D5.1. Review article on the effect of air pollution on airway allergy with a focus on vulnerable populations

CLIMATE CHANGE AND AIR CONTAMINATION:
ARTIFICIAL INTELLIGENCE APPLIED ON THE CORRELATION BETWEEN AIR POLLUTANTS AND NON-COMMUNICABLE RESPIRATORY DISEASES IN EUROPE

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Author(s):	UNIMI – SAS - CHUT
Contributor(s):	Ludovico Furlan – Luca Ferrari – Chiara Bellocchi – Nicola Delcourt – Mathilde Calmels – Eleonora Tobaldini – Nicola Montano – Ibon Eguiluz-Gracia
Reviewer(s):	RSS - Werner Wiedemann
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EXECUTIVE SUMMARY

Outdoor air pollution and climate change are well known health determinants, yet their role in symptoms control in allergic rhinitis (AR) is not completely defined.

We performed a systematic review to evaluate the effect of outdoor pollution and global warming on AR symptoms control.

PubMed was searched without restrictions to identify all original studies involving patients with AR evaluating effect of pollutants on symptoms control. Symptoms could be evaluated either through questionnaires or as unexpected AR visits or medications used for symptoms control between 0 to 7 days after pollutant exposure. We excluded studies on long term incidence or prevalence of AR, indoor exposures, evaluating respiratory diseases other than AR, based on animal or predictive models and reviews.

From the 12,772 records initially identified a final cohort of 30 studies was selected. Studies were mainly ecological time-series, case-crossover, or cross-sectional analyses, most settled in China. Across pollutants, the majority of studies reported significant short-term worsening of AR symptoms related to increasing concentrations of $PM_{2.5}$, PM_{10} and NO_2. Similar findings with smaller overall effect were found for O_3 and SO_2. CO showed more heterogeneous associations. Younger age, residency in urban settings and periods with high pollen concentrations exhibited facilitating effect. Quantitative synthesis was limited by significant heterogeneity in exposure definition and assessment, outcomes and adjustment for confounders among studies.

Current evidence supports a consistent association between short-term exposure to ambient pollutants and poorer symptom control in AR. Dedicated longitudinal studies may evaluate environmental health directed policies as potential mitigation strategies.

1. INTRODUCTION

1.1 DESCRIPTION OF THE DOCUMENT AND PURSUE

Climate change and the associated loss of biodiversity have been defined by *The Lancet* as the greatest threat to global health in the 21st century [1].

In recent years, an exponential growth of evidence has emerged regarding the effects of outdoor ambient pollutants—such as particulate matter, as well as nano- and microplastics—and extreme climate events on human health, with potential impacts on the incidence and prevalence of both communicable and non-communicable diseases, including cardiovascular, respiratory, and oncological conditions [1–3]. Nevertheless, limited data exist on the correlation among outdoor pollution and climate change and their impact on quality of life. Allergic rhinitis (AR) is an inflammatory condition resulting from IgE-mediated sensitization to environmental allergens and affects up to 30% of children and adults in Western countries [4]. The disease accounts for up to 2.0% of all primary healthcare visits [5], and is associated with a decrease of quality of life, loss of productivity and poor school and job performance besides the direct costs related to medications and visits [6]. Studies in the United States have estimated these costs in $ 3.4 billion each year [5]. Recent evidence suggests a potential synergistic effect between particulate matter and the cellular and humoral mechanisms involved in the development of asthma and AR [7]. Also a recent systematic review has confirmed the strict correlation among pollution and the prevalence of AR and asthma [8].

Fewer data are available on how pollution may affect control of symptoms and quality of life in patients with AR. The aim of our study was therefore to summarize the existing evidence on the relationship between exposure to pollution and climate change and disease control in patients with AR.

1.2 WPS AND TASKS RELATED WITH THE DELIVERABLE

This deliverable refers to Task 5.1 included in WP5: Mechanistic Research & Clinical Study I. In this WP we aim to identify the set of variables related to outdoor pollution and climate factors that impact living beings in relation to allergenicity (pollen-producing plants) and allergic immune responses (humans), and to decipher the corresponding mechanisms. With the task 5.1 the specific object was to conduct a literature review to identify relevant variables that impact airway allergy outcomes in humans, with a focus on outdoor pollution and climate patterns.

2. MATERIALS AND METHODS

2.1 Methods

For the purpose of our review, we included only studies reporting original data on AR patients, with no age restriction, assessing the effects of outdoor air pollutants and climate change on symptoms and disease control.

A priori we established to analyse studies based on the type of study and pollutant evaluated.

Pollutants and climate change effect on symptoms control were assessed separately.

Based on such criteria we developed the following PICOS:

P: Allergic Rhinitis

I: Pollution and Climate Change

C: none

O: disease control

S: original studies

We specifically excluded studies assessing diseases other than AR; studies focused on indoor air pollutants or other type of pollutants; studies on prevalence and incidence of AR or not evaluating the short-term effect of pollution or climate change on symptoms development and control, defined as an effect evaluated in between a 7 days log period both in urgent care or ambulatory setting; we excluded narrative reviews, case reports or article not reporting original data, studies describing predictive models or animal models.

PubMed was searched for potentially relevant articles. Based on the prespecified PICOS we identified relevant keywords and mesh terms. Each term was searched singularly and then each search embedded through operators OR and AND. No filters or limits were used.

The following string search was developed: "((((((((((((((Environmental pollution) OR (air pollution)) OR (Particulate matter)) OR (Carbon dioxide)) OR (Carbon monoxide)) OR (Sulfur dioxide)) OR (Nitrogen oxides)) OR (ammonia)) OR (volatile organic compounds)) OR (ozone)) OR (Climate Change)) OR (temperature)) OR (carbon footprint)) AND (((((respiratory allergy) OR (allergic respiratory disease)) OR (ar)) OR (respiratory hypersensitivity)) OR (allergic rhinitis))) AND ((((((((((Exacerbation) OR (worsening)) OR (Severity)) OR (Disease control)) OR (Severity of illness)) OR (patient acuity)) OR (symptoms control)) OR (symptomatic)) OR (sneezing)) OR (nasal symptoms)) OR (rhinorrea)))".

2.2 Studies Selection

Retrieved results were assessed by two reviewers independently (LF and LFe). Potentially relevant articles were included for title and abstract assessment.

Two reviewers (LFe and CB) reviewed included studies titles and abstract to select articles for full text appraisal. A third author (LF) solved potential discordance.

Included articles were then assessed independently by two couples of authors (LF & LFe; and ND & MC) each couple evaluating half of the listed articles, for final inclusion and data extraction.

Other potentially relevant studies were included at this stage by assessing references of full text screened articles.

Articles' screening and selection was performed using a pre-specified Excel® sheet.

2.3 Data extraction and synthesis

We defined as relevant outcome symptoms control in AR patients related to variation in pollutants concentration or temperatures variations. Such outcome could be evaluated both with questionnaires (visual analogue scale, total nasal symptom score, rhinitis control assessment test or control of allergic rhinitis and asthma test or others) or as variation in the number of daily AR visits, or acute visits, or medication free days or intake of symptomatic medications depending on the type of study. We extracted and analysed only data reporting short term exposure effect defined as a maximum interval between exposure and symptoms recording of 7 days.

For each study we recorded type and numerosity of population, age (if reported), exposition (i.e. recorded pollutants), outcome definition, statistical methods, confounders and modifiers and size estimate effect either odds ratio and results with estimates (relative risk, hazard ratio, odds ratio etc.) with relative 95% confidence interval.

Data were recorded in a pre-specified Excel® table.

3. RESULTS

3.1 Characteristics of Included Studies

Enrolment selection process of potentially relevant articles is summarized in **figure 1**. The literature search on PubMed identified a total of 12,772 records. After screening titles and abstracts, 92 records were retained for abstract evaluation. Of these, 35 full-text articles were assessed for eligibility. During full-text screening further 15 articles were selected for full text appraisal from bibliography screening. Of the cohort of 50 articles extensively reviewed, 20 were excluded, 4 because focused on long term prevalence/incidence, 8 because focused on respiratory diseases other than AR (or with no possibility to extract AR patients data), 1 did not reported data on single pollutants, 2 did not report data on symptoms or quality of life, 2 were focused on the association of symptoms with pollen or dust storm exposure, 2 had no full text available and 1 being a narrative review.
A total of 30 articles was included for final analysis.

Regarding geographical distribution, 18 studies were performed in Asia (2 in Taiwan, 16 in China), 9 were conducted in Europe, 1 in South America, 1 in North America, 1 did not report data on geographic location.
Across the 30 included studies, the assessed exposures were nitrogen oxides (mainly NO_2/NOx) in 21/30 (70.0%) [9–29]; PM_{10} in 20/30 studies (66.7%) [9–11, 14–30]; PM2.5 in 16/30 (53.3%) [11, 14, 16–18, 22–28, 30–33]; O_3 in 17/30 (56.7%) [9–11, 13–15, 17, 18, 20–25, 28, 31, 33]; SO_2 in 17/30 (56.7%) [9–11, 13–19, 22–24, 27–29, 33]; CO in 14/30 (46.7%) [9–11, 13–15, 17, 22–26, 28, 30]; ambient temperature or other climatic variables in 6/30 studies (20.0%) [9, 16, 31, 34–36]; and black carbon in 1/30 (3.3%) [37]. Outcomes primarily captured disease control or symptom exacerbations in allergic rhinitis, measured by healthcare visits (emergency/outpatient) or symptom-control questionnaires, consistent with the pre-specified outcome definition.
Study populations ranged from a few dozen to over 120,000 participants, depending on design and data source. Overall, sample sizes were larger in time-series ecological studies, while questionnaire-based cross-sectional studies typically enrolled between a few hundred and a few thousand subjects.
A detailed summary of study characteristics, including population size, pollutant type, and outcome definition, statistics, confounders and results is provided in **Table 1** and **Table 2.**

3.2 Results by exposure type

Across exposure categories, adverse short-term associations with allergic rhinitis outcomes were observed in a substantial proportion of studies. For PM_{10}, 70.0% (14/20) of studies reported significant worsening of symptoms or increases in healthcare visits, while 30.0% (6/20) found no association. Similar patterns were identified for $PM_{2.5}$ (78.6% adverse, 21.4% null), NO_2/NOx (71.4% adverse, 28.6% null), O_3 (70.6% adverse, 29.4% null), and SO_2 (58.8% adverse, 41.2% null). For CO, adverse effects were observed in 50.0% (7/14) of studies. Temperature-related exposures also demonstrated notable heterogeneity, with 66.7% (4/6) of studies detecting adverse associations and 33.3% reporting null findings. Overall, the evidence indicates heterogeneity across pollutants, with adverse short-term effects more consistently detected for particulate matter and nitrogen oxides.

3.2.1 PM2.5 exposure

Multiple studies have investigated the association between particulate matter ($PM_{2.5}$) exposure and the worsening of AR symptoms.

A study conducted across Northern and Central Europe in 2018 found that exacerbations of AR were associated with $PM_{2.5}$ exposure, particularly during the pollen season (grass and birch) [31].

In China, a study evaluating the effects of $PM_{2.5}$ among more than 30,000 preschool children living in six urbanized cities revealed an interesting finding: children in non-urban areas exhibited a higher risk of both incidence and exacerbation of allergic rhinitis symptoms compared to those in urban settings, likely due to $PM_{2.5}$ exposure related to biomass combustion [32].

Supporting evidence also comes from a retrospective Chinese study analyzing correlations between monthly PM concentrations and subjective symptom scores in 351 children with AR (aged 3–16 years) during 2013. PM_{10} and $PM_{2.5}$ levels were positively correlated with symptom scores [16].

A one-year panel study on 49 patients reported an association between pollutant mixtures ($PM_{2.5}$, O3, SO2, and NO2) and allergic rhinitis symptom scores, particularly when all pollutants were above the 70th percentile, with $PM_{2.5}$ emerging as a potential primary contributor [18].

Another prospective cohort study in China including 167 patients confirmed that $PM_{2.5}$ exposure was significantly associated with specific AR symptoms, namely sneezing and nasal blockage [22].

An ecological time-series study conducted in Xinxiang, China (January 2015–December 2018), analyzed 14,965 AR outpatient records and found that each 10 μg/m³ increase in $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO corresponded to respective increases of 0.70% (95% CI: 0.00–1.41%), 0.79% (0.35–1.23%), 3.43% (1.47–5.39%), 4.54% (3.01–6.08%), 0.97% (–0.11–2.05%), and 0.07% (0.02–0.12%) in daily AR outpatient visits. Stronger associations were observed for $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO among patients younger than 15 years [26].

In a different geographical setting, a cross-sectional study conducted in three Polish cities assessed the risk of hospital admissions for AR within eight days of exposure to various air pollutants, stratified by warm and cold seasons. In this analysis, $PM_{2.5}$ alone did not show a significant association with AR exacerbations in either season [14].

3.2.2 PM10 exposure

Across ecological and case-crossover analyses, most studies reported a positive association between short-term PM_{10} exposure and AR outcomes. In Taipei, a time-stratified case-crossover analysis found that for an interquartile increase of PM_{10} (26.81 μg/m³), clinic visits for AR rose significantly (OR = 1.09, 95% CI 1.07–1.10) at higher temperatures and (OR = 1.05, 95% CI 1.04–1.06) at lower temperatures [10]. In Poland, a multicity case-crossover study detected a significant association during the warm season, with cumulative risk over eight days (RR = 1.202, 95% CI 1.044–1.384) and attributable admissions = 8.79% [14]. Similarly, in Belgium, PM_{10} exposure was related to severe pollen allergy events (total-track OR = 1.255, 95% CI 1.007–1.565; lag 0–2 OR = 1.689, 95% CI 1.059–2.696) [21]. Several ecological studies also indicated consistent small-scale increases in AR consultations or hospital visits. For each +10 μg/m³ rise in PM_{10}, outpatient visits for AR increased by +0.79% (95% CI 0.43–1.15%) in Beijing [27] and +0.79% (95% CI 0.35–1.23%) in Xinxiang [26]. In Hangzhou, daily variations in AR outpatients showed modest but consistent excess risks per 10 μg/m³ PM_{10} (lag 0 RR = 1.007, 95% CI 1.001–1.013; lag 4 RR = 1.014, 95% CI 1.008–1.021) [30]. Other ecological work, such as [28], did not find statistically significant associations.

Cross-sectional studies offered additional support for the relationship between PM_{10} exposure and rhinitis severity. Among Shanghai children, a 10 μg/m³ increase in PM_{10} was linked to a +0.02 point rise in subjective symptom scores (r = 0.43, p = 0.033) [16].

A large-scale school-based study similarly found higher odds of rhinitis symptoms per 7.6 μg/m³ PM_{10} increment, with OR = 1.24 (95% CI 1.05–1.45) in unadjusted, OR = 1.28 (95% CI 1.06–1.55) in multivariate, and OR = 1.32 (95% CI 1.07–1.63) in fully adjusted models [19]. Other cross-sectional analyses [32], identified PM_{10} among multiple co-pollutants related to allergic outcomes, though detailed effect estimates were not always specified.

Retrospective studies further supported these findings. Kim et al. reported that PM_{10} exposure was positively associated with both symptom severity (β = 0.104, p = 0.032) and symptom duration (β = 0.127, p = 0.011), indicating aggravation of allergic rhinitis symptoms in exposed adults [38].

Prospective evidence was limited but consistent with short-term effects. A multi-country European cohort assessed $PM_{2.5}$ but not PM_{10} directly [31].

3.2.3 O3 exposure

Among the studies included, several also evaluated the effects of ozone exposure on AR outcomes. Ecological and case-crossover analyses generally reported a positive association between short-term O_3 levels and increased symptom severity or healthcare use. In Taiwan, Chen et al. found that higher ozone concentrations were associated with a greater number of clinic visits for AR (OR = 1.23, 95% CI 1.20–1.26) [10]. Consistent findings emerged from the Belgian case-crossover study by Stas [21], in which dynamic exposure to ozone increased the odds of severe pollen-allergy episodes (lag 0–2 OR = 1.91, 95% CI 1.39–2.62). Retrospective and ecological time-series studies confirmed these patterns: Hajat [15] observed a 37.6% (95% CI 23.3–53.5, p < 0.00001) rise in consultations for AR among children, while Yang [28] and Wang [26] both reported significant short-term associations between daily O_3 levels and outpatient visits for AR. Although ozone was also included in several cross-sectional analyses, these studies did not describe specific associations between O_3 exposure and AR outcomes.

3.2.4 NO2 exposure

Most of the studies assessing nitrogen dioxide exposure reported positive associations between NO_2 levels and AR outcomes. In the time-stratified case-crossover study from Taiwan, Chen et al. [10] found that short-term increases in NO_2 were associated with a higher frequency of clinic visits for allergic rhinitis (OR = 1.16, 95% CI 1.14–1.17 at high temperature; OR = 1.10, 95% CI 1.09–1.12 at lower temperature). Consistent evidence was observed in the multicity Polish case-crossover analysis by Dąbrowiecki et al. [39],

which showed a significant cumulative effect during the cold season (RR = 1.25, 95% CI 1.12–1.40) with 52.7% (95% CI 31.2–65.4%) of hospital admissions attributable to NO_2. Ecological time-series studies also reported significant short-term associations: in Lanzhou, Ji et al. [17] observed relative risks ranging from 1.018 to 1.025 per 10 μg/m³ increase in NO_2, and in Xinxiang, Wang et al. [26] reported a 4.54% (95% CI 3.01–6.08%) increase in daily AR visits per 10 μg/m³ rise. Similarly, [27] Wu documented a +3.05% increase (95% CI 1.72–4.40%) in outpatient visits per 10 μg/m³ NO_2 increment. Cross-sectional studies confirmed these patterns. In Shanghai schoolchildren, Liu [19] found higher odds of rhinitis symptoms with increased annual NO_2 exposure (OR = 1.09, 95% CI 1.03–1.14 in unadjusted and OR = 1.11, 95% CI 1.08–1.13 in fully adjusted models). Other cross-sectional analyses, such as He [16], included NO_2 among tested pollutants but did not report a direct association with symptom scores.

Retrospective evidence from London [15] also suggested that NO_2 contributed to increased consultations for AR, especially in adults, while ecological studies in East Asia [11, 28], and Belgium [21] supported the role of NO_2 as a co-factor enhancing allergic responses in high-pollution settings.

3.2.5 SO2 exposure

Most studies that assessed SO_2 exposure reported significant associations with AR outcomes, particularly in time-series and case-crossover analyses. In Taipei, Chen [10] observed that short-term increases in SO_2 were associated with more clinic visits for AR (OR = 1.05, 95% CI 1.04–1.07 at high temperature; OR = 0.93, 95% CI 0.91–0.94 at lower temperature). In Poland, Dąbrowiecki [39] found no significant relationship between SO_2 and hospital admissions for AR, whereas other pollutants (O_3, NO_2) were associated with increased risk. Hajat et al. [15] reported that in children, SO_2 levels between 13–31 μg/m³ were linked to a 24.5% rise in consultations for AR (95% CI 14.6–35.2, $p < 0.00001$), with smaller effects in adults. In Lanzhou, Ji et al. [17] identified lag effects, with significant increases at lag 1–3 days (RR = 1.036–1.048, 95% CI 1.005–1.081), while in Xinxiang, Wang et al. [26] showed a 3.43% (95% CI 1.47–5.39%) increase in outpatient visits for AR per 10 μg/m³ SO_2 increment. Similarly, Wu at al. [27] observed a 5.01% increase (95% CI 1.18–8.96%) in AR outpatient visits for the same exposure.

Cross-sectional and ecological studies generally confirmed this trend, showing stronger SO_2-related effects in urban and warm-season contexts. Some analyses, such as in [16] included SO_2 among multiple pollutants but did not report pollutant-specific estimates.

3.2.6 CO exposure

The association between CO exposure and AR was evaluated in several ecological, case-crossover, and time-series studies included in the dataset of this systematic review. Overall, findings indicate that CO contributes to the short-term exacerbation of allergic symptoms and healthcare utilization, although with variable magnitude across settings. In Taiwan, Chen at al. [10] reported that increases in ambient CO were significantly related to a higher frequency of AR clinic visits, with odds ratios ranging from 1.03 (95% CI 1.02–1.05) at lower temperatures to 1.20 (95% CI 1.18–1.22) at higher temperatures. Consistent results were observed in Lanzhou [17], where a 10 μg/m³ rise in CO was associated with a 6.3% increase (95% CI 1.0–11.9%) in AR outpatient visits on the same day, with significant lag effects across multiple days. Similarly, Tang et al. [30] identified CO as one of the key pollutants influencing daily AR consultations, showing single-day lag associations (RR = 1.019, 95% CI 1.008–1.047 at lag 0).

Other ecological analyses, including [28], reported that CO showed non-significant or inconsistent effects in multi-pollutant models, while in Poland, Dąbrowiecki et al. [39] did not observe a statistically significant association between CO and AR hospital admissions.

4. TABLES AND FIGURES

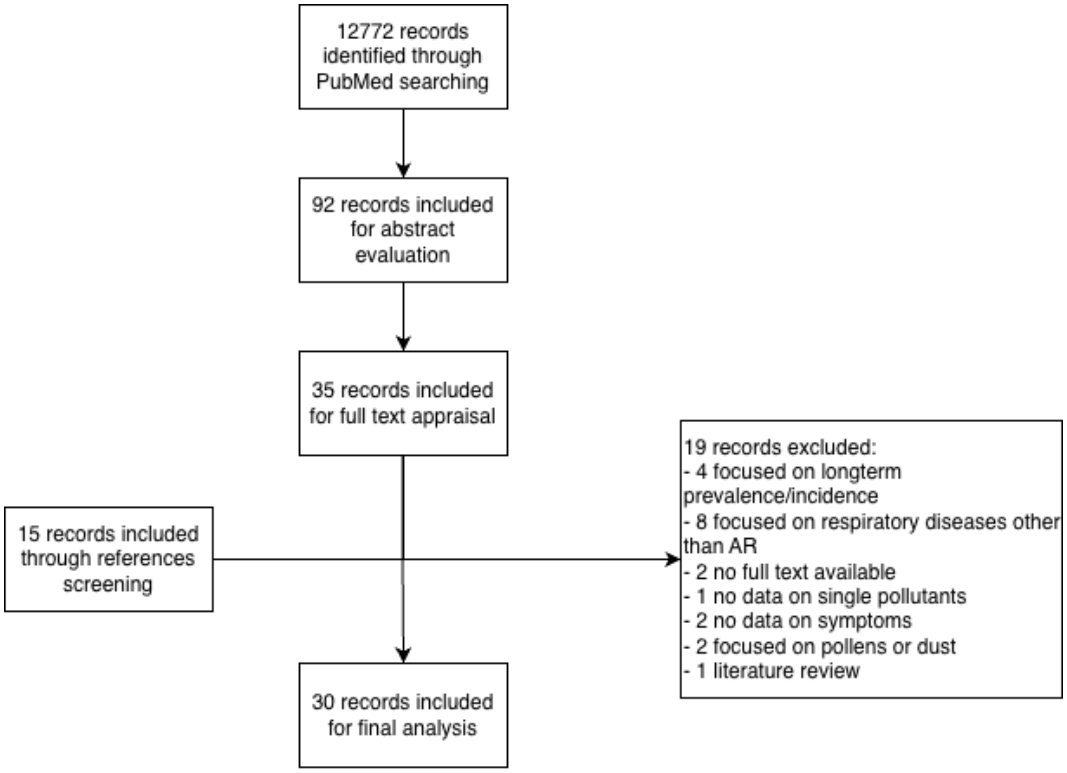

Figure 1. Studies enrollment flowchart.

Study	Type of study	Population	N	Age
Bédard 2020 [31]	Prospective cohort	General population with AR symtoms enrolled in the POLLAR (Impact of Air POLLution in Asthma and Rhinitis) project. Northern and Eastern Europe	36444	34.7 (SD 15.6)
Cabrera 2019 [9]	Retrospective cohort	AR patients with clinical history and sensitized to grass pollen, Madrid, Spain.	48	16-47
Chen 2016 [10]	Time-stratified case-crossover	Outpatients evaluated for AR vs general population in Taipei, Taiwan	124773	na
Chen 2018 [32]	Cross sectional	Children from 205 kindergartens in six cities (Shanghai, Nanjing, Chongqing, Changsha, Urumqi, and Taiyuan) in China	30279	4.6
Chu 2019 [11]	Ecological time series	Outpatients evaluated for AR at the First Affiliated Hospital of Nanjing Medical University, China	33063	69% adults
Cilluffo 2018 [12]	Cross sectional	Schoolchildren, attending the 3rd to 5th years of two primary schools in Palermo, Italy	244	8.98 (SD 0.9)
Dąbrowiecki 2023 [14]	Case-crossover	General population from Tricity, Warsaw and Cracow, Poland	1407	
Gao 2021 [34]	Ecological time-series	Outpatients evaluated for AR in four traditional urban districts, Xinxiang, China	14965	2159 <15 yo; 11,945 15–64 yo; 861 > 65 yo
Hajat 2001 [15]	Ecological time-series	General population evaluated from general practitioners for AR using the General Practice Research Database, London, United Kingdom	44,406–49,596 children (1–14 yo) >185,267–	1-64

			204,039 adults (>14 yo)	
He 2017 [16]	Cross sectional	Children previously diagnosed with AR at Children's Medical Center, Shanghai Jiaotong University School of Medicine, China	351	6.5 (SD 2.4)
Hyrkäs-Palmu 2018 [35]	Retrospective cohort	A stratified random sample from National FINRISK 2007 and FINRISK 2012 databases, Finland	7330	25-74
Ji 2023 [17]	Ecological time-series	Outpatients evaluated for AR in Lanzhou, China	60964	moda 15–59
Kerdkaew 2024 [36]	Randomized cross-over	Adults with AR	15	23.53 (SD 4.28)
Kim 2020 [40]	Retrospective cohort	Adults with confirmed AR from 12 distinct regions around Gwangyang bay, China	590	46.4
Li 2024 [18]	Longitutinal panel	Patients with clinically confirmed AR recruited at Shanxi Provincial People's Hospital Taiyuan, China	49	36.7 (SD 8.4)
Liu 2020 [19]	Cross sectional	Kindergarten children randomly selected from 18 districts in Shanghai, China	13,335	4-6
Riediker 2001 [20]	Interventional	Pollen-sensitized AR outpatients followed by Allergy Unit of the Department of Dermatology, University Hospital in Zurich, Switzerland.	15	22-39
Solé 2007 [13]	Ecological cross sectional	Adolescents from 5 Brazilian centres of the International Study of Asthma and Allergies in Childhood (ISAAC) database	16209	13-14
Stas 2021 [21]	Case-crossover	General population of Belgium with tree pollen allergy	144	40.4 (SD 9.9)

Sun 2024 [22]	Prospective cohort	Outpatients evaluated for AR in Hangzhou City, China	167	35.4 (SD 12.1)
Tang 2023 [30]	Ecological time-series	Outpatients evaluated for AR at the Department of Otolaryngology, Affiliated Hospital of Hangzhou Normal University, China	20653	na
Teng 2017 [23]	Ecological time-series	Outpatients evaluated for AR at the Departments of Otolaryngology-Head and Neck Surgery, First and Second Hospitals, Jilin University, China	23344	na
Tomic-Spiric 2019 [37]	Time-stratified case-crossover	Patients aged 18 years and older living in the Užice region (Sevojno, Čajetina, Kosjerić), Serbia	523	41.43 (SD 18.00)
Villeneuve 2006 [24]	Ecological time-series	Outpatients evaluated for AR from the Ontario Hospital Insurance Plan (OHIP) database, Canada	nr	na
Wang 2013 [25]	Ecological time-series	Outpatients evaluated for respiratory diseases at Landseed Hospital, Taiwan	nr	na
Wang 2019 [33]	Ecological time-series	Outpatients evaluated for AR in Bejing, China	229685	na
Wang 2020 [26]	Ecological time-series	Outpatients evaluated for AR in four hospitals in Xinxiang, China	14965	2159 < 15 yo; 11,945 15–64 yo; 861 ≥ 65 yo
Wu 2022 [27]	Ecological time-series	Outpatients evaluated for AR at Beijing Hospital, China	33599	18–44
Yang 2022 [28]	Ecological time-series	Outpatients evaluated for AR Chongqing Medical University, China	12868	na
Zhang 2011 [29]	Ecological time-series	Outpatients evaluated for AR at Beijing Hospital, China	1506	na

Table 1. **Included studies' population characteristics, numerosity and age**.
na: not available; SD: standard deviation; yo: years old.

Study	Exposition	Outcome	Statistical Method	Confounders and Modifiers	Results with estimates and relative 95% confidence intervals
Bédard 2020 [31]	03, PM 2.5, temperature	Primary outcome: Uncontrolled Rhinitis (MASK Criteria) Secondary outcome: Global VAS score (0–100) for symptoms severity	Generalized Estimating Equations models	Adjustment for daily treatment (i.e. day with/without treatment), gender, age and country of residence of the user. Stratification by pollen seasons. In case of association adjustment for temperature (sensitivity analysis)	Association of pollutants (25^{th}-75^{th} percentile) with uncontrolled symptoms: - O3: OR 1.17 (1.12-1.23) for the year 2017; 1.14 (1.1.-1.17) for the year 2018 - PM2.5 : OR 0.99 (0.97-1.02) for the year 2017; 1.08 (1.06-1.10) for the year 2018.
Cabrera 2019 [9]	SO2, CO, NO2, PM10, O3, temperature	Nasal symptoms in AR (0 = no symptoms; 1 = mild symptoms; 2 = moderate symptoms; ≥3 = severe symptoms)	Categorical principal component analysis (CatPCA)	nr	Categorical principal component analysis with related coefficient (R) Symptoms ↔ Temperature: 1996 R = 0.38; Symptoms ↔ O3: 1996 R = 0.28; 2009 O3: R = 0.35 Symptoms ↔ PM10: 1996 R = 0.18
Chen 2016 [10]	PM10, NO2, SO2, CO, O3	Variation in daily outpatients visits for AR	Time-stratified case-crossover analysis using lag up to 2 previous days.	Adjustment Daily average temperature and humidity on the same day	Number of AR visits at lag02 for each interquartile (75th -25th) increase in pollutant, stratified for different temperature thresholds: - PM 10: OR 1.09 (1.07–1.10) for temp >=23 °C; OR 1.05 (1.04–1.06) for temp < 23°C; - SO2: OR 1.05 (1.04–1.07) for temp >=23 °C; OR 0.93 (0.91–0.94) for temp < 23°C; - NO2: OR 1.16 (1.14–1.17) for temp >= 23 °C; OR 1.10 (1.09–1.12) for temp < 23°C; - CO: OR 1.20 (1.18–1.22) for temp >= 23 °C; OR 1.03 (1.02–1.05) for temp < 23°C; - O3: OR 1.06 (1.05–1.08) for temp >= 23 °C; OR 1.23 (1.20–1.26) for temp <23°C.
Chen 2018 [32]	PM2.5	Allergic symptoms recorded through questionnaire	Hierarchical multiple logistical regression	Adjustment for gender, age, family history of allergic diseases, breastfeeding, indoor variables, household annual income, and city-level variable-annual temperature	Allergic symptoms prevalence for 10 mg/m3 increase of the annual average of PM2.5: OR 1.02 (0.97,1.08)

Chu 2019 [11]	PM10, PM2.5, NO2, SO2, CO, O3	Association between air pollutants and AR	Generalized additive model (GAM). Single pollutant model (single and cumulative days) and two pollutant model	Adjustments for seasonal trends, current-day mean temperature, relative humidity; day of week.	Daily AR at lag0–2, associated with interquartile increase in pollutant concentration (single pollutant model results showed): - PM10: +5.86% (3.00– 8.81%) - PM2.5: +5.39% (2.73–8.12%)
Cilluffo 2018 [12]	Air Pollution: - Proximity to high-traffic roads (≤ 200 m vs. > 200 m); - NO_2 exposure (threshold ≥ 60 µg/m^3)	AR symptoms (4 weeks, 22 equally weighted symptoms)	Multiple logistic and Poisson ridge regression models	gender, age, FSES (cate- gorized as > 49.5, 1st quartile), atopy, doctor diagnosed asthma, parental history of allergy and preterm birth	Risk between exposure to pollution and symptoms: >Proximity ≤200 m to high-traffic roads: Ocular symptoms: OR 1.68 (1.31–2.17); Nasal symptoms: OR 1.49 (1.12–1.98); no statistically significant effect on respiratory or general symptoms >High NO_2 levels (≥60 µg/m^3): General symptoms: OR 1.28 (1.10–1.48); no significant effect on ocular, nasal or respiratory symptoms
Dąbrowiecki 2023 [14]	PM10, PM2.5, NO2, SO2, CO, O3.	Hospital admissions for AR	Distributed lag nonlinear models (DLNM)	temperature, relative humidity, and atmospheric pressure. Stratification for warm and cold temperature	Warm season (April–September) PM10 : Attributable admissions: 8.79% (2.70–14.9%). O3 Attributable admissions: 17.8% (3.44–30.2%). PM2.5, NO2, SO2 → No significant associations. Cold season (October–March) NO2 Attributable admissions: 52.7% (31.2–65.4%). O3 Attributable admissions: 8.14% (3.04–12.6%). PM10, PM2.5, SO2 → No significant associations.
Gao 2021 [34]	Temperature: Daily maximum, minimum, and mean	Variation in daily outpatients visits for AR	Distributed lag non-linear model (DLNM)	Adjustment for humidity, long-time trends, day of the week, public holidays, and air pollutants were controlled as covariates simultaneously.	AR outpatients visits in relation to variation of temperature (only statistically significant results RR reported): > 1st percentile relative to median temperature: no statistically significant results > 25th percentile relative to median temperature: RR 1.27 (1.02–1.58) at lag06; 1.32 (1.05–1.67) at lag07; >75th percentile relative to median temperature: RR 1.14 (1.01–1.27) at lag02; 1.15 (1.02–1.29) at lag03; >99th percentile relative to median temperature: RR 0.59 (0.39–0.88) at lag014; 0.28 (0.16–0.47 at lag015; 0.24 (0.12–0.50) at lag016.
Hajat 2001 [15]	NO2, O3, SO2, Black smoke, CO, PM10	Daily number of consultations to general practitioners for AR	Generalized additive models (GAM)	Adjustment for day-of-the-week, temperature and humidity, variation in the practice population over the 3-year period, pollen measures, daily number of consultations for influenza.	Increase in daily consultations for AR for 10-90th percentile increase in pollutant concentration: >SO2 (13–31 µg/m^3): Childeren +24.5% (14.6–35.2%) consultations at 4 days; Adults +15.5% (9.1, 22.3%) consultations at 5 days >O3 (6–29 ppb): Children +37.6% (23.3–53.5%) consultations at

					3 days; Adults +25.5% (19.2, 32.1%) consultationns at 3 days >NO2 (22.3-46.3 ppb): Children +12.6% (4.6-21.3%) consultations at 4 days; Adults +11.4% (6.8, 15.6%) consultations at 6 days >PM10 (15-8-46.5 ug/m3): Children +17.4 (6.8, 29.0%) consultations at 3 days; Adults +20.2% (14.1, 26.6%) consultations at 6 days
He 2017 [16]	Daily mean temperature, relative humidity, and diurnal temperature range (Diurnal temp SO2, NO, NO2, NOx, PM2.5, and PM10	AR symptoms (Six symptoms graded each 0-4 , asymptomatic to intolerable)	Linear mixed effect model	Adjustment for age, gender, and smoking status collected during baseline survey	Main results reported (limited data on effect size): >Temperature could affect AR scores ($p < 0.001$) >Temperature and humidity were negatively correlated with the AR subjective symptom scores, with a mean increase of 0.04 points in the scores corresponding to a decline of both 1 °C in temperature ($P < 0.0001$) and 10 % in humidity ($P = 0.0412$) >Increase of 10 µg/m3 in PM10 and PM2.5 resulted in a mean increase of 0.02 and 0.03 points, respectively, in the AR subjective symptom scores of the children >NO, NO2, NOx, or O3 added no significantly impacted the AR subjective symptom scores.
Hyrkäs-Palmu 2018 [35]	cold temperature	Self reported functional disability, impaired health and exacerbation of respiratory symptoms	Poisson regression using logarithmic link function.	Adjustment for age, body mass index (BMI), marital status, education, type of work, smoking, second hand smoke exposure, occurrence of other chronic diseases	Cold weather–related functional disability (FD) Allergic rhinitis Men: 25.1% → adjusted prevalence ratio (PR) = 1.19 (95% CI: 1.04–1.37), Women: 19.2% → adjusted PR = 1.26 (95% CI: 1.08–1.46) Cold weather–related impaired health and symptom exacerbation (EH) Allergic rhinitis only: Men: adjusted PR = 1.53 (95% CI: 1.15–2.04), Women: adjusted PR = 1.78 (95% CI: 1.43–2.21)
Ji 2023 [17]	PM2.5, PM10, SO2, NO2, O3, CO	Variation in daily outpatients visits for AR	Quasi-Poisson time series regressions with distributed lag non-linear models (DLNM) Single and cumulative days model	Adjustment for daily mean temperature, relative humidity, day of the week, Holiday. Evaluation of potential effect modification by gender, age and season.	Outpatients visits for AR associated with 10 µg/m (1 mg/m3 for CO) increase in pollutant concentration*: > PM 2.5: RR 1.006 (1.002-1.010) lag 6; 1.035 (1.019, 1.052) lag07 > PM 10: RR 1.002 (1.001-1.008) lag6; 1.006 (1.002-1.011) lag07 > SO2: RR 1.036 (1.005-1.068) lag01; 1.048 (1.017-1.081) lag02 >NO2: RR 1.018 (1.002-1.034) lag01; 1.025 (1.010, 1.041) lag02 > O3(8h) 1.012 (1.005, 1.020) lag0 >CO: 1.063 (1.010-1.119) lag01
Kerdkaew 2024 [36]	temperature	Total Nasal Symptom Score (TNSS) questionnaire (employed at 0, 15,30,45,60, 75,90 with excercise ending at 60 min)	Friedman test and Wilcoxon test	-	Patients generally less symptomatic at 25 °C vs 34°C. Effect reaches statistical significance only in the comparison for nasal congestion symptoms 30 minutes after exercise: 0.20 ± 0.41 vs 0.40 ± 0.50 ($p=<0.001$)

Kim 2020 [40]	PM10	AR Symptoms severity and duration	Multiple linear regression analysis	Adjustment for age, sex, atopic status, region, and the time of enrolment	> Severity of symptoms → multiple regression analysis standardized β = 0.104, P = 0.032; >Duration of symptoms → multiple regression analysis standardized β = 0.127, P = 0.01
Li 2024 [18]	PM2.5, O3, SO2, NO2 alone or as mixture	Symptoms severity: SRS (Allergic Rhinitis Symptom Scale), VAS (Visual Analog Scale), RQLQ (Rhinoconjunctivitis Quality of Life Questionnaire).	Bayesian kernel machine regression (BKMR)	Adjustment forn age, gender, BMI, alcohol consumption, usage of other medications; presence of pets, physical activity, ambient temperature, others related to home habits	SRS positive association with the pollutant mixture when all pollutants were ≥70th percentile. SRS, VAS, and RQLQ exhibited approximately positive trend of linear correlations with O3 and SO2 but displayed a non-monotonic correlation with PM2.5[+]
Liu 2020 [19]	SO2, NO2, PM10	Symptoms (including rhinitis symptoms)	Bivariate (model 1) and multivariate (model 2 and 3) logistic regression analyses	Adjustment for age, sex, ownership of residence, breastfeeding, home damp exposures, environmental tobacco smoke, family history of atopy, usage of heating, and season of questionnaire administration	Any rhinitis symptom with each increment of interquartile range >Exposure to SO2 (increment of 6.2 mg/m3) showed no significant effect on rhinitis symptoms >Exposure to NO2 (increment of 3.0 mg/m3): MODEL 1 OR 1.09 (1.03-1.14); MODEL 2 OR 1.06 (1.03-1.10); MODEL 3 OR 1.11 (1.08-1.13) >Exposure to PM10 (increment of 7.6 mg/m3): MODEL 1 OR 1.24 (1.05-1.45); MODEL 2 OR 1.28 (1.06-1.55); MODEL 3 OR 1.32 (1.07-1.63)
Riediker 2001 [20]	NOX, O3, PM10	Symptom severity (0-10) in the morning, afternoon and combined	Multiple linear regression model (Cochrane-Orcutt approach)	-	Effect Estimates on Rhinoconjunctival Symptoms presented as increase in symptom score per 10-fold increase in exposure (two differente models for estimates): > NOx +1.06 (+0.34-1.78); +1.06 (+0.39-1.73) p<0.01 > O3 +1.59 (+0.59-2.59); 1.47 (+0.53-2.42) p<0.01; >PM10 +0.98 (+0.1-1.86) p<0.05; not significant difference in second model
Solé 2007 [13]	CO, SO2, NO2, O3	Rhinitis-related symptoms	Spearman correlation coefficient	nr	Higher O_3, NO_2, or SO_2 levels generally associated with increased risk of rhinitis and rhinoconjunctivitis symptoms. Some centers showed protective associations for specific outcomes**
Stas 2021 [21]	Black carbon (BC), NO2, O3, PM10	Symptom severity score (0–44) via a mobile app. Severe cases corresponded to the top 25% highest scores recorded per patient.	Case cross-over design using conditional logistic regression for estimate effect	Adjustment for dynamic exposure to birch pollen and air pollutants. Stratification for age, sex and region	Severe tree pollen allergy associated with each unit increase in pollutant concentration in the two days before: - O3: aOR 1.504 (1.281–1.766) - PM10: aOR 1.255 (1.007–1.565) - NO2: aOR 1.555 (1.001–2.416)

Sun 2024 [22]	PM10, PM2.5, O3, SO2, NO2, CO	Symptom severity (scoring system ranged 0-3)	Generalized linear mixed models (GLMMs)	nr	change in symptom scores for each unit increase in pollutant concentration for lag 0 to 6 interval[++] : > PM2.5: sneezing +0.072-0.141 (p-values <0.001-0.041); nasal sneezing +0.072-0.141 (p-values <0.001-0.041); nasal blockage +0.068-0.123 (p-values 0.006-0.034) on lags 0 to 4; > PM10 sneezing + 0.052-0.082 (p-values 0.009-0.045) across lags 0 to 3; nasal blockage +0.071-0.081 (p-values 0.002-0.024) on lags 0 to 2. > CO: sneezing +0.122-0.283 (p-values 0.001-0.021) on lags 0 to 2; nasal blockage +0.101-0.236 (p-values 0.008-0.032) on lags 0 to 2; > SO2: nasal blockage +0.236 (p = 0.008) at lag2. sneezing β = +0.093 (p = 0.025) at lag4
Tang 2023 [30]	PM2.5, PM10, CO	Variation in daily outpatients visits for AR	Generalized additive model (GAM) Single and cumulative model	Adjustment for humidity, temperature, day of the week, holiday. Subgroup analyses for age and sex	Variation in daily AR visits per 10 μg/m3 increase in pollutant*: > PM 2.5: RR 1.008 (1.007–1.015) at lag7; 1.026 (1.008–1.413) at lag0 > PM 10: RR 1.007 (1.001–1.013) at lag0 and lag3; 1.014 (1.008–1.021) at lag4; >CO: RR 1.010 (1.003–1.018) at lag2; 1.019 (1.008–1.047) at lag0 Cumulative exposure model (no raw data available): significant results were observed at lag 01–07 for PM10 and PM2.5 and lag 03–07 for carbon monoxide (CO)
Teng 2017 [23]	PM2.5, PM10, O3, CO, SO2, NO2	Variation in daily outpatients visits for AR	Generalized additive model (GAM)	Adjustment for humidity, temperature, wind speed and barometric pressure, time trends, day of the week	Visits associated with 1 SD increase of current day air pollutant concentration: > PM2.5: RR 1.102 (1.055-1.151) > PM10: RR 1.049 (1.008-1.092) > SO2: RR 1.085 (0.982-1.198) > NO2: RR 1.111 (1.058-1.165) > CO: RR 0.977 (0.907-1.053) > O3: RR 0.993 (0.941-1.048)
Tomic-Spiric 2019 [37]	Black carbon (BC)	Emergency Department visits due to exacerbation of AR	Conditional logistic regression models for early (lag0), delayed (lag1-3) and cumulative effects.	Adjustments for temperature, humidity, and air pressure.	ED visits for AR in the following two days for each BC interquartile increase[++] OR 3.20 (1.00–10.18) p= 0.049 (adjusted for temperature, humidity and air pressure the same day); OR 3.24 (1.03–10.22) p=0.045 (adjusted for temperature and humidity on the previous day); OR 3.59 (1.18–10.89) p=0.024 (unadjusted)
Villeneuve 2006 [24]	SO2, NO2, O3, CO; PM2.5; PM 10; Coarse	Daily variation in consultations with physicians AR	Generalized linear models	Adjustment for day of week, holiday, temperature, humidity, levels of allergens,	No significant differences in the number of visits associated with a 25th to 75th percentile increase in air pollution for single-day

	particulate matter (PMcoarse)				measures on the day of consultation and 1–6 days prior to consultation (no raw data available)***
Wang 2013 [25]	NO, NO2, PM2.5, PM10, CO, O3	Variation in daily outpatients visits for AR	Multiple linear regression analysis	Separate analyses for warm and cool days	> Positive correlation between allergic rhinitis and positively PM10 and PM2.5 in children. > Air pollutants such as PM10, PM2.5 O3, CO, NO, NO2, and SO2 tend to show positive correlations with visits for allergic rhinitis when compared with meteorological factors. When controlled for temperature effect, both cool and warm days exhibit positive correlation coefficients (more pronounced for cool days)+
Wang 2019 [33]	PM2.5	Variation in daily outpatients visits for AR	Generalized additive model (GAM)	Adjustment for daily average temperature, relative humidity, day of the week, calendar time, and public holiday.	Variation in AR outpatients visits for 10-µg/m3 increase in PM2.5 concentration: lag0 +0.47% (-0.39;-0.55%) lag1 -0.41%, (-0.48;-0.34%) lag2 -0.45% (-0.51% - -0.39%) lag02 -0.45% (-0.55% - -0.35%)
Wang 2020 [26]	PM2.5, PM10, SO2, NO2, O3, CO	Variation in daily outpatients visits for AR	Generalized additive model (GAM)	Adjustment for temperature, hyumidity, long-term trends, and day of the week	Variation in AR outpatients visits on the current day with 10 µg/m3 increase in pollutant concentrations: >PM2.5: +0.70% (+0.00–1.41%); >PM10: +0.79% (+0.35–1.23%); >SO2: +3.43% (+1.47–5.39%); >NO2: +4.54% (+3.01–6.08%); >CO: +0.07% (+0.02– 0.12%). Effects of PM10, SO2, NO2, and O3 were stronger in the warm season than in the cool season (statistical significance only for SO2 and O3).
Wu 2022 [27]	PM2.5, PM10, NO2, SO2	Variation in daily outpatients visits for AR	Generalized additive model (GAM)	Adjustment for temperature, humidity, long-term trends, day of the week, holiday	Increase in AR outpatients visits for each 10 µg/m3 increase in pollutant concentration: > PM2.5 +1.24% (95%CI: 0.69%, 1.78%); > PM10: +0.79% (95%CI: 0.43%, 1.15%); > NO2: +3.05% (95%CI: 1.72%, 4.40%); > SO2: +5.01% (95% CI: 1.18%, 8.96%).
Yang 2022 [28]	PM2.5, PM10, SO2, NO2, CO, O3	Variation in additional unexpected visits for AR	Distributed lag nonlinear model (DLNM) and generalized additive model (GAM)	Adjustment for temperature, pressure, humidity, long-term trends, seasonal trends, day of the week effect, and holiday effects	Unexpected AR visits with each 10 µg/m3 increase in pollutant concentration (lowest and highest significant values reported)++: >O3: RR 1.066 (1.008–1.127) lag0, 1.057 (1.005–1.112) lag1 >PM2.5: RR 1.071 (1.002–1.141) on lag11; 1.083 (1.011–1.160) on lag 15

Zhang 2011 [29]	PM10, SO2,NO2	Variation in daily outpatient visits for AR	Generalized model (GAM	additive	Weather conditions, day of the week	Increase in AR outpatients visits for each 10 µg/m3 increase in pollutant concentration 10 ug/m3 increase >PM10: RR 1.0073 (1.0066–1.0080) >SO2: RR 1.0010 (1.0005–1.0014) >NO2: RR 1.0512 (1.0483–1.0542)

Table 2. Included studies' definitions of exposure, outcomes, statistics and results.
AR: Allergic Rhinitis; nr: not reported;
* only lowest and highest statistically significant results reported;
+ relevant findings reported as results are presented in graphs in the article;
**: OR not reported due to lengths of results (results calculated for each enrolled center using the center with the lowest concentration of pollutant as reference standard);
++: due to length of results only statistically significant results are reported
***: no raw data available, only statistically significant findings are reported

5. DISCUSSION

This systematic review summarizes the current evidence on the short-term effects of outdoor air pollutants on the control of AR symptoms. Overall, exposure to fine particulate matter ($PM_{2.5}$) has consistently been associated with exacerbation of AR in both adults and children. Likewise, time-series and case-crossover studies have shown that short-term increases in PM_{10} are linked to modest yet statistically significant rises in AR morbidity. Cross-sectional and retrospective analyses suggest that chronic exposure may further aggravate symptom severity and duration, reinforcing the contribution of particulate matter as a key driver of allergic airway disease. Evidence also points to O_3 as an additional factor in the short-term worsening of symptoms, particularly during warm or high-photochemical periods. Although associations with NO_2 were not uniformly significant, the overall trend across study designs supports a link between NO_2 exposure and the intensification of AR symptoms and healthcare use, especially in urban areas and colder seasons. Short-term SO_2 exposure was similarly related to increased incidence and symptom aggravation, with the strongest effects seen within a few days of exposure and among younger or urban populations. In addition, CO appeared to play a more modest but consistent role in the short-term exacerbation of AR, particularly under warm climatic conditions.

When compared with previous literature on airway allergy and asthma, these findings are largely concordant. Earlier reviews have identified particulate matter and nitrogen oxides as reproducible triggers of airway inflammation[40, 41], and the present synthesis confirms their relevance in AR exacerbations. The seasonal pattern observed, stronger effects during warmer more photochemical periods, supports the hypothesis that oxidative pollutants such as O_3 and NO_2 amplify allergic responses in the presence of high pollen loads and intense solar radiation. In contrast, long-term exposure remains poorly studied, representing an important gap relative to existing asthma research.

Several biological mechanisms may account for these associations. Air pollutants can induce oxidative stress and epigenetic changes in the airway mucosa [42], thus compromising epithelial integrity [43–48], and promoting local inflammatory cascades orchestrated by thymic stromal lymphopoietin, IL-25, IL-33, IL-4 and IL-13 [49–53]. These processes enhance allergen penetration to the lamina propria and facilitate a T2 skewed immune activation towards allergens [54]. On the other hand, outdoor pollution also increases the number of pollen grains and the allergen content per grain produced by allergenic plants, helping explain the observed synergy between pollution peaks and

pollen exposure. Finally, outdoor pollution can nitrate environmental allergens, thus enhancing their capacity to trigger IgE immune responses. There is limited evidence that climate factors, particularly extreme temperatures, may further influence airway permeability [55, 56]. In contrast, there is significant evidence on how global warming extends the pollination periods of allergenic species and promotes the colonization of ecological niches by invasive species or releasing vast amount of allergens (thunderstorm related asthma).

Despite the broad consistency of the findings, considerable heterogeneity persists across studies. Variations in exposure to pollutants and pollens, outcome definitions, and statistical adjustment for confounders reduce comparability and may explain some null results. Most studies relied on fixed monitoring stations rather than personal exposure data, and cross-sectional designs often lacked temporal depth. Moreover, the scarcity of longitudinal and biomarker-based research limits causal interpretation and the understanding of individual susceptibility.

From a public-health perspective, these results highlight the importance of integrating air-quality management and climate-adaptation strategies to mitigate the growing burden of allergic diseases. Future research should prioritize multipollutant and longitudinal designs, refined exposure metrics, and patient-level data. Clinically, identifying pollution peaks as risk periods could inform patient education and tailored preventive interventions.

6. CONCLUSION

The evidence from our systematic review supports a coherent link between short-term exposure to outdoor pollutants and uncontrolled symptoms in AR.

Such findings underscore the need for continued investigation in this field to guide future environmental health directed policies.

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