Chemical composition of atmospheric precipitation in Uzbekistan

Bakhriddin Nishonov, Serik Isabekov, Laylo Saidmakhmudova

Hydrometeorological Research Institute, Tashkent, Uzbekistan. Email: s.isabekov58@gmail.com

Abstract: This article analyzes long-term observational data (2000–2024) collected from 12 hydrometeorological stations in Uzbekistan, focusing on the quantity of atmospheric precipitation, its chemical composition (mineralization, concentrations of anions and cations), and pH (acidity). The average annual pH values of precipitation ranged between 6.2 and 7.2, indicating slightly acidic to neutral conditions, and suggesting the occurrence of acid rain in some regions. The highest mineralization was recorded in Almalyk (188.4 mg/l), Shakhrisabz (157.9 mg/l) and Angren (155.8 mg/l), corresponding to areas with developed industrial sectors. Sulfates (30%), bicarbonates (28%), and calcium (15%) were the dominant ions in precipitation, influenced by both anthropogenic emissions and natural sources such as soil dust and rock weathering. The findings provide insights into the spatial variability of atmospheric pollution across Uzbekistan and highlight the role of both human activities and environmental factors in shaping the chemical composition of precipitation.

[Nishonov B. E., Isabekov S.R, Saidmakhmudova L.A. **Chemical composition of atmospheric precipitation in Uzbekistan**. *Nat Sci* 2025,23(10):10-16]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature 03. doi:10.7537/marsnsj231025.03

Keywords: **A**tmospheric precipitation, chemical composition, anions, cations, pH, Uzbekistan, acid rain, mineralization.

1. Introduction

The Central Asian region is one of the specific areas of Eurasia, distinguished by a unique combination of natural and climatic zones, mainly with a sharply continental climate, an abundance of sunny days, loess soil cover, which is a powerful natural source of soil aerosol entering the atmosphere. The chemical composition of precipitation allows us to judge the degree of integral pollution of the atmosphere in the region under study. Based on the data obtained, it is possible to estimate the range of transfer of pollutants by air masses, and the magnitude of the mass of precipitation of chemical ingredients allows us to identify the contribution of atmospheric precipitation to the pollution of soils and surface waters. Based on long-term measurements of the chemical composition of precipitation, it is possible to detect a trend in changes in the overall level of atmospheric pollution, assess the contribution of individual sources to the formation of precipitation composition in the region under study, and assess the impact of precipitation on the environment: plants, soil, buildings, etc. (Smirnova, et al., 2023). Precipitation chemistry varies globally. Industrialized regions such as North America and Europe have shown progress in reducing acid rain, with lower levels of sulfate and nitrate due to emissions controls (Likens et al., 2019). In Asia, countries such as China and India show high levels of these ions due to rapid industrialization (Tivari et al., 2016; Xinwei Lu., 2018). In Central Asia, including Uzbekistan, studies show that desert dust and agricultural emissions play a large role, with calcium and sulfate often dominating (Jun Xiao, 2016). Uzbekistan, a landlocked country in Central Asia, covers an area of 447,400 square kilometers with a diverse landscape including deserts, mountains, and river valleys. Agriculture is the cornerstone of its economy. This intensive agricultural activity, in particular the use of fertilizers, can affect precipitation chemistry (Behera et al., 2013). Air quality in urban areas such as Tashkent is a concern due to high PM2.5 levels (World Bank, 2021), which may mean that precipitation is transporting more pollutants. However, specific studies of precipitation chemistry in Uzbekistan are limited, and most information is derived from regional trends.

At present, the chemical composition of atmospheric precipitation is the least studied of all natural waters. At present, they are characterized by rapid spatio-temporal changes in their chemical composition. The degree of mineralization of atmospheric precipitation is lower than that of surface and groundwater. They are currently observed in different values at different geographical latitudes (Smirnova, et al., 2023). The main anthropogenic air pollutants in Uzbekistan include sulfur dioxide, nitrogen oxides, carbon monoxide, solid particles of various compositions and origins, and the main sources of pollution are thermal power plants, the construction industry, the mining and chemical industries, the transport complex, etc. 48.4% of the population of the Republic of Uzbekistan live in cities. The location of large urban agglomerations with a high population density and environmentally harmful industries in narrow intermountain depressions, specific natural and climatic conditions that contribute to the accumulation of pollutants in the air, all this has an acute effect on the health of the population (Environmental …, 1993).

The natural geographical and climatic conditions of the regions of Uzbekistan vary, but each region is not composed of regions with identical natural conditions (Kholbaev et al., 2023).

2. Material and Methods

Several analysis methods are used for analysis of physical-chemical characteristics of the atmospheric precipitation. The acidity of precipitation is measured by potentiometric measurement of pH. The amount of ions in precipitation samples – sulfates (SO_4^{2-}) by the turbidimetric method, hydrocarbonats (HCO_3^-) by the titration method, chlorides (Cl^-) by the argentometric method, nitrates (NO_3^-) by the Griess reagent (after reducing in a cadmium column), calcium (Ca^{2+}) and magnesium (Mg^{2+}) by complexometric method, ammonium (NH_4^+) with Nessler reagent, sodium (Na^+) and potassium (K^+) are determined by the atomic absorption method (Semenov, 1977).

3. Results

From a practical point of view, the study of the chemical composition of precipitation and its impact on environmental objects is important for the creation of a sustainable habitat. Determination of various ingredients of rain, snow and ice is important for agricultural purposes. The study examined the amount and chemical composition of precipitation observed at 12 hydrometeorological stations, based on data for the past 22 years (2000-2024) (Yearbooks, 2000-2022). The analysis of the chemical composition of precipitation at the Tashkent Observatory station in Tashkent city, the Angren, Bekobod, Dukent, Almalyk, Tuyabugiz, Chirchik, Chatkal, Yangiyul stations in the Tashkent region, the Fergana station in Fergana city, the Samarkand station in Samarkand city, and the Shakhrisabz station in the Kashkadarya region is carried out mainly on the basis of monthly samples (Fig.1).

The chemical composition of atmospheric precipitation is determined by the following indicators: anions – sulfates (SO_4^{2-}), hydrocarbonats (HCO_3^-), chlorides (Cl^-), nitrates (NO_3^-), cations – calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) and ammonium (NH_4^+).

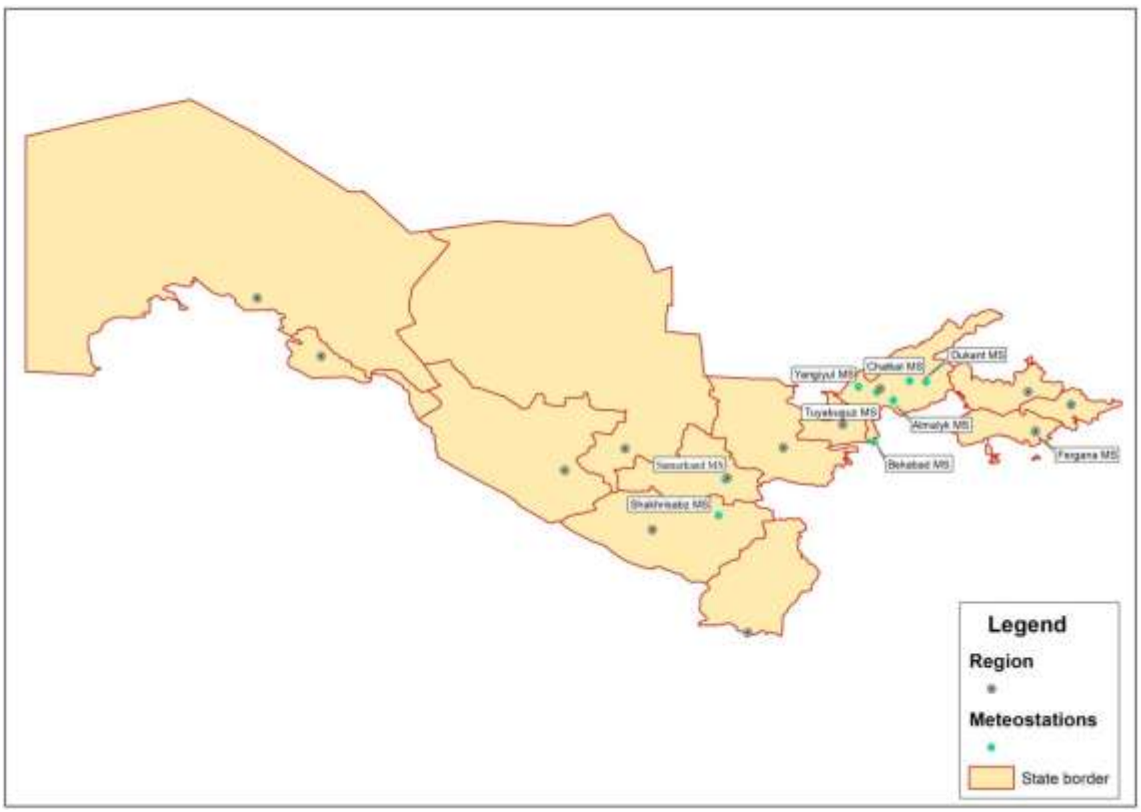
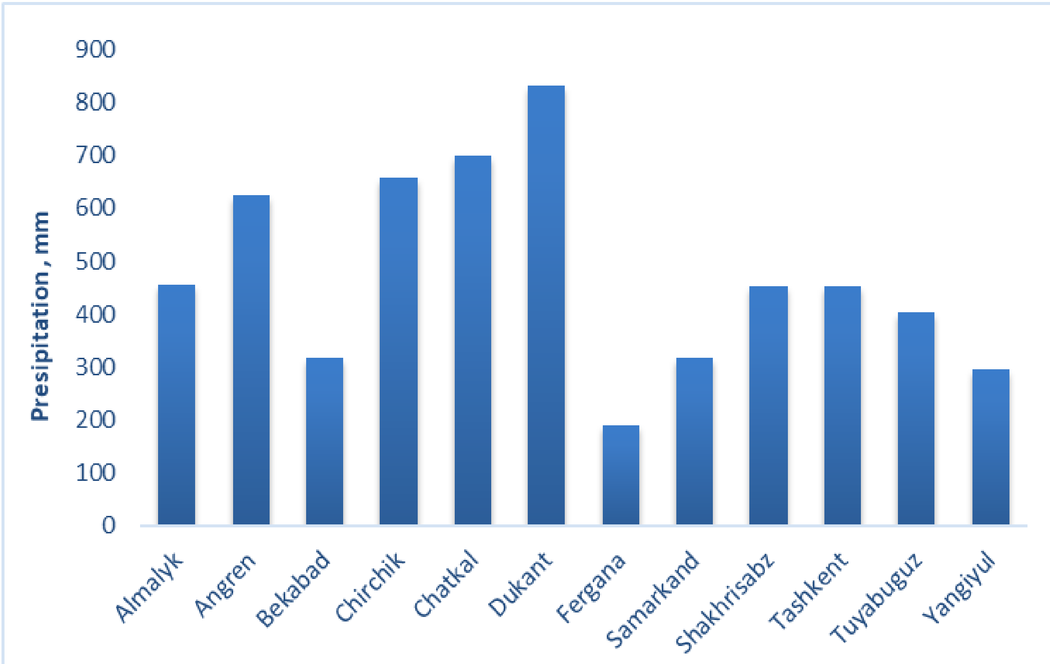
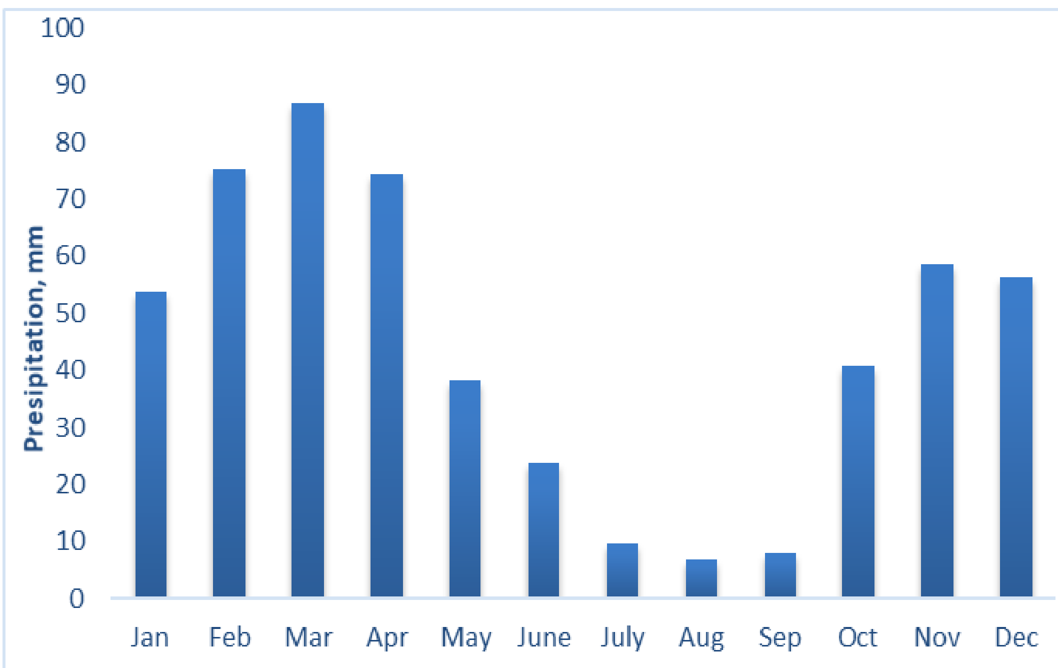


Figure 1. Location of observation points

Precipitation amount. According to the results of the study, the maximum annual amount of precipitation in Uzbekistan for 2000-2024 was observed at the Chatkal station in 2003 (1187.0 mm), and the minimum - at the Fergana station in 2021 (104.0 mm). Also, the greatest amount of precipitation was observed at the Dukent (845 mm), Chatkal (702 mm) and Angren (634 mm) stations located in the Tashkent region. (Fig.2) . Precipitation in Uzbekistan falls mainly in the autumn-winter-spring period and almost does not fall in the summer months.



a)



b)

Figure 2. Long-term changes of precipitation in Uzbekistan (2000-2024) a) by observation stations, b) by months.

Precipitation distribution over the territory ofcountry is rather uneven. In the plain and slightly hillyzones the average annual precipitation in the south andsouth-west is 50 – 150 mm, and in the north – 150 – 200mm. Precipitation fall out mainly as rain, while in themoderately mountainous areas in winter months they arein a form of snow (Khamzaeva et al., 2023).

The average monthly maximum amount at the monitoring stations was observed in March (82.0 mm), and in different years no precipitation was observed at all in June, July, August.

Industrial enterprises are one of the main factors affecting the values of the chemical composition of atmospheric precipitation. The Table 1 presents data on pH and concentration of main anions and cations in precipitation at various meteorological stations in Uzbekistan for the period 2000–2024. This analysis allows to identify spatial and temporal patterns in the chemical composition of precipitation and possible sources of pollution. Average pH values of precipitation fluctuate in the range of 6.2–7.2, indicating a slightly acidic or neutral environment. Minimum pH values (6.2) were recorded in Angren, Almalyk and Chirchik, which may be due to industrial emissions and acid rain. Maximum pH values (7.2) were observed in Bekabad and Chatkal.

Table 1. Long-term changes in the chemical composition of atmospheric precipitation

Stations	pH	Concentration of ions, mg/l									
		Anions				Cations					
		HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	Sum of ions
Angren	6,2± 0,3	38,28± 9,0	62,71± 20,4	6,84± 1,48	14,31± 5,09	25,69± 3,06	7,21± 1,56	3,78± 2,11	2,37± 0,60	0,67± 0,13	155,86±44,63
Bekabad	7,2± 0,1	55,59± 7,7	28,98± 6,68	7,23± 1,80	11,51± 4,53	23,38± 2,80	4,88± 1,14	4,54± 1,52	2,98± 0,41	0,18± 0,09	139,17±26,27
Dukent	6,2± 0,1	16,41± 4,01	7,48± 1,31	3,10± 0,80	3,89 ± 1,99	6,72± 1,58	1,82± 0,32	1,34± 0,40	4,85± 8,67	0,61± 0,12	46,22±19,67
Almalyk	6,3± 0,2	29,85± 10,31	90,92± 29,22	6,17± 2,38	11,73 ±6,30	28,67± 7,01	12,95± 4,80	2,43± 0,82	1,85± 0,43	1,39± 0,34	188,39±62,97
Samarkand	6,7± 0,1	31,49± 5,36	17,79± 4,26	4,31± 0,80	2,87 ± 2,38	11,53± 1,65	3,50± 0,57	1,66± 0,46	1,48± 0,39	0,93± 0,23	75,56±16,31
Tashkent	6,3± 0,1	25,13± 4,49	10,75± 2,21	3,50± 0,85	6,06 ± 1,77	10,43± 1,62	1,95± 0,37	1,79± 0,43	1,13± 0,18	0,82± 0,17	61,56±12,2
Tuyabugiz	6,5± 0,1	30,62± 9,75	44,14± 9,79	5,78± 1,16	20,91 ±13,22	19,46± 2,56	6,88± 1,98	3,87± 0,92	2,35± 0,38	0,32± 0,11	134,33±39,92
Fergana	6,7± 0,1	44,32± 10,30	40,75± 12,36	6,43± 1,74	9,91 ± 3,41	20,88± 3,04	6,37± 1,52	3,32± 1,01	2,74± 0,41	0,99± 0,24	135,71±33,96
Chirchik	6,3± 0,4	18,83± 3,58	11,73± 1,96	3,95± 1,07	5,51 ± 0,94	7,59± 1,29	2,57± 0,97	2,05± 0,62	12,73± 17,09	0,84± 0,18	65,80±28,26
Chatkal	6,9± 0,4	9,92 ±2,28	7,03± 1,41	2,28± 0,70	5,33 ± 1,46	5,91± 1,29	1,48± 0,28	0,76± 0,33	0,43 0,11	0,23± 0,05	33,37±7,78
Shakhrisabz	6,7± 0,1	52,71± 9,42	21,51± 5,12	12,83± 5,84	30,62 ±27,42	18,08± 3,34	5,45± 1,45	11,32± 7,09	4,73± 2,06	0,74± 0,23	157,99±62,45
Yangiyul	6,5± 0,2	30,81± 8,05	38,50± 11,45	7,50± 1,69	12,22 ±3,99	15,45± 2,27	6,19± 1,33	4,14± 1,20	2,30± 0,74	0,75± 0,22	117,86±31,53

Main ions in precipitation. HCO_3^- (hydrocarbonates) - the range of values varies from 9.58 to 57.09 mg/l. The highest concentrations were recorded in Bekabad (57.09 mg/l), Shakhrisabz (53.08 mg/l), and Fergana (41.27 mg/l), which may indicate the influence of dust particles from the soil.

SO_4^{2-} (sulfates) - values range from 7.12 to 93.81 mg/l, with the highest concentrations recorded in Almalyk (93.81 mg/l), Angren (65.61 mg/l), and Tuyabugiz (44.98 mg/l), indicating a significant presence of sulfur compounds, possibly as a result of industrial emissions.

Cl^- (chlorides) - values range from 2.33–13.53 mg/l. High concentrations of chlorides were noted in Shakhrisabz (13.53 mg/l), Yangiyul (7.77 mg/l) and Bekabad (7.41 mg/l), which may also be related to industrial activity.

NO_3^- (nitrates) – range from 2.87 to 30.62 mg/l, with the highest levels recorded in Shakhrisabz (30.62 mg/l) and Tuyabugiz (20.91 mg/l), which may indicate agricultural emissions and pollution from transport.

Ca^{2+} (calcium- fluctuations from 5.87 to 29.06 mg/l, the maximum value was noted in Almalyk (29.06 mg/l), Angren (25.86 mg/l), Bekabad (24.21 mg/l) and

Fergana (20.07 mg/l), which indicates different influences of carbonate sources (soils, construction dust).

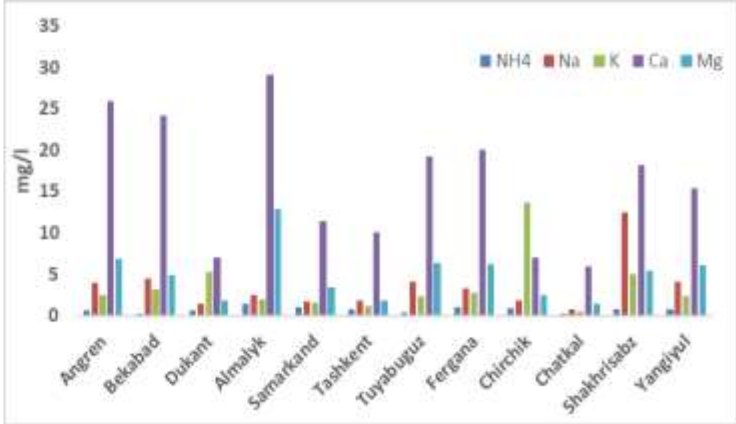
Mg^{2+} (magnesium) - high concentrations are observed in Almalyk (12.83 mg/l), Angren (6.82 mg/l) and Fergana (6.16 mg/l), which is related to the geochemical features of the region.

Na^{+} (sodium) and K^{+} (potassium) - relatively low concentrations (0.42–13.69 mg/l), the highest content in Chirchik (13.69 mg/l) and Shakhrisabz (12.47 mg/l), possibly related to pollution from industrial enterprises.

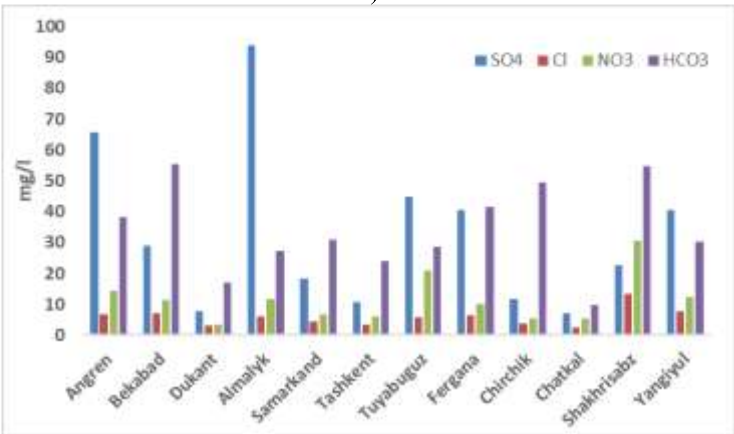
NH_4^{+} (ammonium) – relatively low concentrations from 0.18 to 1.41 mg/l, the highest content is recorded in Almalyk (1.41 mg/l) and Fergana (1.0 mg/l), which indicates a limited influence of agricultural sources.

Mineralization of precipitation (total sum of ionic composition). Precipitation’s mineralization varies from 32.93 to 186.72 mg/l. The highest values were recorded in Almalyk (186.72 mg/l), Angren (164.92 mg/l), and Shakhrisabz (161.86 mg/l), which confirms the high degree of pollution of atmospheric precipitation in large industrial centers. The lowest concentrations were recorded in the mountain stations Chatkal (32.93 mg/l) and Dukent (48.08 mg/l). The main reason for the low mineralization of precipitation at the Chatkal and Dukent stations is the relative remoteness of the observation points from cities and industrial zones.

Regional features and influencing factors. Industrial centers (Almalyk, Angren, Tashkent) have high sulfate and magnesium content, which may be due to emissions from metallurgical and chemical plants. In the Fergana Valley and Yangiyul, increased concentrations of hydrocarbonates and nitrates are observed, indicating the influence of soil particles and agricultural activities. In mountainous areas (Chatkal, Shakhrisabz, Dukent), increased magnesium and calcium content may be due to natural weathering of rocks (Fig.3).



a)



b)

Figure 3. Regional changes in amounts of anions and cations in atmospheric precipitation of Uzbekistan a) cations, b) anions

The pie chart illustrates the long-term average ratio of the main ions contained in atmospheric precipitation of Uzbekistan for 2000–2022 (Fig. 4). It is characterized by the predominance of sulfates (SO_4^{2-}) and hydrocarbonates (HCO_3^-), which account for 30% and 28%, respectively.

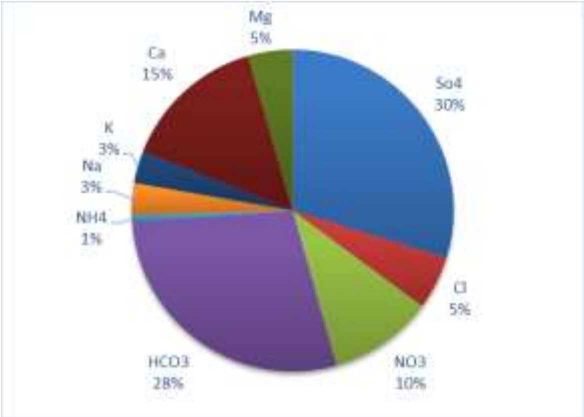


Figure 4. Average long-term ratio of the main ions contained in atmospheric precipitation in Uzbekistan for the period 2000–2022.

The high concentration of sulfates indicates a significant influence of industrial emissions, especially in areas with developed metallurgy and thermal power engineering, such as Almalyk, Angren, and Bekabad Hydrocarbonates, in turn, indicate the influence of soil dust and natural weathering of rocks.

Calcium (Ca^{2+}), which makes up 15% of the total ionic composition. Nitrates (NO_3^-), which account for 10%, are formed under the influence of transport and industrial emissions, and are also partly related to agricultural activities.

Magnesium (Mg^{2+}) in the amount of 5% enters the atmospheric precipitation from soil aerosols and mountain ranges, which is especially typical for the regions of Chatkal, Chirchik and Shakhrisabz.

Chlorides (Cl^-), which make up 5% of the total mass of ions, may indicate industrial emissions. Sodium (Na^+) and potassium (K^+) have approximately equal contents of 3% each, their sources are both soil dust and agricultural activities.

The smallest share falls on ammonium (NH_4^+) - only 1%, which indicates a weak influence of the agricultural sector on the chemical composition of precipitation. In general, the analysis shows that precipitation in Uzbekistan is formed under the combined influence of industrial emissions, soil erosion and natural geochemical processes. The high proportion of sulfates and nitrates indicates the presence of acid rain in certain regions, while the significant content of hydrocarbonates and calcium confirms the influence of an arid climate and dust storms.

Conclusions

1. In Uzbekistan, the chemical composition of precipitation varies across regions, with high levels of sulfates and nitrates in industrial areas.
2. Precipitation in Uzbekistan has a pronounced seasonal pattern, with peaks in spring and autumn and lows in summer.
3. The pH of precipitation also varies seasonally, with acidic values during periods of intense precipitation and more alkaline values during drier months.
4. The observed relationship between precipitation and pH suggests the possible influence of atmospheric pollutants, requiring further analysis of the chemical composition of precipitation.
5. Regional differences in precipitation composition indicate the influence of both natural and anthropogenic factors, including industry, agriculture, and soil dust.

Corresponding Author:
Serik Isabekov, PhD student
Water Quality and Stable Isotope Laboratory
Hydrometeorological Research Institute,
72, 1st Bodomzor yuli str., 100052,
Tashkent, Uzbekistan.
Telephone: +99893-531-58-58
E-mail: s.isabekov58@gmail.com

References

1. Smirnova T., Tolkacheva G. On the chemical composition of atmospheric precipitation collected in the Tashkent region // Ecological Bulletin. 2003 pp. 20-25.
2. Kholbaev G, Egamberdiev Kh, Eshmirzaev B. The Monitoring of Changes in Meteorological Quantities in Different Periods Nat Sci 2023,23(6):51-58].ISSN1545-0740(print); ISSN2375-7167(online). http://www.sciencepub.net/nature07. doi:10.7537/marsnsj210623.07.
3. Adenbaev B.E., Khakimova Z.F., Mirkholikova M.M. Hydrochemistry. - Tashkent: Info capital books, 2022. - 41 p.
4. Environmental Protection and Use of Natural Resources of the Republic of Uzbekistan: Report. - Tashkent: Ukituvchi, 1993.
5. Guide to Chemical Analysis of Surface Waters of Land / Ed. A.D. Semenov. - L.: Gidrometeoizdat, 1977. - 542 p.
6. Behera S.N., Sharma M., Aneja V.P., Balasubramanian R. Atmospheric ammonia: A review of existing detection methods // Environmental Sciences and Pollution Research. -

2013. - https://link.springer.com/ article/10.1007/s11356-013-1741-7.

7. Li Y., Zhang Qu, Ma L. et al. Chemical composition and source identification of rainwater constituents at an urban site in Xi'an // Environmental Earth Sciences. - 2016. - https://link.springer.com/article/10.1007/ s12665-015-4997-z.
8. Likens GE, Driscoll CT, Buso DC, et al. Long-term changes in precipitation and surface water chemistry in the Hubbard Brook Experimental Forest, New Hampshire, USA. Environmental Science and Technology. 2019. https://pubs.acs.org/doi/10.1021/acs.est.8b05827
9. Tiwari S., Srivastava M.K., Bisht D.S. et al. Long-term observations of aerosol composition and sources during winter haze in Delhi // Atmospheric Environment. - 2016. - https://www.sciencedirect.com/science/ article/pii/S136468261630013X.
10. World Bank. Air Quality Assessment for Tashkent and Roadmap to Improve Air Quality Management in Uzbekistan. - 2021. - https://www.worldbank.org/en/country/ uzbekistan/publication/air-quality-assessment-for-tashkent.
11. Xinwei Lua, Loretta Y. Lib, Nan Li. at al. Chemical characteristics of spring rainwater of Xi'an city, NW China // Atmospheric Environment. – 2011. – https://doi.org/ 10.1016/j.atmosenv.2011.06.026

Khamzaeva J.T,, Sagdeev N.Z., Adenbaev B.E. Precipitation as flow-formation factor in Amudarya // Nat Sci 2023;21(10):25-41]. ISSN 1545-0740 (print);ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 05. doi:10.7537/marsnsj211023.05.

9/24/2025