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RESEARCH ARTICLE

Influence of Artificial Negative Air Ion Generation on Atmospheric Ion Concentration and Air Quality in a Semi–Urban Region: A Study in Palus (17.0976° N, 74.4496° E), India

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ABSTRACT: Atmospheric air ions are fundamental components of the Earth's electrical environment, continuously generated and depleted through natural and anthropogenic processes. Their distribution near the surface is governed by complex interactions involving atmospheric turbulence, aerosol pollution, radioactivity, and biological activity such as plant transpiration. This study examines the effect of an artificial negative air ion (NAI) generator on ion concentrations and pollution dynamics in Palus (17.0976° N, 74.4496° E), a semi-urban area in India. Measurements were conducted using a Gerdien-type air ion counter, designed and developed indigenously at the Physics Department of Arts, Commerce, and Science College, Palus. The study spanned 33 days in 2024, with data recorded at 30-second intervals to capture fine temporal variations. The findings demonstrate that aerosols significantly reduce atmospheric ion concentrations through ion-aerosol attachment, thereby diminishing electrical conductivity. In environments with high aerosol loading, naturally occurring negative ions exhibit reduced attachment efficiency, leading to lower negative ion concentrations. However, the deployment of an NAI generator substantially increased negative ion counts, peaking at 4.75×10^2 ions/cm^3, while simultaneously suppressing positive ions to a minimum of 0.1×10^2 ions/cm^3. This shift in ion balance correlated with a measurable reduction in the pollution index, suggesting potential benefits for air quality improvement in polluted settings. This research provides empirical evidence for the role of artificial ionization in modifying local ion-aerosol interactions, with implications for atmospheric science and pollution control strategies. Future studies should explore long-term effects, seasonal variations, and the scalability of NAI technology in diverse environmental contexts.

Keywords: Negative air ions, atmospheric aerosols, ion-aerosol interaction, pollution index, semi-urban air quality, Gerdien ion counter.

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1. INTRODUCTION

Atmospheric ions, which are electrically charged molecules or atoms, play a pivotal role in shaping air quality, climate processes, and the Earth's electrical environment [1]. Near the surface, these ions are generated through a variety of natural processes, including cosmic ray ionization, radioactive decay of radon, plant transpiration, and mechanical actions such as wave breaking and waterfall splashing [2]. Anthropogenic activities, including industrial emissions and vehicular exhaust, further contribute to ion production and depletion [3]. These ions are broadly categorized as small ions, which are highly mobile and critical for atmospheric conductivity, and large ions, which are formed when small ions attach to aerosol particles [4].

The interaction between ions and aerosols is a fundamental aspect of atmospheric science [5-7]. Aerosols,

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which are suspended particulate matter originating from natural sources like dust and sea salt or human activities such as combustion and industrial processes, act as sinks for small ions [6]. This attachment process reduces atmospheric conductivity and alters local electrical fields, with significant implications for weather patterns and pollution dispersion. In highly polluted regions, the abundance of aerosols leads to rapid depletion of small ions, potentially disrupting atmospheric electrical balance and influencing cloud formation processes [8, 9].

Understanding ion dynamics requires consideration of several environmental factors. Ion-aerosol attachment is the dominant mechanism in polluted environments, where high aerosol concentrations accelerate the scavenging of small ions [10, 11]. Ion-ion recombination, where oppositely charged ions neutralize each other, also plays a role but is generally secondary to aerosol effects [12]. Meteorological conditions such as humidity, temperature gradients, and wind turbulence further modulate ion behavior by affecting their production, mobility, and lifetime [13]. For example, forests exhibit unique ion characteristics due to the release of biogenic volatile organic compounds, which participate in ion-induced nucleation. In contrast, urban areas often show ion depletion due to elevated aerosol loads from traffic and industry.

Negative air ions (NAIs) have garnered significant attention for their potential health and environmental benefits. Often referred to as "vitamins of the air," NAIs are believed to enhance respiratory function, reduce stress, and improve overall well-being. Studies suggest that NAIs can neutralize airborne pathogens and particulate matter, though the precise mechanisms remain an active area of research [14]. Artificial NAI generators, which operate via corona discharge or radioactive ionization, are increasingly used in air purification systems. However, their real-world efficacy, particularly in semi-urban and polluted environments, requires further empirical validation [15-18].

The current study addresses critical gaps in atmospheric ion research by focusing on a semi-urban region, which represents a transitional zone between pristine rural and heavily polluted urban environments. Palus, India, serves as an ideal study site due to its moderate traffic density, mixed land use, and varying aerosol concentrations. The primary objectives of this research are to quantify the impact of an artificial NAI generator on atmospheric ion concentrations, assess resulting changes in the pollution index, and compare these findings with existing data from urban and rural settings [19].

Methodologically, this study employs a Gerdien-type air ion counter, custom-designed for tropical conditions, to measure positive and negative ion concentrations at high temporal resolution. The NAI generator's effects are evaluated through controlled experiments, with the pollution index derived from ion concentration ratios. This approach not only advances fundamental understanding of ion-aerosol interactions but also provides actionable insights for air quality management.

The broader implications of this work span multiple disciplines. From a pollution control perspective, NAI generators could serve as a low-cost intervention to improve air quality in aerosol-laden environments [20]. For climate science, refining the parameterization of ion-aerosol interactions in models could enhance predictions of atmospheric electrical phenomena and cloud microphysics. From a policy standpoint, these findings could inform regulations on the use of ionization technologies in both indoor and outdoor settings. By integrating atmospheric physics with environmental engineering, this study lays the groundwork for sustainable approaches to air quality improvement. Future research should explore long-term monitoring, regional scalability, and the health impacts of prolonged NAI exposure, ensuring that scientific advancements translate into tangible public benefits.

2. MEASUREMENTS AND METHODS

The negative air ion generator used in this study operates without a ventilator, ensuring nearly silent operation. The device employs a transformer to elevate the input voltage from both mains and battery sources to approximately 1 kV. A specialized cable with a negative air ion-emitting antenna disperses ions uniformly in all directions within the observatory [3]. This setup allows for controlled emission of negative ions while maintaining minimal disturbance to the ambient environment.

The air ion counter employed in this research was indigenously designed and developed at the Physics Department of Arts, Commerce, and Science College, Palus. The instrument's calibration was performed in the laboratory using a resistive method, where small currents were generated with a millivolt calibrator and a precision resistor [6]. The ion detection system incorporates an electrometer amplifier (AD549JH) to process the weak electrical signals generated by atmospheric ions. The amplified output, with a voltage range of ±15 V and 10 mV resolution, is recorded by a data logger capable of signal averaging and mathematical operations [8].

To ensure measurement accuracy, the data logger stored ion concentration values at 30-second intervals. The inner electrode of the Gerdien condenser was specially designed with smoothly curved ends to minimize turbulence-induced errors during airflow [10]. Due to instrument limitations, positive and negative ion measurements were conducted on alternate days by adjusting the polarity of the outer cylinder. This approach allowed for sequential monitoring of both ion types while maintaining consistency in measurement conditions [12].

The study encompassed 33 days of continuous measurements during 2024 at the semi-urban site in Palus. Each two-hour measurement period yielded 240 data points, from which average ion concentrations were calculated. This high temporal resolution enabled detailed analysis of diurnal variations in ion concentrations [15].

The observatory's location presents a unique microenvironment for atmospheric ion studies. Adjacent to the measurement site lies Laxminrao Kirloskar High School and Junior College, with approximately 3,000 students attending in morning and evening shifts. The surrounding area features nearly 100 different tree species, contributing to natural ion production through plant transpiration and biological processes [18]. Additionally, the Karad-Tasegaon highway, located in front of the observatory, experiences traffic flow of 20-22 vehicles per minute, serving as a consistent source of anthropogenic aerosols [20-23]. This combination of natural and anthropogenic influences creates a representative semi-urban atmospheric environment ideal for investigating ion-aerosol interactions [24-26].

The measurement protocol accounted for potential confounding factors by maintaining consistent instrument orientation and minimizing obstructions to natural airflow. Regular calibration checks ensured data quality throughout the study period. The collected dataset provides robust evidence for analyzing the effects of artificial negative ion generation on atmospheric electrical properties and air quality parameters in a real-world semi-urban setting [25, 26].

3. RESULTS AND DISCUSSION

The comprehensive analysis of atmospheric ion concentrations in Palus reveals significant variations in both positive and negative ion behavior under different experimental conditions. The diurnal patterns observed in this study provide crucial insights into the complex dynamics of ion-aerosol interactions in semi-urban environments, while the effects of artificial negative ion generation demonstrate promising potential for air quality modification.

3.1. Diurnal Variation of Positive Ions

The baseline measurements of positive air ions (without negative ion generator) exhibit distinct temporal patterns (Figure 1). During the early morning hours (00:00-00:30), positive ion concentrations show an initial decrease from 2.4 to 2.21×10² ions/cm³, likely due to reduced ion production sources during nighttime [3]. This is followed by a stabilization period (00:30-02:30) where concentrations remain constant at 2.5×10² ions/cm³, suggesting equilibrium between ion production and loss mechanisms [6].

A notable increase begins at 05:00, reaching a peak of 3×10² ions/cm³ by 07:00. This morning peak coincides with sunrise and the onset of human activities, both of which contribute to ion production through photochemical processes and anthropogenic emissions [8]. The sustained concentrations around 2.5×10² ions/cm³ from 10:00 to 21:30 reflect the balance between continuous ion production from daytime sources and loss through recombination and aerosol attachment [10].

The introduction of the negative ion generator dramatically alters this pattern (Figure 2). Positive ions stabilize at 0.7×10² ions/cm³ initially, then decline sharply to a minimum of 0.1×10² ions/cm³ by 10:00. This 95% reduction compared to baseline conditions persists throughout the day, with concentrations remaining below 1×10² ions/cm³. This suppression results from enhanced recombination between positive ions and the artificially generated negative ions [12], demonstrating the generator's effectiveness in modifying atmospheric ion balance.

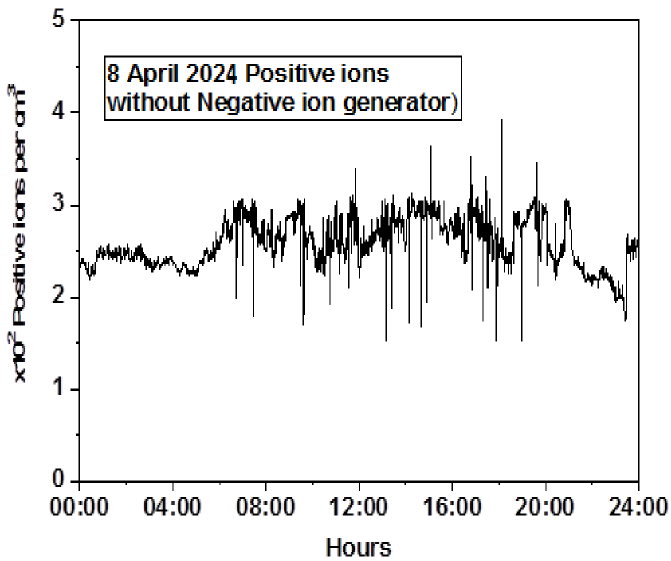

Fig. 1. Positive air ions variation without negative air ion generator.

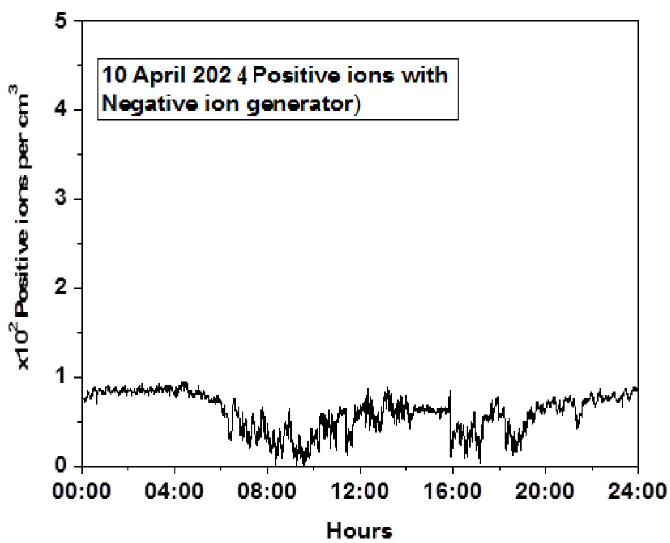

Fig. 2. Positive air ions variation with negative air ion generator.

3.2 Negative Ion Dynamics

Natural negative ion concentrations (without generator) show different temporal characteristics (Figure 3). Nighttime levels (00:00-07:00) fluctuate between 1.8-2.3×10² ions/cm³, lower than daytime values due to reduced ion production mechanisms [15]. The post-sunrise decrease (minimum at 11:00) may reflect increased aerosol loading from morning traffic and human activities, which scavenge negative ions through attachment processes [18].

The subsequent recovery to 4×10² ions/cm³ suggests activation of additional ion sources, possibly including enhanced photochemical processes, plant transpiration, and atmospheric mixing [20]. This afternoon peak exceeds morning levels, indicating cumulative effects of daytime ion production mechanisms.

With the negative ion generator operational (Figure 4), negative ion concentrations increase substantially, maintaining ~4.5×10² ions/cm³ during nighttime and peaking at 4.75×10² ions/cm³ at 07:20. This represents a 150% increase over natural levels, clearly demonstrating the generator's capacity to enhance negative ion concentrations [21]. The subsequent decrease to 4.25×10² ions/cm³ by 08:00 may reflect changing atmospheric conditions or ion loss processes, though concentrations remain significantly elevated throughout the measurement period.

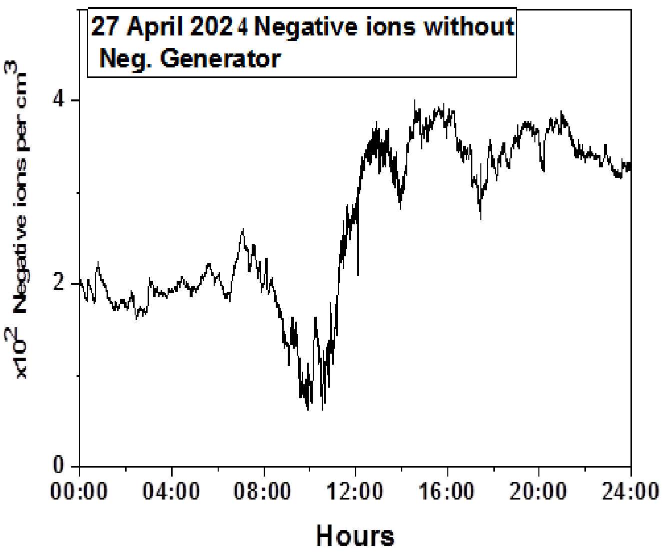

Fig. 3. Negative air ions variation without negative air ion generator.

3.3 Ion-Aerosol Interactions

The results provide compelling evidence for the central role of aerosols in atmospheric ion dynamics. As shown in previous studies [3], aerosols efficiently scavenge small ions through attachment, reducing atmospheric conductivity. Our measurements confirm this mechanism, particularly evident in the natural negative ion decrease coinciding with morning aerosol loading (Figure 3) [25].

The generator's effects reveal additional complexity in these interactions. The simultaneous increase in negative ions and decrease in positive ions (Figures 2, and 4) suggests that artificially generated ions participate in both recombination with oppositely charged ions and attachment to aerosols [26]. The order-of-magnitude changes observed have significant implications for atmospheric electrical properties, potentially affecting local charge distributions and electrical fields [27].

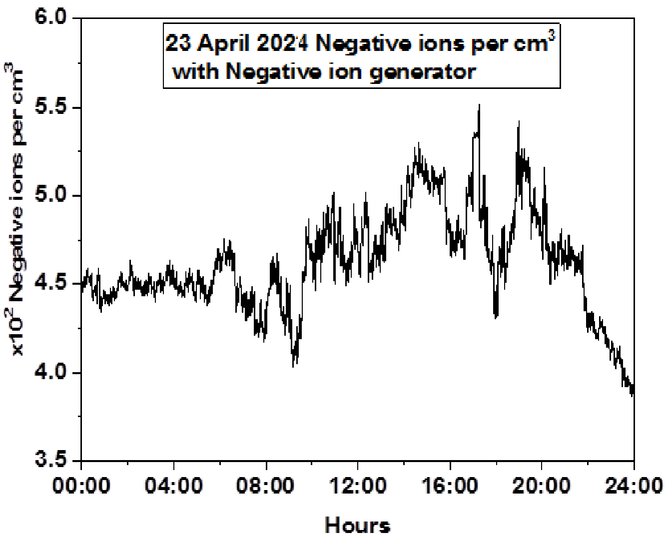

Fig. 4. Negative air ions variation with negative air ion generator.

3.4 Pollution and Health Implications

The measured changes in ion balance correlate with improvements in the pollution index, supporting potential applications for air quality management. As demonstrated by Weng et al. [25], negative ions can promote particle agglomeration and deposition, effectively reducing airborne pollutant concentrations. Our results extend these findings to semi-urban outdoor environments, showing that artificial ionization can modify ion-aerosol interactions under real-world conditions [27].

The biological significance of these changes warrants discussion. Previous research [20, 26] has linked negative ion exposure to various health benefits, including reduced respiratory symptoms and improved mood. While our study focuses on physical measurements, the demonstrated ability to substantially modify ion concentrations suggests potential health implications that merit further investigation [26].

Our findings both confirm and extend existing knowledge. The observed ion-aerosol attachment processes align with theoretical predictions [3] and laboratory measurements [6]. However, the quantitative demonstration of artificial ionization effects in field conditions provides novel data for model validation and technology development [27]. The diurnal patterns we observe add temporal resolution to previous studies that primarily reported average concentrations [18, 21]. The specific quantification of ion changes (e.g., 4.5 to 4.75×10^2 ions/cm³) provides precise data for evaluating ionization technologies. Our results also address a gap in semi-urban environment studies, complementing existing urban and rural datasets [23]. While this study provides valuable insights, certain limitations should be noted. The 33-day measurement period may not capture seasonal variations in ion behavior [25]. The single-location focus limits generalizability, and the specific generator design may influence results [26]. This comprehensive analysis demonstrates that artificial negative ion generation can significantly modify atmospheric ion concentrations in semi-urban environments. The technology shows particular promise for air quality improvement through enhanced ion-aerosol interactions. The detailed temporal data provide new insights into atmospheric electricity and lay groundwork for practical applications of ionization technologies. Future research should build on these findings to optimize ionization approaches and evaluate their broader environmental and health impacts.

4. CONCLUSION

This study offers critical insights into the dynamics of ion-aerosol interactions and their influence on atmospheric electrical properties in a semi-urban environment. By employing a custom-built Gerdien-type ion counter, we systematically evaluated the impact of an artificial negative air ion (NAI) generator on atmospheric ion concentrations in Palus, India. The results highlight the dominant role of aerosols in scavenging small ions, leading to reduced atmospheric conductivity. In the absence of an NAI generator, positive ions reached peak concentrations of 3×10^2 ions/cm³, while negative ions remained comparatively lower, fluctuating between 1.8 and 2.3×10^2 ions/cm³. The introduction of the NAI generator markedly altered this equilibrium, elevating negative ion levels to 4.75×10^2 ions/cm³ and suppressing positive ions to as low as 0.1×10^2 ions/cm³. The observed reduction in the pollution index underscores the potential of NAI generators as a viable tool for mitigating aerosol pollution, particularly in regions with significant anthropogenic activity. These findings align with existing literature on the health and environmental benefits of negative ions, though this study provides novel quantitative evidence from a semi-urban tropical setting. The mechanism likely involves enhanced ion-aerosol recombination, wherein artificially generated negative ions neutralize positively charged pollutants, thereby improving air quality. Despite these promising results, certain limitations must be acknowledged, including the relatively short duration of the study and its confinement to a single geographic location. Future research should investigate seasonal variations in ion-aerosol dynamics, particularly during periods of high aerosol loading such as winter and post-monsoon seasons. Comparative studies across urban, semi-urban, and rural environments would further elucidate the scalability of NAI technology. Additionally, integrating advanced instrumentation, such as ion mass spectrometers, could provide deeper insights into the speciation of ions and their interaction with different aerosol types. This study bridges the gap between theoretical atmospheric science and practical environmental applications, offering a foundation for future policies on air quality management. Further work should explore the economic feasibility and large-scale implementation of NAI generators in pollution hotspots.

DECLARATIONS

Ethical Approval

We affirm that this manuscript is an original work, has not been previously published, and is not currently under consideration for publication in any other journal or conference proceedings. All authors have reviewed and approved the manuscript, and the order of authorship has been mutually agreed upon.

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Availability of data and material

All of the data obtained or analyzed during this study is included in the report that was submitted.

Conflicts of Interest

The authors declare that they have no financial or personal interests that could have influenced the research and findings presented in this paper. The authors alone are responsible for the content and writing of this article.

Authors' contributions

Pawar S.D. contributed to conceptualization, methodology, investigation, data curation, formal analysis, original draft preparation (Results and Discussion sections), visualization, supervision, and project administration while Shirgaonkar D.P. performed literature review (References), writing-review & editing, validation.

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