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Assessment of the Air Quality of Almaty. Focussing on the Traffic Component

The air quality of Almaty, the largest city in Kazakhstan, has been assessed applying the DPSIR (Driving forces, Pressures, Sate, Impacts, Responses) approach as overall framework. The paper focuses on the traffic component that is responsible for approx. 80% of the air pollution in the city. Further factors comprise power plants, minor industrial activities and private heating. Driving forces and pressures are disclosed and the state is elucidated based on extensive chemical analyses of gasoline, car exhaust and ambient air samples. In addition to already available information a broad spectrum of organic substances were found in the city air comprising aliphatic, aromatic and polycyclic aromatic hydrocarbons. Many of these substances are damaging to the human health. Measurement of particulate matter mimicked previous studies, however, it is suggested that further studies focusing on the PM2.5 component is conducted. Almaty traffic is dominated by private transport in aging cars. A series of recommendation ('responses') including actions to reduce the number of aging cars, to reduce private transport, to improve fuel consumption and to reduce through going traffic have been given in addition to suggestions for upgrading the monitoring activities.
Keywords: air quality, Almaty, integrated environmental assessment, dpsir, traffic, health, air pollutants, SPME.

Introduction

Almaty is the largest city in Kazakhstan and one of the largest cities in Central Asia. Almaty used to be a capital of Kazakhstan, and is now the financial, economic, cultural, educational and scientific centre of the country with a population of more than 1.5M people, corresponding to about 10% of the total population of Kazakhstan. The city is generally rich in natural resources like fresh water, forests and mountains. In the vicinity of Almaty, national parks and protected woodlands are located. Since Almaty, in Kazakhstan is considered as one of the premium places to live in Kazakhstan, a constant increase of population due to translocation from rural areas is seen [1].

The air quality of Almaty, Kazakhstan has over the last decades significantly decreased and today the city is rated among the most polluted cities in the world [2]. Thus Almaty in 2010 ranked at the 25th place, three places higher than in 2008, based on an evaluation of air pollution, drinking water quality, recovery and recycling of waste, the availability of hospital services and medical supplies as well as the presence of infectious diseases.

Health problems caused by poor air quality in Almaty are significant. Over the last 10 years the morbidity has increased 1.5 times. In spite of the absence of large industrial facilities in the region of Almaty, the city takes the first place in the republic on respiratory, endocrine and blood diseases, cancer and bronchial asthma [3].

Almaty is located in the valleys of Big and Small Almatinka rivers in the South-East of Kazakhstan at the foot of Trans-Ili Alatau Mountains. Hence, the city is virtually surrounded by mountains and hills, a location that limits or even prevents a horizontal movement of air (Fig.1)

The main part of Almaty is situated 500 – 2200 m above sea level, the center of Almaty placed on 800 m. The mountains partly surrounding Almaty reach 5000 m [4].

Thus, the geographical location in combination with the significant variation in altitude may lead to temperature inversions, which is actually often the case. In Fig. 2 a typical picture from Almaty is seen showing the 'blanket' of smog that covers the city. The brownish smog should be noted as a consequence to high concentration of nitrogen dioxide originating from fuel combustion processes, the major contributors being cars, trucks, busses and the three power plants in and around the city.

Figure 1 – Location of Almaty city.

Major reasons for the low air quality in Almaty can be ascribed to constantly increasing number of cars, part of which are ageing private cars, a high percentage of heavy four-wheal trucks and worn-out busses in combination with a low quality of fuel. Thus, the transport component accounts for close to 80% of the air pollution in the city [5]. It has been estimated [5] that the total amount of emissions of pollutants to Almaty air reached 232.000 tons in 2010 of which approx. 190.000 tons come from more than 500.000 cars.

Thus, today more than half a million cars are registered in Almaty, 50% of which are regarded as technically and morally obsolete [6]. Thus, in June 2011 it was estimated that 283 000 vehicles (54.6 percent) are produced during the years from 1991 to 2003, 108.4 thousand (20.9 percent) from 2003-2008 and only 12.5 thousand (2.4 percent) new cars, i.e., from 2008-2011. Further, taking into account the transit transport the total number reaches more than 700000 [7] and constitute as such the major threat against the air quality of the city.

Further ageing power plants play a role as they, together with minor industrial activities account for close to 20% of the emissions. Human activities does play only a minor role, although in specific areas of the city private coal burning is responsible for the heating, which here may make a significant negative contribution to the air quality.

Figure 2 – The smog in Almaty.

Official information about the air quality of Almaty is reported by in the Hydro meteorological center of Almaty, Kazhydromet [8]. Kazhydromet, as the only legally responsible organization in Kazakhstan, conducts 24-hours monitoring of air, water and soil. Chemical and biological analyses are carried out in Kazhydromet's laboratories and comprise more than 70 pollutants.

Monitoring of air pollution comprise more than 17 pollutants, including: particulate matter (dust), sulfur dioxide, carbon monoxide, nitrogen dioxide, hydrogen sulphide, phenol, formaldehyde, and ammonia.

However, only a rather limited number of factors are reported, including sulfur dioxide, carbon dioxide, nitrogen dioxide, phenol, formaldehyde and particulate matter. According to this information, only nitrogen dioxide generally exceeds the maximum allowed concentration (MAC) [9], the annual average concentrations being displayed in Table 1 [10]

Table 1 – Annual average concentrations of selected substances in Almaty air for 2003-2008 [11].

Element	Wind speed 0-2 m/s	Wind speed 3 m/s
	Concentration (mg m-3)	
Particulate matter (dust)	0.53	0.33
Sulfur dioxide	0.05	0.018
Carbon dioxide	7.6	3.04
Nitrogen dioxide	0.17	0.10
Formaldehyde	0.04	0.03

However, obviously these few substances give only – in the best case – a misleading picture of the actual situation regarding the air quality in the city. Thus, a wide selection of substances, especially (poly)aromatic compounds that have significant negative impact to the human health must obviously be taken into account as well.

In the present paper we focus on the problems associated with the traffic in Almaty such as emissions from cars as well as general more extended measurements of hazardous chemical substances in the city air. Hence, we here present an attempt towards an integrated environmental assessment of the situation with specific focus on the role of the traffic component. The study is partly based on available information and partly based on our studies. The method of choice for the assessment is the DPSIR approach (Driving forces, Pressures, State, Impact, Responses) [12].

Obviously the high number of cars causes frequent traffic jams around the city resulting in significant time where the cars virtually ticking-over. However, it must be remembered that these traffic jams are not only a result of the number of cars but also the traffic pattern and the driving culture/habits of the Almaty drivers most probably play significant roles here. It is outside the scope of the present paper but a thorough study based on chaos theory would be highly interesting in this context.

Materials and methods

2.1 The DPSIR Approach

The DPSIR (Driving forces, Pressures, State, Impacts, Responses) framework takes into account a chain of past and present situations as well as suggests future activities as responses aiming at improving the environmental health [13].

2.1.1 Driving forces

The driving forces are centered on economic sectors and human activities, i.e. activities in the society that directly or indirectly are causing the pressures on the environment. Roughly speaking, the driving forces can be classified as those creating the nuisance and those consuming resources. Thus, in broad terms driving forces comprise population, economy, land use and societal development. More specific examples of driving forces comprise manufacturing and industry, energy production, transport systems, agricultural activities, fisheries, households and consumers and waste treatment, the list by no means being exhaustive.

In sum driving forces can be regarded as 'needs' for individuals, industry or society.

2.1.2 Pressures

The impact (pressure) on the environment develops from the human activities that are associated with meeting the above mentioned 'needs' (driving forces). Thus, the pressures are results of production or consumption processes, such as non-sustainable use of resources, changes in land use, and direct and indirect emissions of chemicals, waste, etc to air, water and soil.

2.1.3 State

The state refers to the environmental and human health as a result of the pressures. Hence, the state comprises a combination the physical, chemical and biological quality of the various environmental compartments, i.e., soil, water and air, as well as their mutual interplay with respect to, e.g., the biodiversity, vegetation water and soil organisms within a specific ecosystem, a specific type of landscape, a given population etc.

2.1.4 Impacts

The impacts refer to environmental and economic factors. Thus, the possible changes in the in the physical, chemical or biological states may unambiguously cause impacts on the environmental and human health, e.g., as a result of increasing concentrations of hazardous chemicals in the environment and eventually on both the economic and social performance of society.

Ultimately the impacts focus on changes in the human welfare comprising both physical and mental health as a result in changes in the quality, e.g., state, of the environment. However, also the possible changes in the environmental health due to changes in the physical, chemical and/or biological state may be covered here.

2.1.5 Responses

The responses comprise a priori the reactions by authorities, regulators or society in general to the changes induced through the other element in the DPSIR chain. Thus, responses could comprise both passive and active measures. Hence a passive measure, relating to driving forces could be initiatives, to change people's transport pattern from private cars to public transportation by making zones where private cars are not allowed, whereas an active measure would be to switch to environmentally more friendly fuels, increasing taxes on gasoline to motivate people to use alternative modes of transportation, creation of infrastructure for bikes and pedestrians, decreasing of problem of traffic jams, increase the number of trees and plants, improvement of the quality of gasoline and diesel fuels.

Responses related to pressures would be various regulations aiming at a reduction of the emissions of hazardous chemicals to the environment, whereas responses related to state would comprise, e.g., cleaning up or remediation projects of contaminated land.

It is noted that basically all responses are caused by the impact element. Impacts are results of possible changes in driving forces, pressures and/or state. In Fig. 3 the complete DPSIR framework is visualized

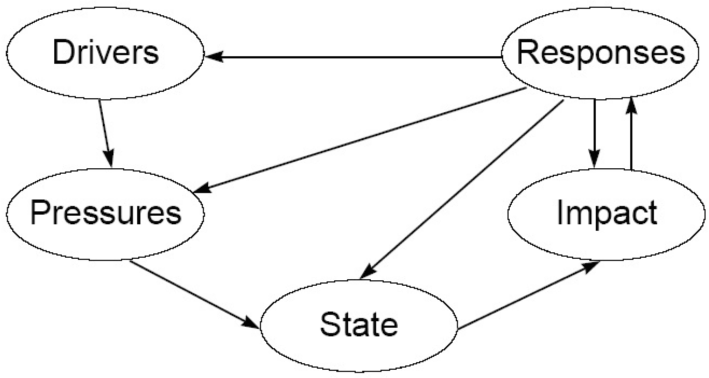

Figure 3 – The complete DPSIR framework.

2.2 Analyses of gasoline quality

Analyses of gasoline were carried out using a 6890 gas chromatograph (Agilent, Santa Clara, USA) equipped with mass selective detector 5973N (Agilent, Santa Clara, USA). Samples of gasoline (0.2 μL) were directly injected in split mode (200:1) using a 5683 autosampler (Agilent, Santa Clara, USA). The mass spectrometric detection was carried out in Scan mode in the range of m/z 10 to 350 a.u. The percentage of single compounds was calculated by normalization using peak areas. Thus, no attempt was made to a true quantitative determination of individual concentrations based on calibration to standards.

2.3 Analyses of car exhausts

Car exhausts were analyzed using GC-MS (Agilent 6890/5973N). Solid phase microextraction (SPME), inexpensive and efficient sampling/sample preparation method [13-14] was applied as a sampling tool. For extraction, 85 μm Carboxen/polydimethylsiloxane fibers were placed at a distance of 20-30 cm from the end of exhaust pipe of a standing ticking-over car with working engine for 1 minute. Subsequently the fiber was introduced into the GC inlet for desorption and direct analysis of the extracted exhausts.

2.4 Analyses of air samples

Air samples were analyzed using a 6890/5973N GC-MS (Agilent, Santa Clara, USA). Solid phase microextraction (SPME) was applied as an air sampling tool providing best sensitivity of VOCs [14] among the methods available in laboratory. Air was sampled at ambient temperature exposing selected fibers for different time period being 0.5, 2.0 and 24 hours to extract the pollutants. Air samples were collected at a height of 15-20 m from the ground. Three different fiber coatings were used for air sampling including 85 μm carboxen/polydymethylsiloxane, 100 μm polydimethylsiloxane and 65 μm polydimethylsiloxane/divinyl¬benzene (all from Supelco, Bellefonte, PA, USA). For protection of fiber coating from wind, rain and snow when sampling from the height of 15-20 m during 24 hrs, it was placed into a 5 L container having removed bottom part.

Results and Discussion

The DPSIR model, as framework for an integrated assessment, in the present case of the air quality in Almaty constitutes an advantageous tool to elucidate the causality of the links between the single elements as illustrated by the arrows in Fig.2.

Obviously the driving forces are the most fundamental in the assessment as these activities are the actual sources to the environmental, and thus eventually human health problems and a possible removal of these activities will unambiguously diminish or, in the long run possible eliminate the problems. It should in this context be noted that in some cases it might be difficult to have a clear boundary between, e.g., driving forces and pressures or between state and impacts. However, as will be seen from the following this is only to a minor extent true looking at the actual example of the air quality in Almaty.

3.1 Driving forces

As mentioned the driving forces can be regarded as 'needs' for individuals, industry or society. Talking about the traffic component the need for individuals for being transported around is obviously the major driving force independently of the actual way of transport, i.e., private or public, respectively. Further the need for society to get goods transported, e.g., for delivery within the city limits constitutes a further driving force.

Although not being the focus of the present paper, needs for other forms of energy consumption, like heating of houses, household activities etc should be mentioned as driving forces eventually contributing to a decrease of the air quality through the emission of harmful substances (pressures).

In sum it is clear that the driving forces, not unexpected can be classified as being related to human activities as well as to economic factors.

3.2 Pressures

3.2.1 Geographical location

The geographical location (vide infra) of Almaty plays a crucial role in relation to the pressures, and thus the state and impact as the surrounding mountains that constitute a barrier for circulation of the air by blocking the city from the South and partly from the East. Further, in general Almaty has only rather light winds. Thus, in summer and winter time the frequency of wind speeds up to 1 m/s have been estimated to be 71% and 79%, respectively, the average wind speed being less than 1,2-1,4 m/s [15] (Table 2). For comparison, the average wind speeds for Astana, which is located in the middle of Kazakhstan without surrounding mountain protection as seen for Almaty, are 3-4 times higher over the year (Table 2).

Table 2 – Average wind speeds, WS (m/s) [16].

Month	Jan	Feb	Mar	Apr	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
Almaty	0.9	0.9	1.1	1.4	1.4	1.4	1.3	1.2	1.0	0.9	0.8	1.2
Astana	4.4	4.2	4.0	4.1	3.9	3.4	3.2	3.5	4.1	4.2	4.0	3.8

The most frequent wind is from the south blowing at night from the mountains, and during the daytime in the opposite direction, bringing not only cool, but also polluted air blown in Northern direction [15]. In Table 3 the average frequencies of various wind directions over the year are given.

Table 3 – The frequency (%) of different wind directions (WD) [16].

WD	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	19	21	18	16	13	11	10	12	14	14	15	17
NE	8	9	9	9	7	7	6	7	7	7	7	7
E	7	8	9	9	10	9	9	8	10	9	9	9
SE	10	9	10	14	16	17	18	18	20	20	14	13
S	22	18	19	24	28	33	34	33	30	28	26	22
SW	11	9	10	8	9	9	10	9	7	8	9	11
W	12	14	14	12	10	8	7	7	6	8	10	12
NW	10	13	12	9	7	7	6	6	7	6	9	9
Calm	33	29	22	13	12	12	9	10	12	21	27	33

As a result of the above, only a limited dispersion of the emissions prevails and the resulting thermal inversion results in a significant smog problem in Almaty (cf. Fig. 2), regardless of the season.

As a rather visible illustration of this, Almaty has in average 40-50 days per year with heavy fog often coinciding with critical levels of air pollution over the city. This periodically paralyzes the air traffic to and from Almaty for shorter or longer times [17].

The average number of days with fog and other weather conditions per month is given in Table 4.

Table 4 – Average number of days with various weather conditions per month [16].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Clear Days	6	6	4	5	4	4	8	10	12	9	7	6	81
Cloudly Days	13	10	10	11	14	17	16	16	13	14	11	11	156
Overcasted Days	13	12	17	14	14	9	7	5	5	9	12	14	131
Fog	7	6	6	0.7	0.2	0.1	0	0	0.2	2	6	11	39

As a consequence, an optimal air situation is observed only in the uptown Southern regions of the city, in a relatively narrow band within 20 km from the foothills [18]. In Fig. 4 the official zoning of Almaty with regard to air quality is shown [19].

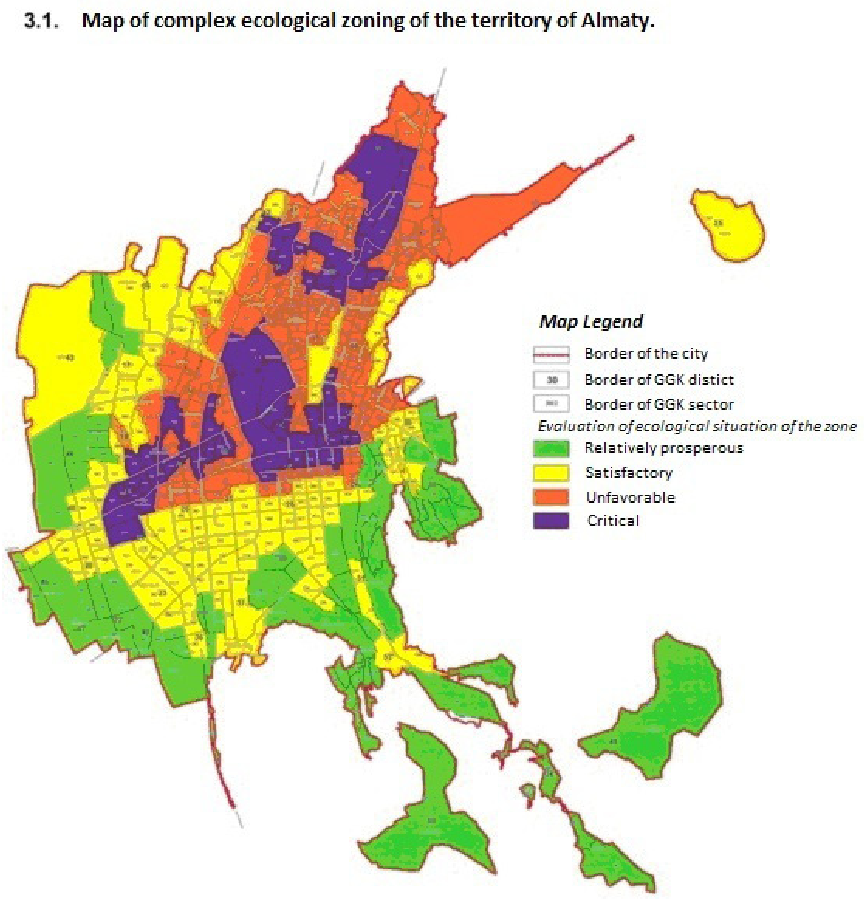

Figure 4 – Map of complex ecological zoning of the territory of Almaty.

3.2.2 Emissions

The traffic component accounts for close to 80% of the emissions of harmful substances in Almaty as a result of the high number of cars (vide supra) many of them being of old age (Table 5) with badly tuned engines and possibly without appropriately working catalytic converters or without working catalyst. Likewise the public transportation system is hampered by aging busses that has already served their time in other countries. However, it should be noted that recent attempts has been made to substitute a number of busses with a newer models running on compressed natural gas or electricity [5].

Table 5 – Age distribution of cars in Almaty [10].

Year of production of cars	Number of cars	Percentage
1960-1979	20000	4
1980-1989	95000	18
1990-1999	309000	59
2000-2008	99000	19

From the data in Table 5 it is seen that more than 80% of the cars in Almaty in 2009 were more than 10 years old and more than 20% even more than 20 years old.

A special twist is the widespread habit of leaving the cars ticking-over for prolonged times before starting driving. This has a rather negative effect on the environment due to significant increased emissions of harmful substances [20]. Further the assumed effect that the engine should warm up is not justified. The possible catalytic converters and particle filters does not work properly before being heating up, which is most optimally achieved by driving immediately after start [21]. It should be noted that when talking about cars of more recent age. In the case of significantly aged cars, as seen in Almaty this initial attempt to warming up may be justified.

As indicated above, power plants, local heating and various minor industrial activities accounts for approx. 20% of the emissions and thus pressures to the environment. In this connection it is worthwhile to mention that the power plant 'CHP-1' is centrally located in the city. A second plant is located in the outskirts of the city and a third located close to the airport significantly contributes to the 'fog' occasionally hampering the air traffic.

Exhaust gases from cars and busses contain more than 200 chemical compounds in addition to particulate matter, many of which are well-known as being harmful to the environment as well as to humans [22].

The problem with air pollution originating from motor transport that today accounts for more than 80% of the total air pollution in Almaty is steadily increasing as a result of an increasing number of cars in the city.

As part of the present study we performed qualitative analyzes of exhausts from a series of 6 artificially chosen cars of different ages and models. A wide variety of organic compounds was detected comprising aliphatic, aromatic as well as oxidized compounds (Table 6). As seen from the Table, newer cars not unexpectedly emit significantly cleaner exhaust than older cars, although examples contradicting this can be noted (see Table 6, Toyota Carina, 1995). The country of origin, which in this context means the last country, in which the car was operating before arriving in Kazakhstan, may play an important role due to different emission standards and control measures prevailing in the different countries of origin.

Table 6 – Compounds detected in the exhaust of 6 arbitrarily chosen cars of different models and production years.

Car model		Toyota Caldina	Toyota Carina	UAZ-3962	Niva 21213	Lexus RX 300	Mitsubishi Pajero IV	Mitsubishi Gallant
Year of production		1993	1995	1998	2000	2001	2007	2008
Origin of car		Japan	UK	Russia	Russia	Germany	UAE	USA
Retention time, min	Compound	Peak area, x10-3 a.u						
1.4	3-Methyl pentane	n/d	n/d	33781	11344	n/d	n/d	n/d
1.6	3-Methyl hexane	n/d	n/d	36221	11070	n/d	n/d	n/d
1.6	Heptane	n/d	n/d	11501	9034	n/d	n/d	n/d

1.7	1-Methyl-2-propyl cyclohexane	n/d	n/d	12425	2736	n/d	n/d	n/d
1.7	(Z)-3-Heptene	n/d	n/d	5083	n/d	n/d	n/d	n/d
1.8	2-methyl heptane	n/d	n/d	17036	4583	n/d	n/d	n/d
1.9	Octane	n/d	n/d	9399	2334	n/d	n/d	n/d
2.0	1,2-dimethyl-cis cyclohexane	n/d	n/d	9810	n/d	n/d	n/d	n/d
2.1	3,5-dimethyl heptane	n/d	n/d	7735	n/d	n/d	n/d	n/d
2.3	4-methyl octane	n/d	n/d	12414	n/d	n/d	n/d	n/d
2.4	2-ethyl 1-hexanol	n/d	n/d	9322	n/d	n/d	n/d	n/d
3.3	Benzene	17678	n/d	23489	8913	9614	n/d	n/d
5.2	Toluene	149344	n/d	212384	38157	98726	473	n/d
9.4	Ethyl benzene	38042	n/d	32236	6455	28822	n/d	n/d
9.5	p-Xylene	n/d	n/d	22443	3665	n/d	n/d	n/d
9.9	m-Xylene	34039	n/d	72259	7217	29285	n/d	n/d
10.3	o-Xylene	85325	n/d	33686	14083	n/d	629	n/d
13.1	Propyl benzene	13845	n/d	5610	734	4746	n/d	n/d
13.5	1-Ethyl-3-methyl benzene	n/d	n/d	22140	5127	n/d	n/d	n/d
14.3	1-Ethyl-2-methyl benzene	n/d	n/d	4601	n/d	n/d	n/d	n/d
14.4	1-Methylethyl benzene	n/d	n/d	n/d	1627	n/d	n/d	n/d
14.5	Styrene	2820	n/d	n/d	n/d	n/d	n/d	n/d
15.0	1,2,3-Trimethyl benzene	78970	n/d	18211	2506	28851	965	n/d
16.0	1,2,4-Trimethyl benzene	n/d	n/d	4308	n/d	n/d	n/d	n/d
16.6	Indane	n/d	n/d	2034	n/d	n/d	n/d	n/d
16.7	1-Propenyl benzene	n/d	n/d	n/d	350	n/d	n/d	n/d
17.3	Methyl indane	n/d	n/d	n/d	n/d	1273	n/d	n/d
18.7	1H-Indene	6595	n/d	n/d	n/d	7620	n/d	n/d
19.3	Benzaldehyde	17633	n/d	n/d	264	1664	n/d	n/d
22.1	Naphthalene	12968	n/d	n/d	n/d	2599	492	n/d
24.9	Phenol	6095	n/d	n/d	n/d	n/d	n/d	n/d

From Table 6 it is immediately seen that the amount of aromatic hydrocarbons (as stated by the individual peak areas in the gas chromatograms) apparently is the highest, which could be linked to the high stability of aromatic hydrocarbons, further the lower volatility of these compounds may play a role. However, also SPME fiber coating composition and response factors may play a role as well.

3.2.3 Gasoline quality

A major problem that strongly affects the emission of harmful substances is the rather low quality of gasoline available in Almaty, presently corresponding to Euro-2 standard from 1993 [23]. In Kazakhstan, a switch to gasoline of Euro-5 standard, which is scheduled for 2014 thus bypassing the Euro-3 and Euro-4 standards will require significant capital investments for upgrading refineries [24]. A major improvement in this connection will be stricter limiting value for the content of benzene in gasoline, which is now limited to 5%. For the Euro-3 (from 2000) and Euro-4 (from 2005) fuel standards the benzene content is limited to max. 1 v/v %. [25].

Another major improvement will be limiting values for the content of aromatic compounds in gasoline which will be 42 and 35% according to Euro-3 and Euro-4 fuel standards, respectively, in contrast to Euro-2 where no limit for the content of aromatic hydrocarbons is set [23;25].

Further also the significantly required reduction in sulfur content will be beneficial for the Almaty environment. Thus, according to the International Centre for Quality Supervision fuel [26], Kazakhstan is in the latest ranking dated April 2011 ranked 89 out of 100 countries based on sulfur limits in gasoline quality. For comparison Germany is ranked on a first place, Japan on a second and the third place being shared by Austria, Hungary, Denmark, Finland, Sweden and Estonia. USA, which is the world's leading consumer of motor fuel, is ranked on a 46th place, whereas Russia is found on the 51th position [26].

A broad selection of gasoline available from Almaty gas stations has been sampled and analyzed. In Table 7, the composition of representative gasoline samples is given. From an overall point of view, the chemical composition of gasoline samples originating from Almaty corresponds to a gasoline being available, e.g., in Europe [27] and North America, although the content of benzene and aromatic hydrocarbons as expected is higher in the samples from Almaty.

Table 7 – Composition of representative gasoline samples from Almaty gas stations based on GC-MS

RT, min	Compound name	CAS No.	Peak area, %	
			AI-93	AI-96
1.76	Butane	000106-97-8	1.2	n/d
2.02	2-Methyl butane	000078-78-4	4.6	1.5
2.17	Pentane	000109-66-0	1.9	1.0
2.79	2,3-Dimethyl butane	000079-29-8	1.0	n/d
2.83	2-Methyl pentane	000107-83-5	4.3	2.3
3.00	2-Methoxy-2-methyl propane	001634-04-4	n/d	2.9
3.04	3-Methyl pentane	000096-14-0	2.9	1.9
3.34	Hexane	000110-54-3	2.5	2.1
4.00	Methyl cyclopentane	000096-37-7	1.1	n/d
5.08	2-Methyl hexane	000591-76-4	1.9	1.7
5.24	Benzene	000071-43-2	4.4	4.5
5.42	3-Methyl hexane	000589-34-4	2.4	2.0
6.57	Heptane	000142-82-5	1.2	1.5
12.09	Toluene	000108-88-3	13.4	15.2
20.79	Ethylbenzene	000100-41-4	2.9	4.0
22.06	p-Xylene	000106-42-3	9.7	11.9
24.09	m-Xylene	000106-42-3	3.6	4.8
29.45	Propyl benzene	000103-65-1	1.1	1.7
30.37	1-Ethyl-3-methyl benzene	000620-14-4	3.2	4.2
30.65	1-Ethyl-2-methyl benzene	000611-14-3	1.3	1.9
31.65	1,2,3-Trimethyl benzene	000526-73-8	1.3	1.7
31.90	1-Ethyl-2-methyl benzene	000611-14-3	1.1	1.5
33.69	1,2,4-Trimethyl benzene	000095-63-6	4.2	5.2
37.64	1,3,5-Trimethyl benzene	000108-67-8	n/d	1.1
41.19	2-Ethyl-1,4-dimethyl benzene	001758-88-9	1.0	n/d

40.70	1-Methyl-3-propyl benzene	001074-43-7	n/d	1.1
40.70	1-Ethyl-2,4-dimethyl benzene	000874-41-9	n/d	1.0
49.70	Naphthalene	000091-20-3	1.0	n/d

The fact that we re-find a majority of the gasoline components in the car exhaust strongly suggests that a significant part of these compounds are emitted directly from cars due to ineffective combustion as a result of inappropriately adjusted or worn-out engines.

A further complication possibly can be ascribed to various impurities in or even adulteration of a gasoline. Thus, a couple of samples analyzed contained water, particulates and even heavy petroleum fractions, which unambiguously may lead to malfunctions of the engine and consequently increased air pollution.

3.2.4 Other pressures

For completeness, other pressures should be mentioned in addition to the above mentioned. Thus, the high consumption of fossil fuel in the transport sector in addition to the direct pollution component gives rise to an increased temperature by up to several degrees in certain part of the city [28]. Obviously the heavy traffic, especially during rush hours further causes a not negligible noise pollution.

In addition to the above mentioned effects of the geographical location of Almaty, also the location and height of buildings play a significant role in relation to the air pollution due to further limitations in the already restricted air flow in the city. Thus, the city council has introduced limitations concerning the height of building in various parts of the city [29] as illustrated in Fig. 5. These directions were adopted in 1996, but several building higher than these limits are found in the city. Further in general it looks like an overall planning of the enlargement or reconstruction of the city is lacking. However, a closer discussion of these potentially important factors is not the scope of the present study.

3.3 State

Air monitoring in Almaty is carried out on a continuous basis by Kazhydromet by a so-called fixed site monitoring (FSM), the monitoring being carried out at five stations distributed around the city [9]. Analyses include a limited number of compounds only (vide supra) in addition to particulate matter (dust) [15], however, not taking compounds like aromatic, especially polycyclic aromatic hydrocarbons (PAHs) – notorious for their, e.g., carcinogenic effects – in account.

The observations are carried out on a daily basis daily 3 times a day at 7 am, 1 and 7 pm for 4 of the stations and additionally at 1 am for the fifth station. Based on these data it is possible to calculate an Air Quality Index (AQI) [8], the conversion from measured concentrations to the AQI is easily achieved by the online calculator provided by the US EPA [10], the resulting levels are subsequently related to levels of Health Concern: 0-50: Good, 51-100: Moderate, 101-150: Unhealthy for Sensitive Groups, 151 – 200: Unhealthy 201 – 300 Very Unhealthy, 301 – 500 Hazardous.

In Table 8 concentration of harmful substances according to the fixed site monitoring (FSM) in Almaty for 14 February 2011 is given and recalculated to AQI.

Table 8 – Average concentrations of selected air pollutants.

Pollutant	MAC daily average, mg m-3	Fraction of MAC values (average)						
		FSM 1	FSM 12	FSM 16	FSM 25	FSM 26	Average	AQI
PM	0.15	0.2	0.4	0.2	0.2	0.2	0.24	33
SO2	0.05	0.05	0.03	0.07	0.08	0.05	0.06	1
CO	5.0	1.1	1.3	0.5	0.9	0.8	0.92	47
NO2	0.04	1.6	2.0	1.3	1.5	1.4	1.56	32
phenol	0.003	0.2	0.5	0.2	0.1	0.2	0.24	na
formaldehyde	0.003	0.7	0.7	0.3	0.1	0.4	0.44	na

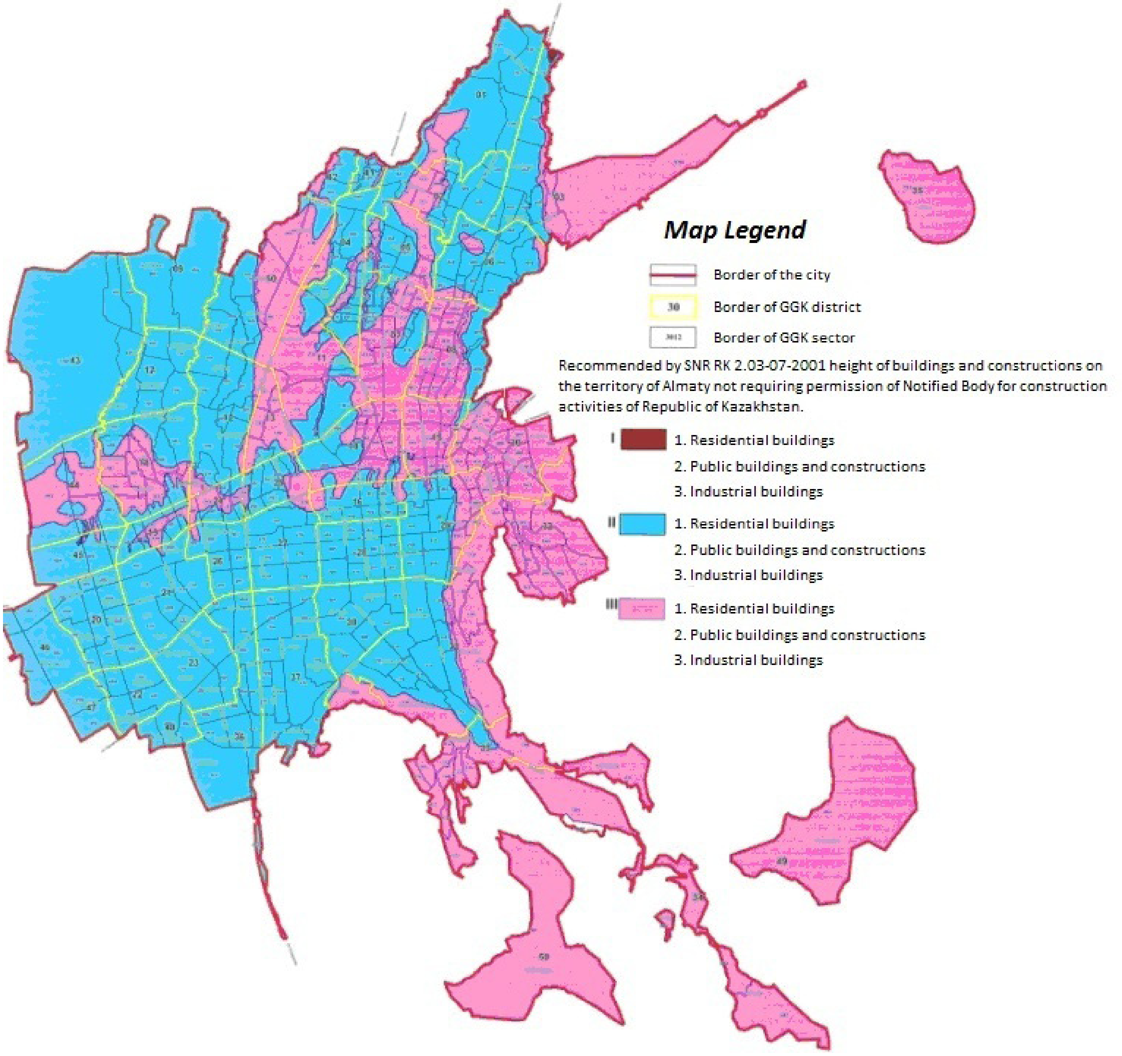

Figure 5 – Map of limitations concerning the height of building in various parts of the city.

The collected data further form the basis for the map displayed in Fig. 4. According to these measurements Kazhydromet concludes that nitrogen dioxide is the only substance of concerning in the Almaty air. Based on our studies reported in the following, we find this statement highly questionable.

No studies on other hazardous organic pollutants, to our knowledge, have been reported. A main topic in this study has been to detect hazardous air pollutants in air of Almaty.

In the present study we analyzed air samples from Almaty taken in the height of 15-20 m. It should be noted that the present study does not as such give actual concentrations but only indications, stated as peak areas, concerning the relative presence of the various compounds detected. However, it can be assumed that the actual concentrations at street levels of the individual compounds most probably is higher than those giving rise to the data here reported (Table 9).

Using different SPME fiber coatings allowed detection of compounds having different properties. Hence, the 85 μm carboxen / polydymethylsiloxane coating was selective to organic compounds having relative low boiling points whereas 100 μm polydimethylsiloxane and 65 μm polydimethylsiloxane / divinylbenzene coatings were sensitive to heavier hydrophobic compounds (Table 9).

In total, we found more than one hundred compounds in Almaty air, the major classes comprising aliphatic, aromatic, and polycyclic aromatic hydrocarbons, phenols, benzaldehydes and indenes (Table 9). A major part of the detected substances is toxic some of them possessing carcinogenic properties.

Table 9 – Compounds detected in air samples using different SPME fiber coatings.

RT, min	Compound name	CAS No.	SPME fiber coating		
			85 µm CAR/PDMS	65 µm PDMS/DVB	100 µm PDMS
			Peak area, x10-6 a.u.		
3.10	Benzene	000071-43-2	40.7	n/d	n/d
4.12	Decane	000124-18-5	8.33	4.50	n/d
5.14	Toluene	000108-88-3	220	2.27	n/d
7.91	Undecane	001120-21-4	n/d	6.83	n/d
8.72	Ethyl benzene	000100-41-4	40.3	n/d	n/d
9.67	p-Xylene	000106-42-3	204	2.77	n/d
11.85	o-Xylene	000095-47-6	79.1	4.61	n/d
12.78	Propyl benzene	000103-65-1	14.96	2.14	n/d
12.93	Dodecane	000112-40-3	13.4	13.3	n/d
13.31	1-Ethyl-3-methyl benzene	000620-14-4	142	11.7	n/d
13.82	1,3,5-Trimethyl benzene	000108-67-8	101	n/d	n/d
13.83	1,2,4-Trimethyl benzene	000095-63-3	n/d	11.8	n/d
14.28	4-Methyl-1-ethyl benzene	000622-96-8	n/d	4.48	n/d
14.29	1-Ethyl-2-methyl benzene	000611-14-3	48.44	n/d	n/d
14.76	1,2,3-Trimethyl benzene	000526-73-8	149	14.7	n/d
15.31	1-Methyl-3-propyl benzene	001074-17-5	39.8	21.2	n/d
15.46	Tridecane	000629-50-5	n/d	13.8	n/d
15.76	1-Ethyl-2,4-dimethyl benzene	000874-41-9	50.7	7.44	n/d
16.31	2-Ethyl-1,4-dimethyl benzene	001758-88-9	20.37	6.69	n/d
16.43	1-Methyl-3(1-methylethyl) benzene	000535-77-3	32.2	10.7	n/d
16.77	1-Methyl-4(1-methylpropyl) benzene	001595-16-0	12.05	3.76	n/d
17.04	1-Methyl indane	000767-58-8	7.48	3.35	n/d
17.31	1,3-Diethyl benzene	000141-93-5	22.1	14.3	n/d
17.56	1,2,3,5-Tetramethyl benzene	000527-53-7	24.6	8.25	n/d
17.73	1,2,4,5-Tetramethyl benzene	000095-93-2	31.6	14.1	n/d
18.00	Acetic acid	000064-19-7	32.7	8.62	n/d
18.32	2,3-Dihydro-4-methyl-1H-Indene	000824-22-6	13.6	7.52	n/d
18.46	1H-Indene	000095-13-6	12.8	3.19	n/d
18.53	1,2,3,4-Tetramethyl benzene	000788-23-3	14.9	n/d	n/d
18.70	1-Ethenyl-1,3-dimethyl benzene	002039-90-9	25.9	13.1	n/d
18.80	Pentadecane	000629-62-9	n/d	9.96	3.1
19.06	Benzaldehyde	000100-52-7	22.6	8.94	n/d
20.18	Hexadecane	000544-76-3	n/d	n/d	4.04
20.44	4-Methyl benzaldehyde	000104-87-0	22.3	16.40	n/d
21.40	Heptadecane	000629-78-7	n/d	n/d	2.60
21.46	4-Methyl benzaldehyde	004748-78-1	9.27	10.4	n/d
21.75	2,5-Dimethyl benzaldehyde	005779-94-2	5.2	2.98	n/d

21.84	Naphthalene	000091-20-3	69.29	55.3	n/d
22.70	3,5-Dimethyl benzaldehyde	005779-95-3	n/d	7.10	n/d
23.13	2-Methyl naphthalene	000091-57-6	18.4	25.9	0.96
23.27	3-Phenyl-2-propenal	000104-55-2	n/d	7.01	n/d
23.51	1-Methyl naphthalene	000090-12-0	12.8	15.1	0.51
23.68	1,4-Butanediol	000110-63-4	n/d	11.6	n/d
24.61	Phenol	000108-95-2	33.4	35.6	n/d
24.71	1,7-Dimethyl naphthalene	000575-37-1	3.39	7.61	n/d
25.38	4-Methyl phenol	000106-44-5	7.71	17.6	n/d
25.45	3-Methyl phenol	000108-39-4	7.72	9.90	n/d
26.28	2-Ethyl phenol	000090-00-6	1.30	6.28	n/d
26.61	Acetonaphthalene	000208-96-8	1.51	4.42	n/d
27.26	Dibenzofurane	000132-64-9	1.29	n/d	0.70
27.90	9H-Fluorene	000086-73-7	n/d	4.4	0.15
31.30	Phenanthrene	000085-01-8	0.51	12.4	2.61
38.45	Fluoranthrene	000206-44-0	n/d	2.1*	0.34*
40.92	Pyrene	000129-00-0	n/d	1.1*	n/d

* Peak area measured using molecular ion chromatogram

Aliphatic and aromatic hydrocarbons as well as phenols and PAHs obviously primarily originate from emission of cars (see above).

Our measurements of total particulate matter in Almaty air made using a local standard method [30] gave concentrations ranging between 0.15 to 0.50 mg m-3 corresponding to the data reported by Kazhydromet [31].

Not surprisingly we do not observe PAHs neither in the exhaust gasses nor in the ambient air samples. However, PAHs as well as heavy metals and, e.g., abrasive particles from car tires are known to be sorbed onto particulate matter [32] and as such the escape detected in pure air samples

3.4 Impacts

In a modern city people are exposed to a wide range of environmental and social factors, mainly determine the adverse effects of people's health. These effects include an increased number of diseases related to the urban way of life (the appearance of the so-called the diseases of civilization). Hence, ambient air pollution in Almaty is a direct threat to environmental and human health. According to the above disclosure of the state of the Almaty air, we must conclude that potentially a significant impact on the human health, probably with a decreased life span as a result prevails. Further this will may cause an increase in expenses for medicare as both the physical and mental health obviously may be damaged. Thus, excessive noise can cause nervous exhaustion, mental oppression, vegetative neurosis, peptic ulcer disease, disorder endocrine and cardiovascular system [33]. However, a specialist discussion of the human health impacts are outside the expertise of the authors but some general remarks seems appropriate.

Thus, among the substances monitored by Kazhydromet we find formaldehyde and as the most important nitrogen oxides [34]. Further, also particulate matter has been detected both by Kazhydromet [35] as well as the present study. The present study further disclosed a broad spectrum of organic compounds (cf Table 9).

Nitrogen dioxide that apparently is the only substance Kazhydromet finds in concentrations exceeding the MAC values is recognized as a lung irritant that further weakens the body's defense again deceases in the respiratory system [36].

It is well know that the inhalation of organic substances significantly may damage the human health. Thus, formaldehyde, as one of the substances being continuously monitored is a strong irritant for both eyes, skin and the respiratory system provoking asthma or asthmatic attacks [21]. Further, formaldehyde may influence the central nervous system [37] and animal studies has suggested carcinogenic acidity of this compounds as well [38]. This is substantiated by a PASS calculation [39] that predicts formaldehyde to be classified as a CARC I compound with a probability of 73.2%. At the same time a 44 and 43% probability, respectively, that formaldehyde is teratogenic and embryotoxic, respectively.

Turning to the broad selection of organic compounds found in exhaust gasses and ambient air samples in the present study is it evident that we are dealing with a potentially hazardous mixture that attacks the central nervous system with effects ranging from changes cognitive and psychomotor functions at low exposures to headaches, dizziness, confusion/disorientation at higher exposures to loss of consciousness, coma, and death at very high exposures [40]. In the cases of low to high exposure, the effects may be reversible. However, in the case where the exposure is due to a daily exposure to the low air quality in the city may obviously lead to conditions constantly being dominated of the mentioned symptoms.

A special issue is benzene. In the currently used gasoline in Kazakhstan the limit is 5% whereas in newer standards (since Euro 3) the limit of benzene in gasoline has been 1%. Benzene is suspected carcinogenic [41], which is substantiated by PASS calculations [39] predicting benzene as Carc I (77.2% probability) and further the substance is predicted possibly teratogenic (45.1% probability) and embryotoxic (44.9% probability), respectively. The 5% limit is refound in the gasoline analyses (Table 7) and in ambient air it is noted that benzene apparently is one of the most abundant substances among those being detected.

The breathing volume of a healthy person in rest is typically around 6 L min-1 [42], corresponding roughly to 8.6 m3 d-1. In the case of physically demanding activities a 10 fold increase of the breathing may prevail, however, depending on the actual physical form of the person [42]. Thus, an average daily breathing volume of 10 m3 appears as a conservative approach, i.e. the minimum daily volume inhaled by an average person. If we assume an excretion of approximately 50% of the inhaled/absorbed dose within 24 h [43], it is possible to obtain a rough estimate of the steady-state concentration, CSS in the body as 2 times the inhaled daily dose, CAV [11] i.e, CSS = 2x10xCAV. Thus, further studies in order to quantify the actual concentrations of selected organics appear as a logical next step in order to specifically to pin-point crucial health problems due to the air quality in Almaty.

Some of the organic compounds are further carcinogenic. Here the polycyclic aromatic hydrocarbons constitute a special group of compounds [44]. They are generated during the combustion [45] and typically attached to particulate matter [32].

Particulate matter constitutes a specific problem. Fine particles (PM10) and ultra-fine particles (PM2.5) has in recent years been reported to cause a series of malfunctions in the human body. Thus, in a recent review it has been summarized that adverse health effect risk in humans can be related to the exposure to traffic generated fine and especially ultra-fine particle the main targets apparently being the cardiovascular and pulmonary systems [46]. Thus, in a study from 2004, focusing at the exposure to traffic-related pollution Peter et al. [47] found an increased elevated risk of myocardial infarction, the odds ratio being 2.92 (CI 2.22-3.83) and Jerrett et al. [48] found an Increased relative risk of death from ischemic heart disease for a 10 μg m-3 increased in ultra-fine particles. Other special effects comprise low birth weight/preterm birth, increase in asthma and other respiratory disease in children, decrease in lung development and function in children, cardiovascular disease including atherosclerosis in adults and cancer [49-50].

Summarizing, a recent compilation of expert judgments it was stated that "the likelihood of an independent causal relationship between increased short-term UFP exposure and increased all-cause mortality, hospital admissions for cardiovascular and respiratory diseases, aggravation of asthma symptoms and lung function decrements" was rated medium to high by most experts and that "the likelihood for long-term UFP exposure to be causally related to all-cause mortality, cardiovascular and respiratory morbidity and lung cancer was rated slightly lower, mostly medium" [51].

Further, it must be remembered that the toxic potential of the ultra-fine particle enhanced as they may freely move within cells and interact with proteins, organelles and DNA [49]. In this connection, it is again worthwhile to mention that, e.g., the carcinogenic PAHs typically will be found sorbed to the particulate matter [52] that subsequently may act as a vehicle for transporting the sorbed substances into the cells.

3.5 Responses

Based on the above reported studies and considerations, a series of obvious responses can be suggested. However, it is necessary to accept as a fact the geolocation of Almaty and as such the thermal inversion currently leading to unwanted situations dominated by smog.

It should also be noted that activities eventually leading to an improvement of the air quality has already been initiated. Thus, as mentioned above, an increasing number of new busses using compressed natural gas as fuel are now in operation in Almaty, facing out old obsolete vehicles.

3.5.1 The car component

In order to reduce the number of old cars, a new import tax has been imposed by July 1st, 2011 [53], which relates to the age of the car. Thus, for cars not older than 3 years, a tax of 0.6-0.75 € per cubic cm of the engine volume is imposed. For cars of age 3-10 years, 10-14 years and over 14 years, respectively the tax amounts to 0.35-0.6, 0.75, and 2€ per cubic cm, respectively. For individuals importing two or more cars during the calendar year, the following taxes are imposed: for cars not older than 3 years 3.5 – 5 € per cubic cm, for 3-7 years old cars 0.85-2.25 €, and for cars more than 7 years old – 2-3€.

Obviously it is the hope that this special tax will significantly decrease the number of older cars from the street.

Nevertheless, the traffic in Almaty is currently dominated by older cars (cf. Table 5) and it appears as a major, necessary task to limit this number or at least take the necessary measures effectively to control the appropriate/optimal operation of the exciting cars. It is no secret that the present bi-annual mandatory inspection of the cars hardly can be described as neither appropriate nor effective. Hence, an efficient system for car checking appears mandatory, possibly requiring training of professionals for tuning engines and injection systems.

Emission control according to the Euro standards appears as an obvious initiative. However, as part of this inspection it appears mandatory that cars are equipped with catalysts or catalytic converters only can pass the check if the catalyst or catalytic converter is functioning according to the guidelines. And in the case of the first registration of cars in Kazakhstan, only cars with functioning the catalyst or catalytic converter can obtain registration.

Finally the inspection system obviously should be given the necessary authority to require obviously obsolete car being de-registered and scrapped and as such removed from the inventory.

3.5.2 The fuel component

Close connection to the problems associated with the aging car park is the quality of gasoline. As mentioned plans to upgrade from Euro-2 to Euro-5 grade gasoline by 2014 will obviously lower the emissions of some of the more hazardous substances as e.g. benzene. However, it further seems that also in the case of gasoline and gas stations an inspection system could be beneficial in order to avoid adulteration of the gasoline (vide supra).

In addition to the foreseen improvement of gasoline quality, the availability of environmentally friendly fuels (compressed natural gas, liquefied petroleum gas, hydrogen, biofuels) should be increased, advantageously combined with an economic incitement for the consumer to use these fuel types. In this connection also economic incitement, such as lower taxation, on hybrid- and fully electric cars should receive attention.

It should be noted that the necessary technology to reduce the amount of hazardous material in car exhaust is available. Thus, the effect of catalytic converters has been studied by the Institute of Organic Catalysis and Electrochemistry in Almaty [54] as illustrated in Table 10.

Table 10 – Emission from cars as a function of various Euro fuel standards.

	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Euro-1 with catalyst1
CO	4.5	4.0	2.1	1.5	1.5	1.51
CXHY	1.1	1.1	0.66	0.46	0.46	0.49
NOX	8.0	7.0	5.0	2.0	2.0	4.3
PM	0.36	0.15	0.1	0.02	0.02	0.08

1 According to studies carried out at the Institute of Organic catalysis, Almaty

From these data it can be noted that using even the Euro-1 fuel in combination with a catalytic converter, the exhaust could be reduced to a level corresponding to what is seen when using Euro-3 fuel.

3.5.3 The traffic component

Obviously a reduction in the private traffic appears as an optimal initiative to reduce the emission of hazardous substances and thus improving the air quality. Without going into details with pro's and con's, a series of initiatives should be mentioned for the consideration of the authorities. Some of these have further been extensively discussed in connection with a possible reduction of other major cities around the globe:

• Public transportation should be upgraded and specific action to motivate people to use public transportation when possible should be installed.

• In Almaty, a metro system has been under construction for the last 25 years but is still not in operation. However, the first phase is now foreseen to open with in total 7 stations by the end of 2011 [55]. Further extension of the metro is foreseen but no scheduled opening is known for the time being [56].

• Busses are often crowded especially in rush hours. Hence, increased frequencies during rush hours should be introduced in parallel to the already on-going exchange of old worn-out busses with new vehicles running on compressed natural gas.

• Road pricing appears as an effective way of reducing traffic within the city limits as has been should in, e.g., Stockholm and London [57-58]. It is, however, evident that introduction of a road-pricing or 'entrance-fee' unambiguously must be accompanied with a significant upgrade of the public transportation and the construction of necessary parking facilities out of the city limits adjacent to public transportation facilities.

• Traffic jams are a constant problem in Almaty.

• To a major extent, these are caused by the traffic pattern and the driving culture. In this connection it can be mentioned that a priori every car in Almaty may act as a taxi – a procedure, which for good reasons is widely used but causes a lot of unintentional stops due to suddenly stopping cars to pick up potential customers.

• Another example is the many pedestrian crossings – even on major roads, which virtually is seriously respected by the drivers. However, these crossing further lead to sudden and unplanned stops in the traffic again contributing to creating traffic jams. Installation of pedestrian bridges and further extension of the relative low number of pedestrian tunnels is suggested to remedy this problem to a large extent. This would further limit the high number of undesirable decelerations and acceleration that is highly fuel consuming and as such significantly contributing to the air pollution by leading to a more uniform and constant speed.

• Through-going traffic appears as a major problem significantly contributing to the amount of vehicles within the city limits. A reduction/elimination of this basically unwanted and unnecessary traffic component is highly desirable. The obvious solution would be to construct by-passes to lead this traffic component around instead of through the city. Ideas in this direction have been aired [59].

3.5.4 The power plant component

As stated above the traffic component accounts for approximately 80% of the air pollution in Almaty, whereas the power plants account for the major part of the remaining 20%.

Looking at the CHP-1 power plant that is located in the central part of Almaty, the first unit has been started under industrial loading by October, 1935. Without going into details with the construction and enlargement history, it should be noted that the last major upgrade of the plant dates back to 1976-79 [60]. Hence, the main equipment is approx. 80 years old. Unambiguously, taking the development in power plant technology into account, it can without exaggeration be concluded that upgrading the power plants by introducing modern technology will significantly reduce the emission from the plant.

Previous CHP extension was carried out from 1969 to 1972 and it was designed according to the general master plan of Almaty. At the end of 2000 year, it was put out of work and dismantled outdated ineffective equipment. After reforming, the CHP-1 has been operational since February 15, 2007 as part of JSC "Almaty Power Station."

3.5.5 Monitoring

The above mentioned possible responses aiming at an improved air quality in Almaty should unequivocally be accompanied by appropriate monitoring activities, i.e., by upgrading the on-going activities by Kazhydromet. Hence, it is suggested that the Kazhydromet monitoring program is extended to include a series of organic pollutant comprising as a minimum both BTEX (Benzene, Toluene, Ethyl benzene, Xylenes), phenols and selected polycyclic aromatic hydrocarbons.

Kazhydromet today also measures particulate matter. However, it is strongly emphasized that based on today's knowledge, especially the ultra-fine particles, i.e., PM2.5, appears to be of high concern (vide supra). Thus, it is strongly emphasized that the monitoring activities are upgraded to specifically measure the PM2.5 component.

Although outside the scope of the present paper, it is strongly emphasized that allocation of the necessary funding for required update of analytical equipment to comply with the suggested monitoring activities should be made available.

Conclusions

In the present paper we have focussed on the traffic component as being the major responsible for the low air quality in Almaty, however, not neglecting the presence of other factors such as power plants.

The study has been carried out applying the DPSIR approach as an overall framework and driving forces and pressures have been disclosed. Based on appropriate analyses, it was found that in addition to the few substances, like NOx and SOx monitored by Kazhydromet a wide variety of organic substances could be detected in the city air. These substances may significantly affect the human health and it is recommended that initiatives are taken to reduce their amount in the Almaty air. Further, especially the amount of NO2, the only compound Kazhydromet finds in concentrations exceeding MAC, should be reduced.

A special issue is the ultra-fine particles. Today only the total particulate matter is monitored. However, based on recent findings, especially the UFPs appear highly damaging for the human health and it suggested that special focus is devoted to the PM2.5.

A series of recommendation (‘responses’) including actions to reduce the number of aging cars, to reduce private transport, to improve fuel consumption and to reduce through going traffic have been given in addition to suggestions for upgrading the monitoring activities.

We are aware that the suggested actions in no way can be looking upon as a ‘quick fix’. It will undisputable take time and significant investments are required. However, to remove Almaty from the unflattering placement among the 25 most polluted cities among the major cities of the world, it appears necessary.

We are further aware about the human factor. A major task will be to chance the attitude among the residents in Almaty to adjust to – for many – a completely new culture regarding private transportation. The psychological factor must in no way be underestimated. To achieve the necessary, a long steady and tough pull can be foreseen.

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References

1 About Kazakhstan, 2011, http://aboutkazakhstan.com /blog /wp-content /uploads /2010 /11 /smog-over-almaty-city-kazakhstan.jpg (Accessed Apr. 2012).

2 Aimanbetova Z., 2010. Алматы – в списке самых грязных городов мира (Almaty – in the list of most dirtiest cities in the world), Voice of America, Russian ed., 2010, 20th Jan.; http://www.voanews.com/russian/news/former-ussr/Almaty-Pollution-2010-01-20 82192382. html (Accessed Apr. 2012).

3 Newsfactory, 2011. Алматы – ядовитый город (Almaty – toxic city), http://www.newsfactory.kz/24639.html (Accessed Apr. 2012).

4 RealKz, 2011. О Казахстане / Алматы (About Kazakhstan/Almaty); http://www.realkz.com/page.php?page_id=145&lang=1 (Accessed Apr. 2012) .

5 Kazakhstan today, 2011. В прошлом году выбросы загрязняющих веществ в атмосферу Алматы составили 232 тысячи тонн (Last year the pollution in the air of Almaty was 232.000 ton), 12th May; http://kt.kz/?lang=rus&uin=1133168098&chapter=1153538055 (Accessed Apr. 2012).

6 Tengrinews, 2011. Больше 100 тысяч алматинцев ездят на старых авто (More than 100.000 Almaty citizens driving old cars), 22th June. (http://tengrinews.kz/kazakhstan_news/191162/) (Accessed Apr. 2012).

7 Zakon, 2010a. В природе ничто не пропадает, кроме ее самой (Nothing vanishes in nature apart from itself), 11th Mar.; http://www.zakon.kz/165629-kakie-mery-prinimajutsja-dlja-reshenija.html (Accessed Apr. 2012).

8 AirNow, 2011a. AirNow: Local air quality conditions and forecasts; http://www.airnow.gov/ (Accessed Apr. 2012).

9 AlmatyMeteo, 2011; http://www.almatymeteo.kz/ (Accessed Apr. 2012)

10 AirNow, 2011b. AQI Calculator: Concentration to AQI; http://www.airnow.gov/index.cfm?action=resources.conc_aqi_calc (Accessed Apr. 2012)

11 Carlsen, L., Kenesova, O.A., Batyrbekova, S.E., 2007. A preliminary assessment of the potential environmental and human health impact of unsymmetrical dimethylhydrazine as a result of space activities, Chemosphere, 67, 1108-1116.

12 Kristensen, P., 2004. The DPSIR Framework, Paper presented at the 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya;

13 Koziel, J.A., Jia, M.Y., Pawliszyn, J., 2000. Air sampling with porous solid-phase microextraction fibers, Anal.Chem., 72, 5178-5186.

14 Koziel, J.A., Pawliszyn, J., 2001. Air sampling and analysis of volatile organic compounds with solid phase microextraction, J.Air Waste Manag.Assoc., 51, 173-184.

15 Pogoda, 2011. Климат Алматы (Almaty Climate); http://pogoda.ru.net/climate/36870.html (Accessed Apr. 2012).

16 http://eurex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0088:0113:EN:PDF (Accessed Apr. 2012).

17 Zakon, 2010b. Туман в Алматы продолжает затруднять авиаполеты (The smog in Almaty continuous to make difficulties in air flights), 14th Dec.; http://afisha.zakon.kz/192977-tuman-v-almaty-prodolzhaet-zatrudnjat.html (Accessed Apr. 2012).

18 Greensalvation, 2009. Комплексная Программа по снижению загрязнения окружающей среды города Алматы на 2009-2018 годы (Complex programme to minimize pollution of the environment of Almaty city); Решением XVII-й сессии Маслихата города Алматы IV-го созыва от 24.04.2009 года № 187 (The decision of XVII th session of Almaty City Maslihat of IV th convocation From 4/24/2009 № 187); http://www.greensalvation.org/uploads///Docs/2009ecoprogram-almaty.doc (Accessed Apr. 2012).

19 Almaty, 2011. План реализации градостроительных регламентовзастройки функциональных зон территории города Алматы (The plan of realization of city building requirement of functional zones at the territory of Almaty city, The official webpage of Almaty); http://www.almaty.kz/page.php?lang=1&page_id=890 (Accessed Apr. 2012).

20 Jørgensen, J., 2011. Danish Automobile Association, Technical Division, personal communication.

21 EPA, 2007. Formaldehyde; http://www.epa.gov/ttn/atw/hlthef/formalde.html (Accessed Apr. 2012).

22 Our Almaty, 2010. В Алматы превышена концентрация загрязняющих веществ (In Almaty the concentrations of pollutants are increasing), Our Almaty (Наша Агаша), 21st Oct.

23 Environment Australia, 2001. Fuel Standard (Petrol) Determination 2001 and the Fuel Standard (Automotive Diesel) Determination 2001, Regulation Impact Statement; http://www.environment.gov.au/atmosphere/fuelquality/publications/ris-2001/options.html (Accessed Apr. 2012).

24 Zakon, 2010c. Казахстан намерен к 2014 году, минуя стандарты Евро-3 и Евро-4, перейти к экостандарту Евро-5 – вице-министр нефти и газа РК А. Магауов (At 2014 Kazakhstan is going to use the Euro-5 eco-standard, skipping Euro-3 and Euro-4 according to vice minister of oil and gas A. Magauov), 22nd Dec.; http://www.zakon.kz/193574-kazakhstan-nameren-k-2014-godu-minuja.html (Accessed Apr. 2012).

25 EC, 2009. Official Journal of the European Union, DIRECTIVE 2009/30/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC.

26 IFQC, 2011. International gasoline rankings – Top 100 sulphur; www.ifqc.org/NM_Top5.aspx (Accessed Apr. 2012).

27 Shell, 2011. Personal communication, Shell, Denmark.

28 Gismeteo, 2009. Отличается ли температура в центре большого города от температуры окрестностей? (Do we have different temperatures inside the city limits and outside?), 4th Febr.; http://

news.gismeteo.ru/news.n2?item=63369420383 (Accessed Apr. 2012).

29 Kazinform, 2009. Экологические проблемы города решаются на системном уровне – представитель акимата Алматы (Ecological problems of Almaty city to be solved on systematical level according to the city administration), Kazinform, 8th Aug.; http://www.inform.kz/eng/article/2190363 (Accessed Apr. 2012).

30 GOST, 1983. GOST 17.2.4.05-83. Nature protection. Atmosphere. Gravimetric method for determination of suspended dust particles, Moscow.

31 KazHydromet, 2011a. Almaty; http://www.kazhydromet.kz/eng/cgm/index.php?id=12 (Accessed Apr. 2012).

32 Academic, 2011. Взвешенная пыль (Superfine particles), Ecological Dictionary; http://dic.academic.ru/dic.nsf/ecolog/184/ВЗВЕШЕННАЯ (Accessed Apr. 2012).

33 Wikipedia, 2011a. Health effects from noise; http://en.wikipedia.org/wiki/Health_effects_from_noise and references cited therein (Accessed Apr. 2012).

34 KazHydromet, 2011b, Качество атмосферного воздуха (The quality of atmospheric air) http://www.kazhydromet.kz/koncentracii/primes.php?id=1 (Accessed Apr. 2012).

35 KazHydromet, 2011c. Мониторинг окружающей среды (Environmental monitoring); http://www.kazhydromet.kz/ultrafiolet/monitoring.php (Accessed Apr. 2012).

36 AirLife, 2011. ПДК диоксида азота (Maximum concentration limit for nitrogen dioxide); http://www.airlife.ru/?m=76&a=112 (Accessed Apr. 2012).

37 Songur, A., Ozen, O.A. , Sarsilmaz, M., 2010. The toxic effects of formaldehyde on the nervous system.

38 NCI, 2011. Formaldehyde and Cancer Risk, National Cancer Institute; http://www.cancer.gov/cancertopics/factsheet/Risk/formaldehyde (Accessed Apr. 2012).

39 PASS, 2011. PASS online: http://www.pharmaexpert.ru/PASSOnline/index.php (Accessed Apr. 2012).

40 Squibb, K., 2011. Toxicity of Organic Compounds: Solvents and Chlorinated Organics, UM Program in Toxicology.

41 EPA, 1998. Carcinogenic Effects of Benzene: An Update, EPA/600/P-97/001F, http://www.epa.gov/ncea/pdfs/benzenef.pdf (Accessed Apr. 2012).

42 CaEPA, 1994. How much air do we breathe?, Research Note 94-11, California Environmental Protection Agency; http://www.arb.ca.gov/research/resnotes/notes/94-11.htm (Accessed Apr. 2012).

43 ILO, 1983. Encyclopedia of Occupational Health and Safety. Vols. I&II. International Labour Office. Geneva, 1070.

44 Codex, 2011. Углеводороды полиароматические (Polyaromatic hydrocarbons), Документ из ИПС "Кодекс" (Codex); http://base.safework.ru/iloenc?print&nd=857300056 (Accessed Apr. 2012).

45 Tox, 2011. Полициклические ароматические углеводороды (Polycyclic aromatic hydrocarbons), Toxicology (Токсикология); http://cld4b.tk/index-130.htm (Accessed Apr. 2012).

46 Politis, M., Pilinis, C., Lekkas, T.D., 2008. Ultrafine particles (UPF) and health effects. Dangerous like no other PM? Review and Analyses, Global NEST Journal, 10, 439-452.

47 Peters, A., von Klot, S., Heier, M., Trentinaglia, I., Hörmann, A., Wichmann, H.E., Löwel, H., 2004. Exposure to Traffic and the Onset of Myocardial Infarction, N.Engl.J. Med., 351, 1721-1730; http://www.nejm.org/doi/full/10.1056/NEJMoa040203 (Accessed Apr. 2012).

48 Jerrett, M., Burnett, R.T. , Ma, R., Pope III, C.A., Krewski, D., Newbold, K.B., Thurston, G., Shi, Y., Finkelstein, N., Calle, E.E., Thun, M.J., 2005. Spatial Analysis of Air Pollution and Mortality in Los Angeles , Epidemiology, 16, 727-736.

49 Froines, J.R., 2006. Ultrafine Particle Health Effects; http://www.aqmd.gov/tao/ultrafine_presentations/Pre-Conference_2_Froines.pdf (Accessed Apr. 2012).

50 Shettler, T., 2005. Болезни сердца и окружающая среда (Heart troubles and environment); www.ecoaccord.org/pop/che/che4.doc (Accessed Apr. 2012).

51 Knol, A.B., de Hartog, J.J., Boogaard, H., Slottje, P., van der Sluijs, J.P., Lebret, E., Cassee, F.R., Wardekker, J. A., Ayres, J.G., Borm, P.J. Brunekreef, B., Donaldson, K., Forastiere, F., Holgate, S.T., Kreyling, W.G., Nemery,B., Pekkanen, J., Stone, V., Wichmann, H.-E., Hoekl, G., 2009.. Expert elicitation on ultrafine particles: likelihood of health effects and causal pathways, Particle Fiber Technol., 6, 19.

52 Kirso, U., Urb, G., Laja, M., Teinemaa, E., Reinik, J., Gebefugi, I., Kettrup, A., 2006. PAH

in airborne particulate matter, Polycycl.Aromat. Comp., 26, 111-119.

53 Zona, 2010. Льготная ставка пошлины на ввоз подержанных автомобилей в Казахстан будет действовать до 1 июля 2011 года (The preferential rate of the duty on import of second-hand cars to Kazakhstan will operate till July, 1st, 2011), Internet newspaper, 2nd July; http://www.zonakz.net/articles/29653 (Accessed Apr. 2012).

54 IOCE, 2011. Personal Communication, Institute of organic catalysis and electrochemistry, Almaty; http://cnzmo.nauka.kz/cat/ (Accessed Apr. 2012).

55 Wikipedia, 2011b. Алматинский метрополитен (Almaty Metro); http://ru.wikipedia.org/wiki/Алматинский_метрополитен (Accessed Apr. 2012).

56 Wikipedia, 2011c, Список станций Алматинского метрополитена (The list of stations of Almaty metro); http://ru.wikipedia.org/wiki/Список_станций_Алматинского_метрополитена (Accessed Apr. 2012).

57 Eliasson, J., 2011. Cost-benefit analysis of the Stockholm congestion charging system Transek AB, http://siteresources.worldbank.org/INTTRANSPORT/Resources/Stockholmcongestion CBAEliassonn.pdf, Accessed Apr. 2012)

58 Litman, T., 2006. London Congestion Pricing. Implications for Other Cities, Victoria Transport Policy Institute, 10th Jan.; http://www.vtpi.org/london.pdf (Accessed Apr. 2012).

59 Zakon, 2011. В городском акимате Алматы прошло совещание по реализации проекта строительства БАКАД (In the government of Almaty, a meeting on realization of construction of Big Almaty Ring Road was held), Oct. 21st; http://www.zakon.kz/4454340-v-gorodskom-akimate-almaty-proshlo.html (Accessed Apr. 2012).

60 Ales, 2011. Алматинская ТЭЦ-1 (Almaty thermal power station-1); http://www.ales.kz/index.php?option=com_content&task=blogcategory&id=23&Itemid=39 (Accessed Apr. 2012).