ГЕОГРАФИЯ

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NATURAL AND ANTHROPOGENIC DETERMINANTS OF ENVIRONMENTAL AIR POLLUTION IN CENTRAL KAZAKHSTAN

Мақалада Орталық Қазақстан территориясындағы атмосфера ластануына әсер ететін табиғи және антропогендік факторлар қарастырылған. Ластанудың уақыт және кеңістік бойынша өгеруі, құрамы талданған. Ауа ластану концентрациясы деңгейіне әсер ететін метеорологиялық, синоптикалық факторлар, сонымен қоса ластанудың негізгі көздері, таралу ерекшеліктері мен көлемдері анықталған.

В статье рассматриваются природные и антропогенные факторы, влияющие на уровень загрязнения атмосферы Центрального Казахстана. Проанализированы состав, изменения по времени и пространству степени загрязнения. Определены метеорологические, синоптические факторы, влияющие на уровень концентрации грязи в атмосфере, а также основные источники, объемы и особенности распространения загрязнения атмосферы.

Determinants of environmental air pollution of any geographic region consist of both natural and man-made factors. Natural factors affecting the course of air pollution include local landscape and topography, and synoptic and meteorological conditions that determine air flow in the region, and affect the conditions of background air pollution. Anthropogenic factors often constitute the main source of environmental air pollution and include factors such as the location of air pollutant emitting facility, its power level, the distribution of pollution in time and space, the type of air pollution, parameters of air pollutant releasing pipes, the type of air-purification procedure, adopted air pollution thresholds, and the extent of environmental protection measures in place.

Central Kazakhstan is located at the most elevated part of the Kazakh Upland Saryarka, which is a unique environmental terrain diverse in its geological and geomorphologic structure. The absolute height of the upland ranges between 400 and 1000 meters. The local topography is complex due to a combination of many small hills and lowlands, river valleys, and dry riverbeds with inland cavities and lake basins. One of the distinctive features of the terrain is the protruding shape of solid rocks appearing as rock faces or cliffs, and piled and scattered stones, which are vastly carved and situated chaotically. The western part of the territory has a flatter shape, appearing as a smoother-surface highland, whereas the eastern part is more elevated with an absolute height of 1,565 meters. The elevated parts of the upland reveal the features of a high altitude. The height of riverbeds ranges between 400–600 m. The average height mountains are located disorderly across the terrain in form of insular elevations. Therefore the landscape conditions of Central Kazakhstan allow for a free circulation of the air flow, which should not promote air pollution by trapping the air.

The analysis of synoptic and meteorological conditions for air pollution in Central Kazakhstan had shown that a complete and objective evaluation of the situation is complicated due to these conditions' high volatility and indistinctiveness, insufficient number and duration of observations, and interrupted data collection process. However, even with such limits imposed on research observation, it is possible to distinguish some steady patterns. Climate of Central Kazakhstan is continental and very droughty. The climate formation process in this territory resulted into continental air of temperate latitudes, which is affected by the westerlies, by air masses formed locally in the heart of Eurasia, and by altered Arctic and Tropical air masses. The duration of solar radiation, which is the main climate-forming factor, is 2300–2400 hours a year, with a maximum in July. The average annual cumulative radiation is 100 kkal/ cm^2, and natural (background) radioactivity is up to 48 kkal/cm^2 per year. The average annual air temperature ranges between +2.4^{0}C in northern and +6.7^{0}C in southern parts of the terrain. The average temperature in January is between -17.9^{0}C in the north and north-east, and -14.4^0 C in the south of the region. The average temperature in July ranges from +18.5^0 C to +20.4^0 C.Duration of the warm season is about 198 days/year in the more elevated eastern part to about 207–220 days per year in the western, lower part of the terrain. Respectively, frost-free season lasts 90–100 and 110–135 days a year [1].

As a result of an increase to sun exposure toward the south of the region, the likelihood of occurrence of anticyclone situations increases toward the south as well. This reinforces the continental climate and decreases the amount of precipitation. The average annual level of precipitation in the northern and eastern parts of the region is 300–350 mm per year, and about 100–150 mm in the south. The highest level of precipitation occurs in July, 41–57 mm, and the lowest in January, 8–18 mm per year. Snow cover stays for 4–5.5 months in most parts of the region, and for about 3–3.5 months in the south. At times of poor snowfall and severe colds, the soil freezes for up to two meters in depth. One of the basic meteorological factors influencing the concentration and distribution of the atmospheric pollution is the wind regime. As it has been noted, the local relief and topography, combined with synoptic conditions, facilitate the formation of an active wind regime. An extensive size and rugged topography of the Central Kazakhstan region cause significant differences in wind speed and wind direction. The average annual wind speed in northern areas is 4.5 — 5 km/hr, and 3,5 — 4,5 km/hr in the southern parts. While observing the influence of basic meteorological factors on the level of air pollution, it has been noticed that a significant role is played by the conditions of general atmospheric air circulation, as well as wind regime, solar radiation, temperature mode, humidity of air and the level of precipitation. In the atmosphere of Karaganda city region, air circulation process is influenced by cyclonic activities, dynamics of which are determined by the western currents. In addition, three types of transformed air masses, the Arctic, Polar and the Tropical currents, reach the territory of this area. All of these flows have their particular influences on the formation and extent of environmental air pollution. During cyclonic periods, a cloudy weather is formed, often accompanied by wind and precipitation. This promotes dispersion of harmful substances in the atmosphere, washing away the pollutant particles and hence reducing the concentration of atmospheric pollution. During cold periods, an essential role is played by the western spur of the Asian anticyclone. At such times, the average daily temperature in January is 12.70^0 C, the wind speed is 2.5 km/hr, and the relative humidity of air reaches 87 % (for the station of Karaganda [2]. Under such meteorological conditions, raised inversion is commonly formed. Inversions are created as a result of the cooling of a terrestrial surface, when warm and cold fronts are merged, i.e. at the occluded front. During cold periods, the probability of their recurrence is 18 %. Inversions create a unique «ceiling» that blocks the warm emissions from industrial plants and prevents their dispersion. The near-ground inversions are formed mostly during the night; therefore an increase in the level of air pollution at night is 1.5–1.7 times higher. The dispersion of these air pollutants takes place during the daytime. The most influential inversions are formed during anticyclone weather in winter time in combination with a strong overnight cooling. According to aerologic observations, the size of such strong inversions is between 200 and 400 m, and most of the time the elevation level ranges between 500 and 1200 m. At times of weak winds scarce and unorganized emissions tend to concentrate at the lowest layer of the atmosphere near the ground. If there are significant winds (7–10 km/hr) and no inversions in the ground layer of the atmosphere, then pollution is disseminated and has a bare contact with the surface of the ground. Strong winds with a speed of 12–15 km/hr or higher can spread the pollution away at significant distances from the sources of emission. The direction of winds influences the contents of environmental air pollution too. The analysis shows that the level of air pollution increases with the arrival of Western, Northern and Northwest wind currents and is lowest when winds arrive from the Southeast. It is explained by location of main sources of environmental air pollution in the territory of those regions.

Solar radiation influences the level and contents of environmental air pollution as well. High intensity of solar radiation triggers complex photochemical reactions in the atmosphere, for example oxidation of sulfur oxides with the formation of sulphatic aerosols. The presence of nitrogen oxides and organic substances in the atmosphere during clear sunny days can lead to formation of extremely hazardous photochemical smog. Atmospheric precipitation, as well as the wind, are considered natural factors of self-purification in the atmosphere. The average annual cumulative precipitation in Karaganda city is about 300 mm. with most of the precipitation (more than 70 %) occurring during warm seasons [1]. There is some decrease in the level of environmental air pollution after precipitation (rainfall and other), which is more than 1,5–2 times during cold seasons, and more than 2–2.3 times during warm seasons. However, precipitation then becomes a source of environmental pollution for soil and water reservoirs. Moreover, only few days a year with precipitation in this region do not help to reduce the general level of environmental air pollution. During transition periods, namely in March and November, most of foggy days occur (on average about 4–5 foggy days a year). The level of air pollution increases during fog episode because drops of fog absorb harmful substances such as air pollutants, both near the ground surface, and from the farthest polluted layers of the air. For example, drops of fog dissolve sulfur dioxide to a more toxic sulfuric acid. Additionally, this process increases the weight of air polluting substances because from 1 gram of sulfur dioxide 1.5 grams of sulfuric acid is formed. In a similar way, the transformation of sulfur dioxide into sulfuric acid takes place in atmospheric precipitation, which is one of the reasons of acid rain formation.

Background pollution is mainly influenced by the leading currents in this area. As it is known, in the latitudes of temperate climate the air flow is from west to east across almost the entire width of troposphere. Therefore, environmental air pollution, carried across large distances by air streams, originates not only in the areas to the west of Central Kazakhstan, but also in the West relative the country as a whole. For example, environmental air pollution in Eastern Europe is transferred from the Western Europe [3]. Background pollution is mostly influenced by natural factors, but the trans-national transfer of environmental air pollution from the territories of bordering countries plays a role too. As it is known, natural zones in Central Kazakhstan are the steppe, semi-desert and desert zones.

Table

Air Pollutant Emissions in the Cities of Central Kazakhstan, by year [4]

Air Pollutant Emissions (thousand tons/ year)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Karaganda	65,3	59,0	63,1	66,5	65,0	54,2	51,6	48,6	47,2	47,4
Temirtau	305,9	345,0	350,0	343,0	350,0	348,3	348,4	329,7	301,9	336,9
Zhezkazgan	140,0	141,7	145,0	141,1	145,0	137,9	147,3	144,5	136,5	127,5
Balkhash	376,8	403,6	449,4	510,5	512,1	718,7	780,8	763,9	689	620,7
TOTAL in the province (Karaganda Oblast)	1009,8	1049,5	1108,5	1142,3	1200	1373,7	1465,2	1415,4	1303,6	1265,9

Reduced annual precipitation in the past several years, subsequent groundwater level decrease, cutting down of trees, and more frequent steppe and forest fires — all of these add to aridization of the territory. The process of ground aridization increases the probability of having dusty storms and promotes the transfer of surface soil on far distances, which increases dustiness of atmosphere. According to the ecologists of Kazakhstan, the borders of natural zones in the country have been displaced to the north approximately by 200–300 km in the last century. Thus, background pollution of the territory is manifested mainly through the ground particles, dust, and plant pollen in the spring and summer.

Central Kazakhstan is one of the leading industrial regions of the country, represented by highly developed heavy industry production complex. These are the coal-mining, metallurgical and chemical-machine-building branches of the country recognized internationally. All of the major branches of the heavy industry are mainly related to coked coal extraction, non-ferrous and ferrous metal ore treatment, rare metal ore treatment, and auxiliary crude materials needed in metallurgy. The core of this industrial complex consists of three industrial hubs — Karaganda-Temirtau, Balkhash and Zhezkazgan. Regional industry specializes on manufacture of power-intensive and a material-intensive ferrous and nonferrous metallurgy, coal mining, and ores of some other valuable minerals. Additionally, mechanical engineering, chemical industry, building materials manufacturing, consumer goods and food-manufacturing industry and other industrial branches are presented here. The borders of the Central Kazakhstan economic region are also the borders of the Karaganda region (administrative province). The most powerful and developed Karaganda- Temirtau industrial hub also includes the cities of Abaj, Saran, Shakhtinsk and a number of urban-type settlements. This industrial hub is connected by a uniform technological stream: coal mines; coal-cleaning plants, and coking plants; including blast-furnace plants, steel foundries, and rolling plants of the Temirtau metallurgical complex. The development of the Balkhash and Zhezkazgan industrial hubs was made possible by the establishment of a full production cycle of nonferrous metallurgy, mainly the copper industry. In each of these there are powerful mining-and-metallurgical integrated works («The Balkhash Mining-and-Metallurgical Integrated Works» and «The Zhezkazgan Mining and Metallurgical Integrated Works»), which include open-pit mineries and quarries, treatment and dressing plants, and copper mills. Both of these hubs contain all the stages of copper manufacturing, including the final refinement and release of copper mill products. There are also the enterprises that produce consumption goods.

The main source of environmental air pollution in the Karaganda region is the fuel and energy complex (thermal power station) — a complex inter-branch system of extraction and manufacture of fuel and energy, their transportation, distribution and use. Substantial portion the electric power in the country, including the Central Kazakhstan area, is developed by thermal power stations which work with coal mined from Karaganda and Ekibastuz.

A significant share of atmospheric pollution in the area (85 %) is attributed to the manufacturing industry. About 1000 to 1400 thousand tons of environmental air pollutant emissions released annually for the considered time period. Emissions from the iron and steel industry make up 98 % of the general air pollution in the area. The analysis of changes in the level of environmental air pollution in the area over years shows that there was a trend towards a decrease of pollution by approximately 13–16 % annually between 1991 and 1997, which is related to a decrease in aggregate manufacturing volumes in the CIS and in the country. Since 1998, there is a steady increase in environmental air pollution by 3–4 % annually (Figure 1). However, since 2005 there is a considerable reduction (by 80–100 thousand tons) of atmospheric pollution. It is known that the most polluted industrial centers in the region are the city of Balkhash, which accounts for 43 % of the overall regional air pollution, followed by Temirtau with 29 % of environmental air pollution. The share of atmospheric pollution of the cities of Zhezkazgan and Karaganda make up 16 % and 7 % respectively [5]. In 2007 the plants in the area had released 1,266,000 tons of harmful substances into the atmosphere. Among the 425 enterprises that emit environmental air pollutants into the atmosphere, there are 6897 registered stationary sources, including 4819 (70 %) of them that are organized. Out of these sources of air pollution, only 29.6 % are equipped with purification technology [6]. Reduction in aggregate emissions in the area since 2005 is the result of more effective measures of air pollutant neutralization. For example, as much as 81.7 % or 5659.3 thousand tons of the total environmental air pollution was captured and neutralized in 2007. The net portion of emitted air pollutants released into the atmosphere without any purification or treatment process, relative to total emissions released from all sources of air pollution makes up 13.8 % [7].

The analysis of contributions by individual business enterprises to the anthropogenic air pollution shows that over the years considered, a significant share of emissions, 40 %, is attributable to the «Kazakhmys» corporation, 27 % of emissions are released by the Balkhash Mining-and-Metallurgical Integrated Works, and 18 % by the «Arsellor Mittal Steel» [8.] The Zhezkazgan Mining and Metallurgical Integrated Works releases about 8 % of environmental air pollution in the region. In Balkhash, about half of the emissions (44 %) are released into the atmosphere without the being purified. This parameter has been improving from year to year. According to the statistics of Karaganda region administration, the average emission level of hazardous substances in Balkhash was 12 tons per person per year in 2004, and 8.4 tons in 2007. In Temirtau, both the 2004 and 2007 values of this parameter equaled 2 tons [9]. The steady growth of the total amount of air pollutant emissions into the environment of the region is related to an increase in volumes of industrial production by plants in various branches of metallurgy, heat power industry, while the reduction in environmental air pollution starting in 2006 is the result of better purification processes in place.

The most widespread and harmful anthropogenic matters in the air of the region are the dust, sulphurous anhydride, hydrogen sulphide, carbon oxides, nitrogen oxides, ammonia, phenol and others. One of the parameters of environmental air pollution is the air pollution index (AIP), which allows estimating summation of effects of a combination of the main air pollutant agents. The analysis has shown that the level of AIP in the city of Karaganda is a little lower than in Temirtau — 8.01 and 9.43 respectively. Time trend by years has shown a tendency towards an increase of the index in both cities. Annual dynamics of AIP in Karaganda city has demonstrated that it reaches its highest values during the cold period, i.e. in January-February, and during the warm period — June and August. In the winter time this is facilitated by the anticyclonic weather and the establishment of still air; in the summer it is explained by an increased dustiness of atmosphere paired with the low-gradient pressure field. In Temirtau, the annual course of AIP move has one peak in March-April and the second maximum peak in October-December.

The analysis of annual air pollutant concentration for separate air pollutants over time shows that the atmospheric dust concentration in Karaganda decreases relation to the maximum allowable concentration (MAC) limit in September. Contrary to that, the concentration of phenol increases up to twice the MAC limits (0.06 mg/m^3) in April. The concentration of other air pollutants such as nitrogen dioxide, carbon oxide, nitrogen oxide, and sulfur dioxide varies little over the course of the year and is rather stable. As of Temirtau, its annual atmospheric dust concentration reaches its maximum in April-May when it is three times higher than the maximum allowable concentration limit (0.45 mg/m^3); the peak for ammonia is in July, exceeding the MAC limits by 1.7 times (0,05 mg/m^3). During the year the level of phenol is highest in November-December, 3.4 times exceeding the MAC limits (0,01 mg/m^3).

The annual dynamics of other air pollutant concentrations — nitrogen oxide, hydrogen sulphide, and sulfur dioxide — is stable and varies a little. Excessive air pollution levels are observed on separate days exceeding the MAC 5 to 10 times under adverse meteorological conditions (AMC), which prevent the dispersion of air pollutants in the atmosphere. The average monthly levels of pollution by types do not exceed the maximum allowable concentration limit. The annual trend of concentrations for nitrogen oxide and sulfur dioxide reveals no significant changes in their level of concentration. Excessive air pollutant concentrations are observed for phenol (with 5.6 times the MAC limit), carbon monoxide (2.2 times higher than the MAC), sulfur dioxide, and formaldehyde. Excessive levels of environmental air pollution are observed in January, February, October and November, mainly in days of still air or with daily average wind speed of 2–3 km/hr. The analysis of environmental air pollution observations for the years between 1998 and 2004 has shown that an excess over the maximum allowable concentration limit is observed for dust concentrations — from 1.8 times the MAC limit and 28 % recurrence rate during the warm period, to 5.6 times the MAC during the cold period and the recurrence rate of 34 %. These hikes are caused by an increased number of still air days during anticyclonic weather in winter, as well as by an increased volume of air pollutant emissions released by the heat power industry, which contains dust and ashes [4].

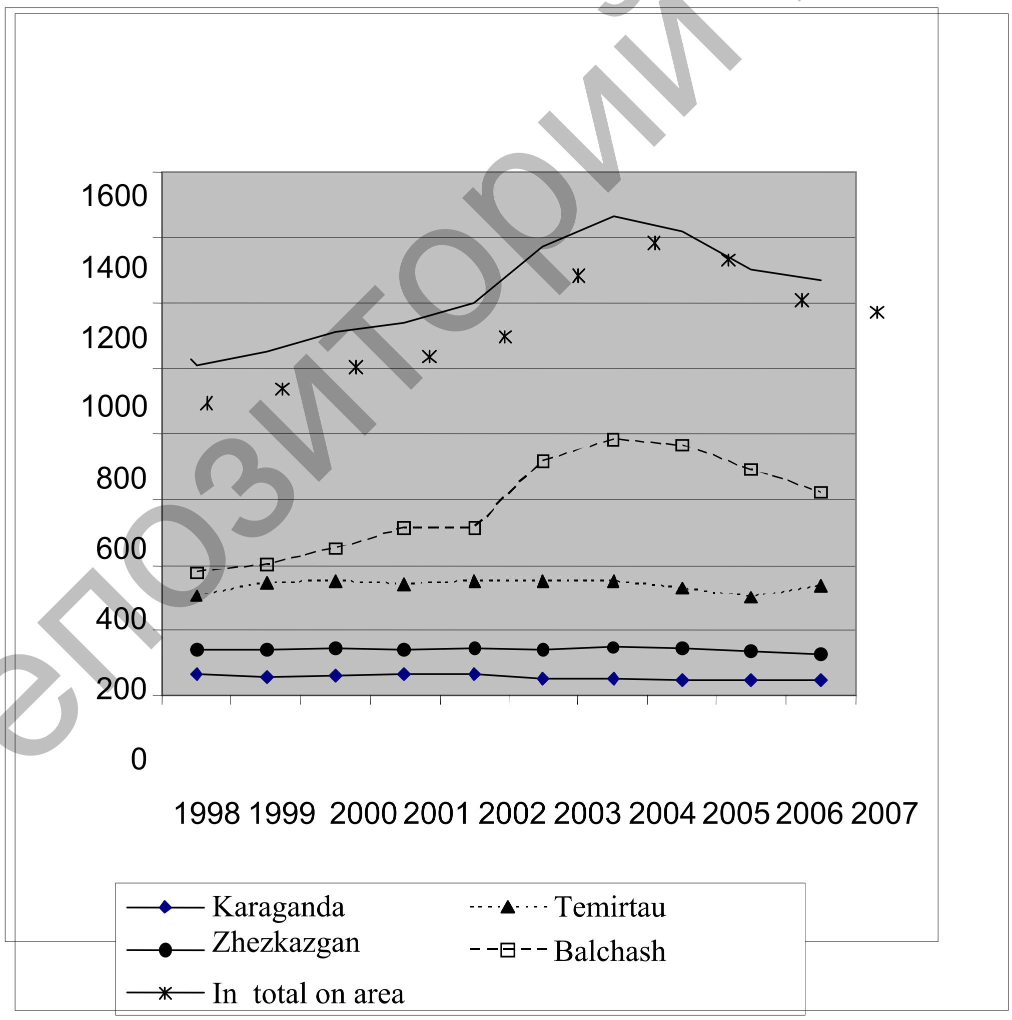

Figure. The Dynamics of Atmospheric Pollutant Emissions in Selected Cities in Central Kazakhstan. (Y: Environmental air pollution, thousand tons; X: Years.)

Conclusions:

1. Natural determinants of environmental air pollution in Central Kazakhstan include synoptic meteorological conditions that can cause an increase in air pollution (stagnant conditions for air masses) as well as a decrease (through wind and precipitation). Background pollution is determined and exacerbated by the process of aridization, which translates into an increase in suspended dust particles in the atmosphere, and by transboundary transfer of air pollution from the territories of bordering countries.
2. Anthropogenic determinants of environmental air pollution in Central Kazakhstan include mining plants, manufacturing industry enterprises, and heat power systems which are considered to be technologically and ecologically the «dirtiest» production processes in the world.
3. The volume of environmental air pollutants released across the Central Kazakhstan has been increasing steadily from approximately 1 million tons to 1.4 million tons between the years 1998 and 2004. Since 2005 there has been a reduction in air pollutant emissions to 1.27 million tons.
4. The most polluted city in the region is Balkhash with 620.7 thousand tons of air pollutants emitted in 2007, of which 43.5 % are released into the atmosphere without the purification procedure.
5. The most widespread anthropogenic air polluting substances in the atmospheric air of the region are the dust, sulphurous anhydride, hydrogen sulphide, carbon oxides, nitrogen oxides, ammonia, phenol and others.
6. On the whole, the natural self-purification process in the atmosphere of Central Kazakhstan promotes dispersion and reduction in the concentration of environmental air pollution.

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