The characteristics of pollution in the big industrial cities of Kazakhstan by the example of Almaty

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Abstract

Background Environmental pollution is a problem in the most industrial cities, including Almaty. These cities are frequently overpopulated and hazardous industrial facilities often have a negative impact on public health. The purpose of this study was to determine the characteristics of pollution in Almaty city and assess possible impact on a human by comparing obtained results with sanitary and hygienic standards. (Hygienic standards (HS) 2.1.7.2042–06. AAC of chemical substances in soil Russia). We used both local standards, such as ST RK 2011–2010 "Water, Food, Stern and Tobacco Products. Determination of Chlororganic Pesticides" and International Standards (Customs Union) Sanitary Regulations and Norms number 4630–88.

Methods The study was conducted by sampling air, water, and soil and subsequently analyzing them via laboratory and instrumental methods.

Results Heavy metals were detected via a high-precision method of atomic absorption spectroscopy. Noise was measured on location. Geographic regions with characteristic types of pollution were discovered. It was found that the main polluting factors were as follows: air pollution – carbon monoxide, suspended solids in the form of dust, lead, and noise; water – ammonium compounds, organic substances (assessed based on the chemical oxygen demand (COD) parameter), polychlorinated biphenyl (PCB); soil – lead and PCB. The amount of suspended solids in the air exceeded standard levels by as much as 13.6 times.

Conclusions We visualized obtained data (using StatSoft Statistica v6.0 Rus and Exhibit 3.0 (MIT Simile Project) Softwares) for three districts of Almaty, which allowed us to compare the results efficiently. The results show the need for a detailed study on the optimization of the state of the environment and public health. Plans for further studies include development of a system that would enable reducing the negative impact of industrial facilities on public health and the environment in general.

Keywords Piedmont regions · Environmental pollution · Carbon monoxide · Suspended solids · Heavy metals · Noise pollution

Background

Pollution has recently become a major problem for cities. Living in heavily polluted districts has a negative impact on

people, especially breastfeeding women [1]. Air pollution in the big industrial cities and mortality from respiratory diseases are interrelated [2]. A significant dependency was discovered between the amount of inhaled suspended solids and the rate of cardiac diseases, the risk groups include smokers and people of a higher social status.

Presently, environmental monitoring is an important issue in many countries [3, 4]. After entering the atmosphere, pollutants are carried over large distances and pose a threat to not only the country of their origin, but also neighboring countries. The environmental dust condition and the concentration of heavy metals are under special scrutiny [5].

A great attention should be paid to air pollution, because it's one of the main environmental problem in Kazakhstan. However, air emissions vary strongly across regions. The amount of emissions in two regions accounts for 52% of overall emissions (27% in Karaganda region and 25% in the

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Pavlodar region), while in Almaty it's only 0.18% [6]. According to the official statistics, almost 86% of total industrial waste in 2014 was accumulated in the Kostanai region, 6.3% in the Karaganda region, 3.6% in the Pavlodar region and 3.6% in Eastern-Kazakhstan [7]. This can be explained by the economic and industrial structure of these regions. Fossil fuels (particularly coal) are used in the industrial and energy plants. This leads to generation of the majority of overall pollution. At the same time, level of usage of the fresh water for industrial processes is the highest in Almaty (19.5% of overall usage in the country) compared with the other regions, where fresh water is used for irrigation and agricultural water supply [7].

In addition, special attention should be paid to analyzing the soil and fauna. In some cases, information about the type of pollution can be obtained through indirect methods, as was the case with the retrospective study of pollution in Paris using secondary mineral deposits [5].

In the Republic of Kazakhstan, the level of pollution of cities and industrial center remains high, despite a decline in manufacturing. According to national statistics, Kazakhstan produces huge amount of waste and even more than France (population of which four times larger than in Kazakhstan and its GDP is ten times higher) or the Netherlands [6]. Although there were attempts to improve environmental protection at the local levels by referral to the local budget all payments and fines for environment pollution (whereas previously they had received up to 50%) from January 2001, total waste generation increased nine fold from 2000 to 2010 and after 2010 started to decrease [6]. Almaty (43°16'39"N 76°53'45"E) is characterized by a challenging environmental situation caused by its location in a piedmont basin. Almaty suffers from gas pollution, people's wish to live near the city center as opposed to its outskirts, slight overpopulation, and massive migration of people from rural areas into the city. The city was originally designed for 400,000 dwellers [8]; however, according to official statistics, the city population amounts to 1,552,349 persons (as of February 1, 2015) [9]. According to latest data, Almaty hosts about 800 thousand automobiles and their number grows every day [10]. These automobiles annually emit about 250–260 tons of hazardous waste into the atmosphere [11]. Therefore, Almaty requires measures that would optimize the state of the environment and public health.

There is a statistical evidence for Almaty that the levels of such impairments as eye diseases, including glaucoma, skin and subcutaneous tissue diseases, endocrine system diseases have essentially surpassed republican rates in 2014–2015 years [12]. Some studies had shown that these pathologies are the signs of PCBs influence [13–15].

Studies of the air, drinking water, soil and level of the noise was conducted in the Almaly, Turksib, and Zhetysu Districts of Almaty. These districts are industrial areas, where the

majority of the population live in the private sector. The following objects are situated there: Combined Heat and Power (CHP-1), LLP "Casting", JSC "Almaty Plant of Heavy Engineering" [16].

Methods

We conducted laboratory and instrumental studies of the air, drinking water, and soil and measured the noise in the Almaly, Turksib, and Zhetysu Districts of Almaty.

The total number of tests was as follows: air tests – 144, water tests – 96, soil tests – 134, noise measurements – 12.

In order to study the soil in Almaty, we took samples from highway areas and territories adjacent to gas stations, where the probability of petroleum and toxic metal pollution was the highest.

Sampling of water was done according to GOST 31861–2012 «Water. General requirements to water sampling», GOST 12.1.005–88 «General sanitary – hygienic requirements to the air of work zone» and GOST 28168–89 «Soils. Sampling».

Methods for sampling and detecting airborne chemical substances

Airborne chemical substances were detected using an AM-0059 bellows-sealed aspirator (Servek Research and Production Company JSC, Russia) and a GANK-4 gas analyzer (Pribor Research and Production Association, Russia). Samples were taken daily, four times per day, from 9 a.m. to 11 p.m. Maximum single and average daily measurements of air pollution were conducted with regard to city-forming enterprises (CHP-1, Casting LLP, and Almaty Heavy Machine Building Plant JSC) in the specified points in the territory of the Zhetysu, Turksib, and Almaly Districts of Almaty. The concentration of airborne hazardous chemical substances was measured under the following parameters: 686–690 mmHg atmospheric pressure; 29–30% relative humidity; 29–36 °C air temperature. Samples were taken using an aspirator and placed on filters with subsequent mineralization. The concentration of heavy metals was measured through atomic absorption spectroscopy using a PinAAcle 500 Flame Atomic Absorption Spectrometer (PerkinElmer, USA) (Dong L., 2003).

Carbon monoxide, nitrogen monoxide nitrogen dioxide, and sulfur dioxide were detected through an express method using the following devices: GANK-4 gas analyzer (Research and Production Association Pribor, Russia), SO Ankat-7631 gas analyzer (SPA Analitpribor FSUE, Russia), Cascade 312.3 gas analyzer (OPTEC JSC, Russia), and Colion 1-V gas analyzer (CHROMDET Analytical Instrument Ltd., Russia). Dust

levels were determined via the gravimetric method (on a filter) using a PU-3E/220 aspirator (NIKI MLT-Povolzhye LLC, Russia). Samples were taken to measure the average daily concentration of dust, which was done continuously for 24 h. The tarred filter with the sample was removed from the filter holder, folded in two with the dust-laden surface on the inside, and placed consecutively in a plastic bag. After this, the filter was reweighed to determine the weight of dust.

Air pollution was assessed based on the average daily (a.d.) and maximum single (m.s.) concentrations of hazardous impurities in the atmosphere (in mg/m^3). The state of air pollution was assessed by comparing the measured concentrations with the respective maximum permissible levels of airborne substances in cities.

Methods of sampling and measuring noise levels

Noise was measured along highways, near industrial facilities, and near residential buildings. The results of measurement of the equivalent noise level was determined through the computational method and compared to standard levels (55 dBA). Measurements were carried out using an SHI-01 V sound level meter with an integrated vibration meter (NTM-Zaschita, Russia).

Methods of sampling and measuring heavy metal pollution levels

The concentration of zinc, cadmium, lead, and copper in the water and soil was assessed through atomic absorption spectroscopy using a PinAAcle 500 Flame Atomic Absorption Spectrometer (PerkinElmer, USA).

Methods of sampling and measuring PCB levels

PCB levels in the water and soil were assessed using a Kristalllux-4000 M gas chromatograph (Meta-chrom Research and Production Company, Russia) and an Agilent GC7890A 7000B gas chromatograph (Agilent Technologies, USA).

Three types of PCB (penta, hexa, and hepta) were detected through gas chromatography using a capillary column. Dioxin-like PCBs were detected using a 7820A GC gas chromatograph with a quadrupole detector (Agilent Technologies, USA).

Availability of data and material The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Results

Air pollution

We discovered the following air pollutants: carbon monoxide, suspended solids (dust), lead, nitrogen dioxide, nitrogen monoxide, sulfur dioxide, and noise.

We assessed the level of air pollution in the Zhetysu, Turksib, and Almaly Districts of Almaty near industrial facilities: CHP-1, Casting LLP, and Almaty Heavy Machine Building Plant JSC (Table 1).

The highest level of pollution (carbon monoxide) was discovered in the Zhetysu and Turksib Districts of Almaty in both average daily and maximum single concentrations, as the maximum permissible level was exceeded by 1.2–1.6 times with average daily sampling and by up to 1.1 times with single sampling (Fig. 1).

High levels of dustiness in all districts of Almaty under consideration were characterized by a presence of suspended solids that exceeded the maximum permissible levels by 1.2–13.6 times (Fig. 1).

In the Turksib and Zhetysu Districts of Almaty, we discovered lead levels that exceeded the maximum permissible level by 1.1–1.5 times, which was indicative of air pollution with lead vapor and hydrocarbon gases emitted by heavy traffic.

The average daily level of pollution ranged: from 0.01 mg/m^3 to 0.03 mg/m^3 for nitrogen dioxide; from 0.02 mg/m^3 to 0.04 mg/m^3 for nitrogen monoxide; from 0.02 mg/m^3 to 0.04 mg/m^3 for sulfur dioxide, which was within reference range.

Areas most exposed to noise included the parts of districts and micro-districts that were located along main urban arteries, which was confirmed by instrumental measurements of noise levels two meters away from residential buildings on Ryskulova Ave., Bukhtarminskoy Str., and generally along Tole bi Str., where equivalent noise levels ranged from 59 to 65 dB. It was found that noise from traffic at measurement points exceeded the permissible level (55 dBA) in 50% of cases. The maximum noise level (65 dBA) was discovered on Ryskulova Ave.

Water pollution

Water in Almaty was studied in four sources (total number of measurements was 96): 1) Yesentay River at the intersection of Tole bi Str. and Kozhamkulova Str.; 2) eastern shore of Sayran Lake; 3) the Big Almaty Canal at the intersection of Zhansugurova Str. and Ryskulova Ave.; 4) Malaya Almatinka Lake at the intersection of Bukhtarminskaya Str. and Maylina Str.; Water samples were tested for heavy metals (lead, cadmium, copper, zinc, and mercury), COD, and ammonia nitrogen.

Table 1 Air pollution in Almaty (maximum single concentration)

Almaty districts	CO, mg/m ³	Lead, mg/m ³	NO ₂ , mg/m ³	NO, mg/m ³	Suspended solids, mg/m ³	SO ₂ , mg/m ³
Almaly	4.61	0.00015	0.08	0.27	0.52	0.123
Zhetysu	5.2	0.004	0.07	0.26	0.52	0.23
Turksib	3.8	0.0005	0.014	0.17	0.46	0.16

Low levels of ammonia nitrogen pollution were discovered in Yesentay River – 2.5 mg/dm³ (maximum permissible level – 2.0 mg/dm³) and the Big Almaty Canal – 2.4 mg/dm³.

Chemical oxygen demand (COD) exceeded the maximum permissible level in Sayran Lake – 160 mg O₂/dm³ (maximum permissible level – 30.0 mg O₂/dm³). In addition, COD exceeded maximum permissible levels in the Malaya Almatinka Lake (34 mg O₂/dm³), the Yesentay River (40 mg O₂/dm³), and the Big Almaty Canal (32 mg O₂/dm³) (Fig. 2). These results are indicative of the presence of large amounts of organic chemical pollutants in waterbodies.

Tests of water for heavy metal pollution showed levels that were significantly lower than the maximum permissible levels; however, lead was found in all samples at a

concentration of 0.1–0.5 mg/dm³, which was significantly higher than the maximum permissible level (0.03 mg/L).

Tests of water for PCB found positive results (higher than the maximum permissible level of 1 µg/L) at two points: Malaya Almatinka Lake – 0.000465 g/L and the Big Almaty Canal – 0.000124 g/L.

Soil pollution

Lead was found in all samples at 2.1–33.1 mg/kg (maximum permissible level – 30 mg/kg), with the highest level found at the Gazprom gas station at the intersection of Kapalskaya Str. and Maylina Str.

Fig. 1 Sampling points for the study of soil contamination

Fig. 2 Air and water sampling points in Almaty

In the Turksib District, PCB was found in five samples at a concentration of 0.227–0.569 mg/kg; in the Almaty District, the concentration of PCB in four samples ranged from 0.248 to 0.704 mg/kg; in the Zhetysu District, the concentration of PCB ranged from 0.113 to 0.388 mg/kg (Fig. 3). The maximum permissible level for PCB (Russia) is 0.06 mg/kg [17]. The highest level of pollution (the maximum permissible level was exceeded by 11.7 times) was found in an industrial area at the intersection of Gogol Str. and Auezov Str. – 0.704 mg/kg.

Thus, soil pollution with PCB across all three districts of Almaty under consideration was found in industrial and transport areas (Fig. 4).

Discussion

The results allow classifying Almaty as a city with adverse conditions in terms of chemical substance levels and physical

Fig. 3 Emissions of carbon monoxide and dust by average daily values in the studied areas of Almaty. Sites of water sampling are also indicated

Fig. 4 Results of water research in Almaty on COD

impact of noise. The results also show a general trend of pollution of the big industrial cities, which causes such serious diseases as bronchial asthma, cardiovascular diseases, neuralgia, allergic diseases, and oncological diseases [1, 18–20].

The discovered excess levels of lead in some samples could be indicative of potential development of kidney diseases, since lead has a negative effect on the functioning of the excretory system. Our data on exceeded levels of lead in the air water and soils are consistent with results of other authors, who had found the biggest concentration of heavy metals in the soil of the transport intersection, airport and the Military Car Base (MCB) branch (Zhetysusky district) [21].

In this study, one of the main tasks was to examine carbon monoxide and dust levels within a specified area, because problem of air pollution in Kazakhstan demands a great deal of attention. Carbon monoxide and dust levels exceeded maximum permissible level in 1.2–1.6 and 1.2–13.6 times respectively. The main reasons of such contamination cover combustion of fossil fuel during power generation, transport and work of the industry sector. Agricultural wastes, forest fires and the use of fertilizers also generate a critical amount of emissions [6]. In the other study, during determination of the effect of emissions from various industrial facilities on the health of people who lived nearby, it was found, that increased emission of fine particles in the form of dust had a carcinogenic effect [22]. This trend was noted across countries in Europe and North America. Meanwhile, Asian countries had a different problem – the quality of treatment systems was insufficient to provide proper treatment, which caused systematic environmental pollution.

One of the most polluted cities in Kazakhstan is Temirtau, the centers of the heavy industry. It is situated in Karaganda region. Examination of children and adult people that don't work in hazardous conditions and live in Temirtau city and Chkalovo village, revealed that physical development of boys was behind age norms; level of sexual development was below the normal level in 33% of girls; brain development of adolescents showed signs of stress; adults showed symptoms of chronic fatigue and depression [23].

This study found that noise levels exceeded the maximum permissible level, which could cause cardiovascular diseases [24] and hearing loss [25].

Previous studies showed that people who lived near sources of loud noise had sleeping problems and insomnia [26], while long-term exposure could cause nervous system and mental state disorders [27]. It is worth bearing in mind that such exposure can make a person irritable, which, in turn, increases the probability of conflicts and increases the level of stress.

It is thought that soil is the best indicator of man-induced pollution of certain region as water and air can rapidly migrate [16]. The main influencing factors on the soil pollutants with carcinogenic substances include the exhausts of motor vehicles, industrial emissions, refined products and export of industrial and domestic waste to junk yards [16]. During our research, it was found that level of PCBs was higher than the maximum permissible level in 11.7 times. It creates a dangerous situation that may lead to skin and subcutaneous tissue diseases, endocrine system disease such as diabetes, eye diseases in the form of glaucoma. Almaty takes the first place among these diseases compared with other 17 regions of

Kazakhstan [16]. The sources of such contamination can be, for example, the flame retardants, components of high temperature carriers, paints, containing PCBs, dielectrics, lacquer fillers, that are widely used in such industrial enterprises of Almaty as the JSC "Almaty Plant of heavy Engineering", Combined Heat and Power (CHP-1) and LLP "Casting".

In general, the current environmental state of Almaty is characterized by excessive accumulation of hazardous substances in the surface layer of the atmosphere, which generates smog.

It is worth noting that the piedmont area of the Ile Atalau is characterized by poor atmosphere self-purification resources. Under poor natural ventilation, air pollution is the most relevant problem that should be solved immediately.

Nowadays, the most common way to deal with air pollution is to distance the pollutants from the point of emission. This is achieved by building high chimneys at factories and power stations. Chimneys emit soot, cinder, and gas into the air streams, which carry them over great distances from the point of emission and scatter it across large volumes of air. However, with growing levels of emission due to the concentration of industrial facilities in relatively small areas, this method has become unacceptable. Therefore, an increasing number of various treatment facilities that reduce atmospheric emissions is being constructed. However, even the best treatment facilities are incapable of filtering out all hazardous substances. Therefore, new plants and power stations should be built downwind from cities or other settlements.

For regions with similar types of pollution, including similar air pollution, several treatment systems, which will reduce the amount of emitted hazardous substances should be used. One such solution can be to use a separation system in case of emission of solid or gaseous bodies, electronic systems of gas emission regulation, and, of course, filters. When it comes to wet treatment techniques, it is possible to use the absorption of acid gas from industrial emissions with water or special liquids.

In addition, it is worth considering increasing the amount of vegetation and green belts, which improve the gas composition of the atmosphere, and placing them around sources of dust.

The data on noise levels in various points of the city will be used to draw a "noise map", which will allow dividing the city into zones with different levels of noise. This will allow each district to use its own specific set of noise-protection measures, such as closing streets for traffic and adjusting public transport routes.

Conclusion

The study provided the following data on the state of the environment in Almaty:

Atmosphere: the highest level of carbon monoxide and lead pollution was found in the Zhetysu and Turksib districts. The concentration of airborne dust in the form of suspended solids exceeded the maximum permissible level in all districts under consideration. The greatest impact of noise was found in the parts of districts and micro-districts that were located along urban arteries. The concentrations of nitrogen monoxide, nitrogen dioxide, and sulfur dioxide were within standard levels.

Water: most studied waterbodies had excessive levels of COD and lead. Significant excess PCB and insignificant excess ammonia nitrogen was found in two points.

Soil: significant excess PCB was found in all samples. Insignificant excess lead was found in some of the samples.

In general, the data obtained during this study lay the foundation for the development of a system of sanitary, hygienic, and preventive measures, with a view to optimizing the state of the environment and public health in the region.

Author contributions All authors read and approved the final manuscript.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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