Perceived Versus Measured Air Quality in Kuwait

The Role of Respiratory Symptoms in Detecting $PM_{2.5}$

Takeaki Toma
College of Engineering and Technology, American University of the Middle East, Kuwait
takeaki.toma@aum.edu.kw (corresponding author)

Nicolas Lopez
College of Engineering and Technology, American University of the Middle East, Kuwait
nicolas.lopez@aum.edu.kw

Suat Kasap
College of Engineering and Technology, American University of the Middle East, Kuwait
suat.kasap@aum.edu.kw

Received: 2 June 2025 | Revised: 8 September 2025 | Accepted: 21 September 2025

 DOI: https://doi.org/10.48084/etasr.12516

ABSTRACT

This study investigated the gap between the perceived and actual air quality in Kuwait and its implications for public health. Perceived air quality data were compared with real-time $PM_{2.5}$, PM_{10}, HCHO, and Total Volatile Organic Compounds (TVOC) measurements. Although the $PM_{2.5}$ and PM_{10} levels were statistically associated with the perceived air quality (Odds Ratios (OD) of 1.04 and 1.03, respectively), the practical effect was minimal. Most participants did not recognize poor air quality until $PM_{2.5}$ exceeded 59 μg/m³ - nearly four times higher than the WHO short-term exposure limit - implying limited real-world sensitivity to pollution. In contrast, health status, particularly chronic cough or asthma, strongly influenced air quality perception. Smoking, frequent exposure to perfume, or exposure to Bukhoor were not significantly associated with the participants' perception of air quality, possibly suggesting olfactory fatigue. These findings pointed to a regional desensitization to air pollutants and highlighted the need for improved public awareness, early alert systems, and protective interventions for at-risk populations.

Keywords-$PM_{2.5}$; perceived air quality; respiratory health; olfactory fatigue; cognitive biases

I. INTRODUCTION

Air pollution from fine Particulate Matter (PM) smaller than 2.5 micrometers, or $PM_{2.5}$, is responsible for millions of deaths annually [1, 2]. While adverse health effects of $PM_{2.5}$ exposure in Kuwait are documented [3-6], a crucial question remains: Do people perceive bad air quality? Perceived air quality can significantly shape public health behaviors, such as using air purifiers or wearing masks [7].

When people breathe $PM_{2.5}$ deep into their lungs, it may enter the bloodstream, triggering heart attacks and strokes and causing damage to the pulmonary and cardiovascular systems, as well as the brain - even at 'normal' $PM_{2.5}$ urban levels [8]. A 16-year cohort study tracking 500,000 adults found that each 10 μg/m³ increase in long-term average $PM_{2.5}$ levels was associated with a 4% rise in all-cause mortality, a 6% increase in cardiopulmonary deaths, and an 8% increase in lung cancer mortality [9]. This link remained statistically significant after being adjusted for smoking, body mass index, dietary habits, occupational exposures, and other risks. Scientific reviews confirmed that inhaling $PM_{2.5}$ leads to inflammation, blood vessel damage, and increased risk of chronic diseases, such as Chronic Obstructive Pulmonary Disease (COPD), lung cancer, arteriosclerosis, myocardial infarction, stroke, and other pulmonary and cardiovascular conditions [8]. The International Agency for Research on Cancer (IARC) classified PM as carcinogenic to humans in 2013 [10]. According to the Global Burden of Disease 2010 comparative risk assessment, the disease burden from $PM_{2.5}$ was 3.2 million worldwide lung cancer, cardiopulmonary mortality, larger than the combined impact of HIV-AIDS and malaria [11]. A case study in Nawabshah, Pakistan, found that air quality was heavily polluted by PM_{10} (Particulate Matter 10 micrometers or less in diameter) and $PM_{2.5}$, with mean concentrations significantly higher than WHO guidelines [12]. The Middle East presents a particularly challenging case, as its hot desert climate generates significant $PM_{2.5}$ pollution and lacks the natural air-cleansing processes of plants and rainfall.

Kuwait faces significant challenges with $PM_{2.5}$ air pollution. Authors in [13] reported high $PM_{2.5}$ levels in Kuwait City between 2017 and 2019, averaging 41.6 μg/m³, a concentration 8.32 times higher than the limit of WHO annual guideline [14]. Similarly, in [4] $PM_{2.5}$ levels in Kuwait reached an annual average of 75.2μg/m³ between 2014 and 2017, contributing to an estimated 487 premature deaths per year, with stroke and heart disease accounting for over 70% of these pollution-related fatalities. In Kuwait City, the primary sources of $PM_{2.5}$ are sand dust (54%), oil combustion (18%), the petrochemical industry (12%), and traffic (11%), with additional contributions from emissions transported from neighboring countries. [15]. Authors in [16] investigated the air quality in two local schools. Their measurements found compounds like Non-Methane Hydrocarbons (NMHCs), which originate mainly from vehicle traffic emissions that exceeded 2 ppm (Kuwait EPA limit: 0.24 ppm between 6 AM and 9 AM), NO_2 levels peaking above 200 ppb (Kuwait EPA limit: 100 ppb) and PM_{10} reaching over 500 μg/m³ (Kuwait EPA limit: 350 μg/m³). This means that children were exposed to traffic-related air pollutants, which could cause asthma, lung inflammation, cardiovascular disease, lung cancer, and leukemia. Similarly, in [17], severe traffic-related contamination was observed, with NMHC levels consistently exceeding regulatory limits (actual: 0.94 ppm; limit: 0.24 ppm), nitrogen dioxide concentrations frequently surpassing standards (peak: 544 ppb; limit: 100 ppb), and PM reaching hazardous levels (up to 803 μg/m³; limit: 350 μg/m³). These levels can be attributed to Kuwait's high vehicle density (377 vehicles per 1000 people), extreme climate necessitating vehicular transport, and historically limited emission regulations. Such heavy air pollution has a tremendous impact on public health in Kuwait. For example, authors in [18] estimated that 15% of adults and 18% of children in Kuwait had asthma. In [19], it was reported that sandstorms in Kuwait during 2021 increased $PM_{2.5}$ levels by 26.6% and were associated with a 21% rise in daily COVID-19 cases and a 61% surge in deaths, suggesting that airborne particles may significantly amplify viral transmission and mortality. The total annual direct cost of asthma treatment, including medication, exceeded 58 million Kuwaiti dinars (approximately USD 207 million), a remarkably high figure given that the country's population at the time was only around one million [18]. Climate change may generate more $PM_{2.5}$ air pollution by increasing dust storms and altering atmospheric conditions, contributing to lung and heart diseases [20]. Urgent control strategies and policy interventions are needed to address Kuwait's critical environmental and public health issues [4, 5].

Although the health risks of $PM_{2.5}$ exposure in Kuwait are well-documented [13, 21], existing studies have largely overlooked how individuals perceive air quality in this unique cultural and environmental context. Burning Bukhoor and frequent exposure to desert dust may desensitize Kuwait residents to harmful pollutants, creating an air quality perception gap. This research bridges the gap between perceived air quality and actual air quality - measured by $PM_{2.5}$, PM_{10}, formaldehyde (HCHO), a harmful gas emitted from building materials and indoor combustion, and TVOC, a class of airborne chemicals released from products, such as perfumes and cleaners. Specifically, this research addresses the following questions:

- RQ-1: Is there any association between the perceived and actual air quality ($PM_{2.5}$, PM_{10}, HCHO, and TVOC) in Kuwait?
- RQ-2: At what levels of $PM_{2.5}$ and PM_{10} do Kuwait residents start to perceive air quality as bad?
- RQ-3: How do demographics and lifestyle affect how Kuwaiti residents perceive air quality?

II. METHODS

A. *Perceived Air Quality Data Collection*

A structured questionnaire was designed with three main sections: demographic information, lifestyle habits, and perceptions of air quality. The first part of the questionnaire collected basic demographic information, including gender and age range, location details, and whether the environment was indoor or outdoor. These questions helped identify patterns in air quality perceptions across different demographic groups and settings. Next, participants were asked to evaluate the air quality at their current location using a 5-point Likert scale ranging from 1 ("Very clean") to 5 ("Very polluted"). The exact question was: "How do you subjectively evaluate the air quality in your current location?" The scale was intentionally left subjective without reference ranges, as this study aimed to capture participants' casual perceptions of air quality rather than a calibrated or standardized evaluation. This approach is consistent with prior studies on perceived air quality [22, 23]. The American University of the Middle East (AUM) research office approved the questionnaire, ensuring that it meets the ethical standards required for academic research.

B. *Objective Air Quality Data Collection*

Immediately after collecting the questionnaire responses, the interviewer entered the corresponding objective air quality data, including $PM_{2.5}$, PM_{10}, HCHO, and TVOC. The air quality measurements were conducted at an identical location. To ensure the stability and accuracy of the readings, the air quality data were recorded 3 min after the device was activated, as this duration allowed the parameter values to stabilize. The Temtop LKC-1000S+ [24] was selected for its portability and sufficient reliability, which is supported by a validation study from the U.S. government's South Coast AQMD that showed a strong correlation with reference instruments, including an R^2 value greater than 0.99 for $PM_{2.5}$ in laboratory tests [25]. This validation and the cross-calibration against a Temtop M2000 unit ensured measurement consistency for this research. Data were collected between February 22nd, 2023, and May 13th, 2023, and Participant characteristics are summarized in Table I. A total of 170 observations were initially gathered, with 149 retained for final analysis after data cleaning procedures.

TABLE I. PARTICIPANT CHARACTERISTICS (N=149)

Characteristics	Category	Number	Percentage %
Gender	Female	107	71.8
	Male	42	28.2
Age group	Below 20	8	5.4
	20-29	88	59.1
	30-39	33	22.1
	40-49	12	8.1
	50-59	6	4.0
	60+	2	1.3
Respiratory condition	No cough/asthma	26	17.4
	Sometimes cough	101	67.8
	Too much cough (not asthma)	18	12.1
	Asthma	4	2.7

C. Statistical Data Analysis

Ordinal logistic regression was applied to assess the influence of actual air quality parameters and demographic and lifestyle factors on perceived air quality. This analytical approach is consistent with established methods in prior air quality perception research [22, 26-28]. R software was used to analyze the collected perceived air quality and measured data.

III. RESULTS

A. RQ-1: Perception of Air Quality versus Measured Pollutants

The ordinal logistic regression analysis revealed that $PM_{2.5}$, PM_{10}, and TVOC were associated with perceived air quality (Table II).

TABLE II. FACTORS INFLUENCING PERCEIVED AIR QUALITY: SINGLE-FACTOR AND COUGH-ADJUSTED MODELS

Factors	Single Factor Model		Cough-Adjusted Model	
	OR	95%C.I.	OR	95%C.I.
$PM_{2.5}$	1.04**	(1.02,1.07)	1.04**	(1.02,1.07)
PM_{10}	1.03**	(1.01, 1.05)	1.03**	(1.01,1.05)
HCHO	0.83	(0.08, 8.94)	0.54	(0.04, 7.12)
TVOC	1.58**	(1.14, 2.18)	1.29	(0.90, 1.87)
Smoke (self)	1.31	(0.66, 2.57)	1.41	(0.70, 2.85)
Smoke (family members)	1.95*	(1.06, 3.57)	1.58	(0.84, 2.98)
Smoke (friends)	5.23***	(2.62, 10.44)	4.29***	(2.15, 8.85)
Perfume	1.35	(0.73, 2.49)	1.12	(0.59, 2.16)
Bukhoor	1.7	(0.92, 3.11)	1.33	(0.69, 2.56)
Exhaust gases from cars, buses, or trucks	5.38***	(2.74, 10.58)	4.94*	(2.43, 10.36)
Cooking	4.26***	(2.22, 8.19)	3.60*	(1.78, 7.41)
Gender	1.02	(0.52, 2)	1.12	(0.53, 2.39)
Age (20-29)	4.94	(1.16, 21.07)	3.90	(0.73, 23.86)
Age (30-39)	4.17	(0.89, 19.67)	3.65	(0.62, 24.02)
Age (40-49)	8.15	(1.43, 46. 41)	10.19	(1.50, 80.46)
Age (over 50)	13.08	(1.92, 89.33)	8.48	(1.06 76.37)
Little cough	8.00***	(3.25, 19.70)		
Too much cough (not asthma)	11.74***	(3.25, 42.38)		
Asthma	9.01**	(1.39, 58.57)		

*P < .05, **p < .01, ** p < .001*

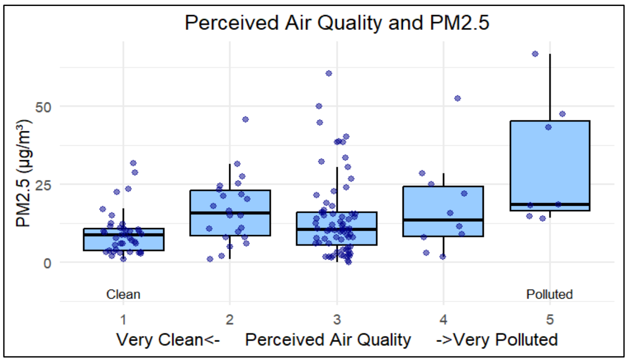

Fig. 1. $PM_{2.5}$ and perceived air quality.

Figure 1 illustrates $PM_{2.5}$ levels across perceived air quality categories. The ordinal logistic regression showed a significant association between $PM_{2.5}$ and perceived air quality (OR = 1.04, 95% Confidence Interval (CI) [1.02, 1.07]). Similarly, Figure 2 demonstrates that PM_{10} was also significantly associated with perceived air quality (OR = 1.03, 95% CI [1.01, 1.05]), consistent with prior studies [23, 28].

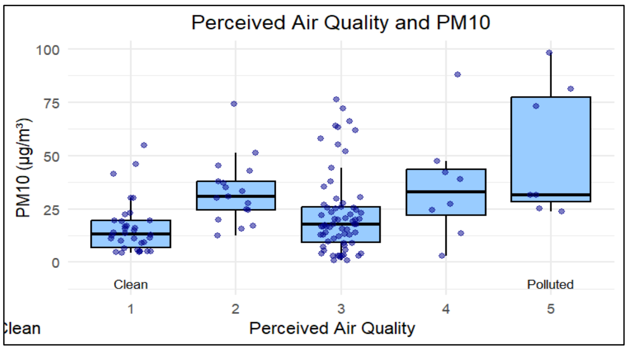

Fig. 2. PM_{10} and perceived air quality.

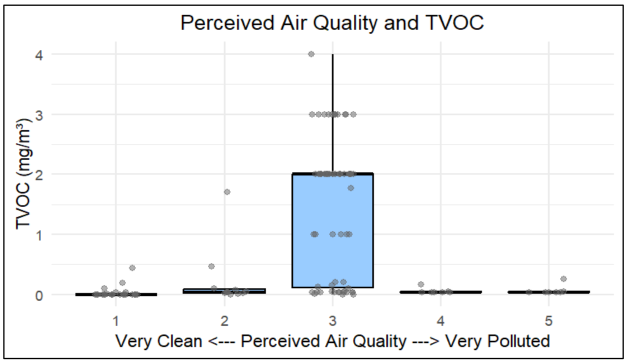

Fig. 3. TVOC and perceived air quality.

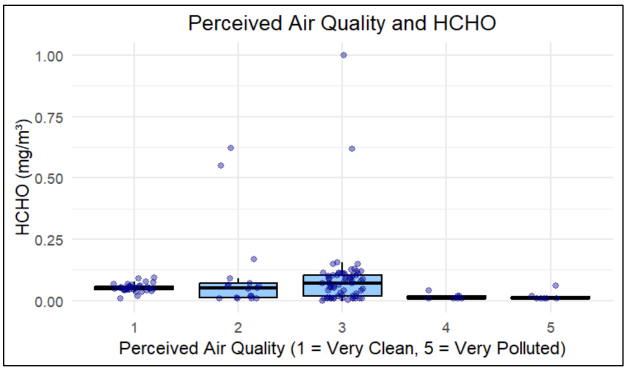

Fig. 4. HCHO and perceived air quality.

Figure 3 presents the relationship between TVOC levels and perceived air quality. A significant correlation was observed in the ordinal logistic regression model (OR = 1.58, 95% CI [1.14, 2.18]). However, given that a large proportion of participants rated air quality as "neutral", this statistical significance should be interpreted with caution. Figure 4 indicates no significant relationship between HCHO and perceived air quality (OR = 0.83, 95% CI [0.08, 8.94]), suggesting that formaldehyde levels were either too low to be noticed or not perceived as harmful by participants.

B. RQ-2: Perceptual Thresholds

Perceived air quality levels 4 and 5 were classified as "bad" and levels 1, 2, and 3 as "good", and the binary logistic regression was analyzed to identify pollution thresholds. The threshold for $PM_{2.5}$ related to "bad" perceived air quality was 59 μg/m³ (95% CI [24.97, 231.74]), consistent with prior research (50 μg/m³ in [29]). The threshold for PM_{10} was found to be 81.08 μg/m³ (95% CI [35.57, 246.56]), which aligned with the 90 μg/m³ threshold reported in [23].

C. RQ-3: Demographic and Lifestyle Influences

Age, exposure to secondhand smoke, traffic exhaust, and cooking-related emissions were all connected with higher levels of perceived air quality. Using the "below 20 years old" group as the reference category, all age groups, particularly those over 50, reported stronger perceptions of pollution (OR=13.08, 95% CI [1.92, 89.33]). This trend underscored a substantial increase in perceived pollution with age.

As for the smoking factor, the exposure to secondhand smoke from friends was related to a significant increase in the perceived air quality (OR=5.23, 95% CI [2.62, 10.44]). On the other hand, the current smokers tended to report better air quality than non-smokers, which is consistent with other studies [22]. Similarly, the individuals who identified exhaust from vehicles as a pollution source were over 5.38 times more likely to report poor air quality (95% CI [2.74, 10.58]). Those identifying cooking as a pollution contributor also had 4.26 times higher OR of reporting higher pollution levels (95% CI [2.22, 8.19]).

In Figure 5, the perceived air quality was significantly related to respiratory conditions. Compared to the healthy group who reported the "Not at all" cough situation, the worst perceived air quality was described for:

- "Sometimes" cough (OR=7.8, 95% CI [3.26, 20.03])
- "Asthma" (OR=8.41, 95% CI [1.25, 62.81])
- "Too much cough (but not asthma)" (OR=8.21, 95% CI [2.31, 30.92])

These results indicated that people with respiratory problems were more likely to perceive air quality as poor, as $PM_{2.5}$ levels increased.

The group with "Not cough/asthma" (*n* = 26) had a threshold for perceiving bad air quality at 100.67 μg/m³ (95% CI: [-448.29, 649.63]), whereas those with cough symptoms or asthma (*n* = 123) showed a significantly lower threshold at 58.64 μg/m³ (95% CI: [12.3, 105.0]). This suggests that individuals with respiratory compromise are more sensitive to $PM_{2.5}$ pollution and begin perceiving air quality as poor at much lower concentrations.

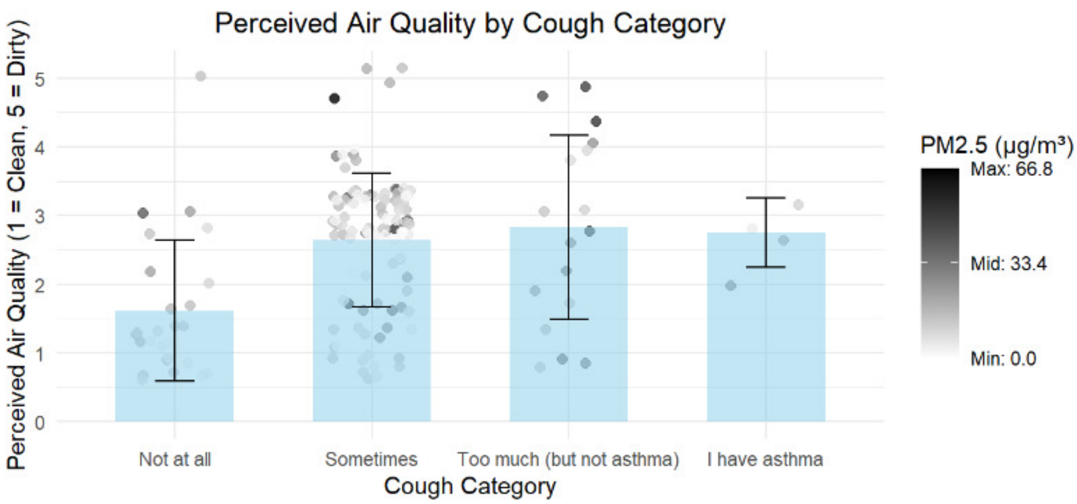

Fig. 5. Respiratory symptoms and perceived air quality.

IV. DISCUSSION

A. Why Do Some People Notice Poor Air Quality?

This study showed a stronger association between respiratory health problems and perceived air quality than measured $PM_{2.5}$ levels. This raises the question: why do individuals with respiratory issues perceive poorer air quality?

$PM_{2.5}$ is significantly associated with increased asthma, particularly in children [30, 31], causing airway inflammation by increasing antioxidant enzyme activity in the lung [32]. In addition, $PM_{2.5}$ induces necroptosis-related inflammation, a form of programmed cell death, in which damaged cells rupture and release inflammatory mediators, thereby amplifying airway inflammation [33]. This process sensitizes airway nerves and promotes hyperresponsiveness, explaining why asthma patients notice $PM_{2.5}$ at lower levels than healthy individuals [34].

Similarly, COPD patients are more likely to notice poor air quality at relatively low $PM_{2.5}$ concentrations because their airways are chronically inflamed and hypersensitive [35]. Different $PM_{2.5}$ substances have distinct mechanisms that exacerbate this condition - for example, metals and Polycyclic Aromatic Hydrocarbons (PAHs) promote oxidative stress, while Carbonaceous Particles (CPs), microorganisms, and PAHs induce inflammation. These processes contribute to lung inflammation, mucus hypersecretion, emphysema, and airway remodeling, which involves structural changes in the airway, such as wall thickening, mucus gland hyperplasia, and smooth muscle hypertrophy [35]. Such changes sensitize airway nerves and lower the threshold for irritation, making COPD patients more likely to perceive deteriorated air quality than healthy individuals [35].

Due to the above physiological mechanisms, people with respiratory problems could be more sensitive to air pollutants. For instance, authors in [6] found that dust storms in Kuwait led to higher hospital admissions for asthma and other respiratory diseases. In [36], an association between living near industrial areas and increased asthma severity in Oman was observed.

Beyond these environmental factors, Bukhoor, a traditional Arabian incense, can also directly exacerbate respiratory sensitivity. Bukhoor can reduce dust-borne fungal allergens from Middle Eastern sandstorms [37]. However, its smoke produces very high levels of $PM_{2.5}$ [38] of harmful Volatile Organic Compounds (VOCs), such as benzene, toluene, formaldehyde, acrolein, metals, and other carcinogenic substances [39, 40], while evidence indicates a strong link with lung cancer [41]. In Oman, the parents of asthmatic children had 2.55 times higher odds of reporting that their child's breathing was affected by Bukhoor. Using Bukhoor more than twice weekly was associated with three times higher odds of breathing problems compared to rare or no use, and 38% of asthmatic children reported worsened wheezing [42]. Additionally, authors in [26] reported that the perceived air quality and adult asthma were significantly related, much more than actual $PM_{2.5}$ air pollution. This phenomenon extends beyond asthma and COPD. People with hay fever also tended to identify poor air quality more often than unaffected people [23]. In essence, the perception of poor air quality by someone with a respiratory illness likely indicates elevated $PM_{2.5}$ levels, even if healthy individuals remain unaware.

B. Why Do Healthy People Not Notice Poor Air Quality?

Healthy individuals had difficulty perceiving poor air quality until $PM_{2.5}$ levels reached dangerously high concentrations. Physiologically, people would notice air pollution with haze (visual cue) or smell the odor (olfactory cue). Visually, it is challenging to notice polluted air with haze. People may notice coarser particles, such as PM_{10}, while it is challenging to notice $PM_{2.5}$, finer PM [43]. Furthermore, olfactory cues can be unreliable due to dysfunction or fatigue (nose blindness). Research has linked long-term $PM_{2.5}$ exposure to a diminished capacity for odor identification [44], and studies in highly air-polluted areas, such as Mexico City, have shown substantial olfactory impairment in residents [45]. In indoor environments, smoking cigarettes is linked to olfactory dysfunction [46, 47], suggesting that the use of Bukhoor incense could similarly impair olfactory function and make people less able to notice poor air quality in Kuwait.

Beyond these physiological limitations, psychological biases may significantly affect the perception of air quality. Authors in [48] claimed that confirmation bias (e.g., confirming only favorable beliefs despite evidence of the harms of polluted air) and the halo effect (e.g., assuming one's home air is clean even when $PM_{2.5}$ levels are high) would affect the perceived air quality. In [49], many people associated pleasant smells from cooking and incense with good air quality, while they linked cigarette smoke with bad air quality, even though all of these could be hazardous to health.

Such psychological biases may be rooted in erroneous mental models and insufficient knowledge about the dangers of poor air quality. For example, research has indicated that lung cancer could develop from inhaling air pollutants released during cooking [50, 51] and burning incense [52-54]. However, students in Kuwait University who smoked waterpipe and cigarettes had a very positive belief about their health [54]. This finding is consistent with research from other regions, such as a study in Florida where 51% of students believed smoking Hookah (waterpipe) is safer than smoking cigarettes [55]. In [56], psychological factors, such as knowledge and attitudes, significantly shaped the perception of air pollution. In summary, healthy individuals often fail to recognize poor air quality due to physiological limitations - such as the inability to see fine particles and a diminished sense of smell - and psychological biases.

C. Perception Gaps at Dangerous $PM_{2.5}$ Levels

The current findings indicated that people, particularly healthy individuals, could not notice $PM_{2.5}$ levels until the exposure level reached high concentrations. Specifically, the ordinal logistic regression model indicated that half of the participants would not notice the air quality as "bad" or "very bad" until $PM_{2.5}$ was over 59 $\mu g/m^3$. This number is consistent with other studies. For example, in [57], participants complained about air quality when $PM_{2.5}$ was larger than 80 $\mu g/m^3$, while very few reported it when $PM_{2.5}$ was less than 60 $\mu g/m^3$. Similarly, in [23], people perceived "dusty" at the $PM_{2.5}$

level of 90 μg/m³. This threshold is significantly higher than the WHO's short-term (one day) exposure limit of 15 μg/m³ and long-term exposure (one year) limit of 5 μg/m³ [13]. However, it has been demonstrated that even a low-dose of PM2.5 exposure increased the mortality rate. In the cohort study for the elderly population (> 65 years old), a 10 μg/m³ increase of $PM_{2.5}$ for short-term exposure (2 days) increased 2.14% mortality and 9.28% for long-term (1 year) exposure [58].

D. Bridging the Gap From Perception to Policy Action

The gap between measured and perceived air quality has led to delays in policy implementation and an underestimation of associated health risks. A multifaceted approach is proposed to fix this. First, air quality alert thresholds in Kuwait should be lowered to better reflect health impacts, with consideration given to issuing warnings at lower $PM_{2.5}$ levels, such as when concentrations exceed 30 μg/m³. While the WHO guideline proposes a 24-h $PM_{2.5}$ limit of 15 μg/m³, which would be exceeded on most days in Kuwait, adopting this value as an informational threshold could still help the public recognize the persistent health risks. A tiered alert system (e.g., informational at 15 μg/m³, advisory at 30 μg/m³, and emergency at higher levels) may provide realism and public health protection.

Second, the enhancement of real-time monitoring and alert systems is crucial. This can be achieved through automated alert systems, mobile applications, and public displays to ensure that residents are informed of the pollution levels. The alerts should be tailored to high-risk groups, such as children, the elderly, and individuals with asthma or COPD, particularly in schools, workplaces, and healthcare facilities.

Third, it is essential to implement measures to protect high-risk populations. This includes the distribution of masks, subsidies for air purifiers, and establishing clean-air shelters in schools. Authors in [59] also supported this notion in their analysis of emergency department visits in an industrial city in Saudi Arabia, emphasizing the need for greater awareness and effective measures to improve the air quality to protect public health.

Fourth, public awareness campaigns should be conducted to educate the public on the hazards of $PM_{2.5}$, its invisible nature, and strategies to mitigate exposure from outdoor and indoor pollution sources, such as Bukhoor and Hookah, with clear visual $PM_{2.5}$ indicators and health warnings during dust storms to enhance risk communication. Implementing these policy interventions and public awareness efforts is essential to reducing the number of pulmonary and cardiac patients exposed to harmful levels of $PM_{2.5}$. It underscores the necessity to reevaluate the perception of air pollution risks and implement stricter policies and monitoring systems.

E. Study Limitation

Although the study provided valuable information about the relationship between perceived and actual air quality data, there are several limitations. First, the analysis identified the associations between perceived and actual air quality but could not establish temporal or causal relationships. Second, health status was self-reported, which may introduce bias due to undiagnosed or misclassified respiratory conditions. Third, while participants indicated whether indoors or outdoors, the study did not fully control for exposure differences between these settings (e.g., ventilation, incense burning, cooking, or traffic). Fourth, the study's relatively small sample size (n = 149) may limit the statistical power and generalizability of the findings to the broader population. This design enhanced data reliability but limited the total number of participants. Finally, the lack of randomization in participant selection constrained the generalizability of the findings. Nevertheless, the observed associations were consistent with findings from other studies and aligned with the current understanding of air quality perception and its influencing factors in the existing literature.

ACKNOWLEDGEMENT

The authors would like to thank Zainab Alsabt, Anwaar Alrashidi, Ayah AlMohammad, Jawaher Alsalih, and Noura Alsanea for their effort in data collection during the Spring 2023 term at the American University of the Middle East

REFERENCES

[1] "State of Global Air 2020: A Special Report on Global Exposure to Air Pollution and Its Health Impacts," Health Effect Institute, Boston, MA, USA, Report, 2020.

[2] "Ambient (Outdoor) Air Pollution." World Health Organization, 2024, https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

[3] S. Achilleos *et al.*, "Acute effects of air pollution on mortality: A 17-year analysis in Kuwait," *Environment International*, vol. 126, pp. 476–483, May 2019, https://doi.org/10.1016/j.envint.2019.01.072.

[4] A. Al-Hemoud *et al.*, "Exposure levels of air pollution (PM2.5) and associated health risk in Kuwait," *Environmental Research*, vol. 179, Dec. 2019, Art. no. 108730, https://doi.org/10.1016/j.envres.2019.108730.

[5] B. Alahmad, J. Li, S. Achilleos, F. Al-Mulla, A. Al-Hemoud, and P. Koutrakis, "Burden of fine air pollution on mortality in the desert climate of Kuwait," *Journal of Exposure Science & Environmental Epidemiology*, vol. 33, no. 4, pp. 646–651, July 2023, https://doi.org/10.1038/s41370-023-00565-7.

[6] L. Thalib and A. Al-Taiar, "Dust storms and the risk of asthma admissions to hospitals in Kuwait," *Science of The Total Environment*, vol. 433, pp. 347–351, Sept. 2012, https://doi.org/10.1016/j.scitotenv.2012.06.082.

[7] J. Zhang and Q. Mu, "Air pollution and defensive expenditures: Evidence from particulate-filtering facemasks," *Journal of Environmental Economics and Management*, vol. 92, pp. 517–536, Nov. 2018, https://doi.org/10.1016/j.jeem.2017.07.006.

[8] C. A. Pope III and D. W. Dockery, "Health Effects of Fine Particulate Air Pollution: Lines that Connect," *Journal of the Air & Waste Management Association*, vol. 56, no. 6, pp. 709–742, June 2006, https://doi.org/10.1080/10473289.2006.10464485.

[9] C. A. Pope III *et al.*, "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution," *JAMA*, vol. 287, no. 9, pp. 1132–1141, Mar. 2002, https://doi.org/10.1001/jama.287.9.1132.

[10] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, *Outdoor Air Pollution*, vol. 109. Lyon, France: International Agency for Research on Cancer, 2015.

[11] J. S. Apte, J. D. Marshall, A. J. Cohen, and M. Brauer, "Addressing Global Mortality from Ambient PM2.5," *Environmental Science & Technology*, vol. 49, no. 13, pp. 8057–8066, June 2015, https://doi.org/10.1021/acs.est.5b01236.

[12] A. A. Siyal, K. C. Mukwana, S. R. Samo, S. A. Jiskani, Z. A. Siyal, and A. Mengal, "Assessment of Air Pollution by PM 10 and PM 2.5 in

Nawabshah City, Sindh, Pakistan.," *Engineering, Technology & Applied Science Research*, vol. 9, no. 1, pp. 3757–3761, 2019.

[13] B. Alahmad *et al.*, "A two-year assessment of particulate air pollution and sources in Kuwait," *Environmental Pollution*, vol. 282, Aug. 2021, Art. no. 117016, https://doi.org/10.1016/j.envpol.2021.117016.

[14] *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon dioxide*, Geneva, Switzerland: World Health Organization, 2021.

[15] M. A. Alolayan, K. W. Brown, J. S. Evans, W. S. Bouhamra, and P. Koutrakis, "Source apportionment of fine particles in Kuwait City," *Science of The Total Environment*, vol. 448, pp. 14–25, Mar. 2013, https://doi.org/10.1016/j.scitotenv.2012.11.090.

[16] E. Al-Bassam, V. Popov, and A. Khan, "Impact of road traffic on air quality at two locations in Kuwait," in *Air Pollution XVII*, Southampton, England: WIT Press, 2009.

[17] E. Al-Bassam and A. Khan, "Air Pollution And Road Traffic In Kuwait," *WIT Transactions on The Built Environment*, vol. 75, pp. 741–750, 2004, https://doi.org/10.2495/UT040721.

[18] M. Khadadah, "The Cost of Asthma in Kuwait," *Medical Principles and Practice*, vol. 22, no. 1, pp. 87–91, Aug. 2012, https://doi.org/10.1159/000341154.

[19] S. A. Meo, F. J. Almutairi, A. A. Abukhalaf, and A. M. Usmani, "Impact of sandstorm on environmental pollutants PM2.5, carbon monoxide, nitrogen dioxide, ozone, and SARS-CoV-2 morbidity and mortality in kuwait," *Journal of King Saud University - Science*, vol. 34, no. 5, July 2022, Art. no. 102109, https://doi.org/10.1016/j.jksus.2022.102109.

[20] B. Alahmad, H. Khraishah, K. Althalji, W. Borchert, F. Al-Mulla, and P. Koutrakis, "Connections Between Air Pollution, Climate Change, and Cardiovascular Health," *Canadian Journal of Cardiology*, vol. 39, no. 9, pp. 1182–1190, Sept. 2023, https://doi.org/10.1016/j.cjca.2023.03.025.

[21] S. M. Al-Salem and A. R. Khan, "Monitoring and Modelling the Trends of Primary and Secondary Air Pollution Precursors: The Case of the State of Kuwait," *International Journal of Chemical Engineering*, vol. 2010, no. 1, 2010, Art. no. 879836, https://doi.org/10.1155/2010/879836.

[22] K. Pantavou, B. Psiloglou, S. Lykoudis, A. Mavrakis, and G. K. Nikolopoulos, "Perceived air quality and particulate matter pollution based on field survey data during a winter period," *International Journal of Biometeorology*, vol. 62, no. 12, pp. 2139–2150, Oct. 2018, https://doi.org/10.1007/s00484-018-1614-3.

[23] M. Nikolopoulou, J. Kleissl, P. F. Linden, and S. Lykoudis, "Pedestrians' perception of environmental stimuli through field surveys: Focus on particulate pollution," *Science of The Total Environment*, vol. 409, no. 13, pp. 2493–2502, June 2011, https://doi.org/10.1016/j.scitotenv.2011.02.002.

[24] *Temtop LKC-1000 Series Air Quality Monitor User Manual*, Temtop UK, London, UK, 2022.

[25] *Elitech LKC-1000S+ Summary Report,* South Coast Air Quality Management District, 2020, https://www.aqmd.gov/docs/default-source/aq-spec/summary/elitech-lkc-1000s---summary-report.pdf.

[26] J. E. Clougherty and P. Ocampo, "Perception Matters: Perceived vs. Objective Air Quality Measures and Asthma Diagnosis among Urban Adults," *International Journal of Environmental Research and Public Health*, vol. 20, no. 17, Aug. 2023, Art. no. 6648, https://doi.org/10.3390/ijerph20176648.

[27] T. Rotko, L. Oglesby, N. Künzli, P. Carrer, M. J. Nieuwenhuijsen, and M. Jantunen, "Determinants of perceived air pollution annoyance and association between annoyance scores and air pollution (PM2.5, NO2) concentrations in the European *EXPOLIS* study," *Atmospheric Environment*, vol. 36, no. 29, pp. 4593–4602, Oct. 2002, https://doi.org/10.1016/S1352-2310(02)00465-X.

[28] W. Song, M.-P. Kwan, and J. Huang, "Assessment of air pollution and air quality perception mismatch using mobility-based real-time exposure," *PLOS ONE*, vol. 19, no. 2, Feb. 2024, Art. no. e0294605, https://doi.org/10.1371/journal.pone.0294605.

[29] J. Pei, M. Qu, L. Sun, X. Wang, and Y. Yin, "The relationship between indoor air quality (IAQ) and perceived air quality (PAQ) – a review and case analysis of Chinese residential environment," *Energy and Built Environment*, vol. 5, no. 2, pp. 230–243, Apr. 2024, https://doi.org/10.1016/j.enbenv.2022.09.005.

[30] R. Khalili *et al.*, "Early-life exposure to PM2.5 and risk of acute asthma clinical encounters among children in Massachusetts: a case-crossover analysis," *Environmental Health*, vol. 17, no. 1, Feb. 2018, Art. no. 20, https://doi.org/10.1186/s12940-018-0361-6.

[31] J. Fan, S. Li, C. Fan, Z. Bai, and K. Yang, "The impact of PM2.5 on asthma emergency department visits: a systematic review and meta analysis," Environmental Science and Pollution Research, vol. 23, no. 1, pp. 843-850, Sep. 2015, https://doi.org/10.1007/s11356-015-5321-x.

[32] K. Liu, S. Hua, and L. Song, "PM2.5 Exposure and Asthma Development: The Key Role of Oxidative Stress," *Oxidative Medicine and Cellular Longevity*, vol. 2022, no. 1, 2022, Art. no. 3618806, https://doi.org/10.1155/2022/3618806.

[33] Y. Zhao, H. Zhang, X. Yang, Y. Zhang, S. Feng, and X. Yan, "Fine particulate matter (PM2.5) enhances airway hyperresponsiveness (AHR) by inducing necroptosis in BALB/c mice," *Environmental Toxicology and Pharmacology*, vol. 68, pp. 155–163, May 2019, https://doi.org/10.1016/j.etap.2019.03.013.

[34] Y. Zhang, X. Yin, and X. Zheng, "The relationship between PM2.5 and the onset and exacerbation of childhood asthma: a short communication," *Frontiers in Pediatrics*, vol. 11, Aug. 2023, https://doi.org/10.3389/fped.2023.1191852.

[35] Q. Wang and S. Liu, "The Effects and Pathogenesis of PM2.5 and Its Components on Chronic Obstructive Pulmonary Disease," *International Journal of Chronic Obstructive Pulmonary Disease*, vol. 18, pp. 493–506, Apr. 2023, https://doi.org/10.2147/COPD.S402122.

[36] S. M. Al Okla *et al.*, "The Impact of Air Pollution on Asthma Severity among Residents Living near the Main Industrial Complex in Oman: A Cross-Sectional Study," *International Journal of Environmental Research and Public Health*, vol. 21, no. 5, Apr. 2024, Art. no. 553, https://doi.org/10.3390/ijerph21050553.

[37] R. Vijayakumar, "Investigating the Effect of Plant Resin Fumes on Sandstorm Allergenic Fungi Isolated from Al Zulfi, Saudi Arabia," *Asian Journal of Pharmaceutics (AJP)*, vol. 19, no. 2, July 2025, https://doi.org/10.22377/ajp.v19i2.6462.

[38] V. K. Yadav *et al.*, "Health and Environmental Risks of Incense Smoke: Mechanistic Insights and Cumulative Evidence," *Journal of Inflammation Research*, vol. 15, pp. 2665–2693, Apr. 2022, https://doi.org/10.2147/JIR.S347489.

[39] Y. Elsayed, S. Dalibalta, I. Gomes, N. Fernandes, and F. Alqtaishat, "Chemical composition and potential health risks of raw Arabian incense (Bakhour)," *Journal of Saudi Chemical Society*, vol. 20, no. 4, pp. 465–473, July 2016, https://doi.org/10.1016/j.jscs.2014.10.005.

[40] G. V. Silva, A. O. Martins, and S. D. S. Martins, "Indoor Air Quality: Assessment of Dangerous Substances in Incense Products," *International Journal of Environmental Research and Public Health*, vol. 18, no. 15, July 2021, Art. no. 8086, https://doi.org/10.3390/ijerph18158086.

[41] H.-W. Tang, F.-L. Voon, and E. U.-H. Sim, "Association Between Incense Burning and the Risk of Lung Cancer in Asian Population: Meta-Analysis of Nine Case–Control Studies," *Cancer Reports*, vol. 7, no. 12, 2024, Art. no. e70095, https://doi.org/10.1002/cnr2.70095.

[42] O. A. Al-Rawas, A. A. Al-Maniri, and B. M. Al-Riyami, "Home exposure to Arabian incense (bakhour) and asthma symptoms in children: a community survey in two regions in Oman," *BMC Pulmonary Medicine*, vol. 9, no. 1, May 2009, Art. no. 23, https://doi.org/10.1186/1471-2466-9-23.

[43] N. Theerawasttanasiri, N. Pattara-anantanop, K. Chamnankong, I. Samdangsuk, and A. Winun,"Accuracy of estimating a human-sighted visual range for short-term particulate matter concentration in Chiang Mai, Thailand," *International Journal of Public Health Asia Pacific*, vol. 12, pp. 46–58, 2024, https://doi.org/10.62992/vfg2zf31.

[44] G. S. Ajmani *et al.*, "Fine particulate matter exposure and olfactory dysfunction among urban-dwelling older US adults," *Environmental Research*, vol. 151, pp. 797–803, Nov. 2016, https://doi.org/10.1016/j.envres.2016.09.012.

[45] R. Hudson, A. Arriola, M. Martínez-Gómez, and H. Distel, "Effect of Air Pollution on Olfactory Function in Residents of Mexico City," *Chemical Senses*, vol. 31, no. 1, pp. 79–85, Jan. 2006, https://doi.org/10.1093/chemse/bjj019.

[46] S.-G. Glennon, T. Huedo-Medina, S. Rawal, H. J. Hoffman, M. D. Litt, and V. B. Duffy, "Chronic Cigarette Smoking Associates Directly and Indirectly with Self-Reported Olfactory Alterations: Analysis of the 2011–2014 National Health and Nutrition Examination Survey," *Nicotine & Tobacco Research*, vol. 21, no. 6, pp. 818–827, May 2019, https://doi.org/10.1093/ntr/ntx242.

[47] G. S. Ajmani, H. H. Suh, K. E. Wroblewski, and J. M. Pinto, "Smoking and olfactory dysfunction: A systematic literature review and meta-analysis," *The Laryngoscope*, vol. 127, no. 8, pp. 1753–1761, 2017, https://doi.org/10.1002/lary.26558.

[48] À. Boso, C. Oltra, B. Álvarez, J. Garrido, Á. Hofflinger, and G. Gálvez-García, "Why do we misperceive air pollution? A scoping review of key judgmental biases," *Air Quality, Atmosphere & Health*, vol. 18, no. 2, pp. 447–460, Oct. 2024, https://doi.org/10.1007/s11869-024-01650-y.

[49] A. Williams, K. Schulte, and D. Varaden, "'Incense is the one that keeps the air fresh': indoor air quality perceptions and attitudes towards health risk," *BMC Public Health*, vol. 24, no. 1, Nov. 2024, Art. no. 3178, https://doi.org/10.1186/s12889-024-20635-1.

[50] Y. Xue, Y. Jiang, S. Jin, and Y. Li, "Association between cooking oil fume exposure and lung cancer among Chinese nonsmoking women: a meta-analysis," *OncoTargets and Therapy*, vol. 9, pp. 2987–2992, May 2016, https://doi.org/10.2147/OTT.S100949.

[51] K. Straif, R. Baan, Y. Grosse, B. Secretan, F. E. Ghissassi, and V. Cogliano, "Carcinogenicity of household solid fuel combustion and of high-temperature frying," *The Lancet Oncology*, vol. 7, no. 12, pp. 977–978, Dec. 2006, https://doi.org/10.1016/S1470-2045(06)70969-X.

[52] J. T. Friborg, J.-M. Yuan, R. Wang, W.-P. Koh, H.-P. Lee, and M. C. Yu, "Incense use and respiratory tract carcinomas," *Cancer*, vol. 113, no. 7, pp. 1676–1684, 2008, https://doi.org/10.1002/cncr.23788.

[53] L. A. Tse, I. T. Yu, H. Qiu, J. S. K. Au, and X. Wang, "A Case–Referent Study of Lung Cancer and Incense Smoke, Smoking, and Residential Radon in Chinese Men," *Environmental Health Perspectives*, vol. 119, no. 11, pp. 1641–1646, Nov. 2011, https://doi.org/10.1289/ehp.1002790.

[54] H. R. Mohammed, Y. Zhang, I. M. Newman, and D. F. Shell, "Waterpipe smoking in Kuwait.," *Eastern Mediterranean Health Journal*, vol. 16, no. 11, 2010.

[55] S. Rahman, L. Chang, S. Hadgu, A. A. Salinas-Miranda, and J. Corvin, "Prevalence, Knowledge, and Practices of Hookah Smoking Among University Students, Florida, 2012," *Preventing Chronic Disease*, vol. 11, Dec. 2014, Art. no. E214, https://doi.org/10.5888/pcd11.140099.

[56] P. R. Hunter, K. Bickerstaff, and M. A. Davies, "Potential sources of bias in the use of individual's recall of the frequency of exposure to air pollution for use in exposure assessment in epidemiological studies: a cross-sectional survey," *Environmental Health*, vol. 3, no. 1, Mar. 2004, Art. no. 3, https://doi.org/10.1186/1476-069X-3-3.

[57] Y. J. Son, Z. C. Pope, and J. Pantelic, "Perceived air quality and satisfaction during implementation of an automated indoor air quality monitoring and control system," *Building and Environment*, vol. 243, Sept. 2023, Art. no. 110713, https://doi.org/10.1016/j.buildenv.2023.110713.

[58] L. Shi *et al.*, "Low-Concentration PM2.5 and Mortality: Estimating Acute and Chronic Effects in a Population-Based Study," *Environmental Health Perspectives*, vol. 124, no. 1, pp. 46–52, Jan. 2016, https://doi.org/10.1289/ehp.1409111.

[59] S. M. AlBalawi, A. Namdeo, S. Hodgson, T. Pless-Mulloli, and R. J. Q. McNally, "Short-term effects of air pollution on daily asthma-related emergency department visits in an industrial city," *Journal of Public Health*, vol. 43, no. 1, pp. e45–e53, Mar. 2021, https://doi.org/10.1093/pubmed/fdaa035.