout both the freezing and frozen layers down to the top of the alluvial deposits where Pb concentrations are reduced to background levels, but may occur as deep as 10-12 m (Figure 8).

In the younger cultural layer (30-40 years), Pb enrichment is low and restricted to the upper 0.2-0.5 m of the ground.

The effect of intensity of anthropogenic load on Pb contents can be seen in samples from two boreholes drilled in the Yakutsk's older neighbourhoods. The cultural layer was determined by drilling to be approximately 4 m thick in both boreholes. However, the distribution of Pb in the cultural layer differs significantly.

Borehole 17 is located in the downtown area with heavy traffic and high atmospheric pollution. Pb concentration is about 50 mg/kg in the upper part of the cultural layer, reducing to a slightly elevated level of 20 mg/kg at the contact with the alluvium.

Borehole 1-1 is located in Zalozhny District (Strod Street) with low traffic density and, therefore, Pb concentrations in the samples are within 15-20 mg/kg (Figure 9).

However, high anthropogenic loading does not always lead to significant ground contamination with Pb. An example is the Yakutsk

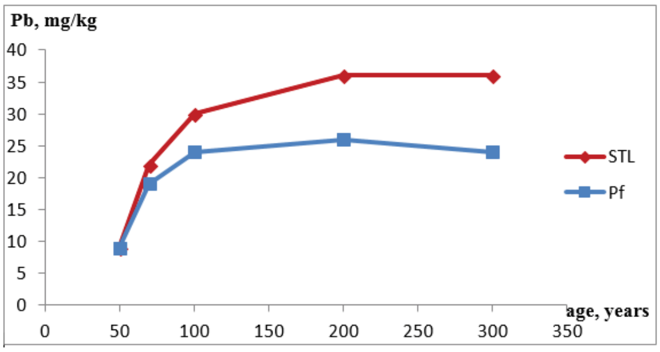

Figure 7: Pb contents in the seasonally thawed layer (STL) and permafrost (Pf) in relation to anthropogenic impact duration.

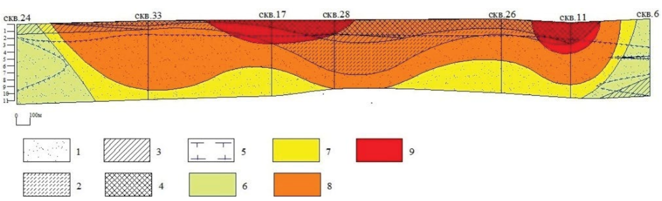

Figure 8: Pb geochemical profile in the cultural layer and alluvium (NW-SE) (1) sand; (2) sandy silt; (3) silt; (4) anthropogenic sediments; (5) permafrost boundary; (6)–(9) Pb levels, mg/kg: (6) ≤ 10, (7) 10-20, (8) 20-30, (9) 30-50.

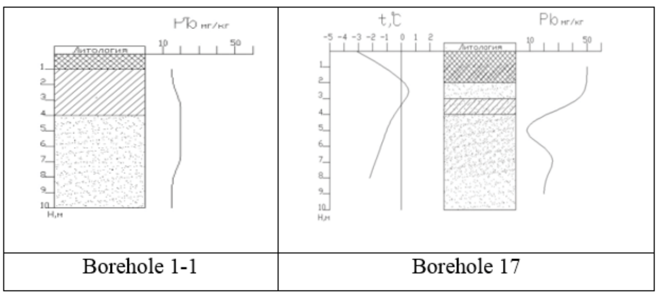

Figure 9: Pb distribution in the cultural layer with different anthropogenic loading.

airport which experiences a higher atmospheric deposition rate of Pb compared to other parts of the city (see Fig. 4).

The soils in the airport area are contaminated with a wide variety of chalcophile elements. Pb concentrations at the ground surface are 1.1 to 1.6-fold higher than the maximum permissible level, but are already within the MPL_{soil} at depths of 0.5-3.2 m, both in the thawed and frozen ground.

Despite the excessive Pb deposition by precipitation, up to 2000 mg/kg in the solid phase of snow, soil concentrations are relatively low in the airport area, 1.6 times the MPL in the topsoil and 0.9 MPL in the lower-lying thawed and frozen ground. It is likely that the deposited Pb is washed off due to the continuous asphalt and concrete pavement, reducing downward movement.

Below the airport runway, slightly elevated levels of total and dissolved Pb are observed to depths of 2-3 m, down to the permafrost table (Figure 10).

Soils and bottom sediments. Tetraethyl lead added to petrol as an antiknock agent and coal burning are the main sources of elevated Pb levels in urban soils. Most of this lead is deposited on the ground surface and then washed off into water bodies, but some of it remains in the air.

In Yakutsk where the climate and terrain conditions impede the dispersion of Pb, the mean soil concentration is almost 1.5 times higher than the MPL, corresponding to the environmental emergency level [19]. The maximum values measured are as high as 700-5000 mg/kg, or 20 to 100 times the MPL (Table 8). In most of the Yakutia's rural communities, no soil contamination with lead is detected.

Soil contamination in turn leads to further deterioration of air quality. Soil dust is the main source of dust in dwellings.

Pb concentrations in Yakutsk soils are distinctly correlated with

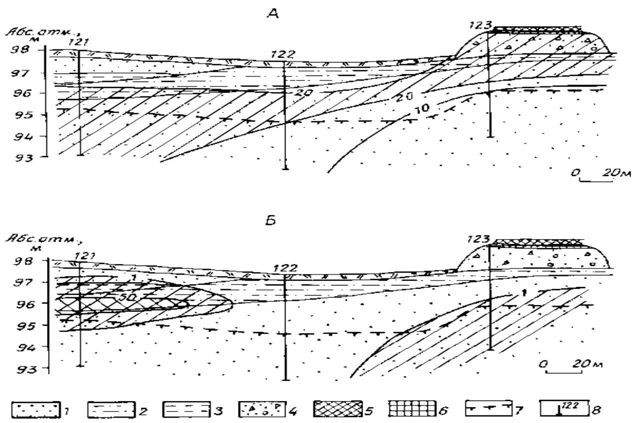

Figure 10: Soil concentrations of total Pb, mg/kg (A) and dissolved Pb, µg/L (B) in the Yakutsk airport area. (1) sand; (2) sandy silt; (3) silt; (4) crushed stone; (5) asphalt; (6) concrete; (7) - permafrost table; (8) borehole number.

Table 8: Soil Pb concentrations in urban and rural communities of Yakutia, mg/kg.

City	Mean	Max.	Village	Mean	Max.
Yakutsk	47.0	5000.0	Bagadya	12.0	21.0
Mirny	49.0	100.0	Mukuchi	12.0	20.0
Aldan	56.0	1000.0	Kokuy	24.0	25.0
Chulman	58.0	500.0	Mastakh	15.0	20.0
Neryungri	14.0	100.0	Zharkhan	10.0	15.0
Verkhnevilyuisk	14.2	–	Chappanda	10.0	15.0
Nyurba	8.8		Nyurbachan	10.0	12.0
Badran	25.7		Dzhakimda	10.0	15.0
Sangar	60.0	100.0	Khatassy	24.6	50.0
		MPL_{soil}			32

infrastructure growth. The number of vehicles and the concentration of lead in soils along major roadways show a nearly synchronous trend and an almost three times increase relative the 1982 levels (Figure 11).

High Pb levels are observed in roadside soils. The mean Pb concentrations along the major roadways in Yakutsk exceed the permissible levels by a factor of 2.4. The strongest Pb anomalies are extended along the roadways that have high traffic densities, with peaks near the intersections of streets (Figure 12).

The zone of vehicular influence is strongly variable, and Pb anomalies in roadside soils can be detected within 150 m from the roadway.

It is noteworthy that the Pb concentration in roadside soils significantly declined between 1995 to 2008. This was attributed to the urban improvement efforts undertaken during this period, including asphalt surfacing and lawn soil replacement, which reduced airborne dust and Pb inputs into the environment.

Lead, like other heavy metals, accumulates in the upper humus horizons of soil. The half-life of Pb in soil (leaching, erosion, plant uptake, deflation) is very long and takes 740 to 5900 years depending on the type of soil.

Soils are considered to be a self-purifying natural filter [20]. In permafrost regions, however, their self-cleaning capacity is largely lost because of the thin soil profile, the thermo-hydrogeochemical barrier to contaminant migration, and weak biochemical activity. These conditions promote the acceleration of soil contamination processes in the area of anthropogenic pressure. The high potential of atmospheric pollution associated with climatic conditions limits the dispersion of pollutants. Compared with the anthropogenic Pb anomalies in the air and precipitation, the soil anomalies are limited in area and less contrasting.

The specific conditions of the geochemical situation of the hypergenesis zone in the city and, above all, the alkaline environment of soil solutions, contribute to the fixation of Pb in the form of poorly soluble compounds. However, the constant increase in the acidity of urban soils in recent years, contributes to an increase in the volume of mobile forms of this metal in the soil and the deterioration of the ecological situation.

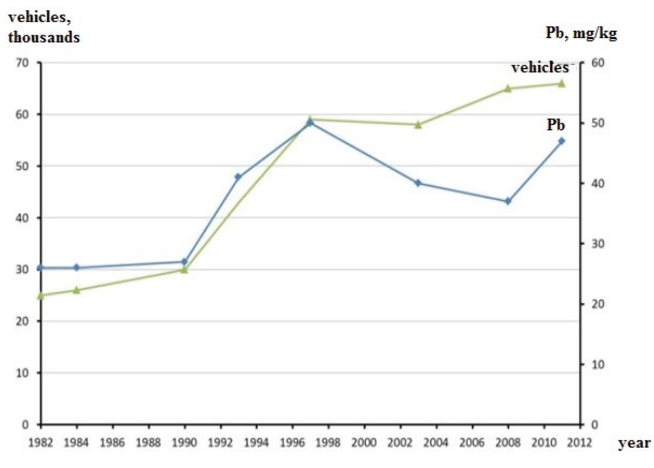

Figure 11: Relationship between the number of vehicles and soil Pb concentration.

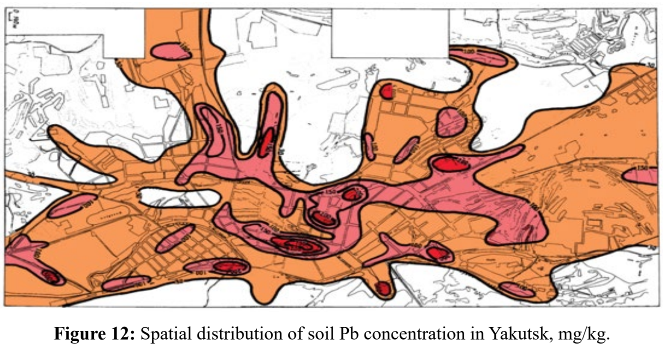

Figure 12: Spatial distribution of soil Pb concentration in Yakutsk, mg/kg.

Atmospheric fallout of Pb through wet deposition and its transportation to surface waters result in increased levels of the element in bottom sediments of the Lena River. Bottom-sediment concentrations near the left bank of the Lena downstream from the sewage discharge site are 30 to 50 mg/kg. Pb contamination extends to depths of 1.0-1.5 m into the sediments.

The lake bottom sediments have Pb levels similar to those in the soils, suggesting transportation from the drainage basin to the lakes in the solid phase as primary and secondary minerals [21]. Bottom-sediment concentrations exceed the MPL for soil by a factor of 1.5–3 in most of the lakes and are as high as 5–9 times the permissible level in the former tannery lake, Khatyng-Urekh, Teploe, and Taloe [11].

Figure 13 shows the distribution of Yakutsk lakes with different levels of bottom-sediment contamination with Pb.

Health effects. Lead is known to be toxic to living organisms. Both deficiency and excess of Pb in humans and agricultural animals can lead to various diseases (Table 9).

Inorganic lead compounds (Pb^{2+}) have been found to affect metabolic processes and inhibit a number of enzymes [22]. Long-term exposure to even low levels of lead in drinking water can cause acute and chronic diseases. Air pollution also has adverse health consequences, because inhaled lead accumulates in the body.

In children, lead accumulation can impair intellectual and physical development. Psychomotor effects on young children are associated with high levels of lead exposure via mouthing and ingesting contaminated soils adhered to fingers or toys. Lead exposure in school-age children is known to affect IQ. Other effects include alterations

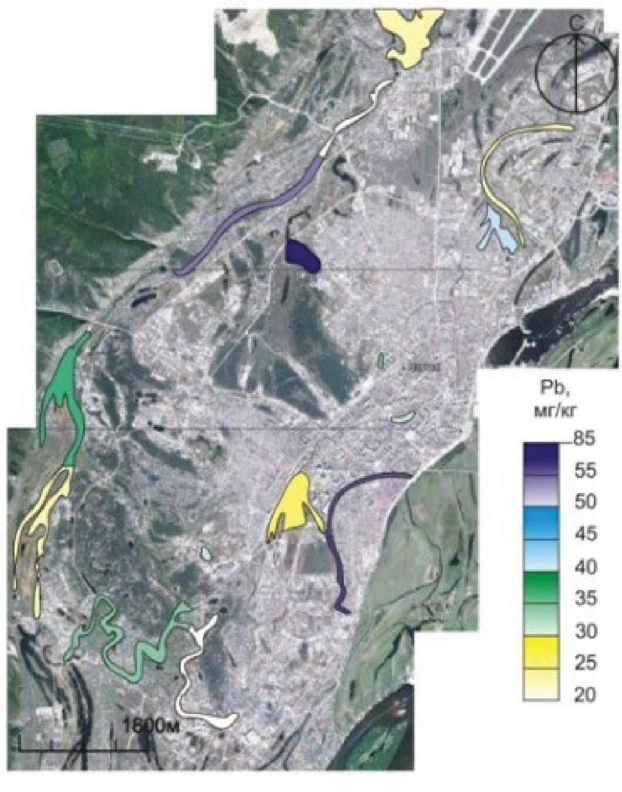

Figure 13: Pb levels in bottom sediments of major lakes in Yakutsk.

to motor activity, coordination, visual and auditory response time, hearing, and memory. Impact on neurocognitive function may also occur in older age children, causing learning difficulties and poor academic performance.

In women, lead is the principal element of concern because it can pass through the placenta and accumulate in breast milk. According to WHO, the blood lead level of 30 μg/L in pregnant women is associated with increased spontaneous abortion.

In Yakutsk, an environmental immunology study was conducted by the physician D.A. Alekseev [23] who assessed the impact of climatic and anthropogenic factors, including Pb, on secretory immunity in children [24-27]. During three seasons (winter, spring, and summer), 338 children aged 5 to 15 years were examined. The detection rate and quantity of protein, mucin, immunoglobulins, lysozyme and lead in saliva were determined [28,29]. The study showed high levels of Pb in the body fluids of Yakutsk residents and suggested a significant contribution of Pb to the poor environmental quality and high morbidity rate, especially in children, in the contaminated areas of the city.

Conclusions

Yakutsk faces a serious problem of lead pollution. All environmental compartments, both accumulating and transporting, contain high Pb levels in excess of the background concentrations and health-based environmental quality standards.

Greater enrichments in Pb are observed in the atmosphere, aerosols, and air dust.

Pb concentrations in natural waters outside the urban zone are well below the clarke concentrations. Within the city, Pb levels are several orders of magnitude higher than background in surface, suprapermafrost and intrapermafrost waters and exceed the MPL in some lakes and in cryopegs.

A Pb enrichment by a factor of 2–10 relative to the clarke contents for plants is observed in common reed growing in the city. There is a significant difference in Pb between below-ground and above-ground biomass, with roots containing 4-9 times more Pb compared to stems. Common reed actively intercepts and accumulates Pb from water and bottom sediments. It has high absorption capacity, tolerance to hydrochemical and hydrological regimes, as well as abundance in the landscape, and thus appears to be promising for the use in bioremediation of contaminated lakes in Yakutsk.

Most of the Pb deposited to the soil surface remain in the form of poorly soluble compounds under local conditions. However, the amount of mobile forms is growing in response to increasing soil acidity, causing deterioration of the urban environment.

In the older areas of Yakutsk, high-contrast Pb anomalies occur throughout the cultural layer, extending in places down to the alluvium. Pb contamination in the recently developed areas is confined to the upper soil horizons.

The geochemical spectra of sedimentary rocks in the Yakutsk area are different for the Palaeozoic and Mesozoic-Cenozoic formations. The Cambrian rocks consisting of limestone, dolomite and marl have a limited amount of excess elements and Pb concentrations below the crustal average. The Mesozoic and Cenozoic rocks, as well as the Holocene alluvial deposits have a significantly wider spectrum of lithophile and chalcophile elements, including Pb, that are in excess of crustal abundances.

An important way to improve the environmental quality in Yakutsk is to reduce harmful emissions from internal combustion engines. Air pollution by motor vehicles can be appreciably reduced by encouraging the use of diesel and natural gas fuel. Natural gas engines are environmentally cleaner, as their exhaust emissions contain no heavy metals or benzo(a)pyrene.

Capital improvement projects, including asphalt pavement and replacement of lawn soil, can significantly reduce airborne dust levels and Pb inputs. For example, a notable decline in soil lead concentrations along the major roadways occurred in 1995-2008 as a result of more active street improvement efforts.

References

1. Benko V, Cikrt M, Lener M (1995) Toxic Metals in the Environment. Prague: Grada 282 p.
2. Shvartsev SL (1978) Hydrogeochemistry of the Hypergenesis Zone. Moscow: Nedra 287 p.
3. Snakin VV (1998) Lead in the biosphere. Vestnik RAN 68: p. 214-224.
4. Ivanov VV (1997) Environmenmtal Geochemistry of Elements: 6-Volume Handbook. Volume 3, Rare p-Elements. Moscow: Nedra 352 p.
5. Ohta S, Murao M, Fukasawa T, Makarov VN (1999) Atmospheric aerosol concentration at Yakutsk, Tiksi and Norilsk. Proceedings of the Fourth Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1995. Japan, Sapporo: Inst. of Low Temperature Sc., Hokkaido University p. 111-115.
6. Bondarevich EA (2019) Ecological and geochemical assessment of technogenic pollution of the urban environment of Chita based on the snow cover condition. *Led i Sneg* 3: p. 51-59.
7. Radomskaya VI, Yusupov DV, Pavlova LM, Sergeeva AG, Borodina NA, et al. (2018) Multivariate statistical analysis of element contents in the snow cover of Blagoveshchensk. Regionalnaya Ekologiya, 2: p. 15-28.
8. Bowen HJM (1966) Trace Elements in Biochemistry. New York: Academic Press 241 p.
9. Gordeev VV (1983) River Flow into the Oceans and Its Geochemical Features/ Moscow: Nauka 160 p.
10. Anisimova NP, Pavlova NA (2014) Hydrogeochemical Studies of Permafrost in Central Yakutia. Novosibirsk: Academic Publishing House "Geo" 189 p.
11. Makarov VN, Sedelnikova AL (2016) Ecogeochemistry of Yakutsk Urban Lakes. Yakutsk: Melnikov Permafrost Institute SB RAS 210 p.
12. Vinogradov AP (1962) Average contents of chemical elements in the main types of igneous rock of the Earth's crust. Geokhimiya 7: p. 555-571.
13. Dobrovolsky VV (1983) Some aspects of environmental pollution with heavy metals. In: Biological Role of Trace Elements. Moscow: Nauka P. 44-54.
14. Kovalsky VV (1974) Environmental Geochemistry. Moscow: Nauka 299 p.
15. Makarov VN (2017) Trace elements in common reed in Yakutsk lakes. Vestnik Zabaikalskogo Universiteta, Nauki o Zemle 23: p. 15-26.
16. Jackson LJ, Rasmussen JB, Peters RH, Kalff J (1991) Empirical relationships between the element composition of aquatic macrophytes and their underlying sediments. Biogeochemistry 12: p. 71-86.
17. Pod'yachev BP (2009) Geochemical anomalies of noble metals in sedimentary sediments of the Yakutsk uplift. In: The Primary Source – Placer System. Yakutsk: Yakutsk Scientific Centre SB RAS p. 166-173.
18. Makarov VN, Torgovkin VN (2018) The geochemistry of anthropogenic deposits in Yakutsk. Kriosfera Zemli 3(XXII) p. 27-39.
19. Makarov VN (2002) Lead in the biosphere of Yakutia. Yakutsk: Permafrost Institute SB RAS 113 p.
20. Nezhdanova IK, Suetin YuP, Sveshnikov GB (1984) On the study of urban soil pollution in relation to environmental protection. *Vestnik LGU* 12: p. 87-91.
21. Makarov VN (2013) Ecological and geochemical monitoring of the environment of Yakutsk City. *Nauka i Obrazovanie* 3: p. 95-100.
22. Avtsyn AP, Zhavoronkov AA, Marachev AG, Milovanov AP (1985) Human Pathology in the North. Moscow: Medicina 416 p.
23. Alekseev DA (1999) The state of secretory immunity in children of Yakutsk: Author's PhD Degree Thesis Abstract (Chelyabinsk State Medical Academy). Chelyabinsk 19 p.

24. Goleva GA (1977) Hydrogeochemistry of Ore Elements. Moscow: Nedra 216 p.
25. Kabata-Pendias A, Pendias H (1989) Trace Elements in Soils and Plants. Moscow: Mir 425 p.
26. Makarov VN (1985) The Geochemical Atlas of Yakutsk. Yakutsk: Permafrost Institute 64 p.
27. Pestrikov SV, Isaeva OYu, Mustafin AG, Suyundukov YaT, Kovtunenko SV, et al. (2007) Justification of the effectiveness of the ecological-geochemical barrier with higher aquatic plants for the purification of waste water from heavy metal ions. *Inzhenernaya Ekologiya* 2: p. 21-28.
28. Savenko VS (1988) The average elementary chemical composition of ocean aerosol. *Geokhimiya* 8: p. 1084-1089.
29. Martin JM, Meybeck M (1979) Elemental mass-balance of material carried by major world rivers. Marine Chemistry 7: p. 173-206.