

Review

The Effects of Elevated Air Quality Index and Air Pollution on the Health of Residents of Kuwait: A Guided Narrative Review

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Abstract

Kuwait experiences persistently high levels of air pollution driven by industrial emissions, transportation, oil-related activities, and frequent desert dust storms. This study aims to synthesize and critically evaluate the available evidence on the relationship between air pollution, Air Quality Index (AQI), and health outcomes in Kuwait using a guided narrative review approach. A guided literature search identified 26 peer-reviewed studies published between 2014 and 2026 about Kuwait air pollution, which were assessed for methodological characteristics, pollutant types, health outcome categories, and vulnerable populations. The most frequently examined pollutants were particulate matter (PM_{2.5}: 69%; PM₁₀: 38%), followed by NO₂ (23%), multi-pollutant and AQI-based (19%), O₃ (12%), SO₂ (12%), VOCs and PAHs (8%). Health-related investigations most commonly addressed mortality and respiratory morbidity, while cardiovascular, metabolic, biomarker-based, and cancer-related outcomes were less frequently represented. Among studies reporting direct health outcomes, elevated PM_{2.5} exposure was generally associated with increased risks of respiratory hospitalizations, cardiovascular events, and all-cause mortality. Susceptible populations identified across the literature include children, older adults, individuals with pre-existing chronic conditions, and outdoor workers, who may experience higher exposure levels and greater health vulnerability. However, a substantial proportion of the included studies focused primarily on exposure characterization or pollutant modeling without direct assessment of health outcomes. These studies nonetheless indicate consistently elevated pollutant levels and seasonal variability, which may plausibly contribute to population health risks. Overall, while the available Kuwait-specific evidence suggests potential adverse health effects linked to air pollution, the strength of direct epidemiological evidence remains limited. Important gaps persist, including the scarcity of long-term cohort studies, limited multi-pollutant analyses, and insufficient integration of AQI categories with health outcomes. These limitations highlight the need for more robust and longitudinal research to better quantify health risks and inform public health policy in Kuwait.

Keywords: particulate matter (PM_{2.5} and PM₁₀); air pollution; Kuwait; air quality index (AQI); desert dust; environmental health



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1. Introduction

Dust storms are a frequent and often intense environmental feature across the Arabian Peninsula and Gulf region [1]. Their occurrence varies by location and season, but desert countries such as Kuwait experience them regularly and sometimes at very high intensity [2]. Kuwait, in particular, faces a unique combination of natural and human-made pollution sources. Kuwait City records one of the highest dust deposition rates in the world, around 270 tons per km² annually, while the country's large oil production and petrochemical industries further contribute to deteriorating air quality [3].

Recent evidence highlights the extent of this issue. Between 2017 and 2019, about 74% of days in Kuwait City and up to 90% of days near petrochemical facilities exceeded the World Health Organization (WHO) daily guideline for fine particulate matter (PM_{2.5}) [4]. More broadly, Kuwait has been identified as one of the most polluted countries in Southwest Asia, largely due to the combined effects of desert dust storm, industrial activity, power generation, and traffic emissions [5]. Key pollutants such as PM_{2.5}, PM₁₀, nitrogen dioxide (NO₂), and sulfur dioxide (SO₂) frequently exceed WHO air quality limits [6], while overall dust deposition levels remain among the highest globally [7].

The health impacts of air pollution are well established worldwide, with extensive evidence from studies conducted in North America, Europe, and Asia [8–10]. However, despite the high exposure levels, epidemiological research in Southwest Asia countries like Kuwait remains relatively limited [11,12]. This lack of localized evidence makes it challenging for policymakers and public health authorities to develop guidelines that accurately reflect the region's specific environmental conditions and health risks.

Air pollution consists of a mixture of harmful substances, including particulate matter (PM_{2.5} and PM₁₀), carbon monoxide (CO), sulfur dioxide (SO₂), ozone (O₃), and nitrogen dioxide (NO₂), all of which can negatively affect human health and quality of life. Rapid urbanization, industrial growth, and increased energy consumption have further intensified pollution levels in many developing regions. According to the WHO, environmental pollution may contribute to around 25% of deaths in developing countries [13]. Long-term exposure has been linked to a wide range of health problems, particularly respiratory and cardiovascular diseases, highlighting the importance of effective monitoring and public awareness.

One of the main tools used to communicate air quality to the public is the Air Quality Index (AQI). The AQI simplifies complex pollution data by combining multiple pollutants into a single value, which is then categorized into levels such as "Good," "Moderate," or "Hazardous." This makes it easier for the public to understand potential health risks. In Kuwait, AQI monitoring is conducted by environmental authorities, including the Environmental Public Authority (EPA) [13]. Although AQI systems differ slightly across countries, they all aim to translate scientific data into accessible information.

The AQI concept has evolved over time. Early versions, developed in the 1960s, focused on only a few pollutants, but modern systems now include multiple key pollutants such as PM_{2.5}, PM₁₀, NO₂, SO₂, CO, and O₃. The United States Environmental Protection Agency (USEPA) played a major role in standardizing AQI reporting through the National Ambient Air Quality Standards (NAAQS), which are now widely used as a reference framework [14]. AQI values are calculated using pollutant-specific indices, with the highest value determining the overall air quality rating for a given location [14].

The AQI is calculated by first determining a sub-index for each pollutant using the following equation:

$$I_p = (I_{Hi} - I_{Lo}) / (BP_{Hi} - BP_{Lo}) \times (C_p - BP_{Lo}) + I_{Lo} \quad (1)$$

where

C_p is the concentration of pollutant, p .

BP_{Hi} and BP_{Lo} are the upper and lower concentration breakpoint.

I_{Hi} and I_{Lo} are the corresponding AQI value for those breakpoints.

The overall AQI is then defined as the highest sub-index value among all pollutants measured, representing the pollutant posing the greatest health risk on that day [14].

AQI values are typically categorized into levels such as Good, Moderate, Unhealthy for Sensitive Groups, and Unhealthy, each associated with specific health implications.

In this review, the AQI is considered alongside individual pollutants including $PM_{2.5}$, PM_{10} , NO_2 , SO_2 , CO , and O_3 to better understand their relationship with health outcomes in Kuwait.

This study adopts a guided narrative review approach to bring together and critically interpret the existing evidence on air quality in Kuwait. The focus is on AQI, key air pollutants (such as $PM_{2.5}$, PM_{10} , NO_2 , and O_3), and their potential health effects. Rather than simply describing individual studies, the review aims to integrate findings across key themes, including air quality trends, health outcomes, pollutant-specific effects, and population vulnerability. It also distinguishes between direct epidemiological evidence and indirect or exposure-based findings, while identifying the main limitations and gaps in the current literature.

Ultimately, this review seeks to support future research and policy development in Kuwait by providing a clearer understanding of what is currently known and what remains uncertain about air pollution and health. The study is guided by the following research questions:

1. What is the relationship between AQI levels and health outcomes among residents of Kuwait?
2. Which health outcomes are most commonly associated with elevated AQI levels?
3. How do individual air pollutants contribute to these health effects?
4. Which population groups are most vulnerable to poor air quality in Kuwait?
5. What are the key limitations and research gaps in the existing literature?

2. Methodology

2.1. Research Design

This study was designed as a guided narrative review with the goal of summarizing and critically evaluating available information on the association between air quality, air pollutant, Air Quality Index (AQI), and health outcomes in Kuwait. Unlike systematic reviews, which strive for complete and totally replicable evidence synthesis, this review takes a more flexible and interpretative approach, allowing for thematic integration of diverse information. However, to enhance transparency and rigor, certain parts of the structured review technique, such as database searching, phased screening, and data extraction, were included.

The review does not adhere to conventional systematic review frameworks, and no protocols were pre-registered. Instead, it prioritizes conceptual depth, contextual significance, and critical synthesis over exhaustive inclusion.

2.2. Literature Search Strategy

A guided literature search was carried out using four main electronic databases: PubMed, Web of Science, Scopus, and MDPI. The last search ended in April 2026. The search phrases included keywords linked to location, exposure, and health effects. The key search concepts included are “Kuwait” and “air pollution” or “air quality” or “AQI”

and “PM_{2.5}” or “PM₁₀” or “particulate matter” and “health effects” or “respiratory” or “cardiovascular” or “mortality”.

To promote transparency, an example of PubMed’s search syntax is provided below: Example (PubMed): (“Kuwait”) AND (“air pollution” OR “air quality index” OR “AQI”) AND (“PM_{2.5}” OR “PM₁₀” OR “particulate matter”) AND (“health” OR “respiratory” OR “cardiovascular” OR “mortality”).

Filters: English, peer-reviewed, publication date > 2014.

The search strings were tailored to the indexing methods and operators of each database. Additionally, we manually screened reference lists from relevant papers to uncover additional research.

2.3. Eligibility Guidelines and Study Selection

Given the narrative form of this review, eligibility criteria were broad but clearly established to maintain conceptual coherence with the study’s objectives. Studies were eligible if they satisfied any of the following:

- Assessed air pollution exposure in Kuwait, including AQI, PM_{2.5}, PM₁₀, and other contaminants.
- Reported health consequences, including respiratory, cardiovascular, and mortality effects.
- Provided exposure characterization, modeling, and prediction for population health contexts.

This strategy purposefully contains both studies with direct epidemiological health outcomes and those that focus on exposure assessment, which are crucial for understanding health risk pathways.

Studies were excluded if they were not peer-reviewed, lack analytical and empirical substance, unrelated to Kuwait’s environmental and health setting.

Study Selection Process

The initial search produced 228 records. After deleting duplicates and screening titles/abstracts, 80 articles were kept. A full-text examination revealed 26 papers for the basic narrative synthesis. A total of 54 studies or articles were used for contextual/background assistance, discussion and comparison with other studies. Multiple authors undertook iterative screening, with discussions utilized to address differences and guarantee relevance.

2.4. Data Extraction and Organization

To facilitate thematic synthesis, relevant data were retrieved using a guided manner. The extracted items included:

- Characteristics of the study, including location, population, and design.
- Type of exposure (e.g., elevated AQI score, PM_{2.5}, PM₁₀).
- Characterization of outcomes (e.g., health or exposure).
- Key results and conclusions.

Multiple writers extracted data and cross-checked chosen papers to reduce bias and ensure consistency.

2.5. Approach to Evidence Synthesis

Thematic narrative synthesis was utilized to organize and interpret the findings. Studies were divided into the following domains:

- Air quality characteristics and trends (AQI).
- Respiratory health outcomes.
- Cardiovascular and systemic effects.
- Mortality and disease burden.
- Pollutant-specific impacts.

- Exposure assessment and modeling studies.
- Vulnerable populations.

Instead of quantitative aggregation, the synthesis concentrated on identifying patterns and consistency, identifying differences between studies, evaluating evidence strength and kind (epidemiological vs. exposure-based), differentiating between direct health evidence and supporting exposure-based data for clear interpretation.

2.6. Methodological Limitations

As a guided narrative review, this study has inherent limitations.

- Potential selection bias owing to incomplete inclusion.
- Lack of systematic meta-analysis and quantitative synthesis.
- No standardized risk-of-bias assessment technique was used.
- Limited repeatability compared to complete systematic reviews, despite increased openness.

However, the adoption of an organized search approach, defined eligibility criteria, and thematic synthesis improves the review's credibility, clarity, and interpretability.

2.7. Study Area

Kuwait is located in the northeastern Arabian Peninsula and covers roughly 17,820 km². It is distinguished by an arid desert environment, frequent dust storms, and high emissions from fossil fuel companies. The population is heavily urbanized, with the majority of inhabitants living in metropolitan regions, which increases exposure to ambient air pollution. These environmental and demographic factors make Kuwait a particularly relevant setting for examining the health impacts of air quality [15].

3. Review on the Effects of Elevated Air Quality Index and Air Pollution on the Health of Habitants of Kuwait

The effects of elevated Air Quality Index and air pollution on the health of residents of Kuwait are outlined below according to the research questions and organized into thematic subsections (e.g., air quality characteristics and AQI trends, respiratory outcomes, cardiovascular outcomes, mortality, vulnerable populations, pollutant-specific effects and others).

3.1. Air Quality Characteristics and AQI Trends in Kuwait

Particulate matter (PM_{2.5} and PM₁₀), largely originating from industrial activities, anthropogenic emissions, and desert dust events, is the dominant factor influencing ambient air quality in Kuwait. Early assessments indicated that gaseous pollutants such as SO₂, NO₂, and O₃ were generally within national and international guideline limits, corresponding to “good” to “moderate” AQI categories [16]. However, more recent evidence shows that concentrations of particulate matter and nitrogen dioxide frequently exceed recommended range, resulting in AQI levels that often fall within “unhealthy” categories, particularly during dust storms and seasonal peaks [4,17].

Air pollution in Kuwait exhibits pronounced seasonal variability. PM₁₀ concentrations typically peak during the summer due to increased dust storm activity, whereas NO₂ levels tend to rise during winter months, and ozone concentrations increase during warmer periods [18]. Long-term exposure assessments further indicate persistently elevated particulate matter levels, often exceeding World Health Organization (WHO) guidelines, suggesting chronic population exposure to poor air quality [19].

At the urban and micro-environmental scale, air pollution is highly spatially variable. Studies show that high-traffic and industrial areas experience elevated PM_{2.5} concentrations, which are a primary driver of AQI fluctuations. Using high-resolution monitoring and machine learning approaches, PM_{2.5} has been identified as the dominant contributor to

AQI variability, with other pollutants (PM_{10} , NO_2 , O_3 , CO , and SO_2) playing secondary roles [20]. This spatial heterogeneity is further supported by urban-focused assessments, which highlight the presence of localized pollution hotspots driven by traffic density and industrial emissions [21].

Beyond individual pollutant concentrations, air quality in Kuwait is shaped by complex interactions between natural and anthropogenic sources. Atmospheric chemistry analyses demonstrate that pollutant levels are influenced not only by emission sources but also by secondary formation processes involving desert dust, industrial emissions, and photochemical reactions [22]. The interaction between dust events and industrial pollution further amplifies overall pollution levels, creating combined exposure scenarios that increase environmental risk [23].

Desert dust plays a particularly significant role in Kuwait's air quality profile. Dust storms can substantially elevate particulate matter concentrations, especially during seasonal peaks, and are a major driver of short-term AQI deterioration [12]. Recent regional studies reinforce the importance of sand and dust storms as key contributors to air pollution variability, emphasizing their role in driving extreme pollution episodes and shaping overall air quality patterns [24].

In addition to environmental factors, broader structural drivers such as energy consumption, industrial activity, and economic development contribute significantly to air pollution levels. Evidence suggests that Kuwait's reliance on fossil fuels and energy-intensive sectors plays a central role in emissions generation, reinforcing the contribution of anthropogenic sources to long-term air quality trends [25].

Overall, the available evidence indicates that air quality in Kuwait is characterized by persistently high particulate matter levels, strong seasonal and spatial variability, and complex interactions between natural and human-driven sources. These factors collectively contribute to fluctuating AQI levels, with frequent exceedances of health-based thresholds, particularly in urban and dust-affected environments.

3.2. Respiratory Health Outcomes

Respiratory illness represents the most frequently reported health outcome associated with elevated AQI and air pollution exposure in Kuwait. Increased concentrations of particulate matter, particularly PM_{10} during dust storm events, have been significantly associated with higher hospital admissions for asthma, upper and lower respiratory tract infections, and other respiratory conditions [26]. Similarly, time-series analyses indicate that short-term increases in $\text{PM}_{2.5}$ are linked to statistically significant rises in respiratory hospitalizations within brief lag periods [27]. In addition to particulate matter, short-term exposure to nitrogen dioxide (NO_2) has been associated with an increased incidence of respiratory disorders [28].

These associations are supported by established biological mechanisms, including airway inflammation, oxidative stress, and the exacerbation of pre-existing respiratory diseases. The contribution of dust storms is particularly important in the Kuwait context, as such events substantially elevate particulate concentrations and increase respiratory health risks by facilitating the inhalation of fine and coarse particles [24]. This interpretation is further supported by broader evidence indicating that desert dust particles can carry biological and chemical constituents that impair lung function and trigger respiratory morbidity, including asthma exacerbations and respiratory infections [12].

Overall, the evidence consistently identifies $\text{PM}_{2.5}$ and PM_{10} along with NO_2 , as key drivers of respiratory health burdens in Kuwait, with dust-related exposures playing a significant amplifying role.

3.3. Cardiovascular and Systemic Health Effects

Air pollution in Kuwait is associated with a range of cardiovascular and systemic health effects that extend beyond the respiratory system. Elevated exposure to fine particulate matter (PM_{2.5}) has been linked to increased risks of ischemic heart disease, stroke, and chronic obstructive pulmonary disease (COPD) [29], while time-series studies further suggest associations between PM_{2.5} and cardiovascular mortality [3]. These relationships are supported by biomarker-based evidence demonstrating that individuals exposed to higher pollution levels exhibit increased oxidative stress and reduced antioxidant defense capacity [30].

Emerging evidence also highlights the broader systemic impact of air pollution. Higher exposure to dust-related particulate matter has been associated with increased hospitalizations for metabolic conditions such as diabetes, particularly during periods of extreme heat [31]. In addition, pollutant-specific effects have been observed in chronic inflammatory diseases, with exposure to NO₂ and O₃ linked to increased disease activity in conditions such as rheumatoid arthritis, suggesting cumulative and delayed inflammatory responses [32].

The role of desert dust is particularly relevant in the Kuwait context, as dust-related particulate exposure contributes to systemic inflammation and oxidative stress, which are key mechanisms underlying cardiovascular risk [12].

Overall, the available evidence indicates that air pollution in Kuwait affects multiple physiological systems, with cardiovascular, metabolic, and immunological pathways all contributing to the overall burden of disease associated with elevated pollutant exposure.

3.4. Mortality and Burden of Disease

Elevated AQI levels, particularly those driven by particulate matter, are associated with increased mortality and overall disease burden in Kuwait. Short-term increases in PM_{2.5} concentrations have been linked to rises in cardiovascular and all-cause mortality [3], while higher daily death rates have also been observed during dust storm events and periods of reduced visibility, which serve as proxies for elevated particulate pollution [33].

Long-term exposure assessments further indicate that air pollution contributes substantially to population health burden, with elevated PM_{2.5} and PM₁₀ levels associated with significant years of life lost (YLL) and cumulative adverse health effects over time [34]. Evidence suggests differential impacts by particle size, with fine particulate matter more strongly associated with adult mortality, while coarse particles contribute more prominently to infant mortality.

Extreme pollution events provide additional insight into the health impacts of particulate exposure. For example, elevated PM_{2.5} levels exceeding World Health Organization (WHO) guidelines have been linked to increased injuries and fatalities during major pollution episodes, such as oil well fires [35]. Although some studies report only modest associations between PM_{2.5} and specific outcomes such as COVID-19-related mortality, the overall evidence supports a relationship between elevated particulate pollution and increased mortality risk in Kuwait.

Collectively, these findings underscore the significant contribution of particulate matter, particularly PM_{2.5}, to mortality patterns and the overall burden of disease in Kuwait.

3.5. Pollutant-Specific Effects

Distinct pollutant-specific patterns characterize the health impacts of air pollution in Kuwait. Fine particulate matter (PM_{2.5}) is consistently identified as the most significant pollutant due to its ability to penetrate deeply into the respiratory system and enter systemic circulation, contributing to both cardiovascular and respiratory diseases [29]. Its

dominant role is further supported by evidence indicating that PM_{2.5} is the primary driver of AQI variability and associated health risk potential in Kuwait [20]. In addition, atmospheric chemistry studies suggest that secondary particle formation driven by nitrogen oxides, sulfur compounds, and photochemical reactions contributes to the persistence and composition of PM_{2.5}, further reinforcing its central role in health-related air quality impacts [22].

PM₁₀, largely associated with desert dust events, has been significantly linked to acute respiratory morbidity and mortality [26]. Among gaseous pollutants, nitrogen dioxide (NO₂), which frequently exceeds regulatory limits, is associated with respiratory morbidity and chronic inflammatory responses [28], while ozone (O₃), even when within permissible limits, has been linked to delayed inflammatory effects in chronic diseases [32].

Exposure to hazardous air pollutants such as benzene and benzo(a)pyrene has also been associated with increased long-term cancer risk, particularly in high-exposure environments [36]. Although gaseous pollutants contribute to specific health outcomes and may exert synergistic effects, the overall evidence indicates that particulate matter especially PM_{2.5} remains the dominant contributor to AQI-related health risks in Kuwait.

3.6. Vulnerable Populations

Certain population groups in Kuwait are disproportionately affected by the adverse health impacts of air pollution. Children and newborns are particularly vulnerable, as particulate exposure has been associated with increased risks of respiratory disease and postneonatal mortality [26]. Older adults are also at higher risk of respiratory and cardiovascular complications, while individuals with pre-existing conditions such as diabetes, rheumatoid arthritis, asthma, chronic obstructive pulmonary disease (COPD), and cardiovascular diseases are more susceptible to pollution-related exacerbations [31,32].

Exposure patterns further influence vulnerability. Occupational exposure places outdoor workers at increased risk, while non-Kuwaiti populations have been reported to experience higher mortality rates, likely due to greater environmental and occupational exposure [33]. In addition, geographic variability plays a role, with populations residing in coastal and industrial areas facing higher pollutant exposure and associated health risks [36].

AQI-based assessments reinforce these findings, indicating that elevated AQI levels pose greater risks to sensitive groups, including children, older adults, pregnant women, and individuals with pre-existing cardiovascular conditions, even in studies where direct health outcomes were not assessed [20]. Dust storm events further amplify these risks, as they disproportionately affect vulnerable populations through increased exposure to high concentrations of particulate matter [24].

Overall, vulnerability to air pollution in Kuwait is shaped by a combination of biological susceptibility, environmental exposure, and socio-occupational factors, highlighting the need for targeted public health interventions and risk mitigation strategies.

3.7. Exposure Dynamics and Indoor–Outdoor Relationships

Air pollution exposure in Kuwait is influenced by both indoor and outdoor environments, reflecting the pervasive nature of ambient particulate pollution. Studies indicate that outdoor pollutants, particularly particulate matter, readily infiltrate indoor spaces, resulting in substantial indoor exposure levels [37]. Although behavioral responses such as closing windows during dust storms can reduce indoor pollutant infiltration, overall population exposure remains significant due to the consistently high ambient pollution levels.

Exposure dynamics are further shaped by spatial variability and human behavior. Differences in ambient air pollution across locations can influence patterns of outdoor activity,

thereby modifying individual exposure levels and associated health risks. This highlights a dynamic interaction between environmental conditions and behavioral responses, where individuals may alter their activities in response to pollution levels, yet still remain exposed due to the widespread nature of air pollution in Kuwait [38].

Overall, these findings emphasize that air pollution exposure in Kuwait is not limited to outdoor environments but is a complex interplay between ambient conditions, indoor infiltration, and behavioral adaptations.

3.8. Distinction Between AQI-Based and Pollutant-Based Evidence and Limitations of AQI

A clear distinction emerges between studies using pollutant-specific exposure data and those relying on Air Quality Index (AQI)-based measures to evaluate health risks in Kuwait. AQI provides a simplified, composite representation of air quality by integrating multiple pollutants ($PM_{2.5}$, PM_{10} , NO_2 , O_3 , SO_2 , and CO) into a single index designed primarily for public communication. AQI-based studies, including those using proxy indicators such as visibility or categorized pollution levels, generally show that periods of poorer air quality are associated with increased mortality and morbidity, particularly during dust storm events [33]. However, such studies are relatively limited in Kuwait and are often indirect, focusing on AQI trends or prediction rather than explicit epidemiological relationships with health outcomes [18,20].

In contrast, pollutant-specific studies provide more robust and consistent epidemiological evidence. Direct associations have been reported between particulate matter ($PM_{2.5}$ and PM_{10}) and respiratory morbidity [26,27], cardiovascular disease and mortality [3,29], as well as between NO_2 exposure and respiratory disorders [28]. Mechanistic and biomarker-based studies further support these findings by demonstrating systemic and inflammatory responses, including oxidative stress and autoimmune activity [30,32]. Collectively, these studies offer clearer exposure response relationships and consistently identify $PM_{2.5}$ as the primary driver of adverse health outcomes in Kuwait.

Despite its utility, AQI has several limitations as a proxy for health risk in the Kuwait context. First, it simplifies multi-pollutant exposure into a single value, potentially masking the combined or synergistic effects of pollutants in environments characterized by mixed sources such as industrial emissions, traffic, and desert dust. Second, AQI does not adequately capture the dominant role and varying toxicity of specific pollutants, particularly $PM_{2.5}$. Third, reliance on modeled estimates or proxy indicators (e.g., visibility) may introduce exposure misclassification, especially during rapidly changing conditions such as dust storms [33]. Fourth, AQI lacks sufficient spatial and temporal resolution to reflect localized pollution hotspots and short-term exposure peaks, which are important determinants of health risk. Fifth, it does not account for population heterogeneity, overlooking differences in susceptibility among vulnerable groups.

Additional evidence further underscores these limitations. Atmospheric chemistry analyses indicate that air pollution in Kuwait involves complex interactions between multiple pollutants and secondary formation processes, which are not fully captured by a single AQI value [22]. Similarly, urban studies demonstrate significant spatial variability in pollutant concentrations, suggesting that AQI may not adequately reflect localized exposure differences, particularly in high-traffic and industrial areas [21].

Overall, while AQI remains a useful tool for public communication and general exposure categorization, it has limited utility as an epidemiological indicator of health risk in Kuwait. Pollutant-based evidence particularly for $PM_{2.5}$ provides more reliable and mechanistically supported associations with respiratory, cardiovascular, and mortality outcomes. Future research should therefore prioritize integrated multi-pollutant approaches and direct AQI–health linkage studies using high-resolution exposure and health data.

3.9. Evaluation of Evidence Strength and Study Quality

The strength and quality of evidence on air pollution and health in Kuwait vary considerably across studies, reflecting differences in methodological rigor, exposure assessment, and capacity for causal inference. Overall, the literature can be broadly categorized into strong, moderate, and weak forms of evidence, highlighting an uneven and heterogeneous evidence base.

Studies providing the strongest evidence are time-series and longitudinal epidemiological analyses that directly link pollutant exposure particularly PM_{2.5} to health outcomes such as hospital admissions and mortality. These studies typically employ advanced statistical approaches (e.g., distributed lag models) and account for key confounders, including meteorological factors and temporal trends, enabling more reliable exposure–response assessment. Burden of disease analyses, such as estimates of years of life lost, further contribute to understanding long-term population-level impacts.

Moderate strength evidence is derived from cross-sectional studies, biomarker-based investigations, and analyses using modeled or area-level exposure data. These studies provide important mechanistic and associative insights, including evidence of oxidative stress and systemic responses to pollution exposure. However, their ability to support causal inference is limited by factors such as potential exposure misclassification, lack of individual-level data, and incomplete adjustment for confounders.

A substantial portion of the literature consists of weak or indirect evidence, including descriptive air quality assessments, modeling and prediction studies, and research relying on proxy indicators such as visibility. While these studies are valuable for understanding exposure patterns and trends, they do not directly link pollution to health outcomes and therefore provide limited epidemiological insight. Similarly, risk assessments based on external exposure–response functions may not fully reflect Kuwait’s specific environmental and demographic context.

Across all study types, several recurring limitations constrain the overall strength of evidence. These include limited multi-pollutant analyses, insufficient long-term cohort studies, inadequate individual-level exposure assessment, and weak integration between AQI metrics and health outcomes. In addition, reliance on non-local exposure–response estimates and limited demographic stratification restrict the ability to assess population-specific risks.

In summary, while a subset of high-quality epidemiological studies provides relatively strong evidence linking particulate matter, particularly PM_{2.5}, to adverse health outcomes in Kuwait, much of the available literature remains descriptive or indirect. Strengthening the evidence base will require a shift toward well-designed, longitudinal, multi-pollutant studies that integrate high-resolution exposure data with robust health outcome measures.

The evidence summarized in Table 1 shows that research on air pollution and health in Kuwait is diverse in both methods and strength. The strongest evidence comes from time-series and case-crossover studies, which consistently link particulate matter, especially PM_{2.5}, to adverse health outcomes such as mortality, respiratory illness, and cardiovascular disease. These studies provide the most reliable indication that fine particulate matter is a key driver of health risks in Kuwait.

In contrast, a large portion of the literature is based on descriptive monitoring, AQI modeling, and exposure assessments. While these studies are important for understanding pollution levels, sources, and trends, they generally do not establish direct links to health outcomes. Studies of moderate strength, including biomarker research, atmospheric chemistry analyses, and risk modeling, add valuable insight into underlying mechanisms such as oxidative stress, pollutant interactions, and potential long-term risks like cancer, but they remain partly indirect.

Table 1. Integrated summary of evidence on the effects of elevated AQI and air pollutants on health in Kuwait.

Study	Thematic Subsection	Evidence Type	Health Link	Key Pollutant	Strength	Key Insight
Alahmad et al. (2023) [3]	Mortality; Cardiovascular; Pollutant-Specific	Time-series	Direct	PM _{2.5}	High	PM _{2.5} significantly associated with mortality increases
Alahmad et al. (2021) [4]	Air Quality Characteristics; Pollutant-Specific	Source apportionment	None	PM _{2.5}	Low	Identifies dust and combustion as key PM sources
Goudie (2014) [12]	Respiratory; Cardiovascular/Systemic	Review	Indirect	Desert dust	Moderate	Links dust exposure to respiratory and systemic health effects
Al-Awadhi (2014) [16]	Air Quality Characteristics; Research Gaps	Descriptive monitoring	None	NO ₂ , SO ₂ , O ₃ , PM ₁₀	Low	Baseline air quality patterns; no direct AQI–health linkage
Al-Hurban et al. (2021) [17]	Air Quality Characteristics	Monitoring study	Indirect	PM ₁₀ , NO ₂ , SO ₂ , CO	Low	Frequent exceedance of pollutant thresholds
Alsowaidan et al. (2024) [18]	Air Quality Characteristics; Research Gaps	AQI modeling	None	Multi-pollutant	Low	AQI trends analyzed without health linkage
Li et al. (2021) [19]	Air Quality Characteristics; Research Gaps	Exposure modeling	None	PM _{2.5}	Low	Long-term exposure levels frequently exceed WHO limits
Alrashidi et al. (2025) [20]	Air Quality Characteristics; Pollutant-Specific; Vulnerable Populations; Research Gaps	ML prediction	None	PM _{2.5}	Low	PM _{2.5} dominates AQI variability; no direct health linkage
Matar et al. (2024) [21]	Air Quality Characteristics; Exposure Dynamics	Urban monitoring	Indirect	PM _{2.5} , NO ₂	Moderate	Urban pollution hotspots driven by traffic and industry
Alenezi & Aldaihani (2023) [22]	Air Quality Characteristics; Pollutant-Specific	Atmospheric chemistry	Indirect	Multi-pollutant	Moderate	Air pollution shaped by chemical interactions and secondary formation
Al-Hemoud et al. (2026) [23]	Vulnerable Populations; Air Quality Characteristics	Risk assessment	Indirect	Dust, industrial PM	Moderate	Highlights community-level vulnerability to combined exposures
Middleton & Al-Hemoud (2024) [24]	Respiratory; Vulnerable Populations; Air Quality Characteristics	Review	Indirect	Dust PM	Moderate	Dust storms identified as major drivers of exposure and health risk
Raihan (2024) [25]	Air Quality Characteristics; Research Gaps	Environmental analysis	None	Multi-sector emissions	Low	Links pollution to energy use and economic activity
Al-Hemoud et al. (2018) (Dust) [26]	Respiratory; Mortality; Pollutant-Specific; Vulnerable Populations	Time-series	Direct	PM ₁₀	High	Dust-related PM strongly linked to respiratory morbidity and mortality

Table 1. Cont.

Study	Thematic Subsection	Evidence Type	Health Link	Key Pollutant	Strength	Key Insight
Albahar et al. (2022) [27]	Respiratory; Pollutant-Specific; Vulnerable Populations	Time-series	Direct	PM _{2.5}	High	Strong link between PM _{2.5} and respiratory admissions
Al-Hemoud et al. (2021) [28]	Respiratory; Pollutant-Specific; Vulnerable Populations	Exposure–response	Direct	NO ₂	Moderate	NO ₂ associated with increased respiratory disease risk
Al-Hemoud et al. (2019) [29]	Respiratory; Cardiovascular; Mortality; Pollutant-Specific; Vulnerable Populations	Risk assessment	Modeled	PM _{2.5}	Moderate	PM _{2.5} identified as dominant contributor to health burden
Almutairi et al. (2020) [30]	Cardiovascular/Systemic; Pollutant-Specific	Biomarker study	Indirect	PM ₁₀ , SO ₂	Moderate	Evidence of oxidative stress linked to pollution exposure
Alahmad et al. (2024) [31]	Cardiovascular/Systemic; Vulnerable Populations	Case-crossover	Direct	Dust PM _{2.5}	High	Dust exposure linked to increased diabetes admissions
Alsaber et al. (2025) [32]	Cardiovascular/Systemic; Pollutant-Specific; Vulnerable Populations	Clinical linkage	Direct	NO ₂ , O ₃	Moderate–High	Air pollution exacerbates rheumatoid arthritis activity
Achilleos et al. (2019) [33]	Mortality; Air Quality Characteristics; Vulnerable Populations	Time-series (proxy)	Direct	Dust (proxy)	Moderate	Reduced visibility linked to increased mortality
Al-Hemoud et al. (2018) (YLL) [34]	Mortality; Vulnerable Populations; Pollutant-Specific	Burden modeling	Modeled	PM _{2.5} , PM ₁₀	Moderate–High	Substantial years of life lost attributable to particulate exposure
Halos et al. (2022) [35]	Mortality (limited); Research Gaps	Correlational	Weak	PM _{2.5}	Low	Limited association with COVID-19 outcomes
Munshed et al. (2023) [36]	Pollutant-Specific; Vulnerable Populations	Risk modeling	Modeled	VOCs, PAHs	Moderate	Elevated cancer risk in high-exposure areas
Yuan et al. (2020) [37]	Exposure Dynamics; Research Gaps	Exposure study	None	PM _{2.5} , PM ₁₀	Low	Indoor–outdoor exposure relationships characterized
Feyissa et al. (2026) [38]	Exposure Dynamics; Vulnerable Populations	Cross-sectional	Indirect	Multi-pollutant	Moderate	Pollution influences physical activity and exposure patterns

Recent research further highlights that air pollution in Kuwait is complex and influenced by multiple interacting factors, including desert dust storms, industrial emissions, and urban activities. It also shows that exposure can vary across locations and populations, with vulnerable groups and urban residents often facing higher risks. However, respiratory and mortality outcomes remain the most consistently supported, while cardiovascular, systemic effects, and population-specific vulnerabilities are less extensively studied.

Despite growing evidence, important gaps remain. There is still a lack of long-term cohort studies, limited multi-pollutant analyses, and heavy reliance on indirect or modeled data. In particular, AQI-based research is scarce and often not directly linked to health outcomes, with most studies relying instead on pollutant-specific measures.

Overall, the evidence base is expanding but still fragmented. Stronger, more integrated research especially longitudinal and population-based studies that combine exposure and health data is needed to improve causal understanding and better inform air quality policy and public health strategies in Kuwait.

4. Discussion

4.1. Major Air Pollutants in Kuwait

This review confirms that Kuwait's air quality is influenced by a mix of particulate matter (PM_{2.5} and PM₁₀), NO₂, SO₂, O₃, CO, and hazardous compounds such as VOCs and PAHs. Among these, particulate matter, especially PM_{2.5}, emerges as the dominant pollutant driving health risks, consistent across multiple epidemiological and modeling studies [20,29].

Recent atmospheric chemistry evidence further shows that air pollution in Kuwait is not driven by single pollutants, but by complex interactions between desert dust, industrial emissions, and secondary chemical formation processes [22]. This highlights the importance of considering multi-pollutant systems rather than isolated exposures.

4.1.1. Particulate Matter (PM)

PM_{2.5} and PM₁₀ are the most critical air pollutant in Kuwait due to its ability to penetrate deep into the respiratory system and enter the bloodstream, contributing to both respiratory and cardiovascular diseases [29,39]. According to the United States Environmental Protection Agency, particulate matter consists of fine solid and liquid particles suspended in air, including PM_{2.5} ($\leq 2.5 \mu\text{m}$) and PM₁₀ ($\leq 10 \mu\text{m}$) [40].

Their impact is amplified by Kuwait's environment, where frequent dust storms significantly elevate PM concentrations, particularly during summer months [26]. Both short- and long-term exposure to particulate matter have been associated with respiratory infections, cardiovascular disease, and immune dysfunction [41].

Globally, similar associations have been well established, with PM_{2.5} strongly linked to premature mortality [42]. In Kuwait, this burden is further intensified by dust-related exposure, which carries biological and chemical components harmful to health [12,24].

4.1.2. Gaseous Pollutants (NO₂, SO₂, CO, O₃)

Gaseous pollutants contribute to air quality degradation in Kuwait, although their effects are generally secondary to particulate matter. Nitrogen dioxide (NO₂), mainly emitted from traffic, is associated with respiratory inflammation and chronic lung disease [28,43,44]. In addition to human health effects, NO₂ has broader environmental impacts, including reduced agricultural productivity, impaired plant growth, and decreased visibility [45].

Sulfur dioxide (SO₂), largely originating from fossil fuel combustion and industrial activities, is linked to respiratory irritation and bronchospasm, particularly among vulnerable groups [10].

Ozone (O₃), formed through photochemical reactions involving nitrogen oxides and VOCs, has been associated with respiratory and cardiovascular effects, especially during warmer months [10].

Although carbon monoxide (CO) is less frequently studied in Kuwait, it remains important due to its role in reducing oxygen delivery and contributing to cardiovascular stress [46].

Overall, while gaseous pollutants independently affect health, their impact in Kuwait is often amplified through interactions with particulate matter and atmospheric processes [22].

4.1.3. Hazardous Pollutants (VOCs and PAHs)

Hazardous pollutants such as benzene, PAHs, and VOCs are particularly relevant in industrial and urban areas. These compounds are linked to long-term cancer risks and systemic toxicity [36,47,48]. Their health impact is often underestimated due to limited monitoring, yet risk modeling studies indicate significant carcinogenic potential, especially in high-exposure zones.

4.2. Health Impacts of Air Pollution

The findings of this review are consistent with global evidence showing that air pollution is associated with a wide range of adverse health outcomes, particularly affecting the respiratory and cardiovascular systems [49,50]. Long-term exposure to pollutants such as PM_{2.5} and NO₂ has been linked to chronic respiratory diseases, lung cancer, and cardiovascular conditions including ischemic heart disease and stroke [49–51].

Air pollution also contributes to health inequalities, as vulnerable populations such as low-income communities and those living near industrial or high-traffic areas experience disproportionately higher exposure levels [52,53]. In addition, the economic burden associated with pollution-related diseases is substantial, particularly in industrialized and rapidly developing regions [54,55].

Exposure to pollutants including particulate matter, carbon monoxide, and VOCs increases the risk of respiratory infections and acute illness, especially among children and women [56–58]. Rapid urbanization and industrial activity further intensify these risks by increasing ambient pollution levels [59–62], while occupational exposure in sectors such as manufacturing and agriculture adds another layer of health risk [63,64].

At the biological level, air pollution has been shown to influence immune function, including increased inflammatory responses, elevated IgE levels, and altered T-lymphocyte activity, which contribute to respiratory and allergic diseases [65]. This is reflected in the rising prevalence of conditions such as asthma, rhinitis, and eczema, particularly among children exposed to PM_{2.5} and PM₁₀ [66,67].

Short-term exposure to pollutants is associated with acute respiratory effects, while long-term exposure leads to chronic conditions, reduced lung function, and increased mortality [65]. Studies consistently show that increase in PM_{2.5} concentrations are associated with higher mortality rates from respiratory and cardiovascular diseases, with similar patterns observed across Europe, North America, and other regions [65].

Air pollution also increases the risk of respiratory infections, including pneumonia, particularly among children, and has been linked to the spread and severity of infectious diseases such as COVID-19 [65]. Furthermore, exposure to NO₂ and particulate matter has been associated with increased hospitalizations and medication use among asthma patients, especially in children [68].

Beyond respiratory and cardiovascular outcomes, emerging evidence suggests that air pollution may also affect neurological health, contributing to cognitive decline, reduced aca-

demic performance, and increased risk of neurodegenerative diseases such as Alzheimer's and Parkinson's disease [69].

Importantly, particulate matter and ambient air pollution have been classified as carcinogenic, with strong links to lung cancer development [70].

In arid regions such as Kuwait, these health effects are further intensified by dust storm exposure, which significantly elevates particulate concentrations. Evidence from Middle Eastern studies shows that increased PM₁₀ levels during dust events are associated with higher cardiovascular and respiratory mortality, with a substantial proportion of health effects occurring during severe dust conditions [71]. These findings reinforce the critical role of dust-driven particulate pollution as a major determinant of health risk in the region.

4.3. Kuwait in the Regional and Global Context

Compared to other countries in the region, Kuwait shows a moderate overall mortality burden but high exposure levels, particularly for PM_{2.5} [72–75]. While absolute mortality is lower than in larger countries like Saudi Arabia, trends in chronic disease burden (DALYs) remain concerning.

Globally, air pollution is a leading cause of premature mortality [42], and Kuwait follows similar patterns, though shaped by its unique desert climate and industrial profile.

4.4. Distinctive Characteristics of Air Quality in Kuwait

Air quality in Kuwait is shaped by a unique combination of environmental and anthropogenic factors.

First, particulate matter remains consistently elevated, with reported annual concentrations far exceeding WHO guidelines (e.g., ~30.2 µg/m³ compared to the recommended 10 µg/m³) [76]. This confirms findings across the reviewed literature that PM_{2.5} is the dominant pollutant influencing air quality and health outcomes in Kuwait.

Second, desert dust plays a central role. Kuwait's arid environment and frequent dust storms significantly increase airborne particulate concentrations, particularly during summer months [77]. Even in the absence of anthropogenic emissions, natural dust contributes substantially to baseline PM levels, often dominating the atmospheric particle load [78]. This is consistent with regional evidence highlighting dust storms as a major driver of air pollution variability [24].

Third, air pollution in Kuwait reflects a combination of natural and human sources, including industrial emissions, fossil fuel combustion, and traffic-related pollution [25]. Studies suggest that mineral dust, fossil fuel combustion, and traffic emissions together account for a large proportion of PM_{2.5} composition [78].

Fourth, temporal and spatial variability is pronounced. Seasonal patterns show higher PM levels during dusty summer periods, while pollutant accumulation can occur during stagnant atmospheric conditions [20]. Urban studies further confirm that pollution levels vary across locations, with higher concentrations in industrial and high-traffic areas [21].

Finally, real-time monitoring shows that AQI levels frequently reach "unhealthy" categories, particularly during dust events [17]. However, such AQI spikes may not always fully reflect the complexity of multi-pollutant exposure in Kuwait.

4.5. Policy Implications, Remedial Strategies and Future Directions

Given that PM_{2.5} is the reported primary driver of health risk, mitigation strategies should prioritize:

1. Reducing industrial and traffic emissions.
2. Controlling dust through land management and urban planning.

3. Expanding green infrastructure and vegetation barriers to reduce dust resuspension.
4. Implementing urban dust management strategies, such as soil stabilization and regulated construction activities.
5. Strengthening air quality monitoring and AQI-based alert systems.

Special attention should be given to vulnerable populations, including children, the elderly, and outdoor workers [23]. These interventions are critical, as even modest reductions in PM_{2.5} (e.g., 10 µg/m³) have been shown to significantly improve health outcomes, including reduced mortality and hospital admissions [79].

In addition, targeted policies are needed to address gaseous pollutants (NO₂ and O₃), particularly in high-traffic and industrial zones. Continuous monitoring and integration of AQI forecasting systems into public health planning are also essential.

Protecting vulnerable populations should be a priority, including the development of AQI-based public warning systems, workplace protections for outdoor workers, and indoor air quality improvements (e.g., filtration systems).

Future research should focus on integrated, multi-pollutant approaches, combining environmental monitoring with health data. This includes improving exposure assessment, validating models with measured data, and developing locally relevant exposure–response relationships [80].

4.6. Limitations and Research Gaps

Despite growing evidence, several gaps remain:

1. Limited AQI–health linkage studies [18,20].
2. Heavy reliance on modeled or indirect exposure data.
3. Lack of multi-pollutant and long-term cohort studies.
4. Underrepresentation of vulnerable populations and indoor exposure.

Additionally, current evidence does not fully capture the complex chemical interactions of pollutants, which are increasingly recognized as important [22].

4.7. Future Research Directions

Future research in Kuwait should focus on linking AQI directly to health outcomes, developing multi-pollutant exposure models, conducting longitudinal and cohort studies, improving high-resolution exposure assessment, and integrating environmental, clinical, and behavioral data. Such approaches will provide stronger evidence for policy-making and public health interventions.

In summary, the evidence clearly shows that air pollution in Kuwait driven primarily by PM_{2.5} is a significant public health concern. While the research base is expanding, it remains methodologically diverse and partially fragmented. Strengthening epidemiological evidence and integrating complex exposure pathways will be essential for effective policy and health protection strategies.

5. Conclusions

This review highlights that air pollution in Kuwait is a significant and multifaceted public health concern, driven by a unique combination of natural and anthropogenic sources. Fine particulate matter (PM_{2.5}) consistently emerges as the most critical pollutant, with strong and repeated evidence linking it to respiratory disease, cardiovascular outcomes, and premature mortality [3,29]. The contribution of frequent dust storms further amplifies exposure levels, making Kuwait's air quality profile distinct from many other regions and reinforcing the importance of considering both environmental and climatic factors in health risk assessments [24,26,33].

The current body of evidence demonstrates clear associations between air pollution and adverse health outcomes; however, it remains methodologically uneven. While high-quality epidemiological studies provide robust support for pollutant–health relationships, a substantial portion of the literature relies on descriptive, modeled, or indirect evidence. In particular, the limited use of Air Quality Index (AQI) as a direct epidemiological tool highlights an important gap between public air quality reporting and health-based research [18,20].

Emerging studies also emphasize the complexity of air pollution in Kuwait, including pollutant interactions, atmospheric chemical transformations, and spatial variability in exposure [21,22]. These factors, along with behavioral and environmental dynamics, influence real-world exposure patterns and contribute to unequal health risks across the population. Vulnerable groups including children, the elderly, and individuals with pre-existing conditions are disproportionately affected, underscoring the need for targeted interventions [31,33,38].

Overall, while the evidence base is growing, there is a clear need for more integrated, high-quality research. Future studies should prioritize multi-pollutant approaches, improved exposure assessment (including indoor and personal exposure), and stronger linkage between AQI metrics and health outcomes. Longitudinal and population-based designs will be essential to strengthen causal inference and better quantify long-term health impacts.

From a policy perspective, the findings support prioritizing particulate matter reduction, enhancing monitoring systems, and implementing targeted public health strategies, particularly during high-risk events such as dust storms. Strengthening the alignment between environmental monitoring and health data will be critical for developing effective, evidence-based air quality management policies in Kuwait.

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Abbreviations

AAP	Ambient Air Pollution
AQG	Air Quality Guidelines
AQI	Air Quality Index
BC	Black Carbon
CI	Confidence Interval
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COH	Coefficient of Haze
COPD	Chronic Obstructive Pulmonary Disease

COVID-19	Coronavirus Disease 2019
CVD	Cardiovascular Disease
DALYs	Disability-Adjusted Life Years
DNA	Deoxyribonucleic Acid
EPA	Environmental Protection Agency
FEV ₁	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
GBD	Global Burden of Disease
GLO	Ground-Level Ozone
H ₂ S	Hydrogen Sulfide
IARC	International Agency for Research on Cancer
IgE	Immunoglobulin E
IHD	Ischemic Heart Disease
K-EPA	Kuwait Environmental Public Authority
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen Oxides
O ₃	Ozone
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
PM _{2.5}	Particulate Matter ≤ 2.5 μ m
PM ₁₀	Particulate Matter ≤ 10 μ m
ppm	Parts Per Million
RA	Rheumatoid Arthritis
SO ₂	Sulphur Dioxide
TRAP	Traffic-Related Air Pollution
VOCs	Volatile Organic Compounds
WHO	World Health Organization
YLL	Years of Life Lost

References

1. World Bank. *Sand and Dust Storms in the Middle East and North Africa Region—Sources, Costs, and Solutions*; World Bank Publications: Washington, DC, USA, 2019.
2. Li, J.; Garshick, E.; Al-Hemoud, A.; Huang, S.; Koutrakis, P. Impacts of meteorology and vegetation on surface dust concentrations in Middle Eastern countries. *Sci. Total Environ.* **2020**, *712*, 136597. [[CrossRef](#)] [[PubMed](#)]
3. Alahmad, B.; Li, J.; Achilleos, S.; Al-Mulla, F.; Al-Hemoud, A.; Koutrakis, P. Burden of fine air pollution on mortality in the desert climate of Kuwait. *J. Expo. Sci. Environ. Epidemiol.* **2023**, *33*, 646–651. [[CrossRef](#)]
4. Alahmad, B.; Al-Hemoud, A.; Kang, C.M.; Almarri, F.; Kommula, V.; Wolfson, J.M.; Bernstein, A.S.; Garshick, E.; Schwartz, J.; Koutrakis, P. A two-year assessment of particulate air pollution and sources in Kuwait. *Environ. Pollut.* **2021**, *282*, 117016. [[CrossRef](#)]
5. Barkley, M.P.; Gonzalez, G.A.; Kurosu, T.P.; Spurr, R.; Torbatian, S.; Lerot, C. OMI air-quality monitoring over the middle east. *Atmos. Chem. Phys.* **2017**, *17*, 4687–4709. [[CrossRef](#)]
6. Tsiouri, V.; Kakosimos, K.E.; Kumar, P. Concentrations, sources and exposure risks associated with particulate matter in the middle east area—A review. *Air Qual. Atmos. Health* **2015**, *8*, 67–80. [[CrossRef](#)]
7. Al-Awadhi, J.M.; Alshuaibi, A.A. Dust fallout in Kuwait City: Deposition and characterization. *Sci. Total Environ.* **2013**, *461*–462, 139–148. [[CrossRef](#)]
8. Liu, C.; Chen, R.; Sera, F.; Vicedo-Cabrera, A.M.; Guo, Y.; Tong, S.; Coelho, M.S.Z.S.; Saldiva, P.H.N.; Lavigne, E.; Matus, P.; et al. Ambient Particulate Air Pollution and Daily Mortality in 652 Cities. *N. Engl. J. Med.* **2019**, *381*, 705–715. [[CrossRef](#)]
9. Fuller, R.; Landrigan, P.J.; Balakrishnan, K.; Bathan, G.; Bose-O'Reilly, S.; Brauer, M.; Caravanos, J.; Chiles, T.; Cohen, A.; Corra, L.; et al. Pollution and health: A progress update. *Lancet Planet. Health* **2022**, *6*, e535–e547. [[CrossRef](#)]
10. Manisalidis, I.; Stavropoulou, E.; Stavropoulos, A.; Bezirtzoglou, E. Environmental and Health Impacts of Air Pollution: A Review. *Front. Public Health* **2020**, *20*, 14. [[CrossRef](#)] [[PubMed](#)]

11. Abdo, N.; Khader, Y.S.; Abdelrahman, M.; Graboski-Bauer, A.; Malkawi, M.; Al-Sharif, M.; Elbetieha, A.M. Respiratory health outcomes and air pollution in the Eastern Mediterranean Region: A systematic review. *Rev. Env. Health* **2016**, *31*, 259–280. [[CrossRef](#)] [[PubMed](#)]
12. Goudie, A.S. Desert dust and human health disorders. *Environ. Int.* **2014**, *63*, 101–113. [[CrossRef](#)]
13. Shah, D.P.; Patel, P. A review of chronological evolution of air quality indexing systems (1966 to 2021) current world environment. *Curr. World Environ.* **2021**, *16*, 704–725. [[CrossRef](#)]
14. Seth, A.; Horn, S.A.; Dasgupta, P.K. The Air Quality Index (AQI) in historical and analytical perspective a tutorial review. *Talanta* **2024**, *267*, 125260. [[CrossRef](#)]
15. Al-Hemoud, A.; Al-Dousari, A.; Misak, R.; Al-Sudairawi, M.; Naseeb, A.; Al-Dashti, H.; Al-Dousari, N. Economic Impact and Risk Assessment of Sand and Dust Storms (SDS) on the Oil and Gas Industry in Kuwait. *Sustainability* **2019**, *11*, 200. [[CrossRef](#)]
16. Al-awadhi, J. Measurement of Air Pollution in Kuwait City Using Passive Samplers. *Atmos. Clim. Sci.* **2014**, *4*, 253–271. [[CrossRef](#)]
17. Al-Hurban, A.; Khader, S.; Alsaber, A.; Pan, J. Air Quality Assessment in the State of Kuwait during 2012 to 2017. *Atmosphere* **2021**, *12*, 678. [[CrossRef](#)]
18. Alsowaidan, S.; Al-Hurban, A.; Alsaber, A.; Anbar, A. Assessment of seasonal variations in the air quality index (2019–2022) in Al-Jahra city, Kuwait. *Kuwait J. Sci.* **2024**, *51*, 100280. [[CrossRef](#)]
19. Li, J.; Garshick, E.; Hart, J.E.; Li, L.; Shi, L.; Al-Hemoud, A.; Huang, S.; Koutrakis, P. Estimation of ambient PM_{2.5} in Iraq and Kuwait from 2001 to 2018 using machine learning and remote sensing. *Environ. Int.* **2021**, *151*, 106445. [[CrossRef](#)]
20. Alrashidi, H.; Sibai, F.N.; Abonamah, A.; Alrashidi, M.; Alsaber, A. PM_{2.5}: Air Quality Index Prediction Using Machine Learning: Evidence from Kuwait's Air Quality Monitoring Stations. *Sustainability* **2025**, *17*, 9136. [[CrossRef](#)]
21. Matar, H.B.; Al-Otaibi, F.A.; Almutairi, S.K.; Alhubail, J.A. Air Quality in Kuwait Urban Areas. *Environ. Qual. Manag.* **2024**, *33*, 555–566. [[CrossRef](#)]
22. Alenezi, R.A.; Aldaihani, N. Investigation of the Atmospheric Chemical Properties over Kuwait. *Water Air Soil Pollut.* **2023**, *234*, 216. [[CrossRef](#)]
23. Al-Hemoud, A.; Darvishi Bolorani, A.; Soleimani, M.; Estifaei, S.; Nasiri, N.; Amiri, F.; Al-Dashti, H.; Malek, M.; Kamal, H.; Thomas, M.; et al. Community vulnerability to dust-related and industrial air pollution in Kuwait. *Geomat. Nat. Hazards Risk* **2026**, *17*, 2636714. [[CrossRef](#)]
24. Middleton, N.; Al-Hemoud, A. Sand and Dust Storms: Recent Developments in Impact Mitigation. *Sustainability* **2024**, *16*, 7121. [[CrossRef](#)]
25. Raihan, A. Environmental impacts of the economy, tourism, and energy consumption in Kuwait. *Kuwait J. Sci.* **2024**, *51*, 100264. [[CrossRef](#)]
26. Al-Hemoud, A.; Al-Dousari, A.; Al-Shatti, A.; Al-Khayat, A.; Behbehani, W.; Malak, M. Health Impact Assessment Associated with Exposure to PM₁₀ and Dust Storms in Kuwait. *Atmosphere* **2018**, *9*, 6. [[CrossRef](#)]
27. Albahar, S.; Li, J.; Al-Zoughool, M.; Al-Hemoud, A.; Gasana, J.; Aldashti, H.; Alahmad, B. Air Pollution and Respiratory Hospital Admissions in Kuwait: The Epidemiological Applicability of Predicted PM_{2.5} in Arid Regions. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5998. [[CrossRef](#)]
28. Al-Hemoud, A.; Gasana, J.; Alajeel, A.; Alhamoud, E.; Al-Shatti, A.; Al-Khayat, A. Ambient exposure of O₃ and NO₂ and associated health risk in Kuwait. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 14917–14926. [[CrossRef](#)] [[PubMed](#)]
29. Al-Hemoud, A.; Gasana, J.; Al-Dabbous, A.; Alajeel, A.; Al-Shatti, A.; Behbehani, W.; Malak, M. Exposure levels of air pollution (PM_{2.5}) and associated health risk in Kuwait. *Environ. Res.* **2019**, *179*, 108730. [[CrossRef](#)]
30. Almutairi, A.M.; Akkam, Y.; Alajmi, M.F.; Akkam, N. Effect of Air Pollution on Glutathione S-Transferase Activity and Total Antioxidant Capacity: Cross Sectional Study in Kuwait. *J. Health Pollut.* **2020**, *10*, 200906. [[CrossRef](#)]
31. Alahmad, B.; Ali, H.; Alwadi, Y.; Al-Hemoud, A.; Koutrakis, P.; Al-Mulla, F. Combined impact of heat and dust on diabetes hospitalization in Kuwait. *BMJ Open Diabetes Res. Care* **2024**, *12*, e004320. [[CrossRef](#)]
32. Alsaber, A.; Al-Herz, A.; Al-Mazedi, M.; Abu Doush, I.; Abdullah, A.; Alkandary, D.; Al-Sultan, A.T.; Setiya, P.; Pan, J. Predicting the Impact of Air Quality Index on Rheumatoid Arthritis Disease Activity. *Arthritis Care Res.* **2025**, *77*, 1340–1349. [[CrossRef](#)]
33. Achilleos, S.; Al-Ozairi, E.; Alahmad, B.; Garshick, E.; Neophytou, A.M.; Bouhamra, W.; Yassin, M.F.; Koutrakis, P. Acute effects of air pollution on mortality: A 17-year analysis in Kuwait. *Environ. Int.* **2019**, *126*, 476–483. [[CrossRef](#)]
34. Al-Hemoud, A.; Gasana, J.; Al-Dabbous, A.N.; Al-Shatti, A.; Al-Khayat, A. Disability Adjusted Life Years (DALYs) in Terms of Years of Life Lost (YLL) Due to Premature Adult Mortalities and Postneonatal Infant Mortalities Attributed to PM_{2.5} and PM₁₀ Exposures in Kuwait. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2609. [[CrossRef](#)] [[PubMed](#)]
35. Halos, S.H.; Al-Dousari, A.; Anwer, G.R.; Anwer, A.R. Impact of PM_{2.5} concentration, weather and population on COVID-19 morbidity and mortality in Baghdad and Kuwait cities. *Model. Earth Syst. Environ.* **2022**, *8*, 3625–3634. [[CrossRef](#)] [[PubMed](#)]
36. Munshed, M.; Van Griensven Thé, J.; Fraser, R.; Matthews, B.; Ramadan, A. Extending Multi-Pathway Human Health Risk Assessment from Regional to Country-Wide—A Case Study on Kuwait. *Atmosphere* **2023**, *14*, 1247. [[CrossRef](#)]

37. Yuan, Y.; Alahmad, B.; Kang, C.-M.; Al-Marri, F.; Kommula, V.; Bouhamra, W.; Koutrakis, P. Dust Events and Indoor Air Quality in Residential Homes in Kuwait. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2433. [CrossRef]
38. Feyissa, T.R.; Oguoma, V.M.; Alsharrah, S.; Schroers, R.D.; Al-mulla, F.; Daniel, M. Spatial analysis of physical activity and ambient air pollution in Kuwait: A cross-sectional study. *Sci. Rep.* **2026**. [CrossRef]
39. Zhang, X.; Jin, Y.; Dai, H.; Xie, Y.; Zhang, S. Health and economic benefits of cleaner residential heating in the Beijing–Tianjin–Hebei region in China. *Energy Policy* **2019**, *127*, 165–178. [CrossRef]
40. U.S. Environmental Protection Agency Guideline 2018. Available online: <https://www.epa.gov/pm-pollution/particulate-matter-pm-basics?> (accessed on 10 January 2026).
41. Scott, R.R.; Sanborn, M.; Wright, C. State of New Hampshire 2020 Air Quality Update pp 1–29. 2021. Available online: <https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/r-ard-21-05.pdf> (accessed on 10 January 2026).
42. Lelieveld, J.; Evans, J.S.; Fnais, M.; Giannadaki, D.; Pozzer, A. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* **2015**, *525*, 367–371. [CrossRef]
43. Richmond-Bryant, J.; Owen, R.C.; Graham, S.; Snyder, M.; McDow, S.; Oakes, M.; Kimbrough, S. Estimation of on-road NO₂ concentrations, NO₂/NO_x ratios, and related roadway gradients from near-road monitoring data. *Air Qual. Atmos. Health* **2017**, *10*, 611–625. [CrossRef]
44. Hesterberg, T.W.; Bunn, W.B.; McClellan, R.O.; Hamade, A.K.; Long, C.M.; Valberg, P.A. Critical review of the human data on short-term nitrogen dioxide (NO₂) exposures: Evidence for NO₂ no-effect levels. *Crit. Rev. Toxicol.* **2009**, *39*, 743–781. [CrossRef] [PubMed]
45. Taha, S.S.; Idoudi, S.; Alhamdan, N.; Ibrahim, R.H.; Surkatti, R.; Amhamed, A.; Alrebei, O.F. Comprehensive review of health impacts of the exposure to nitrogen oxides (NO_x), carbon dioxide (CO₂), and particulate matter (PM). *J. Hazard. Mater. Adv.* **2025**, *19*, 100771. [CrossRef]
46. Reboul, C.; Boissière, J.; André, L.; Meyer, G.; Bideaux, P.; Fouret, G.; Feillet-Coudray, C.; Obert, P.; Lacampagne, A.; Thireau, J.; et al. Carbon monoxide pollution aggravates ischemic heart failure through oxidative stress pathway. *Sci. Rep.* **2017**, *7*, 39715. [CrossRef]
47. Abdel-Shafy, H.I.; Mansour, M.S.M. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egypt. J. Pet.* **2016**, *25*, 107–123. [CrossRef]
48. Kumar, A.; Singh, B.P.; Punia, M.; Singh, D.; Kumar, K.; Jain, V.K. Assessment of indoor air concentrations of VOCs and their associated health risks in the library of Jawaharlal Nehru University, New Delhi. *Environ. Sci. Pollut. Res. Int.* **2014**, *21*, 2240–2248. [CrossRef]
49. Hales, S.; Atkinson, J.; Metcalfe, J.; Kuschel, G.; Woodward, A. Long term exposure to air pollution, mortality and morbidity in New Zealand: Cohort study. *Sci. Total Environ.* **2021**, *801*, 149660. [CrossRef]
50. Sinharay, R.; Gong, J.; Barratt, B.; Ohman-Strickland, P.; Ernst, S.; Kelly, F.J.; Zhang, J.J.; Collins, P.; Cullinan, P.; Chung, K.F. Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: A randomised, crossover study. *Lancet* **2018**, *391*, 339–349.
51. de Bont, J.; Jaganathan, S.; Dahlquist, M.; Persson, Å.; Stafoggia, M.; Ljungman, P. Ambient air pollution and cardiovascular diseases: An umbrella review of systematic reviews and meta-analyses. *J. Intern. Med.* **2022**, *291*, 779–800. [CrossRef]
52. Etchie, T.O.; Etchie, A.T.; Sivanesan, S.; Adewuyi, G.O.; Krishnamurthi, K.; Pillarisetti, A.; George, K.V.; Rao, P.S. Dangerous organic chemicals identified in inhalable particulate matter air pollution. In *IOP Conference Series: Materials Science and Engineering*, 1st ed.; Institute of Physics Publishing: Bristol, UK, 2019; Volume 640, p. 012094. [CrossRef]
53. Ferguson, L.; Taylor, J.; Davies, M.; Shrubsole, C.; Symonds, P.; Dimitroulopoulou, S. Exposure to indoor air pollution across socio-economic groups in high-income countries: A scoping review of the literature and a modelling methodology. *Environ. Int.* **2020**, *143*, 105748. [CrossRef] [PubMed]
54. Balmes, J.R. Household air pollution from domestic combustion of solid fuels and health. *J. Allergy Clin. Immunol.* **2019**, *143*, 1979–1987. [CrossRef] [PubMed]
55. Sana, A.; Kafando, B.; Dramaix, M.; Meda, N.; Bouland, C. Household energy choice for domestic cooking: Distribution and factors influencing cooking fuel preference in Ouagadougou. *Environ. Sci. Pollut. Res.* **2020**, *27*, 18902–18910. [CrossRef]
56. Lv, Y.; Zhu, R.; Xie, J.; Yoshino, H. Indoor environment and the blood pressure of elderly in the cold region of China. *Indoor Built Environ.* **2022**, *31*, 2482–2498. [CrossRef]
57. Deepthi, Y.; Shiva Nagendra, S.M.; Gummadi, S.N. Characteristics of indoor air pollution and estimation of respiratory dosage under varied fuel-type and kitchen-type in the rural areas of Telangana state in India. *Sci. Total Environ.* **2019**, *650*, 616–625. [CrossRef]

58. Woolley, K.E.; Dickinson-Craig, E.; Lawson, H.L.; Sheikh, J.; Day, R.; Pope, F.D.; Greenfield, S.M.; Bartington, S.E.; Warburton, D.; Manaseki-Holland, S.; et al. Effectiveness of interventions to reduce household air pollution from solid biomass fuels and improve maternal and child health outcomes in low- and middle-income countries: A systematic review and meta-analysis. *Indoor Air* **2022**, *32*, e12958. [\[CrossRef\]](#)
59. Chaudhary, A.; Prakash, C.; Sharma, S.K.; Mor, S.; Ravindra, K.; Krishnan, P. Health risk assessment of aerosol particles (PM_{2.5} and PM₁₀) during winter crop at the agricultural site of Delhi, India. *Environ. Monit. Assess.* **2023**, *195*, 1297. [\[CrossRef\]](#) [\[PubMed\]](#)
60. Jain, S.; Sharma, S.K.; Vijayan, N.; Mandal, T.K. Investigating the seasonal variability in source contribution to PM 2.5 and PM₁₀ using different receptor models during 2013–2016 in Delhi, India. *Environ. Sci. Pollut. Res.* **2021**, *28*, 4660–4675. [\[CrossRef\]](#) [\[PubMed\]](#)
61. Sen, A.; Karapurkar, S.G.; Saxena, M.; Shenoy, D.M.; Chatterjee, A.; Choudhuri, A.K.; Das, T.; Khan, A.H.; Kuniyal, J.C.; Pal, S. Stable carbon and nitrogen isotopic composition of PM₁₀ over Indo-Gangetic Plains (IGP), adjoining regions and Indo- Himalayan Range (IHR) during a winter 2014 campaign. *Environ. Sci. Pollut. Res.* **2018**, *25*, 26279–26296. [\[CrossRef\]](#)
62. Sun, C.; Zhang, W.; Luo, Y.; Li, J. Road construction and air quality: Empirical study of cities in China. *J. Clean. Prod.* **2021**, *319*, 128649. [\[CrossRef\]](#)
63. Mikerov, A.N.; Bezrukova, G.A.; Novikova, T.A. Occupational non-communicable respiratory diseases in industrial and agricultural workers. *Hyg. Sanit.* **2023**, *102*, 1056–1062. [\[CrossRef\]](#)
64. Shan, S.; Li, Y.; Zhang, Z.; Zhu, W.; Zhang, T. Identification of key carbon emission industries and emission reduction control based on complex network of embodied carbon emission transfers: The case of Hei-Ji-Liao, China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2603. [\[CrossRef\]](#)
65. Santos, U.P.; Arbex, M.A.; Braga, A.L.F.; Mizutani, R.F.; Cançado, J.E.D.; Terra-Filho, M.; Chatkin, J.M. Environmental air pollution: Respiratory effects. *J. Bras. Pneumol.* **2021**, *47*, e20200267. [\[CrossRef\]](#) [\[PubMed\]](#)
66. Rosario, C.S.; Urrutia-Pereira, M.; Murrieta-Aguttes, M.; D'Amato, G.; Chong-Silva, D.C.; Godoi, R.H.M.; Rosario Filho, N.A. Air pollution and rhinitis. *Front. Allergy* **2024**, *5*, 1387525. [\[CrossRef\]](#)
67. Tiotiu, A.I.; Novakova, P.; Nedeva, D.; Chong-Neto, H.J.; Novakova, S.; Steiropoulos, P.; Kowal, K. Impact of Air Pollution on Asthma Outcomes. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6212. [\[CrossRef\]](#)
68. Aithal, S.S.; Sachdeva, I.; Kurmi, O.P. Air quality and respiratory health in children. *Breathe* **2023**, *19*, 230040. [\[CrossRef\]](#)
69. de Prado Bert, P.; Mercader, E.M.H.; Pujol, J.; Sunyer, J.; Mortamais, M. The Effects of Air Pollution on the Brain: A Review of Studies Interfacing Environmental Epidemiology and Neuroimaging. *Curr. Env. Health Rep.* **2018**, *5*, 351–364. [\[CrossRef\]](#)
70. Lim, E.H.; Franklin, P.; Trevenen, M.L.; Nieuwenhuijsen, M.; Yeap, B.B.; Almeida, O.P.; Hankey, G.J.; Golledge, J.; Etherton-Beer, C.; Flicker, L.; et al. Exposure to low-level ambient air pollution and the relationship with lung and bladder cancer in older men, in Perth, Western Australia. *Br. J. Cancer* **2023**, *129*, 1500–1509. [\[CrossRef\]](#)
71. Khaniabadia, Y.O.; Bahramia, P.; Birganic, P.M.; Rashidid, R.; Naqvie, H.R.; Anbarif, K. Risk assessment of exposure to the Middle Eastern dust storms in Iran. *Hum. Ecol. Risk Assess. Int. J.* **2023**, *29*, 743–756. [\[CrossRef\]](#)
72. WHO. Addressing the Impact of Air Pollution on Health in the Eastern Mediterranean Region. 2014. Available online: https://www.emro.who.int/about-who/rc61/impact-air-pollution.html?utm_source=chatgpt.com (accessed on 27 January 2026).
73. Meo, S.A.; Shaikh, N.; Meo, A.S. Effect of particulate matter (PM_{2.5}, PM₁₀) on deaths and disability-adjusted life years (DALYs) in Gulf Cooperation Council countries: Global burden of disease time trend analysis 1990–2021. *Pak. J. Med. Sci.* **2025**, *41*, 2875–2882. [\[CrossRef\]](#) [\[PubMed\]](#)
74. Motairek, I.; Ajluni, S.; Khraishah, H.; AlAhmad, B.; Al-Dulaimi, S.; Khalil, C.A.; Rajagopalan, S.; Al-Kindi, S. Burden of cardiovascular disease attributable to particulate matter pollution in the eastern Mediterranean region: Analysis of the 1990–2019 global burden of disease. *Eur. J. Prev. Cardiol.* **2023**, *30*, 256–263. [\[CrossRef\]](#)
75. Daniyal, M.; Alyami, H.; Alqahtani, A.J.; Talha, M.; Rahman, A.; Al Mutair, A. Modeling and forecasting air pollution for public health protection based on ML and time series models in Gulf Cooperation Council (GCC) countries. *BMC Public Health* **2026**, *26*, 280. [\[CrossRef\]](#) [\[PubMed\]](#)
76. Air Quality in Kuwait City. Available online: <https://www.iqair.com/kw/kuwait/al-asimah/kuwait-city> (accessed on 2 February 2026).
77. Aldekheel, M.; Tohidi, R.; Al-Hemoud, A.; Alkudari, F.; Verma, V.; Subramanian, P.S.G.; Sioutas, C. Identifying urban emission sources and their contribution to the oxidative potential of fine particulate matter (PM_{2.5}) in Kuwait. *Env. Pollut.* **2024**, *15*, 123165. [\[CrossRef\]](#) [\[PubMed\]](#)
78. Al-Hemoud, A.; Al-Senafi, A.; Al-Khayat, A.; Behbehani, W.; Al-Dashti, H.; Al-Dabbous, A.; Al-Qadeeri, G.; Gasana, J.; Mihalkov, V.; Petrov, P.; et al. The complex chemical effects of air pollutants, meteorology and dust on the concentrations of criteria and non-criteria air pollution in Kuwait. *Discov. Atmos.* **2024**, *2*, 15. [\[CrossRef\]](#)

79. Akagbue, B.O.; Ibrahim, M.N.; Ofure, O.F.; Ekugbe, O.U.; Amaobichukwu, C.T.; Kyrian, O.; Aminu, M.B.; Dung, P.D.; Salisu, S.M.; Babale, S.I.; et al. Comprehensive Assessment and Remediation Strategies for Air Pollution: Current Trends and Future Prospects; A Case Study in Bompai Industrial Area, Kano State, Nigeria. *Commun. Phys. Sci.* **2023**, *10*, 1–13.
80. Vilcassim, R.; Thurston, G.D. Gaps and future directions in research on health effects of air pollution. *EBioMedicine* **2023**, *93*, 104668. [[CrossRef](#)] [[PubMed](#)]

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