RESEARCH ARTICLE

A Study on Air Pollution Levels in Kabul City, Afghanistan

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Abstract

This study examines the air pollutant concentration levels, emission, sources, and variability of air pollutants in Kabul City, Afghanistan, through a comprehensive two-year air quality assessment (2022–2023). Data were collected using stationary monitoring devices operated by the National Environmental Protection Agency (NEPA) at the Darul-Aman urban district, with seasonal analysis supported by the Air Quality Laboratory (AQL). Results revealed pronounced seasonal trends: ozone (O_3) eight-hour averages consistently exceeded 100 µg/m^3 during winter months (January–March and December) in both years, reflecting increased precursor emissions and stagnant atmospheric conditions. Nitrogen dioxide (NO_2) exhibited bimodal peaks, with elevated concentrations in January–March and July 2022, followed by a shift to July–August in 2023, suggesting changing traffic or industrial emission patterns. Sulfur dioxide (SO_2) levels were highest in January and December, correlating with heightened fossil fuel combustion for heating. Carbon monoxide (CO) one-hour averages persistently breached national standards, underscoring chronic exposure risks. Particulate matter analysis showed that PM_{10} 24-hour concentrations in 2022 complied with standards except in winter months (January–February and December), but 2023 saw widespread exceedances (all months except April), indicating escalating pollution. Similarly, $PM_{2.5}$ 24-hour averages in 2022 were substandard only in winter, whereas 2023 violations spanned most months (excluding April–May), implicating growing anthropogenic influences. The Air Quality Index (AQI) transitioned from "good" to "satisfactory" (2022) to predominantly "moderate" (2023) for PM_{10} and $PM_{2.5}$, signaling accelerating air quality degradation. These trends highlight the interplay of seasonal emissions, meteorological factors, and rising pollution sources. The findings necessitate urgent, seasonally tailored mitigation strategies—such as winter fuel restrictions and year-round traffic controls—to curb Kabul's deteriorating air quality and associated public health burdens.

Highlights

- The main elements of air pollution (CO, SO_2, CO_2, NO_2, NO PM10, PM2.5) are directly emitted to the atmosphere.
- The main air pollutant sources are transportation, industrial processes, stationary sources, fuel combustion, etc.
- The secondary air pollutant components are SO_3, SO_4, H_2SO_4, HNO_3, NO_3, O_3, PANs, salts.
- Pollutants are formed by three types of components, liquid droplets, solid particles, and gases.
- The air pollutants are classified by manmade and natural sources that cause health effects.

Keywords: Air quality index, Carbon monoxide, Ozone, Sulphur dioxide, PM10, PM2.5

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Introduction

At a height of 1791 meters above sea level, Kabul is a city in the eastern region of Afghanistan and is home to 4.635 million people as of the 2015 census, it is the country's capital and a hub for both the economy and culture. its Urban Area is Around 275 km^2 (106 sq. mi), Metropolitan Area Roughly 1,023 km^2 (395 sq. mi) (includes surrounding districts), Kabul is among the cities whose infrastructure and urbanization are growing at the quickest rates in the globe.

This has resulted in pollution-related problems in Kabul city, where elevated PM2.5 readings have been observed recently. The term "particulate matter" (PM2.5) refers to airborne particles in the ambient that are no larger than 2.5 microns in size, PM2.5 data measured in 62, 85, and 92 countries capital (2018, 2019, 2020), IQAir's

Air visual published an indicative ranking that Kabul city ranked as the 3rd and 4th polluted capital city in the world with 61.8, 58.8, and 48.5 µg/m^3 PM2.5 annual concentration that shows so higher concentration than WHO PM2.5 target which is 10 µg/m^3 yearly average (World Air Quality Report, 2018, 2019, 2020). Only air pollution equipment has been collecting samples from air components since the Afghan government changed in 2021, and no foreign organization has published data on the city of Kabul's air quality.

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Due to their minuscule size, the particles can penetrate the bloodstream *via* the respiratory system and disperse throughout the body, adversely impacting multiple health aspects, including heart disease, lung cancer, and asthma. Coarse and fine particulate matter (PM) are extremely detrimental to the environment and public health in addition to other pollutants. The presence of heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), ozone, carbon monoxide, oxides of sulphur (Sox), oxides of nitrogen (NOx), and volatile organic compounds (VOCs) in high concentrations is harmful to human health.

The root cause of numerous chronic illnesses. The aforementioned pollutants originate from several sources and are primarily found in heavily populated parts of the city. Nonetheless, throughout the year, there is intra-seasonal variability in these pollutants. In addition, wind speed, temperature, and humidity are significant meteorological factors that affect how pollutants are distributed both horizontally and vertically.

The condition of atmospheric air when there is no pollution in the air is known as ambient air, In general. It consists of 78% nitrogen and 21% oxygen. Carbon, hydrogen, argon, methane, and helium make up the final 1%. The World Health Organization (WHO) describes potentially harmful particles emitted by residences, places of business, automobiles, and trucks as ambient air pollution. The most detrimental to human health among all of these contaminants is fine particulate matter.

Since humans discovered how to use fire, there has been anthropogenic air pollution, although it has grown significantly with industrialization. It was widely believed up until the middle of the 1980s that ambient pollution levels in Europe posed no health risks to people. Nonetheless, during the past 15 years, epidemiological research has consistently demonstrated that exposure to low and moderate quantities of conventional pollutants, like ambient particles, can have an impact on health in the short and long term. It is often acknowledged that human health and well-being depend on clean air.

Air pollution can occur both indoors and outdoors and affects both the entire population and an individual. The majority of structured monitoring systems regularly measure a variety of ambient gas and particle concentration indicators. The analysis of air pollution's chemical makeup is a very intricate field that requires ongoing observation. There are several levels of ambient air pollution, ranging from local to global. The local scale covers a maximum of 5 km of the surface of the planet. Vallero (2008) states that the continental scale is between 500 and several thousand kilometers, the urban scale is approximately 50 km, and the world scale is global.

Salvador (2018) defines air pollutants as airborne elements (solids, liquids, or gases) that are present in such quantities to harm the health of people and animals, destroy structures and vegetation, or contaminate a specific area. This pollutant might be one of the principal ones that is directly emitted into the atmosphere.

Secondary pollutants are created when main pollutants react with pre-existing contaminants. Some pollutants can be both primary and secondary, which means they can come from other primary pollutants and be discharged on their own. Pollutants, particulate matter, and black carbon are the main pollutants that are assumed to produce air Particulate matter, carbon, nitrogen dioxide, sulphur dioxide, ground-level ozone, and carbon monoxide are a few examples of pollution, however, they are not only ones.

Air pollution is a global issue that primarily stems from the origin of the pollutants. Pollution in urban areas originates from a variety of sources and is directly correlated with time, temperature, population density, and city location. Therefore, in this study, the contribution of pollutants, their sources, and variability during two consecutive years 2022 and 2023, and air quality assessment has been carried out over Kabul city.

Materials And Methods

Study area

Kabul city is Situated in a narrow valley across the Kabul River and nestled between the Hindu Kush mountains, the city is 1800 m above sea level and lies between latitude 34.54 North and longitude 69.17 East. The river Kabul and the mountain range that runs northeast to southwest are the main features of the city of Kabul.

Approaching from the southwest, the river slashes through the mountain range to create a striking valley. It then gets even smaller in the Deh-Mazang ravine, which sits between Mt. Shir Darvaza (2,222 m) in the south and Mt. Asmai (2,110 m) in the north. Situated between Mt. Shir Darvaza and the southern bank of the Kabul River is the city center. The city is shielded from the north by the Kabul River, but there are also other obstacles in place, including the hills on the left bank of the river and the marshy areas that extend eastward to the hill of Maranjan. The city is bordered to the north and northeast by the hills of Shahr-Ara, Kulula-Pushta, and Bibi Mahru. There's a stretch of marshes beyond these hills that leads to the airport. The eastern boundaries of the urban fringes are delineated by a comparable marsh, which characterizes a broad expanse spanning from Maranjan Hill to the eastern flank of Mount Shir Darvaza. A path leading to the Logar valley opens up between the hills of Maranjan, the marshland of the hill, and the hill of Bala-Ḥeṣar (Wilde A, 2012). The natural physical features of Kabul Province were depicted on the map below, which was created using a 3D mapping program called Map Hill's Gallery (Team, 2011) (Fig. 1).

The 16 urban districts make up the majority of the municipal districts' 394.78 km^2 of territory, while the other 6 peripheral districts are made up of villages and agricultural terrain. Situated in the heart of the city, District 1 represents the Old City of Kabul, which dates back 3500 years and developed its modern fundamental layout in the 1940s and 1950s.

Farmland has gradually been converted to residential neighborhoods, causing the old city's surrounding districts to become more urbanized. The planned urban areas that flank the western and northwestern parts of the city center are determined under the master plans for 1964–1978. They include a portion of districts 2, 3, 5, 10, and 15, as well as the majority

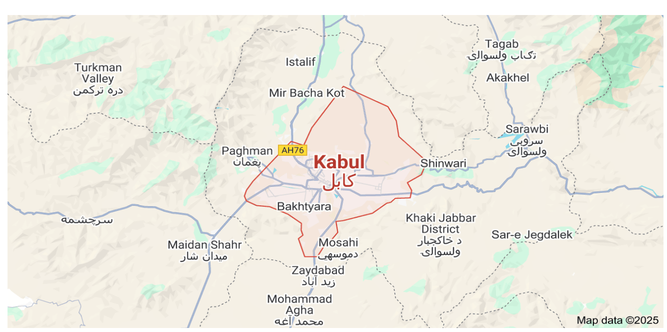

Fig. 1: Kabul Map (2025)

Fig. 2: Kabul PD maps (2024)

of districts 4 and 11. They also include tiny portions of districts 7, 8, 16, and 17. District 6 was almost entirely urbanized after 1919 until the 1964 master plan was created. Over the past 20 years, practically all of District 13's residual areas, as well as the remaining portions of districts 7, 9, and 10, have been turned into residential areas; development is done both for sales purposes and without the required legal authorization. The proliferation of unplanned residential areas in many regions was strengthened by the swift growth in population. Certain villages are located on public land and may be found near the city center and its environs, particularly in the steep regions that the 1978 master plan designated as forests.

When examining the urban character of Kabul overall, it is clear that the political centrality pattern predominates over the hierarchical pattern in the social, ecological, or economic centralities. The original master plan created for the city in 1964 included this matrix as well as the classification of land use based on function. Substantial changes occurred after 2001, and residential settlements currently occupy the suggested ecological land uses. There are 65 active public parks in Kabul City, covering 309 hectares in total, for 0.78% of the 394.78 km total land area (Mushkani and Ono, 2021). The urban design framework for Kabul City (MUDH, 2018) is depicted in the map below, which was created by SASAKI with assistance from the Ministry of Urban Development and Housing (Fig. 2).

Analysis

The data was collected using stationary air quality monitoring devices operated by the National Environmental Protection Agency (NEPA). Air samples were taken over 24 hours in Kabul's

Table 1: National air quality standard for Afghanistan

Parameter	*Unit* $\mu g/m^3$	*Time weighted average*	*Maximum allowable concentration*
TSP		24 Hours	300
PM10		Annual	70
		24 Hours	150
PM2.5		annual	35
		24 Hours	75
Nitrogen dioxide (NO2)		Annual	40
		24 Hours	80
Sulfur dioxide (SO2)		24 Hours	50
Ozone (O_3)		8 Hours	100
Carbon monoxide (CO)		8 Hours	10
		1 Hour	30
		Half Hour	60
Lead (Pb)		Annual	0.5

Table 2: Average air pollutant parameters of Kabul city during the year 2022

Months	*Air pollutant parameters during 2022*					
	O_3	*NO_2*	*SO_2*	*CO*	*PM10*	*PM2.5*
	$\mu g/m^3$ 8 hours	*$\mu g/m^3$ 24 hours*	*$\mu g/m^3$ 24 hours*	*mg/m^3 1 hour*	*$\mu g/m^3$ 24 hours*	*$\mu g/m^3$ 24hours*
Jan-22	129	184	105	10	202	183
Feb-22	146	184	61	6	208	157
Mar-22	105	208	7	4	102	78
Apr-22	59	73	4	1.4	110	54
May-22	46	79	2.6	0.9	89	44
Jun-22	48	83	0.7	1	101	63
Jul-22	28	134	4	1.4	99	74
Aug-22	32	67	1.4	1.4	67	39
Sep-22	36	82	1.8	1.6	84	31
Oct-22	61	75	10	2.5	111	25
Nov-22	94	53	11	2.7	97	30
Dec-22	133	34	102	5.1	166	74

Table 3: Air pollutants parameter statistical values

		Months	O3	NO2	SO2	CO	PM10	PM2.5
N	Valid	12	12	12	12	12	12	12
	Missing	0	0	0	0	0	0	0
Mean		6.50	76.42	104.67	25.88	3.17	119.67	71.00
Median		6.50	60.00	80.50	5.50	2.05	101.50	58.50
Std. deviation		3.606	42.809	57.787	39.807	2.721	46.206	50.009
Range		11	118	174	104	9	141	158
Minimum		1	28	34	1	1	67	25
Maximum		12	146	208	105	10	208	183
Sum		78	917	1256	311	38	1436	852

Table 4: Frequency

		Frequency	Percent	Cumulative percent
Valid	January	1	8.3	8.3
	February	1	8.3	16.7
	March	1	8.3	25.0
	April	1	8.3	33.3
	May	1	8.3	41.7
	June	1	8.3	50.0
	July	1	8.3	58.3
	August	1	8.3	66.7
	September	1	8.3	75.0
	October	1	8.3	83.3
	November	1	8.3	91.7
	December	1	8.3	100.0
	Total	12	100.0	

Darul-Aman district and analyzed for annual and seasonal variations. Key pollutants measured included ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter (PM_{10} and $PM_{2.5}$). These pollutants pose significant environmental and health risks, making their monitoring crucial.

This study highlights Kabul's worsening air pollution crisis, driven by vehicle emissions, industrial activities, and climate conditions. By examining these pollutants, the research provides insights into health risks and regulatory challenges. The findings stress the need for stricter air quality regulations, pollution control measures, and public awareness campaigns. Addressing these challenges through policy interventions and sustainable urban planning is essential for improving air quality and safeguarding public health..

Results

Figures 1 and 2 present Maps of Kabul City, while Table 1 outlines Afghanistan's national ambient air quality standards. The average air pollutant parameters for Kabul City in 2022 are depicted in Table 2 and Figure 2, whereas the corresponding

Table 5: Average air pollutant parameters of Kabul city during the year 2023

Months	Air pollutant parameters during 2023					
	O_3	NO_2	SO_2	CO	PM10	PM2.5
	$\mu g/m^3$ 8 hours	$\mu g/m^3$ 24 hours	$\mu g/m^3$ 24 hours	mg/m^3 1 hour	$\mu g/m^3$ 24 hours	$\mu g/m^3$ 24 hours
Jan-23	181	29	116	6.6	199	110
Feb-23	180	6.7	25	5.3	172	87
Mar-23	109	35	6.02	3.3	168	77
Apr-23	94	31	2.02	0.9	144	57
May-23	56	63	2.1	1	151	64
Jun-23	28	81	1.19	0.8	181	98
Jul-23	14	107	1.5	1.4	211	126
Aug-23	15	100	1.7	3.1	165	88
Sep-23	26	85	0.8	3.9	186	100
Oct-23	62	53	0.6	5.1	177	78
Nov-23	80	60	9.2	5.3	191	79
Dec-23	108	40	103	8.9	214	93

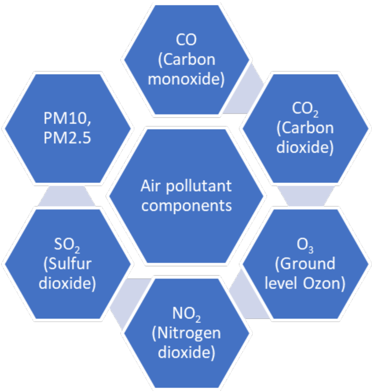

Fig. 3: Air quality parameters selected for the study

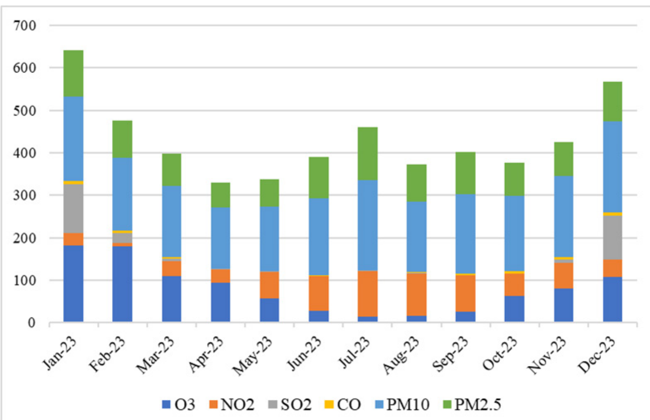

Fig. 4: Air pollutant parameters of Kabul city during the year 2022

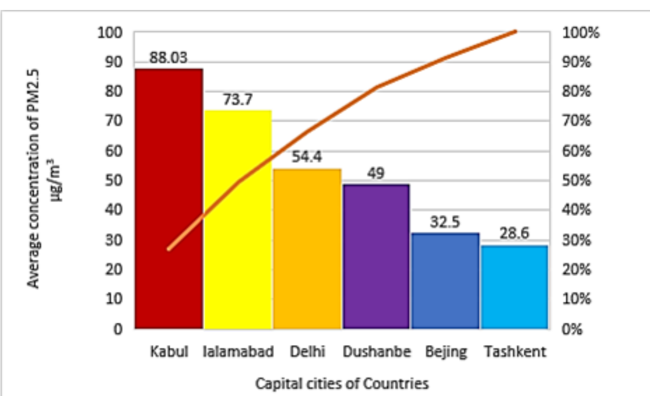

Fig. 5: Annual average concentration of PM 2.5 Kabul city and neighboring countries during 2023

values for 2022–2023 are shown in Tables 2 and 5, along with Figure 3. Air quality parameters are further illustrated in Figure 3, while Table 3 provides statistical values for air pollutant parameters. The frequency distribution of pollutants is detailed in Table 4, and Figure 5 compares the annual average concentrations of PM2.5 and PM10 with those in neighbouring countries. Additionally, Table 6 presents statistical values of air pollutant parameters, and Table 7 details their frequency distribution. The concentration levels of particulate matter (PM10 and PM2.5) in Kabul's air during 2022–23 are listed in Table 9. The 8-hour average ozone concentration in the atmosphere ranged from 32 to 146 µg/m^3 in 2022 and from 15 to 181 µg/m^3 in 2023. The 24-hour average NO_2 concentration varied between 34 and 208 µg/m^3 in 2022 and between 29 and 107 µg/m^3 in 2023. Similarly, the 24-hour average SO_2 concentration fluctuated between 0.7 and 105 µg/m^3 in 2022 and between 0.6 and 116 µg/m^3 in 2023. The hourly CO concentration ranged from 0.9 to 10 mg/m^3 in 2022 and 0.9 to 8.9 mg/m^3 in 2023. Furthermore, in 2022, the 24-hour mean PM10 and PM2.5 concentrations were 67 to 208 µg/m^3 and 25 to 183 µg/m^3, respectively, while in 2023, they were 144 to 214 µg/m^3 and 57 to 126 µg/m^3, respectively.

Discussion

About 5% of our planet's land is covered by cities. The main characteristic of urban areas is high population density, which has prompted the development of expansive housing developments, road networks, manufacturing and service industries, and recreational facilities. Given that half of the world's population lives in cities now, 5% of the world's territory is inhabited by people. The world's population is becoming more urbanized every day, which is harming the environment. Among the worst of these effects is the diminishing quality of the air in many of the fastest-growing cities. By 2025, 60% of people on the planet are expected to live in cities, according to scientists.

As a result, 93% of urban growth will occur in emerging nations, with 80% of this development occurring in Asia and Africa. The main cause of air pollution is usually densely populated urban centers, particularly in developing countries where environmental laws are weak. Comparatively deficient or non-existent. As a result, urban air quality is a major global concern. For example, in 2004 the 10^{th} global risk factor for mortality was urban outdoor air pollution. Sometimes the resulting quantities of Pb, CO, NOx, O3, and TSP are many times higher than the WHO's recommended air quality criteria.

In addition, other countries have comparably high levels of SOx, NOx, and particulate matter Due to the proximity of industrial enterprises and coal-fired power stations to city borders. Overcrowding, pollution, and poverty are the results of population growth that frequently outpaces economic growth in many cities, including Karachi, Pakistan, Delhi, India, and Kabul, Afghanistan. In most cities, air pollution is mostly caused by motor vehicles, and idling autos generate a lot of emissions. In developing countries, almost all cities still use leaded gasoline; many vehicles are diesel-powered trucks and buses without pollution controls; many roads are unpaved; and traffic congestion exacerbates pollution. Consequently, pollutants might be solids, liquid droplets, or gases.

Ozone (O_3)

Ground-level ozone is a key contributor to photochemical pollution and poses a serious health concern associated with asthma, respiratory disorders, decreased lung function, and breathing difficulties. It is a secondary pollutant as it is not emitted into the atmosphere directly. Instead, it is produced through the oxidation of carbon monoxide, methane, other volatile organic compounds (VOCs), and sunlight. In addition to serving as ozone precursors, CO, VOCs, and NOx are regarded as dangerous air pollutants.

Chemical solvents, industrial facilities, and motor vehicle exhaust emissions are major sources of NOx and VOCs. The primary sources of methane emissions are the fossil fuel and agricultural sectors, along with waste. Apart from its detrimental effects on health, one of the most important greenhouse gases and a transient climatic pollutant (WHO, 2021). According to World Health Organization recommendations, an 8-hour average of 100 µg/m^3 is the recommended level of ozone. (WHO, 2006).

Nitrogen dioxide (NO_2)

Nitrogen dioxide, mostly released by transportation, power plants, and industries, makes up a major portion of particulate matter and ozone. There is mounting evidence that it can exacerbate asthma and bronchitis symptoms, cause respiratory infections, impede lung development, and lower lung function on its own (WHO, 2021). Furthermore, evidence suggests that NO2 exposure may be linked to a considerable number of illnesses, such as cardiovascular and respiratory diseases that are linked to early mortality and morbidity. The World Health Organization (WHO, 2006) has established annual limits of 40 µg/m^3 and hourly limits of 200 µg/m^3.

Sulphur dioxide (SO_2)

Sulphur dioxide is mostly produced by burning fossil fuels like coal and oil and by smelting mineral ores that contain sulfur. Exposure to SO2 not only irritates the eyes but also has an impact on lung health and the respiratory system. Asthma and chronic bronchitis can worsen due to respiratory tract inflammation caused by SO2.

Additionally, it increases the chance of infection, which in turn elevates hospital admissions and ER visits. The main component of acid rain, sulfuric acid, is produced when atmospheric water and SO2 combine (WHO, 2021). Regardless of particle presence, the World Health Organization (WHO) establishes standards for 24-hour SO2 exposure of 125 µg/m^3, 10-minute exposure of 500 µg/m^3, and an annual average of 50 µg/m^3 (WHO, 2006).

Carbon monoxide (CO)

When exposed to elevated levels, carbon monoxide, an odorless and colorless gas, can be harmful to humans. Diminishing the blood's ability to supply vital organs with oxygen. Significant outdoor emissions can occur, particularly in developing countries, even though elevated CO concentrations are more hazardous indoors. New research also links low quantities of exposure over an extended period to several health effects.

Vehicle exhaust and equipment that burns fossil fuels are the main sources of ambient CO (WHO, 2021). The WHO offers recommendations for air quality, for 30 minutes at 60 mg/m^3, 1 hour at 30 mg/m^3, 8 hours at 10 mg/m^3, and 15 minutes at 100 mg/m^3. There are no typical long-term recommendations (WHO, 2006).

Particulate Matters (PM10 and PM2.5)

As per the WHO (2021) definition, particulate matter (PM) comprises respirable and inhalable particles such as mineral dust, water, sulfate, nitrates, ammonia, sodium chloride, and black carbon. The PM10 unit of measurement is used to quantify particles with a diameter of less than 10 microns, which includes PM2.5 particles. The atmospheric life of black carbon is limited. After CO2, black carbon plays a secondary role in global warming. According to WHO (2021), there is also evidence that it accelerates glacier melting and reduces agricultural production. The biggest health dangers come from PM2.5 which can reach the lungs and circulation. A wide range of industrial processes, including mining, smelting, construction, and the production of cement, ceramics, bricks, and brick combustion engines powered by gasoline and diesel, produce particulate matter. PM is also produced in homes and businesses by the combustion of solid fuels (WHO, 2021). WHO standards state that PM2.5 has an annual limit of 10 µg/m^3 and a 24-hour limit of 25 µg/m^3, while PM10 has an annual limit of 50 µg/m^3 and a 24-hour limit of 50 µg/m^3 (WHO, 2006). Black carbon, sometimes called a "short-lived climate pollutant," is a primary contributor to PM2.5 and the primary driver of global warming.

The particulate matter may harm ecosystems and human health because it may contain harmful or acidic species, such as heavy metals, acids, and organic chemicals that cause cancer. Moreover, the impact of particulate matter, research indicates a strong correlation between elevated levels of SO_2 and NOx and some health outcomes, including cardiovascular disorders and respiratory conditions like bronchitis and asthma. These results may also have important implications for development and reproduction, including an increased risk of preterm birth (Gul Hamdard et al., 2019).

Table 6: Air pollutants parameter statistical values

		Months	*O3*	*NO2*	*SO2*	*CO*	*PM10*	*PM2.5*
N	*Valid*	*12*	*12*	*12*	*12*	*12*	*12*	*12*
	Missing	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Mean		6.50	79.42	57.56	22.43	3.80	179.92	88.08
Median		6.50	71.00	56.50	2.06	3.60	179.00	87.50
Std. Deviation		3.606	58.090	30.939	41.331	2.555	21.773	19.157
Range		11	167	100	115	8	70	69
Minimum		1	14	7	1	1	144	57
Maximum		12	181	107	116	9	214	126
Sum		78	953	691	269	46	2159	1057

Table 7: Frequency

		Frequency	Percent	Cumulative Percent
Valid	January	1	8.3	8.3
	February	1	8.3	16.7
	March	1	8.3	25.0
	April	1	8.3	33.3
	May	1	8.3	41.7
	June	1	8.3	50.0
	July	1	8.3	58.3
	August	1	8.3	66.7
	September	1	8.3	75.0
	October	1	8.3	83.3
	November	1	8.3	91.7
	December	1	8.3	100.0
	Total	12	100.0	

Diseases linked to air pollution claim the lives of almost 3,000 people in Afghanistan each year. Based on data from the Ministry of Public Health in Afghanistan, 2,900 of these 3000 individuals died from respiratory ailments, and the remaining ones died from heart diseases. Air pollution in many cities is mostly caused by motor activity. Increased levels of air pollutants, which are caused by vehicle emissions and harm both human and environmental health, include respirable and suspended particulate matter, sulfur, oxides of nitrogen, and other organic and non-organic pollutants like heavy metals.

The quantity and composition of pollution emissions are altered by the number of vehicles on the road, especially in terms of fine and ultrafine particle concentration. Air pollution in Kabul city is primarily caused by traffic, the use of antiquated cars and the prohibition on importing them, burning of plastic, used motor oil, animal waste, and tires, old brick kilns, re-suspension of dust and windblown dust, using coal for home heating in the winter, exhaust from diesel and gasoline engines, and road dust (Air Pollution (NEPA, 2019).

Table 8: AQI value and health impact description

Description	AQI	PM10	PM2.5
		$\mu g/m^3$ 24 hours	$\mu g/m^3$ 24 hours
Good Satisfactory	0–100	0–100	0–60
Moderate	101–200	101–250	61–90
Poor	201–300	251–350	91–120
Very Poor	301–400	351–430	121–250
Severe	401–500	431–550	251–350

Sources: AQI 2023

Air Quality Data

The air quality data (Table 6) was obtained from an immobile device used by the National Environmental Protection Agency (NEPA, Afghanistan) over the city of Kabul; it is not indicative of the average air pollution levels across Kabul's districts. Particulate matter (PM10 and PM2.5), sulfur dioxide (SO2), and nitrogen dioxide (NO2) are measured using the 24-hour average. The eight-hour average of ground-level ozone (O3) and the one-hour average of carbon monoxide (CO) are given in Tables 7 and 8. The suggested units of measurement for air pollutants were mg/m3 for ozone (O3), $\mu g/m^3$ for sulfur dioxide (SO2), nitrogen dioxide (NO2), and particulate matter (PM10 and PM2.5).

Air quality statistics of Kabul City, which were gathered over a day from multiple districts inside the city, are compared with the national air quality standard values Table 9 displays the national air quality guidelines for Afghanistan. January, February, June, July, and September of 2022 had NO2 concentrations in 24-hour averages that were higher than the national air quality threshold.

In June, July, August, and September of 2023, it was found to be higher than the National Air Quality The 24-hour average of SO2 concentration in January, February, and December of 2022 was higher than the National Air Quality limit. Readings between January and December of 2023 exceeded the national standard for air quality. The national air quality standard was exceeded by the eight-hour average of ozone concentration in January, February, March, and December of 2022 and 2023.

Table 9: Level of PM10 & PM2.5 in the Kabul air during 2022-23

Months	Description 2022	PM10	Description	PM2.5	Description 2023	PM10	Description	PM2.5
January	Poor	202	Very poor	183	Moderate	199	Poor	110
February	Poor	208	Very poor	157	Moderate	172	Moderate	87
March	Moderate	102	Moderate	78	Moderate	168	Moderate	77
April	Moderate	110	Good	54	Moderate	144	Good	57
May	Good	89	Good	44	Moderate	151	Moderate	64
June	Moderate	101	Moderate	63	Moderate	181	Poor	98
July	Good	99	Moderate	74	Poor	211	Very poor	126
August	Good	67	Good	39	Moderate	165	Moderate	88
September	Good	84	Good	31	Moderate	186	Poor	100
October	Moderate	111	Good	25	Moderate	177	Moderate	78
November	Good	97	Good	30	Moderate	191	Moderate	79
December	Moderate	166	Moderate	74	Poor	214	Poor	93

The national air quality standard was not met by the CO concentration in the one-hour average for 2022 and 2023. The 24-hour average of PM10 concentration was higher than the National Air Quality guideline in January, February, and December of 2022. Every month in 2023 recorded a concentration over the National Air Quality Standard, except for April. The 24-hour average of PM2.5 concentration in January, February, and March of 2022 was higher than the National Air Quality limit. Its concentration exceeded the national air quality criteria in every month of 2023, except April and May.

Air Quality Index

The state of the air surrounding you, the degree of pollution, and any possible health hazards. One way to educate the public about the condition of the air is through the air quality index. In certain other places, the air quality index (AQI) is used to report the daily air quality. It acts as a barometer for the immediate health effects of air pollution. It shows the amount of pollution and air quality in your immediate area as well as any possible health issues. The air quality index demonstrates how the public is informed about the state of the air. Put another way, the air quality index's primary goal is to inform the public about the health concerns related to the local air quality. The prospective health effects of breathing in polluted air for hours or even days after exposure are calculated by the air quality index or AQI.

Different point scales are used by different nations to report air quality. Nitrogen dioxide (NO2) and five other significant air pollutants are included in the World Metrological Organization's (WMO) calculation of the AQI. Good + Satisfactory, moderate, poor, very poor, and severe are the five AQI classifications used by the WMO AQI (Davda, 2019).

They are all classified under these headings. Different point systems are employed by various countries for reporting air quality. To safeguard human health, the World Meteorological Organization (WMO) has established air quality guidelines for five major air pollutants, for which the AQI is computed. These include ground-level ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), and particle pollution (PM10 and PM2.5). The WMO AQI has five AQI classifications: Good + Satisfactory, moderate, poor, very poor, and severe (Davda, 2019). Each of these categories is based on a health breakpoint, which shows the anticipated health impacts of air pollution at ambient concentrations.

Reginal countries' Air Pollution Scenario

Kabul (Afghanistan)

PM2.5 concentration is the highest among the compared cities at 88.03 µg/m^3, indicating severe air pollution, exceeding safe levels, Islamabad (Pakistan)The second highest concentration at 73.7 µg/m^3, shows significant air pollution, though slightly lower than Kabul, Delhi (India) PM2.5 level is 54.4 µg/m^3, moderate compared to Kabul and Islamabad but still problematic, Indicates ongoing pollution challenges, Dushanbe (Tajikistan):

A lower concentration of 49 µg/m^3, showing relatively better air quality compared to the top three cities, Beijing (China) PM2.5 level is 32.5 µg/m^3, indicating considerable improvement compared to previous years and significantly better than Kabul, Tashkent (Uzbekistan)

The lowest PM2.5 concentration at 28.6 µg/m^3, reflecting relatively cleaner air among the studied capitals.

Insights

Kabul's PM2.5 level is significantly higher than all other cities, making it the most polluted in this comparison, Tashkent has the cleanest air, with PM2.5 levels nearly three times lower than Kabul.

Mitigation Strategies and Policy Recommendations for Air Pollution Control

- Strengthening Institutional Frameworks.
- Transitioning to Cleaner Energy Sources.
- Transportation Reforms.
- Enhanced Waste Management Practices.
- Urban Planning and Green Infrastructure.
- Industrial Emission Controls.
- Public Awareness and Community Engagement.
- Monitoring and Research.
- International Collaboration.
- Policy Enforcement and Governance.

Summary and Conclusion

This study deals with the variability of different air pollutants over the Kabul city region. The two-year (2022–2023) investigation of the components of air pollution in Kabul reveals significant seasonal variations in the concentration of air pollutants caused by burning fossil fuels during the winter and low-quality fuel and unpaved streets during other seasons.

Monthly variations in air pollutant parameters of Kabul city found that the ozone level was more than 100 ug/m^3 in January, February, March, and December in an 8-hour average during 2022 and 2023. Nitrogen dioxide was high in January, February, March, and July in the year 2022, whereas it was high in July and August 2023.

Sulfur dioxide was high in January and December in both the years 2022 and 2023. CO level in one hour average was more than the air quality standards throughout the years 2022 and 2023. Except for January, February, and December in 2022, the 24-hour average of PM10 concentration was under the Air Quality standard every month.

In contrast, in 2023, the concentration was over the limit in every month except for April. Except for January, February, and March in 2022, the 24-hour average of PM2.5 concentration was under the National Air Quality standard every month. In contrast, in 2023, the concentration was over the limit in every month except April and May. In 2022, Kabul City's PM10 and PM2.5 values fell into the good and satisfactory category, while in 2023, they were moderate, according to AQI.

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Author contributions

Mohammad Zamir Taqwa has collected the data from Kabul City Afghanistan, prepared the original draft, and designed the study.

The final editing was done by Tharavathy NC, the authors read and confirmed the final draft of the manuscript.

Conflict of interest

The writers declare that they have no conflicting interests.

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