The Issue of transporting pollutants with atmospheric precipitation

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Abstract. A research of the pollution of atmospheric precipitation was conducted. The database of the chemical composition of atmospheric precipitation made by National Monitoring Network of the Republic of Kazakhstan for the period from 2000s to 2011 was generalized and analyzed. The research area covers the big territory of Ile-Balkhash river basin in the South-East Kazakhstan. The research shows that pollutants can be transported over long distances with atmospheric precipitation. Based on the results of the air masses tracking we identified that the main sources of emissions is located in the city of Balkhash.

1. Introduction

At the present stage of development of the Republic of Kazakhstan the positive trend of industry, energy, production of nonferrous and ferrous metals, increasing of resources consuming is observed. At the same time increasing of pollutant emissions to the atmosphere was detected. For example, emissions have increased by several times in comparison with the level of 1950s which leads to heavy pollution of the atmosphere, surface water and soil [1, 2].

In recent years another source of environmental pollution has appeared - atmospheric precipitation. This source of pollutants is not under control and it is quite difficult to take it into account. However, evaluation of its impact is required for analysis, forecast, regulation and quality management of natural environments. In this regard, the assessment of the influence of atmospheric precipitation on the territory of the Ile-Balkhash basin is relevant and has important economic significance.

Many studies have been devoted to the study of transport and deposition of pollutants in the atmosphere [3-10]. A number of works, which deal with spatial and temporal features of the distribution of pollutants in the atmospheric precipitation, is devoted to the research of atmospheric pollution, as one of the individual components of air pollution in the territory of the Republic of Kazakhstan (RK) [11, 12]. The distribution of atmospheric pollution has mostly uneven nature. The concentrations of heavy metals (HM) are located in industrialized advanced regions or in urbanized areas, in addition, and they have a certain downward trend [13-16]. Despite the reduction in the content of HM in atmospheric precipitation over the last decade, the level of air pollution still remains high, and the amount of research is inadequate. At the same time, the research of the chemical composition has other important value. Precipitation contribute to the cleansing of the atmosphere by washing various impurities out of the atmosphere, and their chemical composition is an integral characteristic of pollution of a certain layer of the atmosphere which they have been passed through. In addition, all substances, which have been washed out from the atmosphere, precipitate at various distances from the source of pollution, depending on weather conditions [17-19].
The purpose of the work is to study the qualitative state of the chemical composition of atmospheric precipitation according to data of the Weather Station (WS) located in the Ile-Balkhash basin.

2. Data and research methods
Currently according to the decision of the World Meteorological Organization (WMO) a network of stations to determine trends of global environmental pollution was created. The program of work includes studies of the chemical composition of atmospheric precipitation [20]. In the RK, these obligations are assigned to "KazHydromet", where the monitoring of the state of atmospheric precipitation is conducted, the results of this research are reflected in the newsletters (http://aarhus.kz/ru/1-10/). The chemical composition of atmospheric precipitation for the period of 2000-2011 was analyzed. WS Balkash, Aul-4, Kapshagai, Almaty, Mynzhylky located directly in the Ile-Balkhash basin were selected as the object of the research (figure 1).

![Figure 1. Research area and location of Meteorological station.](image)

Manual on control of air pollution [21] was used to determine the chemical composition of precipitation samples, and The European Monitoring and Evaluation Programme (EMEP) manual - for quality control of the measurements [22]. The methods of estimation of atmospheric pollutions which was used in that research were fully described in [21, 23, 24]. The turbidimetric analysis was used to determine sulfates, titration analysis was used to estimate chloride and alkalinity, photocolorimetry was used to determine ammonium ion and nitrate. Potassium and magnesium ion content was evaluated by atomic absorption analysis, and sodium and potassium ion was determined by flame photometry. Hydrogen ion pH was estimated by using glass electrode; electrical conductivity was evaluated in the cell with electrodes from non-blackened platinum where temperature control at 25°C was used.

These methods of determining pollutants have a number of advantages over other methods. It is one of the easiest methods available for experimental material, the possibility to assess the ways, sources, speed and dynamics of entering of pollutants, to identify the places of their accumulation.

3. Results and discussion
The formation of the chemical composition is a complicated process, in which the important role is played by the weather conditions. Cloud droplets formed as a result of condensation and the process of
coagulation, are determined in their chemical composition by the nature of the condensation nuclei. The life and development of individual droplet or crystal run in an environment characterized by various meteorological variables. The processes of evaporation or condensation of water vapor in the atmosphere can affect the concentration of impurities in the precipitation. Therefore, while studying the process of the formation of precipitation composition, it is necessary to take into account the whole range of weather conditions, from macro-synoptical, determining the transfer of condensation nuclei in the free atmosphere, to the microphysical, causing the onset and development of elements of precipitation [17].

Figure 2(a) shows the diagram of the annual atmospheric precipitation. Their amount varies widely, from 129 to 900 mm·year⁻¹. WS Balkash and WS Aul-4 have the least amount of precipitation (not more than 130 mm·year⁻¹). The biggest amount of precipitation falls at the WS Mynzhylki, more than 900 mm/year falls here. Large differences in the amounts of precipitation are caused by the climatic conditions.

![Graphs and diagrams]

**Figure 2.** Distribution of the average annual amount of precipitation, mm/year (a), wind speed, m/s (b), recurrence of wind directions in Balkash city (c), recurrence of wind directions (Aul-4) (d) for the period 2000-2010 years.

The changes of wind speed is shown in Figure 2b, high wind speeds of 4.4 m·s⁻¹, 2.9 m·s⁻¹, 2.4 m·s⁻¹ are observed at the WS Balkash, WS Aul-4 and WS Kapshagai, respectively. The maximum of speeds occurs during the spring period, so the maximum of 4.9 m·s⁻¹ is reached at the WS Balkash in March. Wind roses at the Balkash and Aul-4 were constructed to identify possible pollutants carryover area (figure 2c, d). It is established that wind of north-east direction was observed most often, their recurrence reaches up to 37%. Thus, based on the local weather conditions, i.e. deficit of precipitation,
high wind speed, recurrence of wind, it can be assumed that the conditions for the transport of pollutants are favorable enough.

In this research [25] the author examined in detail the issues of the impact of pollution from the tailing dump of the Balkhash - Ore-dressing and processing plant, where up to 60 thousand tons of tailing [26] can be carried over in a single dust storm, at the same time researches [27-31] show that pollutants entering the atmosphere spread in it over long distances and the influence of a large industrial city is found at a distance of up to 100-150 km from it in the direction of the wind. Atmospheric precipitations, being a sensitive indicator of air pollution in this work, are used as one of the parameters of the study of the transport of pollutants at the distances, in this regard it is interesting to trace whether the fallout of pollutants is found in distant from the sources, in this case, from Balkhash city. The spatial distribution of pollutants in atmospheric precipitation is shown at the Figure 3. There is a marked increase in the concentration of basic anions over WS Aul-4, where the average values of sulfates can reach 32.29 mg·l⁻¹, of chlorides – 16.25 mg·l⁻¹, nitrates - up to 36.48 mg·l⁻¹. These values are several times smaller in other observation points (figure 3a).

The distribution of the main cations is characterized by high variability (figure 3b). The prevailing cations are presented by ions of ammonium and sodium, there content amounts to 13.8 and 14.94 mg·l⁻¹ at the WS Aul-4 and Mynzhilki, and to a lesser extent by ions of potassium, manganese and calcium with their average concentration of 0.32; 0.44; and 1.2 mg·l⁻¹ respectively. Ions of ammonium and sodium are the main soluble component of the continental aerosol in areas remote from sources of pollution [32]. The predominance of this compound in the precipitation may mean the impact of long-range transport of impurities on the surface of Balkhash lake up to the delta of Ile river, where the Aul-4 station is located. The increase in cations at the Mynzhylki point may indicate the impact of city on air pollution. The polluting impurities penetrate in the vertical direction influencing the physical and chemical processes in the atmosphere.

![Figure 3](image_url)

**Figure 3.** Distribution of long-term concentrations of pollutants: a) Anions; mg/l; b) Cations, mg/l; c) Microelements, µg·l⁻¹; d) Amount of fallout of microelements µg · m⁻².
An important indicator of the quality of atmospheric precipitation is the content of microelements. On the studied territory of Ile-Balkhash basin, precipitation is characterized as polluted with these compounds (figure 3c). The content of cadmium in the city of Balkhash is especially marked. It concentration reaches 3.03 µg·l\(^{-1}\) in Balkash and 1.43 µg·l\(^{-1}\) in Aul-4, with the maximum permissible concentration (MPC) – 1 µg·l\(^{-1}\) [33]. That can worsen quality of soil by getting to the ground as well as natural waters by falling directly to the water body of due to surface runoff. The existing pollution confirms the existence the powerful source of entering pollutants to the atmosphere and transportation of these pollutants to the large distance up to 300 – 400 km.

It was also of scientific interest in the assessment of quantitative fallout of microelements on the underlying surface of the earth. It was revealed that the amount of their fallouts depends on the intensity of precipitation only for copper (correlation coefficient is 0.59). As it shown in Figure 3d copper and lead fall mostly with precipitation. In addition, the center of fallout is characteristic in the Almaty city, where the main factor of pollution is vehicles. Therefore it is not surprising that up to 10.76 mg·m\(^{-2}\) of copper and 4.1 mg·m\(^{-2}\) of lead fall there.

The interrelationship of fallout of heavy metals were calculated, so the correlation coefficients between the metal concentrations were as follows: 0.91 for arsenic and cadmium, 0.98 for copper and arsenic, 0.88 for copper and lead, 0.71 for lead and cadmium, 0.90 for lead and arsenic, which indicates the presence of a single source of incoming of these microelements. Negative correlation coefficients of the amount of precipitation were obtained for copper, lead, arsenic (-0.57,-0.23,-0.49, respectively) between their concentrations in atmospheric precipitations and the amount of precipitation, which may indicate the presence of a slight effect of "dilution and washout".

**Conclusion**

As a result of the study, it was found out that the considered meteorological characteristics, such as water scarcity, high wind speeds, recurrence of wind direction contribute to the transport of pollutants. It was revealed that the impact of pollution of the major metallurgical plant is found at a distance from it of up to 300–400 km, at the WS Aul-4. Also, it was identified that polluting impurities penetrate in the vertical direction to a height of 3 km, the height of location of the WS Myzhylyki. Heavy metals, in particular, cadmium, as a result of the transport, reaches the delta of Ile river, where its concentrations exceed the MPC almost in 1.5 times. It was revealed that the amount of fallout of heavy metals has a weak relationship to the intensity of precipitation; their high correlation dependences indicate the general source of pollutants entering the atmosphere.

Atmospheric precipitation should be considered as another source of pollution of river waters, so the assessment of the impact of atmospheric precipitation on the chemical composition of river waters is relevant and important in assessing the quality of river waters and planning water protection activities and runoff regulation.

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