A systematic review and meta-analysis of short-term relationship between ambient air pollution and psoriasis

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Abstract

Exposure to air pollution is emerging as a risk factor for psoriasis, but with conflicting findings. The objectives of this meta-analysis were to investigate and summarize the study on the association between short-term exposure to air pollution and psoriasis. We searched the Embase, PudMed, Web of Science and Cochrane Library for indexed publications up to March 17, 2023. We extracted quantitative measures for air pollution effects on psoriasis with acute effect (single lag: lag 0 or lag 1) and short-term cumulative lag effects (cumulative lags: lag 0-5 or lag0-7 days). The random-effect model was the primary approach used to calculate the excess risk percentage (ER%) and confidence intervals (CI) for particulate matter (PM) with diameter ≤ 10 μm (PM10) and ≤ 2.5 μm (PM2.5), nitrogen dioxide (NO2), sulfur dioxide (SO2) and ozone (O3). For acute effect, ER% for each 10 μg·m⁻³ increase of pollutants was 2.0% (95% CI: 0.4%, 3.7%) for NO2. For the short-term cumulative lag effects, ER% for each 10 μg·m⁻³ increase of pollutants was 3.0% (95% CI: 0.2%, 5.9%) for NO2, 1.2% (95% CI: 0.3%, 0.21%) for PM10 and 0.2% (95% CI: 0.2%, 0.3%) for PM2.5. The results of subgroup analysis suggested that female may be more sensitive to PM2.5 and compared with the warm season, the effects of NO2 and PM2.5 on psoriasis were more significant in the cold season. Systematic reviews have shown that short-term exposure to ambient air pollutants (NO2, PM2.5, PM10) are associated with an increased risk of psoriasis.

Keywords: Air pollutants, Skin disease, Immune-mediated disease, Short-term exposure
1 INTRODUCTION

Many studies have shown that air pollution has harmful consequences on human health, including cardiovascular diseases (Hamanaka and Mutlu, 2018), respiratory diseases (Olive et al., 2021), and allergic diseases (Hassoun et al., 2019). According to statistics, deaths due to air pollution accounted for 11.6% of global deaths in 2019 (Hu et al., 2023). Skin, the largest and outermost organ of the human body, is more susceptible to air pollution (Fussell and Kelly, 2020). Many studies have shown that air pollution can contribute to a range of skin problems, such as acne, hyperpigmentation, atopic dermatitis, psoriasis and so on (Ngoc et al., 2017; Hsiao et al., 2022; Yue et al., 2022). Air pollution is playing an increasingly important role in our most common skin conditions (Roberts, 2021).

Psoriasis is a systemic, immune-mediated disease characterized by chronic inflammatory manifestations of the skin and joints (McCall, 2011). The prevalence of psoriasis is high, and it recurs periodically. In severe cases, it can lead to disfigurement and many other comorbidities (such as cardiovascular disease, arthritis, depression, etc.), significantly impacting patients’ health and quality of life (Boehncke and Schön, 2015). Current research evidence shows that many risk factors are related to the pathogenesis of psoriasis, such as immune, environmental and genetic factors (Kamiya et al., 2019; Grželj and Sollner Dolenc, 2020). Recent studies have reported that many air pollutants may cause skin inflammation, and increasing the risk of psoriasis (Ryu et al., 2019; Cheng et al., 2020; Park et al., 2022). Additionally, research found that short-term exposure to NO2 can cause alterations to the skin's surface, particularly a disruption in the function of the epidermal barrier (Eberlein-König et al., 1998). Several studies
have concluded that alterations in DNA methylation, which were identified shortly after daily exposure to air pollution, are the processes implicated in the relationship between air pollution and psoriasis (Zhou et al., 2016; Li et al., 2018).

Psoriasis is increasing in prevalence and incidence in adults and children of all ages, affecting approximately 100 million people worldwide (Mehrmal et al., 2021). Summarizing the impact of short-term air pollution on psoriasis is of great necessity. However, the association between the two is still unclear (Puri et al., 2017). The results of several recent studies in this regard are inconsistent (Lan et al., 2022; Park et al., 2022; Wang et al., 2022a; Wu et al., 2022). For instance, certain scholars discovered a statistically significant connection between air pollution and psoriasis (Chao et al., 2021; Lan et al., 2022; Wang et al., 2022c; Wu et al., 2022; Fadadu et al., 2023), while others found no correlation between the two (Lee et al., 2022). Hence, a systematically review is needed.

To supply reliable data to researchers, this study systematically assessed the short-term impact of air pollutants on psoriasis using psoriasis-related outpatients or hospitalizations as the primary endpoint.

2 METHODS

2.1 Data sources and search strategy

We did a systematic review and meta-analysis of articles that examined the effect of outdoor air pollution on psoriasis outpatient dermatological visits and were published up through March 17, 2023. This review was based on PRISMA 2020 statement (Page et al., 2021). These studies were indexed in Embase, PudMed, Web of Science, and Cochrane Library. Utilizing pertinent
terms, search queries tailored to the database were created (see supplement material). The search was restricted to English documents.

2.2 Study selection

The collected records were examined individually by two reviewers (WY and XM). If there was a disagreement, a third independent reviewer (PL) was requested to assist in reaching a judgment. EndNote X9 was used to screen the retrieved material. First, we deleted duplicate literature by using the ‘detect duplicate literature’ program. Manual screening will be done on duplicate material that EndNote is unable to identify. After that, all the titles and abstracts are screened, with some relevant articles selected for full-text review. Our review includes articles that satisfied the following standards: (1) studies examining the short-term effects (within 0–7 days) of ambient air pollutants on psoriasis; (2) studies reporting estimates for the general population; and (3) studies providing statistical data for the effects (relative risk (RR) or excess risk (ER) and their 95% CI).

The following studies were excluded from consideration: (1) studies estimating occupational exposure without quantifying exposure; (2) studies ignoring the short-term effects of air pollution on psoriasis; (3) studies not including psoriasis as an outcome; (4) studies using animals; (5) studies lacking specific diagnostic criteria; and (6) studies for which the data could not be obtained after screening supplemental material.

2.3 Data extraction

Two reviewers (WY and MX) separately gathered information on the impact of air pollution on psoriasis from each study and entered it into a uniform Excel file. The following details were noted: (1) citation details (title, first author, and publication year), (2) study context (location,
country, and study period), (3) design of the study (time series or case-crossover analyses, and so on), (4) daily mean number of events or total events, (5) measurement of exposure, air pollutant level and definition of health result (6) for a time-series study, risk ratios derived from either the single or cumulative lag model, and (7) final data point. In order to obtain additional information not included in the report and supplementary documents, we also got in touch with the study's authors. Any disagreements were settled with the assistance of a third author.

2.4 Risk of bias assessment

The World Health Organization's (WHO) domain-based ROB assessment approach was utilized to evaluate the risk of bias. We will make sure that two members (WY, ZH) independently complete the risk of bias assessment for every eligible research using the assessment tool for systematic reviews informing WHO global air quality standards (WHO., 2020). For included studies, the risk of bias for six areas, including confounding, selection bias, exposure assessment, outcome measurement, missing data and selective reporting, was assessed using the tool as mentioned above. Each domain comprised 1-3 subdomains. The risk of bias was assessed as “low”, “moderate” or “high”, and presented graphically. Discussion with a third independent reviewer (PL) resolved disagreements in the assessment.

2.5 Statistical analysis

Studies using either time series or case-crossover analyses were eligible for meta-analyses. We estimated pooled acute effects (lag0 or lag1) and short-term cumulative lag effects (lag0-5 or lag0-7) separately for different pollutants in the short term. For the estimates of acute effects, we used the shortest lag in the pooled estimations from studies that reported multiple lags. If no single lag estimate is provided, a cumulative lag (e.g., lag 0-1 days) is used. All relative risks (RR)
were normalized to a concentration increment of 10 µg·m\(^{-3}\) for PM\(_{2.5}\), PM\(_{10}\), NO\(_2\), SO\(_2\), O\(_3\), and CO in order to combine the effects. Different units of air pollution were converted to the same unit (µg·m\(^{-3}\)) for each pollutant. We converted ER to RR by applying the equation:

\[ RR = 1 + ER \]  

(1)

ER is the percentage change in daily outpatient visits for psoriasis reporting in the research (Nhung et al., 2017). For research reporting RR\(_U\) per U units rather than a reference level (such as 10 units), the RR\(_{\text{standardised}}\) was figured out by:

\[ RR_{\text{standardised}} = \frac{RR_U}{U} \]  

(2)

U is the increment utilized to evaluate the effects in the initial study (Nhung et al., 2017).

We used the Cochrane Q test to measure heterogeneity between studies in the analyses and quantified with the \(I^2\) statistic, where \(I^2\) values of 25 %, 50 %, and 75 % represent low, moderate, and high degrees of heterogeneity, respectively. To determine whether certain studies had an impact on the pooled estimates, we repeated the meta-analysis, omitting each study one at a time. We evaluated potential publication bias utilizing Egger’s test while used funnel plots to visualize asymmetry.

A random-effects model was used as the primary method for pooled effect estimation since our meta-analysis comprised various sample populations, which could capture potential variation in true effect across studies. In addition, a fixed-effect model was used as an alternative approach when the heterogeneity across included studies was less than moderate (\(I^2<50\%\)). We further analyzed results by subgroup according to gender, season and age.
Statistical analysis was performed using Stata version 16.0. Summary statistics are presented as the percentage change in psoriasis outpatients (ER%) with 95% CIs for an increase of 10 µg·m⁻³ in pollution concentration. Results were deemed statistically significant at P < 0.05.

3 RESULTS

3.1 Study characteristics

As shown in Fig. 1, 664 studies (210 from Embase, 203 from PubMed, 6 from Cochrane, and 245 from Web of Science) were found. After removing 101 duplicates, we screened titles and abstracts of 563 records. The full texts of 13 articles were selected for further evaluation. We further excluded two studies not providing quantitative results for the effects (Bellinato et al., 2022; Lee et al., 2022), three studies not reporting short term effects (Adami et al., 2022; Lowe et al., 2022; Park et al., 2022) and one studies not including psoriasis (Fadadu et al., 2021). Finally, we selected 7 studies in our meta-analysis (Faustini et al., 2018; Chao et al., 2021; Lan et al., 2022; Wang et al., 2022a; Wang et al., 2022c; Wu et al., 2022; Fadadu et al., 2023)(Fig.1).

Table 1 provides a list of the study characteristics used in this study. Those studies were carried out in China, the United States and Italy. Five of these studies (Chao et al., 2021; Lan et al., 2022; Wang et al., 2022a; Wu et al., 2022; Fadadu et al., 2023) employed a time-series study design, while two used a case-crossover approach (Faustini et al., 2018; Wang et al., 2022c). Only one study was adjusted for influenza peaks (Faustini et al., 2018) (Table S1), whereas the seasonality, historical trends, and meteorological elements like temperature and relative humidity were taken into account in six studies. In one study, visits to psoriasis clinics after California wildfires were
correlated with increases in PM$_{2.5}$ (Fadadu et al., 2023). Six studies defined the outcome by using the International Classification of Diseases (ICD) version 9 (codes 696.1) or ICD10 (codes L40). Each study used exposure data from a fixed monitoring location. Table S2 displays the average concentrations of several pollutants across the research period as well as the lag times between exposure and endpoint assessments.

3.2 Risk of bias assessment

Figure 2 displays the findings of the Risk of Bias (RoB) assessment based on the modified WHO standards. Overall, six studies were of moderate quality, and one study was of good quality. In the domains of outcome measurement and missing data, all studies were rated as low RoB. Due to insufficient adjustment for important potential confounders as influenza peaks, four studies were given a moderate RoB in the confounding domain. The study in the domain of selection bias and exposure assessment was rated as moderate because “Chinese Guidelines for the Diagnosis of Psoriasis” served as the inclusion criterion for patients with psoriasis and the number of fixed monitoring stations was not reported (Wang et al., 2022a).

3.3 The acute effect of air pollution on psoriasis by meta-analysis

Fig. 3 displays the effect estimates and forest plots from the random-effects meta-analyses for several types of air pollution. The acute effect (lag0 or lag1), excess risk percentage (ER%) per 10 µg·m$^{-3}$ increase of pollutants was 2.0% (0.4%,3.7%) for NO$_2$ (Fig.3). No significant association was found between PM$_{2.5}$ (ER%=0.1% (-0.4%,0.6%)), SO$_2$ (ER%=2.3% (0.0%,4.7%)), O$_3$ (ER% = -0.2% (-1.4%,1.0%)) and psoriasis (Fig.3). When one study (Wang et al., 2022a) was excluded from the meta-analysis (Fig. S3), the association between PM$_{2.5}$ and psoriasis was significant (ER%=0.3%, p<0.01). Considering the scant number of studies, no
meta-analysis was done for CO, and the available studies did not show that CO had a significant impact on psoriasis outpatient visits. (Lan et al., 2022). However, P values for heterogeneity (P < 0.001 for PM$_{2.5}$, NO$_2$ and O$_3$) and I$^2$ values (74.7 %, 87.6 % and 88.8 % for PM$_{2.5}$, NO$_2$ and O$_3$, respectively) showed that the outcomes of the meta-analysis that were included showed high heterogeneity.

3.4 The short-term cumulative lag effects of air pollution on psoriasis by meta-analysis

Fig. 4 shows the forest plots of the short-term cumulative lag effects of air pollution on psoriasis by meta-analysis using the random-effects model. For the short-term cumulative lag effects (lag0-5 or lag0-7), NO$_2$ (ER$\%$=3.0$, 95\% CI: 0.2\%—5.9\%; I$^2$=67.5$\%$) and PM$_{10}$ (ER$\%$=1.2$, 95\% CI: 0.3\%—2.1\%; I$^2$=0.0$\%$) was significantly related with an increased possibility of psoriasis(Fig.4). As shown in Fig.S4, the association of PM$_{2.5}$ with the likelihood of psoriasis was significant according to the meta-analysis using the fixed-effects model (ER$\%$=0.2$, 95\% CI: 0.2\%—0.3\%; I$^2$=39.0$\%$). There was no significant association between SO$_2$ (ER$\%$=10.3$, 95\% CI: 0.0\%—21.8\%; I$^2$=58.0$\%$), O$_3$ (ER$\%$=0.2$, 95\% CI:-0.1\%—0.5\%; I$^2$=62.6$\%$) and risk of psoriasis (Fig.4). The short-term cumulative lag effects of NO$_2$, SO$_2$ and O$_3$ showed moderate heterogeneity and PM$_{2.5}$ showed low heterogeneity. Considering the scant number of studies, no meta-analysis was conducted for CO, and the available studies did not show a significant correlation between CO and psoriasis outpatient visits (Lan et al., 2022).

3.5 Subgroup analyses

In the case of PM$_{2.5}$, NO$_2$, and SO$_2$, we conducted subgroup analyses based on age, gender, and season. When age-stratified the comparison, as shown in Fig. 5(a), the relationship between air pollution and the likelihood of incident psoriasis was consistent in the younger ($\leq$65 y) patients
and the older ones (>65 y). Additionally, a gender-based analysis revealed that female patients were more susceptible to PM$_{2.5}$ (ER = 0.4%, 95% CI: 0.3%—0.4%) than males (ER = 0.1%, 95% CI: -0.3%—0.4%) (Fig. 5(b)). In addition, when the comparison was stratified by the season, the relationship between PM$_{2.5}$ and the incidence of psoriasis was inconsistent in the cold season and warm season. In the cold season, an increase of 10 µg·m$^{-3}$ in PM$_{2.5}$ were significantly related to an increase of 0.3% (0.2%, 0.4%) in outpatient visits to psoriasis clinics, while in the warm season, the relationship was not statistically significant (ER = 0.6%, 95% CI: -0.1%—1.3%). Compared with the warm season (ER = 1.7%, 95% CI: 0.7%—2.6%), the impact of NO$_2$ on psoriasis was more significant in the cold (ER = 0.9%, 95% CI: 0.2%—1.6%) (Fig. 5(c)).

3.6 Sensitivity analysis and publication bias

Egger's tests and funnel plot analysis of the studies (Table. S3 and Fig. S1) showed that the risk of publication bias was low in both the acute effect and the short-term cumulative lagged effects of pollutants on psoriasis. Due to a limited amount of research, sensitivity analysis and publication bias tests were performed only for PM$_{2.5}$ and NO$_2$. The sensitivity analysis results are presented in Supplementary Fig. S2. Fig. S2(c) shows that excluding one study (Wang et al., 2022a) from the analysis of the acute effect of PM$_{2.5}$ greatly impacts on the results, and the meta-analysis results are not robust. When this study was excluded from the meta-analysis (Fig. S3), the heterogeneity was significantly reduced, and the association between PM$_{2.5}$ and psoriasis was significant (ER% = 0.3%, P<0.01). According to sensitivity analysis of the short-term cumulative lag effects of NO$_2$, the results of the meta-analysis were susceptible to considerable change as a result of the small number of studies and lack of robustness (Fig. S2(b)). However,
the sensitivity analysis of the short-term cumulative lag effects of PM$_{2.5}$ and the acute effect of NO$_2$ showed that the pooled estimates remained stable (Fig. S2(a), Fig. S2(d)).

4 DISCUSSION

In this meta-analysis, researchers used the findings of 7 separate epidemiological studies to evaluate the short-term effects of air pollution on psoriasis. We discovered that elevated levels of NO$_2$, PM$_{2.5}$, and PM$_{10}$ may raise the chance of developing psoriasis. Exposure to NO$_2$ and PM$_{2.5}$ presented acute effects and short-term cumulative lag effects, while exposure to PM$_{10}$ showed short-term cumulative lag effects. Particulate matter disrupts the keratinocyte differentiation, and upregulates genes associated with inflammation and psoriasis, and NO$_2$ could contribute to skin microbiota dysbiosis (Cheng et al., 2020; Janvier et al., 2020), which would increase the risk of psoriasis. The impacts of air pollution on psoriasis are delayed and cumulative because air pollutants can enter the skin and mucosa, collect there, and circulate in the circulation to cause inflammation (Pan et al., 2015; Wang et al., 2022a). Additionally, various research has examined the potential molecular biological processes of ozone in psoriasis and reported on the use of ozone therapy in the treatment of psoriasis (Gao et al., 2020; Zeng et al., 2020; Liu et al., 2022). However, this meta-analysis found no significant benefits of ozone in reducing the risk of psoriasis. Only a few studies in this study may help explain this. Therefore, more investigation is required to completely comprehend the relationship.

There was a significant level of heterogeneity seen in this meta-analysis. To measure study heterogeneity, the subgroup analyses of PM$_{2.5}$, NO$_2$, and SO$_2$ were carried out. Previous studies
showed that psoriasis exists seasonally (Vinnik et al., 2017; Jensen et al., 2022), and also be affected by age and gender (Duvetorp et al., 2021). Therefore, we performed subgroup analyses for PM$_{2.5}$, NO$_2$, and SO$_2$ according to age, gender, and season.

In comparison to males, females showed greater correlations between PM$_{2.5}$ and psoriasis, according to gender-subgroup analyses. The possible reasons for this result are as follows. Female patients with psoriasis are sensitive to changes in air pollutant concentrations, possibly because air pollutants can affect estrogen regulatory pathways (Wenger et al., 2009). Due to symptoms, females with psoriasis are more prone to feel anxiety and sadness, which increases the frequency of hospital visits as the condition develops (Duvetorp et al., 2021).

Compared with the warm season, the effects of NO$_2$ and PM$_{2.5}$ on psoriasis were more significant in the cold season. Several studies have indicated that climate change and exposure to sunshine can affect the prevalence of psoriasis (Vinnik et al., 2017; Jensen et al., 2022). Some studies have found sunlight is the main source of cutaneous vitamin D production (Zheng et al., 2021). Low level of vitamin D cannot prevent skin lesions from inhibiting the proliferation and inducing differentiation of keratinocyte (Bikle, 2011). The sunshine time in the cold season is shorter than in the warm, which aggravates psoriasis patients. In addition, exposure to low humidity and low temperatures can lead to reduced skin hydration, resulting in impaired skin barrier function (Denda et al., 1998). Thus, the decrease in temperature and humidity in the cold season is also a significant element influencing the aggravation of psoriasis patients (Pascoe and Kimball, 2015; Chen et al., 2017). However, the warm season's wet weather aids in moisturizing the skin and easing psoriasis symptoms.
Previous studies have shown that age is also essential (Duvetorp et al., 2021). However, we observed roughly consistent results for age. Because the age distribution varied among the studies, we pooled the results for only the two age groups (≤65y and >65y). It is necessary to take care when interpreting the pertinent results. To ascertain whether the assessment criteria have an influence on the results of the analysis, we need to do further research and incorporate more papers.

The heterogeneity may be due to differences in study populations, air pollutant exposure measurements, and outcome ascertainment methods. In analyzing the acute effect of PM$_{2.5}$, the differences in the definition of psoriasis patients between the Wang et al. Study (Wang et al., 2022a) and other studies are an important factor of heterogeneity in estimating the effects. Even though the majority of the pollutants in this study showed significant heterogeneity, the effects were still positive when we stratified the analyses for NO$_2$ and PM$_{2.5}$ based on interaction variables including age, gender, and season.

Although the precise methods by which air pollution might worsen psoriasis are unknown, recent scientific research has offered several possibilities. According to research, air pollution may aggravate psoriasis by altering the skin microbiome, impairing the integrity of the skin barrier, triggering inflammatory responses, and increasing oxidative stress (Martic et al., 2022). The skin microbiome has been demonstrated to be altered by air pollution, and this impact is linked to dysbiosis in psoriasis (Janvier et al., 2020; Gough et al., 2022; Noh et al., 2022). One study has highlighted a significant deleterious effect of NO$_2$, particularly for human skin commensal bacteria S. capitis MFP08 and C. tuberculostearicum CIP102622 (Janvier et al., 2020).
Second, air pollution may impair the skin's protective barrier and cause inflammatory reactions that can lead to the onset and worsening of allergic illnesses like psoriasis. Skin barrier failure was brought on by PM-induced tumor necrosis factor-α (TNF-α), which decreased filaggrin (FLG) levels in the skin (Kim et al., 2021). Exposure to air pollution reduces the function of the epidermal barrier by triggering several inflammatory pathways, altering T cell differentiation, activating the nucleotide-binding oligomerization domain-like receptor family pyrin domain-containing protein 3 (NLRP3) inflammasome, and increasing the release of pro-inflammatory cytokines (Park et al., 2018; Rehman and Koh, 2022). Air pollutants have been shown to increase the number of reactive oxygen species (ROS) in keratinocytes, which can cause inflammation, aging, and a reduction in the skin's capacity to retain moisture (Teng et al., 2021). The study focused on air pollutants that can cause skin barrier dysfunction and set off a chain reaction of inflammatory reactions by causing the production of reactive oxygen species, pro-inflammatory cytokines, and matrix metalloproteinases. Additionally, psoriasis-related genes' expression may be influenced by air pollution. For instance, experimental research in mice revealed that exposure to air pollution might hasten the onset and progression of psoriasis by activating the AKT (protein kinase B)/mTOR (mammalian target of rapamycin)/HIF-1α (hypoxia-induced factor-1α) signaling pathway in a Keratin 17 (KRT17)-dependent manner (Wang et al., 2022b). According to a study on human embryonic stem cells, particulate matter disturbed keratinocyte development and increased expression of genes linked to inflammation and psoriasis (Cheng et al., 2020; Dong et al., 2020).
To our knowledge, this is the first systematic review and meta-analysis to thoroughly summarize the association between air pollution and psoriasis. We comprehensively analyzed the acute effect and short-term cumulative lag effects of multiple air pollutants on psoriasis clinic visits. However, there are several restrictions that have to be taken into account. First, we did not perform subgroup analyses of other air pollutants due to the limitations of the available literature. Second, rather than capturing individual exposures, environmental data from permanent monitoring sites reflect the population's average level of environmental exposure. Fixed-site monitoring data could not accurately reflect ambient concentrations in the regions where people with psoriasis dwell since spatial variance differs between contaminants. Third, when trying to generalize our findings, the representation needs to be improved, the majority of the included studies were carried out in China, and the short-term effects on populations in other countries needs to be better studied. In addition, the majority of these studies made adjustments for weather variables such temperature, humidity, and seasonality (Table. S1), but just one research made adjustments for flu outbreaks. This can lead to unexpected confusion. Finally, we searched a limited database and may not have been able to identify all relevant studies. There is limited literature on the inclusion of each pollutant, especially PM$_{10}$, SO$_2$ and O$_3$. Although the short-term effects of some pollutants are not significant in the results of this study, the discussion should be more cautious, and more relevant data should be provided in subsequent studies for verification. Despite these limitations, we believe that this analysis provides an informative and up-to-date summary of the association between air pollution and psoriasis.

5 CONCLUSIONS
Our systematic review showed that short-term exposure to ambient air pollutants (NO₂, PM₂.₅, PM₁₀) is associated with an increased risk of psoriasis. For acute effect, the excess risk percentage for each 10 µg·m⁻³ increase of pollutants was 2.0% (95% CI: 0.4%, 3.7%) for NO₂. For the short-term cumulative lag effects, the excess risk percentage for each 10 µg·m⁻³ increase of pollutants was 3.0% (95% CI: 0.2%, 5.9%) for NO₂, 1.2% (95% CI: 0.3%, 0.21%) for PM₁₀ and 0.2% (95% CI: 0.2%, 0.3%) for PM₂.₅. The associations of air pollutants varied with gender and season. Cold weather can worsen the effects of exposure to air pollutants on psoriasis. Females exposed to PM₂.₅ are more likely to develop psoriasis than males. The basic decrease of air pollutant concentrations is the most crucial step in order to successfully minimize the influence of air pollutants on psoriasis, in addition to concentrating on vulnerable groups and seasonal factors. To better comprehend the relationship between air pollution and psoriasis in other parts of the world, further studies can be conducted on populations in regions such as Africa.

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DISCLAIMER
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1. Main characteristics of studies included in the meta-analysis.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Location</th>
<th>Period</th>
<th>Study design</th>
<th>Exposure</th>
<th>Data source of outcomes</th>
<th>Number of events</th>
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<td>Fadadu, R. P.</td>
<td>2023</td>
<td>U.S.</td>
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<td>Time-series</td>
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<td>an academic medical center in San Francisco</td>
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<td>China</td>
<td>2015-2019</td>
<td>Time-series</td>
<td>PM$<em>{10}$,PM$</em>{2.5}$,SO$_2$,NO$_2$,CO, O$_3$</td>
<td>the Department of Dermatology, Wuhan Union Hospital</td>
<td>13536</td>
<td>outpatient visits</td>
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<td>Wang, Yu</td>
<td>2022</td>
<td>China</td>
<td>2014-2020</td>
<td>case-crossover</td>
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<td>the Dermatology Hospital of Southern Medical University, Guangzhou, China</td>
<td>62305</td>
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<td>China</td>
<td>2015-2018</td>
<td>Time-series</td>
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<td>China</td>
<td>2015-2019</td>
<td>Time-series</td>
<td>PM$_{2.5}$,SO$_2$,NO$_2$,O$_3$</td>
<td>the First Affiliated Hospital of the University of Science and Technology of China and the First Affiliated Hospital of Anhui Medical University</td>
<td>54064</td>
<td>outpatient visits</td>
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<td>Italy</td>
<td>2003-2014</td>
<td>case-crossover</td>
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<td>China</td>
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<td>PM$_{2.5}$</td>
<td>the Beijing Medical Claim Data for Employees database</td>
<td>500266</td>
<td>outpatient visits</td>
</tr>
</tbody>
</table>

$^a$ Each study used exposure data from fixed monitoring station (The number of monitoring stations is shown in Table S1).

$^b$ For studies that did not provide the total number of occurrences, total events were determined by multiplying the daily mean number of incidents by the number of days in the period.
Fig. 1. Flowchart of literature screening process.
Fig. 2. Figure of risk of bias assessment
Fig. 3. Forest plot for the acute effect of air pollutants on psoriasis.

Relative risks (RRs) are based on an increase in air pollution of 10 µg/m³. The I² statistic shows the percentage of overall impact estimate variability that is related to heterogeneity. $I^2$ has a range of 0 to 100%, where 0 to 25%, 25% to 50%, and above 75%, respectively, reflect low, moderate, and high heterogeneity.
**Fig.4.** Forest plot for the short term cumulative lag effects of air pollutants on psoriasis.
Fig. 5. The lag 1 day effect of air pollution on psoriasis, stratified by age(a), gender(b), season(c).