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Shodmonova Sarvinozkhon Gani qizi *– PhD student*
sarvinozxonshodmonova@gmail.com
Alimov Zikrilla Bobamuratovich *DSc., doctor of technical science.*
zikrillamov@mail.ru
Research Institute of Environment and Nature Conservation Technologies, Green University

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CHARGED PARTICLES IN ATMOSPHERIC AIR: SIGNIFICANCE, PROPERTIES, AND IMPLICATIONS

Abstract: The study of charged particles, or ions, in atmospheric air is of paramount importance in contemporary atmospheric science. These charged particles play a crucial role in various atmospheric processes, influencing cloud formation, precipitation patterns, and even the propagation of lightning. Understanding their properties and interactions is essential for gaining insights into weather phenomena, climate change dynamics, and strategies for mitigating environmental impacts. Charged particles also have significant implications for human activities, technological systems, and public health, making it imperative to examine their effects comprehensively. Moreover, exploring the realm of charged particles in atmospheric air offers opportunities for scientific advancements, providing valuable insights into the Earth's electrical environment and its relationship with solar and cosmic radiation. This manuscript delves into the complexities of charged particles in atmospheric air, highlighting their significance in advancing atmospheric science, weather prediction, climate change mitigation, technological innovations, and public health preservation.

Keywords: atmospheric air, particulate matter, charged particles, ions, ion chromatography, environmental impacts, human health, air quality.

1. Introduction

While numerous scholars have proposed approaches to analyze the pollution caused by high concentrations of $PM_{2.5}$ from various perspectives, the precise details and underlying theory of the particulate explosive growth process remain ambiguous and inadequately explained. Although secondary reactions may play a role in the increased growth of particle number concentration [1], the rapid pace of chemical reactions complicates the development of a coherent theory. During the onset of severe haze conditions, the phenomenon of explosive growth in PM2.5 concentration likely involves a series of intricate physical-chemical processes, where charged particles exert a significant influence. The presence of charges and ions on particle surfaces can impact the collision and coagulation behavior of particles, as well as subsequent chemical reactions occurring within the porous surfaces of the particles [2].

Aerosols, regardless of their form (solid, air, or liquid), including cloud aerosols, fog aerosols, and smog aerosols, are typically electrically charged, whether naturally occurring or of artificial origin [3]. Various natural and artificial factors can lead to the charging of aerosol particles, such as cosmic rays in space, radiation emitted by radioactive materials in the atmosphere and on the Earth's surface, atmospheric lightning, electromagnetic radiation, high-temperature discharges, and static electricity generated by particle collisions [4].

The seemingly simple composition of atmospheric air belies a hidden complexity illuminated by the presence of charged particles. In today's world, understanding these charged particles, commonly referred to as ions, holds paramount importance for several compelling reasons [5].

Primarily, charged particles play a pivotal role in a myriad of atmospheric processes. They influence cloud formation dynamics, precipitation patterns, and even the propagation of lightning [6]. Furthermore, their presence contributes to air quality concerns, necessitating a comprehensive study of their interactions. Such investigations offer insights into weather phenomena, climate change dynamics, and potential strategies for mitigating its impacts.

Additionally, charged particles interact significantly with human activities and technological systems [7]. Their influence extends to the performance of electronic devices, communication systems, and can pose health risks in enclosed spaces. Thorough examination of these interactions is essential for maintaining the functionality of critical infrastructure and safeguarding public health.

Moreover, delving into the realm of charged particles in atmospheric air unveils avenues for exciting scientific advancements [8]. They provide a unique window into the Earth's electrical environment and its intricate interplay with solar and cosmic radiation. Understanding these interactions not only enriches our understanding of atmospheric dynamics but also sheds light on space weather phenomena [9].

In essence, the investigation of charged particles in atmospheric air transcends academic curiosity. It carries profound implications for understanding and predicting weather patterns, mitigating the impacts of climate change, fostering technological innovations, and preserving public health. This research endeavors to unravel the complexities of these charged particles, illuminating their significance in the contemporary world [10].

2.1. Methods and materials

2. Properties and Significance of Studying of Charged Particles in Atmospheric Air

Charged particles, also known as ions, constitute a captivating and indispensable element of atmospheric composition. These particles bear an electrical charge, acquired through the gain or loss of electrons, and their properties play a fundamental role in shaping various atmospheric processes and phenomena.

Atmospheric ions manifest as either positive (cations) or negative (anions) entities. Positive ions typically derive from nitrogen and oxygen molecules, while negative ions often comprise oxygen molecules with attached electrons or other molecules such as water vapor and carbon dioxide [11].

Compared to typical neutral gas molecules, atmospheric ions exhibit larger dimensions, ranging from a few nanometers to tens of nanometers. Their concentration varies with geographical location, altitude, and prevailing weather conditions, with higher concentrations observed closer to the Earth's surface and diminishing with altitude. Influential factors like sunlight, pollution, and atmospheric disturbances such as thunderstorms significantly impact ion concentrations [12].

Charged particles display mobility, enabling them to traverse through the atmosphere under the influence of electric fields. This mobility, coupled with ion concentration, determines the electrical conductivity of the atmosphere, a critical factor in atmospheric electricity phenomena and the formation of lightning discharges [13].

Atmospheric ions actively engage with other components within the atmosphere. Through collisions with neutral gas molecules, they transfer momentum and heat, contributing to atmospheric dynamics. Moreover, they partake in chemical reactions, exerting influence on the formation of atmospheric aerosols and cloud condensation nuclei [14].

Weather and Climate Prediction: Insights into ion concentration and mobility aid in forecasting cloud formation processes and precipitation patterns, thereby enhancing weather prediction models and informing assessments of climate change impacts.

Air Quality Monitoring: Knowledge of the interactions between charged particles and pollutants enables the development of more accurate methods for monitoring and assessing air quality levels, crucial for safeguarding public health and environmental well-being.

Technological Impacts: Awareness of the effects of atmospheric ions on electronic devices and communication systems is vital for devising strategies to mitigate potential disruptions and optimize technological performance in various sectors [15].

2.2. Toxicity of Charged Particles in Atmospheric Air: Environmental and Human Health Perspectives.

While charged particles, or ions, play pivotal roles in various atmospheric processes, their direct toxicity remains a subject of ongoing research. Here's a breakdown of the current understanding and potential concerns:

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Limited Direct Toxicity:
• In general, charged particles are not considered highly toxic in the short term at typical atmospheric concentrations, primarily due to their large size, which limits their ability to penetrate deep into the respiratory system [15].
• However, interactions between charged particles and other atmospheric components can pose concerns. For instance, they may attach to pollutants and allergens, potentially enhancing their penetration into the lungs and causing irritation [16].
Environmental Concerns:
• Charged particles can influence the formation of atmospheric aerosols—tiny suspended particles in the air. These aerosols have significant implications for climate, as they can reflect sunlight and influence cloud formation. Moreover, certain aerosols can adversely affect air quality [17].
• Interactions between ions and atmospheric components, particularly nitrogen oxides, can contribute to the formation of ground-level ozone. Elevated ozone levels have detrimental effects on both plant life and human health, leading to respiratory issues [18].
Human Health Concerns:
• While direct toxicity is limited, studies suggest potential associations between exposure to high concentrations of charged particles and respiratory problems, particularly among individuals with pre-existing conditions like asthma [9].
• Some research indicates a correlation between exposure to specific types of charged particles and mood changes or headaches. However, further investigation is necessary to establish a causal relationship [10].
Uncertainties and Ongoing Research:
The long-term health effects of chronic exposure to charged particles in atmospheric air remain uncertain. Furthermore, the types and concentrations of ions can vary significantly depending on location and environmental factors. Therefore, more research is imperative to comprehend the intricate interactions between charged particles, air quality, and human health.

2.3. Study area and sampling location

The particle number have been measured in Tashkent, Surkhandarya and Nukus during 2021/08/017-09/15 (Figure 1). Study area and sampling location Tashkent is the most populous city in Uzbekistan with approximately 2.5 million inhabitants. Tashkent is warm continental climate in the arid region [11]. Measurements were made on the second floor of Uzbek-Japan Innovation Center of Youth at Tashkent State Technical University. This site is located in a high-density Student City in Uzbekistan and 200 m from road traffic. Methane gas (Natural gas) is used by main parts of transports. Natural gas is the primary fuels for domestic and small building heating in Tashkent. Many large buildings used central heating systems of Tashkent. Moreover, wood and coal are actively used by residential and food industry. The second study area (Surkhandarya) is a rural area with low-density inhabitants. Surkhandarya is located in the cold-semi-arid climate. The sampling devices were set on the rooftop of one-floor building in residential area. Tashkent is warm continental climate in the arid region [11]. This site is located in a low-density residential area of Oltinsoy and 500 m from rural field. Methane gas (Natural gas) is used by main parts of transports. Wood, coal and propane gas are the primary fuels for domestic heating in Tashkent.
The third Study area (Nukus) is urban city in Uzbekistan a low density with approximately 0.5 million inhabitants. The climate of Nukus is cold desert climate [11]. The sampling devices were set on the second floor of Karakalpak State University. This site is located in Nukus City and 300 m from road traffic. Methane gas (Natural gas) is used by main parts of transports in Nukus. Natural gas is the primary fuels for domestic and small building heating. Many large buildings used central heating systems of Nukus. Moreover, wood and coal are actively used by household and food industry. Nukus is surrounded by three deserts, Kyzyl-Kum, Kara-Kum and White-Kum (Aral-Kum).

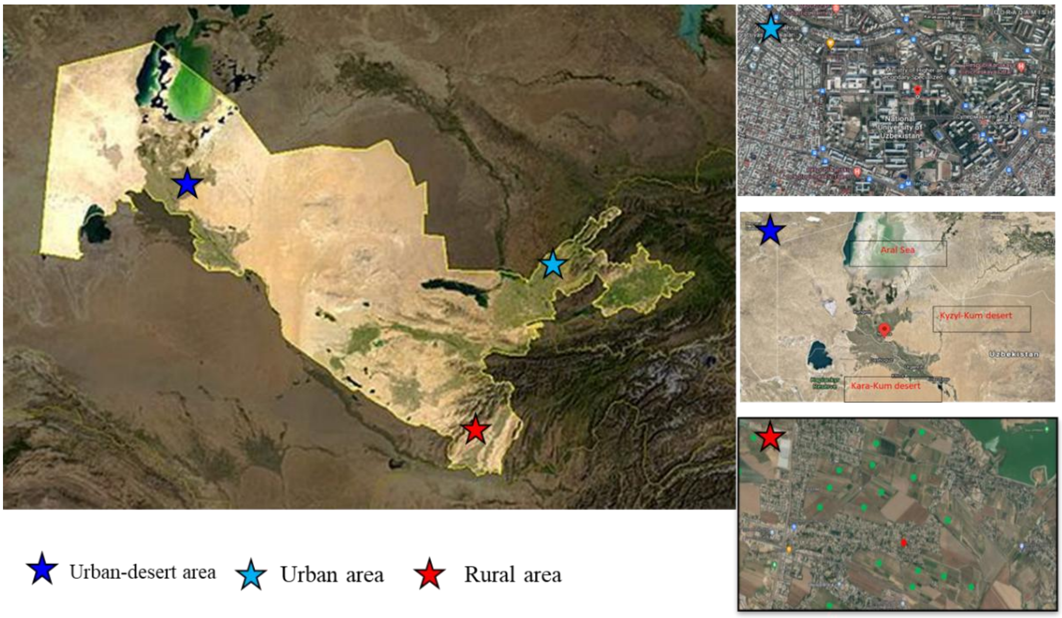

Figure 1 The locations of sampling sites. Source: google.map.com

2.4. Collection Samples of TSP and $PM_{2.5}$

Three TSP as well as three $PM_{2.5}$ samples were simultaneously collected using the SilVy-5 [12]. TSP and $PM_{2.5}$ were collected on PTFE and QR-100 filters. I used impactors by placing a donut filter (QR-100) between the nozzle plate and impaction plate to collect particles larger than 2.5 μm, which let $PM_{2.5}$ particles be collected on the sampling filters.

The samples have been collected in Tashkent during 2021/08/19-21, 2021/08/31-09/03 and 2021/09/15-18, Oltinsoy (Surkhandarya) during 2021/08/24-30 and Nukus during 2021/09/08-13. Samples have been collected using PTFE and QR-100 for 48 and 72 hours. The air flows rate was fixed 12.8~16.8 L/min through each impactor.

Mass concentration was determined by following the official method (JIS Z 8851:2008). $PM_{2.5}$ and TSP were calculated through weighing PTFE filters before and after sampling. Weighing was carried out by electric balance Sartorius (resolution d=0.1 mg) in room temperature 25±3°C, and relative humidity below 30%**.** Also, the atmospheric concentrations of $PM_{2.5}$ were measured periodically using $PM_{2.5}$ Tester (PMT-2500).

2.5. Water-Soluble Ion Analysis

One-third of the filter sample was cut and extracted using ultra-pure water. The sample solution was analyzed using an ion chromatography (IC) system (Dionex AS-AP, ICS-2100 and ICS-1100, Thermo Fisher Scientific Inc., USA) for anion species (Cl^-, NO_3^-, SO_4^{2-}) and cation species (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}). Chromeleon Chromatography Data System version 7.2 was used to analyze the chromatogram. Previously examined CRM#28 (Urban Aerosols, NIES, National Institute for Environmental Studies Onogawa, Tsukuba, Japan) was used as a reference material to check the accuracy of the analysis. The limit of detection (LOD) for Cl^-, NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+} was 750, 6200, 4437, 323, 260, 154, 229, and 463 µg/g, respectively; the LOD value was calculated with standard deviation multiplied by eight of the replication analyses of standard solution. The precision (coefficient of variation) for five times repetition analysis of standard solution was less than 8.6%.

3. Results and discussion

3.1. Water-soluble ion analysis using ion chromatography

Figures 2 and 3 shows the mass concentration of ion compounds determined using Ion chromatography in the $PM_{2.5}$ and TSP filter samples collected using SilVy-5 in Uzbekistan from August to September 2021.

The concentration of NO_3^-, SO_4^{2-} and Ca^{2+} were found higher than 1.0 μg/m³. The other ion components represented less than 1.0 μg/m³, excluding the concentration of Cl^- in the Nukus #2 sample.

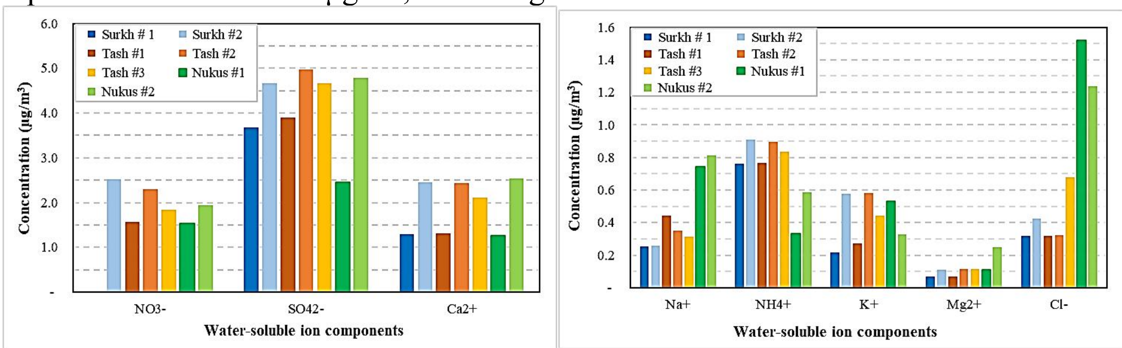

Figure 2. Mass concentration of water-soluble ion components in the $PM_{2.5}$ samples collected in Uzbekistan.

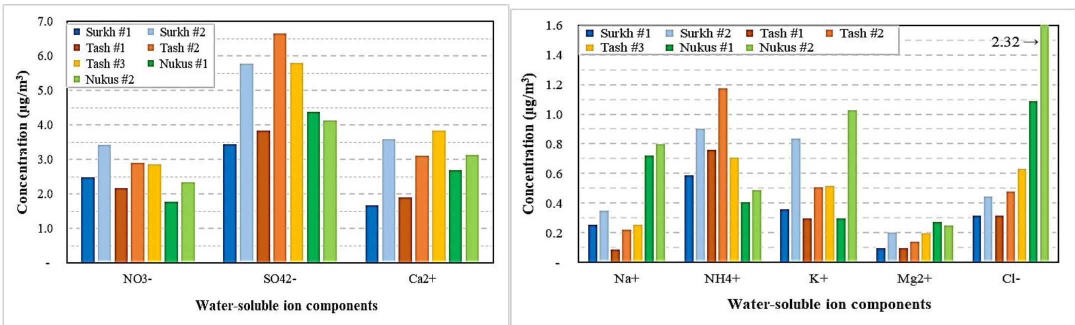

Figure 3. Mass concentration of water-soluble ion components in the TSP samples collected in Uzbekistan.

Surkhandarya was interpreted as a rural area because high concentrations were found for a crustal element such as Ca and components of agriculture chemicals, e.g., NH_4^+, K^+, NO_3^- and SO_4^{2-}. This sampling site is covered by mainly grape fields and the households around the sampling site are engaged in gardening, vegetables, melon crops. Because of the hot climate, chemicals such as pesticides and fungicides against insect pests, viruses, and bacteria are widely used. An unexpected high concentration of SO_4^{2-} in the rural area is generated due to using lime sulfur ($3Ca(OH)_2 + 6S \rightarrow 2CaS_2 + CaS_2O_3 + 3H_2O$) and Copper(II) sulfate ($CuSO_4 \cdot 5H_2O$) in grape growing [13]. Moreover, stimulants containing potassium and nitrogen are actively used in vegetables and melon crops. Therefore, the soil in the sampling site was enriched with the compounds of sulfur, potassium, and nitrogen.

The ion components of combustion sources such as NH_4^+, NO_3^- and SO_4^{2-} were determined with higher concentrations at the Tashkent sampling site than at other sites. The high concentration of sodium and potassium is elevated by crustal and combustion. The extracted natural gas and oil in Uzbekistan are richer in sulfur, therefore, the request for sulfur concentration in the product is higher than in developed countries [14].

Nukus is highly specific for chlorine and sodium, and also, calcium and potassium were found with higher concentrations at this site. The components are mainly generated by the dried Aral Sea because Nukus is the nearest city to the dried Aral Sea, about 150 km. The soils in Nukus and its around have been enriched over the past 50 years, which is a period of active drainage of the Aral Sea [15,16].

4. Summary

The samples of $PM_{2.5}$ and TSP from Tashkent (Urban area), Surkhandarya (Rural area) and Nukus (Urban and Desert area) in Uzbekistan were collected to investigate the impacts of pollutant emission on plants and living organisms, and particle behaviors and characteristics.

Surkhandarya was interpreted as a rural area because high concentrations were found for a crustal element such as Ca^{2+} and components of agriculture chemicals, e.g., NH_4^+, K^+, NO_3^- and SO_4^{2-}. The ion components of combustion sources such as NH_4^+, NO_3^- and SO_4^{2-} were determined with higher concentrations at the Tashkent sampling site than at other sites. Nukus is highly specific for chlorine and sodium, and calcium and potassium were found with higher concentrations at this site.

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