



Review article

Indoor air pollution and exposure assessment of the gulf cooperation council countries: A critical review

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ABSTRACT

Indoor air pollution is one of the human health threat problems in the Gulf Cooperation Council (GCC) countries. In these countries, due to unfavorable meteorological conditions, such as elevated ambient temperature, high relative humidity, and natural events such as dust storms, people spend a substantial amount of their time in indoor environments. In addition, production of physical and biological aerosols from air conditioners, cooking activities, burning of Arabian incense, and overcrowding due to pilgrimage programs are common causes of low quality indoor air in this region. Thus, due to infiltration of outdoor sources as well as various indoor sources, people living in the GCC countries are highly exposed to indoor air pollutants. Inhalation of indoor air pollutants causes mortalities and morbidities attributed to cardiorespiratory, pulmonary, and lung cancer diseases. Hence, the aim of this review study is to provide a summary of the major findings of indoor air pollution studies in different microenvironments in six GCC countries. These include characterization of detected indoor air pollutants, exposure concentration levels, source identifications, sustainable building designs and ventilation systems, and the mitigation strategies. To do so, > 130 relevant indoor air pollution studies across the GCC countries were critically reviewed. Particulate matters (PM₁₀ and PM_{2.5}), total volatile organic compounds (TVOCs), carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and heavy metals were identified as the reported indoor air pollutants. Apart from them, indoor Radon and bioaerosols were studied only in specific GCC countries. Thus, future studies should also focus on the investigation of emerging indoor air pollutants, such as ultrafine and nanoparticles and their associated health effects. Furthermore, studies on the mitigation of indoor air pollution through the development of advanced air purification and ventilation systems could improve the indoor air quality (IAQ) in the GCC region.

1. Introduction

Indoor air pollution is a serious health problem as it causes about 4.5 million annual deaths globally resulting from pneumonia (12%), stroke (34%), ischemic heart diseases (IHD) (26%), chronic obstructive pulmonary diseases (COPD) (22%), and lung cancer (LC) (6%) (Amoatey et al., 2017; Tageldin et al., 2012; Thurston et al., 2016; WHO, 2018). Indoor air pollution has been extensively studied in homes (Morawska et al., 2017; Rohra and Taneja, 2016), schools (Cai et al., 2015; Forns et al., 2017), hospitals (Cabo Verde et al., 2015; Wang et al., 2015b), offices (Azuma et al., 2018; Song et al., 2015), restaurants (Dai et al., 2018; Fazlzadeh et al., 2015), and subway metros (Kim et al., 2015; Xu and Hao, 2017). However, indoor air pollution continues to be a global problem, especially in developing countries. Research studies have shown that about 90% of time is being spent in the aforementioned indoor environments (Andrade and

Dominski, 2018). This is about 5 times higher than that of average time spent in outdoor environments, which indicates the enormity of human health risk posed by the indoor air pollutants (Andrade and Dominski, 2018; Boor et al., 2017; Cincinelli and Martellini, 2017; Du et al., 2018). These indoor air pollutants generally originate from the ambient environment. However, in cities with high ambient air pollutant levels, indoor air pollutants may be of greater concern (Morawska et al., 2017).

Higher ambient temperature and humidity in the Gulf Cooperation Council (GCC) countries has increased the time duration, which is being spent at homes, offices, cafés, shopping malls, and similar indoor places (Ali et al., 2016b). Further, the GCC countries are categorized as developing countries and they are well-known as the hub for the majority of global oil reserves and crude oil production plants. Hence, with the recent increase in industrial activities, infrastructural developments, and population growth, which are coupled with unfavorable outdoor

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weather conditions, indoor air quality (IAQ) can be counted as a great concern for human health. This affirms that there can be a high risk of exposure to indoor air pollutants compared to the countries with favorable weather conditions, where people spend much of their time in outdoor environments.

Since external and internal air pollutant sources and activities may vary significantly among the GCC countries, the review provides an in-depth analysis of indoor air pollution, according to different geographic locations (Bahrain, Kingdom of Saudi Arabia (KSA), Kuwait, Oman, Qatar, and United Arab Emirates (UAE)). For all of these countries, most indoor air pollution studies have been focused on measuring the concentration levels and characterization of chemical species. Previous reviews have shown that particulate matters (PMs), carbon monoxide (CO), carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen dioxide (NO₂) and heavy metals were the major indoor air pollutants in the GCC countries (Abdul-Wahab and Yaghi, 2004; Al-Rehaili, 1999; Al Mulla et al., 2015; Argyropoulos et al., 2016; Elkilani and Bouhamra, 2001; Elsayed et al., 2016; Farahat, 2016; Omidvarborna et al., 2018; Saraga et al., 2017). Recent studies in KSA have identified Radon (²²²Rn) gas as another indoor air pollutant (Abo-Elmagd et al., 2018; Alghamdi and Aleissa, 2014). Moreover, it has been reported that indoor air pollution in most cities in the GCC region is due to the infiltration of ambient air pollutants into residential buildings, poor ventilations, burning of biomasses (Arabian incense), and overcrowding (Argyropoulos et al., 2016; Fadeyi et al., 2014; Jomehzadeh et al., 2017; Weitzman et al., 2016; Yaghi and Abdul-Wahab, 2003). For example, incomplete burning of Arabian incense emits CO, PM₁₀, PM_{2.5}, polycyclic aromatic hydrocarbons (PAHs), and black carbon (BC), which cause deleterious health effects for the exposed population (Du et al., 2018). To critically assess the current state of indoor air pollution in the GCC countries, this structured review was conducted to characterize emission of indoor air pollutants, identify the sources, discuss the possible mitigation strategies, identify knowledge gaps, and recommend future research works. For this purpose, > 130 research articles were selected and reviewed.

2. Methods

Based on the state-of-the-art scientific literature guidelines, a search was conducted in Web of Science and PubMed for original and review English papers published after 2010 and a few papers published after 1986. The terms employed during the search were (“indoor air pollution in GCC” or “indoor air quality in GCC”), (“indoor air quality in < name of the GCC country >” or “indoor Radon in GCC” or “Building ventilation in GCC” or “sustainable buildings in GCC”), and also “indoor < name of the pollutants >”. For the respective countries, “ambient” or “outdoor” research studies were excluded. Since many published peer reviewed articles were not indexed in the above scientific electronic databases, gray search procedures in Google search engine were carried out based on the similar terminologies. In addition, published documents found on the national and international organization websites, such as the World Health Organization (WHO), were also considered.

The order of the countries in this review study is based on the top-to-bottom approach, which represents how detailed an IAQ study has been conducted by a particular country. Thus, countries with detailed studies came to the top list, followed by less detailed ones. This approach will help the readers to follow the trend of indoor air pollution in the GCC countries.

3. UAE

Environmental issues, including air pollution, have been one of the top policy agendas in UAE, following rapid industrialization and expansion of many commercial cities in the region. As the population growth and infrastructure developments continued to increase, indoor air pollution is deemed as one of the public health problems in UAE

Table 1
Population and the economics activities in the GCC countries.

Country	~Population (× 10 ³)				*GDP (× 10 ⁶ USD)	
	Total	Males	Females	Children (0–4 yrs.)	Per capita	Real estate developments
^a UAE	9120	6298	2822	N/A	44,808	49,140
^b KSA	32,612	18,746	13,866	2734	20,912	48,410
^c Qatar	2617	1975	642	138	67,537	15,819
^d Kuwait	4500	2838	1662	311	28,710	11,230
^e Oman	4414	2887	1527	393	16,790	3313
^f Bahrain	1424	889	535	11.4	22,714	1775

^a FCSA (2017).

^b GASTAT (2018).

^c MDPS (2018).

^d PACI (2018).

^e NCSI (2017).

^f IEGA (2018).

^g GCC-STAT (2018).

(Loney et al., 2013).

The population, economic growth, and real estate data of UAE are summarized in Table 1. Comparatively, UAE has a smaller population than that of KSA, but it is ranked as the second highest gross domestic product (GDP) per capita after Qatar with the highest investment in real estate developments among the GCC countries. Currently, UAE is undergoing massive economic and infrastructural growth with lack of country-specific local IAQ guidelines. Thus, indoor air pollution is going to be a serious public health issue of the residential population.

Environmental agencies in Abu Dhabi and Dubai Municipalities have embarked on various environmental health projects aimed at characterizing indoor air pollutants in various residential buildings in UAE. Despite these interventions, indoor air pollutions continue to be a health threat to UAE populations as it has been estimated to cause 290 deaths and about 89,000 hospital emergency visits annually (Funk et al., 2014). To date, about 30 articles on IAQ in UAE were published, while they focused mostly on characterization of trace gases and PMs with excessive attention to IAQ measurements within similar indoor environments (e.g., residential homes). Most of these studies were conducted in cities, while very limited studies in rural and per-urban locations have been carried out. The details of available local and international guidelines and indoor air pollutants and concentration levels in UAE are summarized in Tables 2 and 3, respectively.

3.1. Air pollutants in UAE

Measurement of indoor pollutions from different human living environments (homes, offices, and restaurants) is known to give rise to different concentration levels, chemical species, and human exposure levels (Xu and Hao, 2017). Different types of air pollutants were found in UAE indoor environments, where these pollutants were emitted from household materials, kitchen activities, infiltration from ambient sources, burning of incense, secondhand smoke, and overcrowding (Cohen et al., 2013; Meier et al., 2015; Vanker et al., 2015) (Table 4). Further, infiltration of PMs from outdoor sources is the major contributor to indoor PM levels in UAE; because, SO₂ can be converted to sulfate PMs as a result of high ambient temperature, which favors photochemical reactions (Hamdan et al., 2018).

Few studies identified that burning of Arabian incense in various homes, restaurants, and offices is the main source of indoor air pollution in UAE, as it can emit a wide amount of air pollutants (Balasubramanian et al., 2017; Jetter et al., 2002). Elsayed et al. (2016) characterized a complete profiling of Bakhour (an Arabian incense), as a commonly burnt indoor household biomass used in UAE (commonly produced in Sharjah). It was found that Bakhour emitted trace metals such as Pb, Zn, Cd, Al, Fe, Co, and other known or suspected

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