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Satellite and Ground-Based Air Quality Assessment in Al-Diwaniyah

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ABSTRACT

***Objective**: Ambient atmospheric pollution represents a critical threat to human health globally. Within Iraq, air quality has drastically diminished due to harsh climatic dust events and expanding unregulated anthropogenic factors. The primary goal of this investigation is to establish a thorough comparative analysis of air quality across the urban and rural sectors of Al-Diwaniyah Province. **Method:** A comparative cross-sectional design was carried out from mid-September 2025 through January 2026 across six strategic sampling locations. Ground-level monitoring utilized a calibrated Temtop M2000 device to log particulate metrics, while space-borne observations were acquired via the Sentinel-5P TROPOMI satellite for gaseous pollutants. A composite Z-score air quality index (AQI) evaluated safety thresholds, with statistical analysis processed through SPSS v26 software. **Results:** Ground measurements revealed that average $PM_{2.5}$ (34.87 $\mu g/m^3$) and PM_{10} (101.37 $\mu g/m^3$) drastically outpaced WHO safety limits ($p < 0.001$). Satellite monitoring demonstrated a significant abundance in tropospheric NO_2 (63.54 $\mu mol/m^2$) and O_3. The index classified 73.3% of the total observations as unhealthy for sensitive demographics. Urban sectors displayed significantly higher concentrations of $PM_{2.5}$, PM_{10}, and CO_2 than rural environments ($p < 0.001$), though rural locations showed a high prevalence (80.0%) of air quality categorized as hazardous for sensitive groups. **Novelty:** Al-Diwaniyah Province experiences severe atmospheric degradation. While urban centers undergo heavier pollution loads from concentrated traffic and fuel combustion, rural zones present distinct ambient threats to vulnerable populations from agricultural operations and dust.*

INTRODUCTION

Ambient air pollution is a serious global environmental and public health concern for the twenty-first century. According to the World Health Organization's (WHO) new global guidelines, prolonged exposure to air pollutants, particularly fine and coarse particulate matter, is directly associated with increased morbidity and premature mortality rates globally [1]. The concentrations of these airborne particulates and their associated trace gases exhibit pronounced spatial variations across diverse residential settings, establishing a clear dichotomy between urban and rural atmospheric quality [2]. Urban centers typically experience intense degradation due to concentrated anthropogenic operations. Recent epidemiological and environmental evidence underscores that urban environments are characteristically plagued by elevated levels of $PM_{2.5}$ and NO_2, driven primarily by high traffic density and industrial fuel combustion [3][4]. Furthermore, source apportionment models in regional urban zones confirm that road traffic emissions and vehicular exhaust act as the dominant contributors to particulate pollution in highly populated areas [4]. Conversely, rural regions are not entirely sheltered from atmospheric pollution; instead, they display unique emission profiles that severely impact public health. Atmospheric research indicates that rural populations frequently suffer from substantial exposure to particulate matter arising from localized agricultural practices, biomass burning, and wind-blown dust [5]. Interestingly, comparative geographical assessments have demonstrated that due to these distinct outdoor and domestic emission sources, overall environmental exposure to pollutants in rural zones can occasionally surpass the levels recorded in major metropolitan cities [6]. To effectively investigate these complex environmental disparities, contemporary research increasingly integrates ground-level monitoring with advanced space-borne remote sensing [7].

Satellite-derived observations, particularly from the Tropospheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor satellite, provide high-resolution spatial and temporal tracking of critical gaseous pollutants such as NO_2, SO_2, O_3, and CO [8]. When combined with Geographic Information Systems (GIS), this technology facilitates the comprehensive mapping of AQI and identifies shifting pollution boundaries. Within Iraq, ambient air quality has deteriorated rapidly due to a combination of severe climatic conditions, such as recurrent dust storms, and anthropogenic factors, including unregulated emissions and rapid demographic growth [9]. Recent literature utilizing Sentinel-5P observations has highlighted the shifting landscape of atmospheric pollutants across Iraqi provinces, emphasizing the need for localized investigations [10].

While regional literature has historically focused on capital cities, a significant research gap remains concerning the Middle Euphrates region, specifically Al-Diwaniyah Province. This province features a unique geographical blend of dense urban cores and expansive agricultural zones, making it an ideal setting for evaluating urban-rural exposure dynamics. Therefore, this study provides a comprehensive comparative assessment of air quality parameters across urban and rural sectors in Al-Diwaniyah.

RESEARCH METHOD

Study Design and Timeframe

A cross-sectional, descriptive, and comparative research design was implemented to evaluate and contrast ambient air quality profiles across distinct residential settings within the Al-Diwaniyah Governorate. To capture the atmospheric and seasonal variations of criteria pollutants, systematic environmental monitoring and field data collection were carried out over a designated timeframe extending from September 15, 2025, until the end of January 2026.

Study Setting and Monitoring Sites

The spatial scope of this investigation was centered in Al-Diwaniyah Province (officially recognized as Al-Qadisiyah Province), located in the central region of Iraq, approximately 200 km south of the capital city, Baghdad. The province encompasses a total geographic area of about 8,153 km^2, which constitutes roughly 1.9% of the total territory of Iraq. To establish a rigorous comparative framework, field observations and atmospheric sampling were executed across six strategically designated sampling points. The geographical coordinates (latitude and longitude) of each urban and rural monitoring site were precisely recorded using a Global Positioning System (GPS) to ensure accurate spatial mapping. These monitoring sites were explicitly selected to represent and differentiate between distinct residential environments within the governorate.

Air Quality Instrumentation and Parameters

Ambient air quality parameters were monitored, measured, and logged utilizing a calibrated, high-precision portable air quality monitoring instrument (Temtop M2000). This instrumentation was selected due to its field reliability, operational convenience, and optimized capability for real-time ambient assessment. The primary environmental parameters quantified during the study included fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), and the total particle number concentration (quantified as particles per liter). The inclusion of particle number concentration served as an essential, complementary metric to monitor and assess ultrafine particles, which are crucial for evaluating total atmospheric degradation.

Data Collection and Environmental Monitoring Protocol

Field monitoring was systematically conducted at the six designated urban and rural sampling stations throughout the study duration. At each location, the portable Temtop M2000 device was positioned in strict accordance with ambient monitoring protocols—placed at an appropriate breathing-zone height and away from immediate micro-localized obstructions—to ensure that the collected samples were fully representative of the general ambient air quality. Continuous tracking of particulate concentrations allowed for the evaluation of exceedances against international reference thresholds, such as the WHO air quality guidelines, thereby mapping the spatial dynamics between the heavily commercialized urban cores and the peripheral agricultural rural sectors.

Data scoring

Air Quality Index Calculation using Z-score

In order to measure the air quality, four major air pollutants ($PM_{2.5}$, PM_{10}, NO_2, and O_3) were taken into consideration in the analysis. The concentrations were initially standardized based on the Z-score method because of the fact that these pollutants are measured using different scales and also because they cover different ranges. The Z-score of every pollutant was determined by using the formula:

$$Z = \frac{X - \mu}{\sigma}$$

Where X is the measured concentration, μ is the mean, and σ is the standard deviation of the pollutant. A composite air quality index (AQI Z) was formed after the standardization by averaging the Z-scores of four pollutants:

$$AQI\_Z = \frac{Z_{PM2.5} + Z_{PM10} + Z_{NO2} + Z_{O3}}{4}$$

The greater the values of AQI Z, the worse the quality of air is, and the lesser the values of AQI Z, the better. This is used to multiply several pollutants into one standard index, thereby enabling a comparison of many sites or years. AQI Z was < -1 assessment as "Mild or Healthy AQ", -1 to 1 assessment as "Unhealthy for sensitive", while > 1 assessment as "Unhealthy".

Statistical Analyses

Data coding, arrangement, and organization were done with utmost attention in this study with Microsoft Excel, both to maintain accuracy and consistency of the data. The statistical analyses were performed with the help of SPSS (version 26) software. Continuous variables were summarized using mean and standard deviation (Mean ± SD), whereas categorical variables were expressed as frequencies and percentages. Prior to inferential analyses, the normality of quantitative variables should be assessed using the Shapiro–Wilk test. One-sample t-tests were employed to compare the observed mean concentrations of pollutants with established international reference values, including WHO guideline thresholds. Independent-samples t-tests were used to compare pollutant concentrations between urban and rural monitoring sites. All analyses were regarded as statistically significant with a p-value of ≤ 0.05 [11].

Ethical Considerations

Official approval to done the study was obtained from the College of Health and Medical Techniques in Basra, as well as from Al-Diwaniyah Directorate (Human Development and Training Center) to visit the health care sectors in Al-Diwaniyah City.

RESULTS AND DISCUSSION

The Air Quality Parameters

In **Table 1**, the environmental monitoring data indicated a clear increase in most air quality parameters, particularly particulate matter (PM) and carbon dioxide (CO_2), relative to recommended guidelines.

Table 1. The comparison of the air quality parameters with the recommended value.

Parameters	Mean	± SD	Reference value	*P- value
$PM_{2.5}$ (μg/m3)	34.867	6.837	15 μg/m3	**<0.001**
PM_{10} (μg/m3)	101.367	11.938	45 μg/m³	**<0.001**
Particles (per\L)	7870.700	1293.595	-	
HCHO (mg/m3)	0.001	0.001	0.1 mg/m³	**<0.001**
CO_2 (ppm)	1031.467	186.928	1000 ppm	0.364

***One-Sample t-test**

In **Table 1**, The current study established a comprehensive assessment of the atmospheric conditions, and the ground-based measurements of ambient air quality parameters were compiled and evaluated. The results demonstrate a significant increase in particulate pollution. The mean concentrations of $PM_{2.5}$ (34.87 ± 6.84 μg/m³) and PM_{10} (101.37 ± 11.94 μg/m³) substantially exceeded the WHO limits of 15 μg/m³ and 45 μg/m³, respectively [1]. This unhealthy exposure is primarily driven by local anthropogenic sources, such as road traffic and waste burning, which aligns with regional findings in Kuwait identifying traffic emissions as a dominant PM contributor [4]. Additionally, the high total particle concentration (7,870.70 ± 1,293.60 particles/L) emphasizes the presence of ultrafine particles, serving as a crucial metric that traditional mass-based measurements often miss [12]. Regarding gaseous pollutants, outdoor formaldehyde (HCHO) was remarkably low (0.001 ± 0.001 mg/m^3), remaining significantly below the 0.1 mg/m^3 threshold ($p < 0.001$). This expected outcome is due to rapid atmospheric dilution and photochemical degradation in outdoor settings [13]. Conversely, the ambient CO_2 level (1031.47 ± 186.93 ppm) was notably elevated above the global outdoor average of 400-450 ppm [14]. This surge strongly suggests the impact of localized pollution sources and poor atmospheric dispersion, corroborating recent studies that link high outdoor CO_2 to traffic congestion and continuous fossil fuel combustion [15].

In **Table 2**, To complement the ground-based findings, satellite-derived (TROPOMI) column data indicated a significant increase in most gaseous pollutants, particularly nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO), compared to reference standards.

Table 2. Parameters of Ambient Air Quality and Comparison with Reference Standards.

Parameters	Mean	± SD	Reference value	*P- value
NO_2 (µmol/m^2)	63.540	19.485	20 µmol/m^2	**<0.001**
SO_2 (µmol/m^2)	-132.841	99.313	5 µmol/m^2	**<0.001**
O_3 (mol/m^2)	0.130	0.007	0.12 mol/m^2	**<0.001**
CO (mol/m^2)	0.032	0.002	0.03 mol/m^2	**<0.001**
RH%	105.732	65.447	50%	0.454

***One-Sample t-test**

In **Table 2**, the satellite-derived (TROPOMI) tropospheric column measurements revealed significant deviations from reference standards for most gaseous pollutants ($p < 0.001$). The mean concentration of nitrogen dioxide (NO_2) was markedly elevated at 63.54 ±19.49 µmol/m2 against the reference of 20 µmol/m^2 ($p < 0.001$), primarily driven by intense combustion activities such as vehicular emissions and electricity generators [16]. This high NO_2 abundance likely facilitated the photochemical production of tropospheric ozone (O_3), which was marginally yet significantly elevated (0.130 ± 0.007 mol/m^2, $p < 0.001$), corroborating regional evidence in Iran of strong NO_2-O_3 correlations in polluted urban zones [17]. Similarly, carbon monoxide (CO) levels (0.032 ± 0.002 mol/m^2) exceeded the 0.03 mol/m^2 threshold, indicating substantial incomplete combustion from fossil fuels, a trend characteristic of developing urban regions [18]. Sulfur dioxide (SO2) showed a negative mean value (-132.84 µmol/m^2), a common issue in satellite remote sensing due to algorithmic corrections or instrumental noise. Despite this, the significant statistical findings ($p < 0.001$) indicate notable variations in SO2 concentrations during the monitoring period. A study in Arak, Iran, highlights that negative satellite SO2 measurements can still offer valuable insights into trends near coal-fired power stations and fuel-burning activities [19]. Unlike the atmospheric pollutants, relative humidity (RH) did not show a statistically significant difference relative to the reference standard (p = 0.454). Despite a high mean value (105.73%), the extreme standard deviation (pm 65.45 %) reflects high natural meteorological fluctuations, confirming that humidity patterns are governed by seasonal atmospheric dynamics rather than local anthropogenic factors [20].

Air Quality Level in Al-Diwaniyah Province

In **Table 3,** based on the ambient and satellite-derived parameters analyzed above, the comprehensive AQI was calculated to categorize the health risk levels for each pollutant. It shows the air quality in Al-Diwaniyah Province is generally unhealthy, as most of the observations (73.3%) were rated as unhealthy for sensitive groups, and 20.0% as unhealthy for all people. On the other hand, a limited number (6.7%) were classified as mild or healthy.

Table 3. The pie chart illustrates the total practice score of the participants.

Air quality level (AQ)	No.	%
Mild or Healthy AQ	2	6.7
Unhealthy for sensitive	22	73.3
Unhealthy	6	20.0

In **Table 3**, regarding the air quality level, predominantly unhealthy air quality poses severe respiratory risks, especially for vulnerable demographics. This degradation primarily stems from local traffic, power generation, and dust. Exposure to these emissions strongly exacerbates respiratory allergic diseases [21]. Furthermore, pollutants synergistically interact with airborne allergens, intensifying their biological potency and persistence. This mechanism explains the disproportionately high risk observed for sensitive groups before affecting the general population [22].

In **Table 4,** This table provides a comprehensive comparison of environmental parameters between urban and rural areas. It highlights significant differences in pollutant concentrations, emphasizing the impact of location on air quality. The data presented herein is crucial for understanding the environmental challenges faced by different communities.

Table 4. The comparison of parameter concentrations between urban and rural areas.

Parameters	Residence		*P- value
	Urban	Rural	
	Mean± SD	Mean	
$PM_{2.5}$ (µg/m3)	39.600±5.841	30.133±3.833	**<0.001**
PM_{10} (µg/m3)	108.067±11.010	94.667±8.821	**<0.001**
Particles(per\L)	8810.733±1112.107	6930.667±579.620	**<0.001**
HCHO (mg/m3)	0.001±0.001	0.001±0.0001	0.287
CO_2 (ppm)	1173.067±166.244	889.867±42.159	**<0.001**
***Independent Samples t-test**			

In **Table 4**, Our outcomes demonstrated that urban environments exhibited significantly higher pollution levels than rural areas for most parameters ($P < 0.001$). Mean concentrations of $PM_{2.5}$ (39.6 vs. 30.1 µg/m³), PM_{10} (108.1 vs. 94.7 µg/m³), and CO_2 (1173 vs. 889 ppm) were consistently elevated in urban settings. This disparity is primarily driven by dense human activity, traffic emissions, and fossil fuel combustion, aligning with global environmental assessments [23][24]. Conversely, formaldehyde (HCHO) showed no significant urban-rural variance ($P = 0.287$), indicating that HCHO exposure is largely dictated by indoor micro-environments rather than outdoor conditions [25].

Table 5 shows the comparative assessment of AQI levels, demonstrating a statistically significant variation between urban and rural residential environments, highlighting higher pollution severity in urban settings.

Table 5. The comparative analysis of air quality levels by residential setting.

Air quality (AQ)	Residence				P-value
	Urban		Rural		
	No.	%	No.	%	
Mild or Healthy AQ	0	0.0	2	13.3	**0.048**
Unhealthy for sensitive	10	66.7	12	80.0	
Unhealthy	5	33.3	1	6.7	
Independent Samples t-test					

In **Table 5**, a statistically significant difference in air quality between urban and rural environments ($P = 0.048$). Urban areas showed a higher proportion of unhealthy air quality (33.3%) compared with rural areas (6.7%), while rural areas were more frequently classified as unhealthy for sensitive groups (80.0% vs. 66.7%). In addition, healthy air quality was observed only in rural areas (13.3%). These findings suggest that urban residents are exposed to more severe air pollution, likely due to traffic emissions, industrial activities, and population density. Similar findings were reported in Saudi Arabia, where urban environments were associated with higher levels of $PM_{2.5}$ and NO_2 pollutants [3]. However, the predominance of the unhealthy for sensitive groups category in rural areas indicates that rural populations may also experience considerable exposure to pollutants from sources such as biomass burning, agricultural activities, and dust [5][6].

CONCLUSION

Fundamental Finding : This study found that ambient air quality in Al-Diwaniyah Governorate has deteriorated substantially, with particulate matter ($PM_{2.5}$ and PM_{10}) and several gaseous pollutants exceeding international guideline values. Ground-based and satellite observations consistently showed that urban areas experienced significantly higher pollutant concentrations than rural areas due to traffic emissions, fossil fuel combustion, and intensive human activities. Despite lower overall pollution levels, rural areas exhibited a high proportion of air quality classified as unhealthy for sensitive groups, indicating that agricultural activities, biomass burning, and dust also contribute considerably to air pollution exposure. **Implication :** The findings highlight the urgent need for location-specific air quality management strategies that address the distinct pollution sources in urban and rural environments. Urban pollution control should prioritize reducing traffic-related and combustion emissions, while rural interventions should focus on minimizing emissions from agricultural practices, biomass burning, and dust exposure to protect vulnerable populations and reduce adverse public health outcomes. **Limitation :** This study was conducted using a cross-sectional design within a single governorate over a limited monitoring period, which may not fully capture long-term seasonal and interannual variations in air quality. Furthermore, the assessment focused on selected particulate and gaseous pollutants without incorporating detailed source apportionment analyses or evaluating individual health outcomes associated with pollutant exposure. **Future Research :** Future studies should perform long-term and multi-season monitoring across different regions of Iraq to better characterize temporal and spatial variations in air pollution. Further research should also integrate source apportionment techniques, meteorological modeling, and epidemiological analyses to identify dominant pollution sources and quantify the health impacts of prolonged exposure among different population groups.

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