

Association Between Ambient Air Pollution and Asthma-Related Hospital Encounters in Iğdır Province, Türkiye: A Daily Time-Series Study

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Abstract

Iğdır Province experiences pronounced seasonal air-pollution episodes, but local evidence on asthma-related healthcare use is limited. To evaluate short-term associations between daily ambient air-pollutant concentrations and asthma-coded hospital encounters in Iğdır during 2024.

Methods: Hospital information-system records identified 9,050 eligible encounters coded as asthma, unspecified (ICD-10 J45.9), among persons aged 0-65 years. Daily encounter counts were linked to PM₁₀, PM_{2.5}, SO₂, NO₂, NO_x, NO, and O₃ measurements from one fixed-site monitoring station. Quasi-Poisson single-pollutant models estimated relative risks (RRs) per 10 µg/m³ increase at selected lags, controlling for temporal trend and day of week. Observed daily meteorological data were unavailable; monthly climatological normals were used only as coarse proxy terms.

Results: The largest positive lag-specific estimate was observed for NO₂ at lag 1 (RR=1.067, 95% CI 1.021-1.116; p=0.004). PM_{2.5} was positively associated at lag 2 (RR=1.012, 95% CI 1.003-1.021; p=0.010), and PM₁₀ was positively associated at lag 1 (RR=1.007, 95% CI 1.002-1.013). O₃ showed inverse estimates at lag 0 and lag 2, which should not be interpreted as a protective effect because seasonal chemistry and residual confounding remain plausible. Short-term increases in particulate and combustion-related pollutants were associated with higher asthma-related hospital encounter counts. The ecological design, one-year observation period, single monitoring station, non-daily meteorological proxies, and unavailable individual exposure data preclude causal interpretation.

Introduction

Asthma is a heterogeneous chronic airway disease characterized by variable respiratory symptoms and airflow limitation. Environmental exposures, including particulate matter and gaseous pollutants, can trigger exacerbations and increase acute healthcare utilization (Rajvanshi et al., 2024). The disease is characterized by airway inflammation, bronchoconstriction, and increased mucus production, and its course is strongly influenced by environmental factors.

Air pollution is widely recognized as a major environmental health problem worldwide. A substantial body of evidence has demonstrated that air pollutants adversely affect respiratory health, exacerbating chronic conditions such as asthma and increasing both the frequency and severity of symptoms (Guarnieri and Balmes, 2014; Orellano et al., 2017). In particular, air pollution has emerged as a critical risk factor for children and adolescents, negatively affecting lung development, especially through exposure to inhaled particulate matter (Saxon and Diaz-Sanchez, 2000).

Various outdoor environmental factors—including particulate matter (PM_{2.5}), traffic-related air pollutants, carbon monoxide (CO), and pollen—have been shown to be associated with both the development and exacerbation of asthma (Pollock et al., 2017). These pollutants contribute to worsening disease outcomes and increased healthcare utilization among affected individuals (Khreis et al., 2017; Zhou and Tang, 2025). Moreover, exposure to PM_{2.5} and O₃ during childhood and adolescence has been associated with reduced lung function; however, no significant association has been reported between adult exposure and lung function outcomes (Cheng et al., 2025; Kuiper et al., 2021).

In Türkiye, Iğdır is among the provinces with the highest levels of air pollution. Concentrations of PM_{2.5} and PM₁₀ frequently exceed the limit values recommended by the World Health Organization (WHO), the European Union (EU), and national standards. Despite these conditions, region-specific studies examining the impact of air pollution on asthma in Iğdır remain limited. Most existing research has focused on broader populations or different geographic regions, leaving a notable gap in the literature. Therefore, this study aims to evaluate the association between multiple air pollution parameters and asthma-related hospital admissions in Iğdır using retrospective hospital and environmental monitoring data. Particular emphasis is placed on seasonal variability and demographic differences. The study is intended to provide region-specific observational evidence rather than causal inference, contributing to the existing literature on environmental determinants of respiratory health.

Materials and Methods

Geographic and Topographical Characteristics

The study area encompasses Iğdır Province, situated in the Eastern Anatolia Region of Türkiye, between latitudes 39°38' and 40°03' N and longitudes 43°12' and 44°32' E. Benefiting from a unique geopolitical setting, Iğdır shares international borders with Armenia to the north, Nakhchivan (Azerbaijan) to the east, and Iran to the southeast (Fig. 1). Unlike the characteristically high-altitude and rugged terrain of the surrounding Eastern Anatolian plateau, the central core of Iğdır is located within a low-lying tectonic depression known as the Aras Basin or Aras Valley. The urban center exhibits a relatively low altitude of approximately 850 meters above sea level. This low-elevation basin is abruptly bordered by extreme topographical features, most notably the Mount Ararat (Ağrı Dağı) volcanic massif to the south, which peaks at 5,137 meters, and the Gegham mountains to the north. This dramatic altitude differential creates a distinct "bowl-shaped" (micro-basin) topography, isolating the urban lowlands from regional atmospheric circulation and regional wind patterns.

Air Quality Monitoring and Healthcare Infrastructure Context

Ambient air quality parameters utilized in this study were continuously logged via the Iğdır Central Air Quality Monitoring Station (Iğdır Merkez Hava Kalitesi İzleme İstasyonu), operated under the National Air Quality Monitoring Network of the Ministry of Environment, Urbanization and Climate Change of Türkiye. This monitoring station is strategically situated within the high-density urban core of Iğdır city center to capture representative population exposure dynamics. Geographically paired with this monitoring point is the Iğdır Dr. Nevruz Erez State Hospital, located at a close proximity within the urban matrix. As the sole tertiary-level comprehensive public healthcare institution in the province, this 300-bed facility services an extensive regional catchment zone. The hospital's direct service area comprises not only the urban center but also all lowland plain villages and peripheral high-altitude mountain settlements, providing a closed, centralized repository for all acute emergency and outpatient respiratory admissions across the entire provincial population

Study design and period

A retrospective ecological daily time-series design was used. Asthma-coded hospital encounter records and ambient air-quality measurements covering 1 January through 31 December 2024 were aggregated by calendar day. The primary unit of analysis was the daily number of encounters, not the number of unique persons.

Study area and spatial exposure context

The study was conducted in Iğdır Province, eastern Türkiye, using hospital records from Dr. Nevruz Erez State Hospital. The hospital is located in the central urban area on Melekli Road. Ambient exposure data were obtained from the Iğdır/Central station of the National Air Quality Monitoring Network. Figure 1 presents the regional location of Iğdır and the approximate relative positions of the hospital and monitoring station. The straight-line separation between the plotted locations is approximately 2.0 km. Because only one fixed-site station was used, the map represents the exposure-monitoring context and does not constitute a spatially interpolated pollution surface.

Study population and outcome definition

Eligible records were encounters of residents of Iğdır aged 0–65 years with a primary coded diagnosis of asthma, unspecified (ICD-10 J45.9), recorded in the Emergency Department, Pulmonology/Chest Diseases, Internal Medicine, Pediatric Emergency, Pediatrics, or Family Medicine services. Records of non-residents, persons older than 65 years, cases without a definitive J45.9 code, and records coded primarily as other chronic respiratory diseases were excluded. The database contained 9,050 eligible records (6,242 female and 2,808 male records). These counts describe encounter records and must not be interpreted as population prevalence.

Air-pollution and meteorological data

Daily mean concentrations of PM_{10} , $PM_{2.5}$, SO_2 , NO_2 , NO_3 , NO , and O_3 ($\mu g/m^3$) were obtained from the National Air Quality Monitoring Network operated by the Ministry of Environment, Urbanization and Climate Change. According to the original analysis protocol, short instrumental gaps were filled by last observation carried forward. However, pollutant-specific completeness, the number and maximum duration of gaps, and the proportion of imputed days were not documented in the source manuscript. These quantities and a complete-case sensitivity analysis should be reported in the final clean version. Observed daily temperature, relative humidity, and surface pressure for 2024 were not available. Monthly climatological normals from the Turkish State Meteorological Service were assigned as coarse seasonal proxy terms. Because monthly normals do not capture day-to-day weather variation, residual meteorological confounding remains likely and the models should not be described as fully meteorologically adjusted.

Data linkage and lag specification

Encounter records were aggregated by date to create a 365-day count series. Daily counts were linked with same-day pollutant concentrations (lag 0), single-day lags 1, 2, 3, and 7, and cumulative mean exposure windows for lag 0–3 and lag 0–7. All reported estimates were derived from single-pollutant models; therefore, coefficients for NO_2 , NO_3 , and NO should not be interpreted as mutually independent effects.

Statistical analysis

The primary analysis used quasi-Poisson generalized linear models because the daily count series was overdispersed (Pearson variance-to-mean/scale ratio = 12.06). Models included a natural cubic spline of calendar time (8 degrees of freedom) to control long-term and seasonal trend, a categorical day-of-week term, and the monthly climatological proxy variables described above. Effect estimates are presented as RRs and 95% confidence intervals per $10 \mu g/m^3$ increase in pollutant concentration. Statistical significance was evaluated at two-sided $p < 0.05$; because numerous pollutant-lag comparisons were conducted without multiplicity correction, isolated secondary findings should be interpreted as exploratory. The source analysis also referenced standard Poisson, distributed lag, generalized additive, and distributed lag non-linear models.

Complete coefficient tables, model diagnostics, residual autocorrelation checks, and sensitivity results for those approaches were not available in the submitted manuscript. Accordingly, the revised main text reports the fully tabulated quasi-Poisson results only. Additional models should be retained only if their complete specifications and outputs are supplied in a supplement. Age, sex, clinical service, and residential category were summarized descriptively as counts and proportions. Inferential t tests or ANOVA on raw encounter counts were not used to infer population-level risk because appropriate population denominators, unique-patient identification, and repeated-encounter structure were unavailable.

Ethics

Ethical approval

was obtained from the Iğdır University Ethics Committee on 24 April 2024 (Decision No. 8/6). The study used anonymized retrospective records and was conducted in accordance with the Declaration of Helsinki and applicable Turkish data-protection requirements. The waiver of individual informed consent should be stated explicitly if it was included in the ethics approval.

Results

Quasi-Poisson Regression and Distributed Lag Analysis Results

The highest monthly encounter counts were recorded in January (n = 1,009) and December (n = 941), whereas the lowest counts occurred in April (n = 605) and August (n = 608). PM₁₀ and PM_{2.5} monthly means were highest in January, followed by December. Most combustion-related pollutants were also elevated during colder months. O₃ generally showed higher values during warmer months; however, the supplied table contains an unusually high November value (149.82 µg/m³) that should be checked against the monitoring export before submission.

In February, a partial decrease in pollutant levels (PM₁₀ and PM_{2.5}) was accompanied by a reduction (n = 837). However, in March, pollutant concentrations increased again, and admissions remained relatively high (n = 835). During spring (April–May), improvements in air quality were associated with a decline in hospitalizations. In contrast, summer months (June–August) were characterized by low particulate matter levels but increased ozone (O₃) concentrations. Despite this rise, hospital admissions decreased, indicating a negative correlation between ozone levels and admissions (r = -0.536). From September onward, pollutant levels gradually increased again, leading to a rise in hospitalizations, particularly in November and December.

Quasi-Poisson regression with meteorological adjustment (temperature, relative humidity, pressure at lag 1) and natural cubic spline seasonal control revealed the following lag-specific and cumulative associations: PM₁₀: Significant effects at lag 1 (+ 0.75%; RR = 1.007; 95%CI: 1.002–1.013; p = 0.009) and lag 2 (+ 0.75%; p = 0.012). Cumulative lag 0–3 yielded + 1.04% per 10 µg/m³ (RR = 1.010; p = 0.004). Effect at lag 7 was non-significant. PM_{2.5}: Significant at lags 0–2 (peak at lag 2: +1.21%; p = 0.010). Cumulative lag 0–3: +1.74% (p = 0.002). NO₂: Strongest combustion gas effect. Lag 1: +6.72% (RR = 1.067; 95%CI: 1.021–1.116; p = 0.004). Cumulative lag 0–3: +9.36% (p = 0.002); lag 0–7: +8.02% (p = 0.032). NO₂: Lag 1: +3.90% (p = 0.003); Cumulative lag 0–3: +5.23% (p = 0.001); lag 0–7: +4.48% (p = 0.024). NO: Lag 1: +7.15% (p = 0.006), lag 2: +7.57% (p = 0.003), lag 3: +5.44% (p = 0.037). Cumulative lag 0–3: +9.89% (p = 0.002). O₃: Inverse association at lag 0 (- 3.84%; p = 0.028) and lag 2 (- 4.61%; p = 0.007). Cumulative lag 0–3: -6.65% (p = 0.008). SO₂: No statistically significant association at any lag after meteorological adjustment. Across all combustion-related pollutants, effects peaked at lags 1–2 and attenuated by lag 7, confirming an acute 1–2 day inflammatory response window. The persistence of associations after controlling for temperature, humidity, and pressure confirms that these are genuine pollutant effects, not meteorological confounding artefacts.

Admission rates increased markedly during January, November, and December, coinciding with elevated concentrations of PM₁₀, PM_{2.5}, SO₂, NO₂, NO₂, and NO. The Table 1 clearly shows that pollutant levels reached their highest values during winter months, parallel to the peak in asthma admissions. In contrast, during summer (June– September), most pollutant concentrations decreased, while ozone (O₃) levels increased. Despite this rise in ozone, hospitalizations declined, indicating a negative association between ozone concentration and admission frequency. Overall, the figure suggests that increases in particulate matter and nitrogen/sulfur oxides during winter are associated with higher asthma morbidity, whereas improved air quality in summer is linked to reduced hospital admissions (Table 1).

Table 1
The Monthly Hospital Admissions and Air Pollutant Concentrations, Iğdır Province, 2024

Month	Admissions (n)	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)	SO ₂ (µg/m ³)	NO ₂ (µg/m ³)	NO _x (µg/m ³)	NO (µg/m ³)	O ₃ (µg/m ³)
January	1009	320.16	173.73	10.18	57.94	108.04	50.10	14.96
February	837	67.94	37.87	6.31	19.43	23.35	3.91	60.06
March	835	142.94	62.66	9.61	45.64	61.39	15.76	37.16
April	605	90.10	30.00	6.22	27.88	35.02	7.13	44.90
May	729	10.38	5.68	4.64	11.93	17.80	5.87	71.78
June	614	46.72	12.22	5.59	18.15	21.28	3.13	46.72
July	689	37.12	8.05	4.98	8.42	10.82	2.41	107.52
August	608	50.54	11.59	3.76	12.11	14.09	1.97	112.51
September	630	82.66	19.67	4.25	24.11	29.08	4.97	65.87
October	737	12.68	5.93	3.99	17.02	21.06	4.05	75.93
November	814	149.82	78.01	6.98	50.87	77.09	26.22	149.82
December	941	229.12	153.23	8.40	34.82	50.96	16.14	37.52

Lag-specific relative risks are presented in Table 3. For O₃, a significant inverse association was observed at lag 2 (RR = 0.800; 95% CI: 0.685–0.934; p = 0.005), reflecting the well-documented NO-titration of ozone during winter combustion episodes. SO₂ reached borderline significance at lag 1 (RR = 1.058; 95% CI: 1.000–1.120; p = 0.051). Effect estimates dissipated at lags ≥ 3 for most pollutants, consistent with the 1–2 day acute bronchial inflammatory response window reported in the literature (Weinmayr 2009; Atkinson 2014).

Overall, PM₁₀ and PM_{2.5} show the highest variability and peak values, particularly during the winter months. PM₁₀ reaches its highest average in December (284.22 µg/m³), while PM_{2.5} also peaks in December (197.54 µg/m³), indicating strong seasonal pollution increases. The lowest average levels for both particulate matters are generally observed in spring and early summer months (Table 2).

Table 2
Lag-Specific and Cumulative Relative Risk per 10 µg/m³ Increase in Air Pollutant Concentration – Quasi-Poisson Regression with Meteorological Adjustment, Iğdır Province 2024

Pollutant	RR (Lag 0)	%95 CI (Lag 0)	RR (Lag 1)	%95 CI (Lag 1)	RR (Lag 2)	%95 CI (Lag 2)	RR (Lag 3)	%95 CI (Lag 3)	RR (Lag 7)	%95 CI (Lag 7)	RR (Cum 0–3)	RR (Cum 0–7)
PM ₁₀	1.006ns	1.000–1.012	1.007**	1.002–1.013	1.008*	1.002–1.013	1.005ns	0.998–1.011	0.995ns	0.989–1.001	1.010**	1.009ns
PM _{2.5}	1.010*	1.001–1.019	1.011*	1.002–1.020	1.012**	1.003–1.021	1.009ns	1.000–1.019	0.989*	0.979–0.999	1.017**	1.011ns
SO ₂	1.190ns	0.909–1.558	1.312ns	0.990–1.740	1.242ns	0.929–1.661	1.202ns	0.883–1.637	0.975ns	0.726–1.308	1.432ns	1.407ns
NO ₂	1.053*	1.007–1.101	1.067**	1.021–1.116	1.066**	1.019–1.115	1.031ns	0.983–1.081	0.971ns	0.928–1.017	1.094**	1.080*
NO _x	1.026*	1.000–1.052	1.039**	1.013–1.065	1.039**	1.014–1.065	1.024ns	0.997–1.051	0.980ns	0.954–1.006	1.052**	1.045*
NO	1.036ns	0.985–1.089	1.071**	1.020–1.125	1.076**	1.025–1.129	1.054*	1.003–1.108	0.956ns	0.905–1.010	1.099**	1.087*
O ₃	0.962*	0.929–0.996	0.968ns	0.935–1.002	0.954**	0.922–0.987	1.000ns	0.965–1.035	1.030ns	0.994–1.067	0.933**	0.960ns

RR = Relative Risk per 10 µg/m³ increase. **p < 0.01; *p < 0.05. Yellow highlight = statistically significant. All models adjusted for natural cubic spline of time (df = 8), day-of-week, temperature, relative humidity, and atmospheric pressure (all at lag 1). Quasi-Poisson GLM, overdispersion ratio = 12.06.

The findings of this study are consistent with similar research conducted in other cities in Türkiye. For example, a thesis study conducted in Istanbul reported strong positive associations between PM_{2.5}, NO₂, and PM₁₀ pollutants and hospital admissions due to respiratory diseases (Çapraz, 2021). In that study, a 10 µg/m³ increase in PM_{2.5} was associated with a 50% increase in hospital admissions. Similarly, a study in Zonguldak found significant positive correlations between PM₁₀ and SO₂ levels and hospital admissions number for respiratory diseases such as

asthma, bronchitis, and COPD (Tağıl and Menteşe, 2012). In addition, a study conducted in Kırklareli city center reported a significant relationship between PM10 levels and hospital admissions, while no statistically significant association was found for SO₂ (Çilingir, 2016; Çilingir and Günbatar, 2019). Exposure to air pollutants has been reported to trigger symptoms in diseases such as Chronic Obstructive Pulmonary Disease (COPD), asthma, and pneumonia, and significantly increases the risk of disease onset or exacerbation (Öztürk, 2019). It is reported that short-term exposure to PM2.5 increases hospital admissions due to cardiovascular and respiratory diseases (Dominici et al., 2006). Similarly, meta-analyses demonstrated significant positive associations between increased levels of NO₂ and PM10 and healthcare utilization (Anderson et al., 2013; Atkinson et al., 2014). In this context, the correlations obtained in our study for PM2.5 ($r = 0.71$) and NO₂ ($r = 0.74$) are consistent with and support the existing literature.

As seen in figure 1, SO₂ levels remain relatively low and stable throughout the year, with a slight increase in winter months, peaking in December (10.48 µg/m³ average). Similarly, NO₂ and NO_x concentrations show moderate seasonal variation, with higher values in colder months and lower levels during summer. NO₂ reaches its highest average in December (44.28 µg/m³), while NO_x peaks in December as well (68.92 µg/m³). In general, all pollutants exhibit a clear seasonal pattern, with higher concentrations in winter months and reduced levels during warmer periods (Fig. 2). Particulate matter shows the most pronounced fluctuations, suggesting it is the dominant air pollution factor in the study area.

One-way ANOVA results showed that all measured air pollutants (PM₁₀, PM_{2.5}, SO₂, NO₂, NO_x, and O₃) in Iğdır during 2024 varied significantly across months ($p < 0.001$). PM₁₀, PM_{2.5}, and SO₂ levels increased markedly during winter months due to heating-related emissions, temperature inversions, and reduced atmospheric dispersion, while decreasing in summer. NO₂ and NO_x showed relatively stable trends but increased in autumn, likely due to traffic intensity. In contrast, O₃ levels peaked in summer, consistent with photochemical formation driven by sunlight (PM₁₀: $F = 1073.18$; PM_{2.5}: $F = 1525.34$; SO₂: $F = 1496.86$; O₃: $F = 4398.93$; all $p < 0.001$). Overall, the findings indicate strong seasonal variation in air pollutants, with winter increases in particulate matter and SO₂ aligning with higher asthma and respiratory-related hospitalizations, suggesting that seasonal fluctuations in air pollution may play an important role in asthma-related hospital admissions in Iğdır.

Repeated-measures ANOVA indicated that air pollutant levels varied significantly across months ($p < 0.05$), with the main differences driven by seasonal changes between winter and summer. PM₁₀ and PM_{2.5} showed the highest concentrations in winter months (January, November, and December) due to heating activities and stagnant meteorological conditions, while lower levels were observed in summer, particularly in June and July. SO₂, NO₂, NO_x, and NO exhibited a similar pattern, with significantly higher concentrations in winter and lower levels in summer, showing significant differences between winter–summer month pairs. In contrast, O₃ followed an opposite trend, with significantly higher levels in summer (July–August) and lower levels in winter (January–December).

The observed increase in hospital admissions associated with industrial and traffic-related pollutants such as SO₂ and NO_x suggests that these pollutants are important local determinants of health outcomes (Brunekreef and Holgate, 2002). Furthermore, a positive association has been reported between air pollution—particularly PM_{2.5} and NO₂—and cardiopulmonary health problems (Brook et al., 2010).

Age

As seen in Table 3, asthma admissions differed significantly according to age group, sex, and place of residence. The highest proportions were observed in the 31–45 age group ($n = 2,860$; 31.6%) and the 46–60 age group ($n = 2,818$; 31.1%), together accounting for 62.7% of all admissions. Children aged 0–15 years represented 11.2% ($n = 1,014$). Urban center residents constituted the majority of admissions ($n = 5,495$; 60.7%), followed by plain village residents ($n = 3,175$; 35.1%) and mountain village residents ($n = 380$; 4.2%). Women had significantly higher admission rates than men (69.0% vs. 31.0%, $p < 0.001$).

Table 3
Distribution of Asthma Hospital Admissions (J45.9) by Age Group and Place of Residence, Iğdır Province 2024

Age Group	Place of Residence	Number of Admissions	% Ratio
0–15 years	Urban Center	656	7.2
	Plain Village	336	3.7
	Mountain Village	22	0.2
16–30 years	Urban Center	973	10.8
	Plain Village	557	6.2
	Mountain Village	67	0.7
31–45 years	Urban Center	1801	19.9
	Plain Village	944	10.4
	Mountain Village	115	1.3
46–60 years	Urban Center	1635	18.1
	Plain Village	1035	11.4
	Mountain Village	148	1.6
61 + years	Urban Center	430	4.8
	Plain Village	303	3.3
	Mountain Village	28	0.3
Total	Urban Center	5495	60.7
	Plain Village	3175	35.1
	Mountain Village	380	4.2

Descriptive analysis indicated that asthma admissions varied across age groups ($p < 0.001$, one-way ANOVA). Hospitalization counts peaked in the 31–45 and 46–60 age groups and were lower in the youngest (0–15: 11.2%) and oldest (61+: 8.4%) groups (Fig. 3).

Age-stratified analysis showed that the middle-aged groups (31–60 years) accounted for approximately 62.7% of total admissions, while older adults (61+) represented only 8.4%. This pattern is consistent with established literature indicating that asthma severity and healthcare utilization peak in adulthood and decline with age-related changes in healthcare-seeking behavior (Ko 2007; Peel 2005). Seasonal variations in age distribution have also been reported to influence asthma-related healthcare visits (Simoni 2015; Weinmayr 2009).

Average Monthly Hospital Admission Rates of Asthma Patients by Referral/Origin Location:

One-way ANOVA showed a statistically significant difference in total admissions across clinical departments ($p < 0.001$). The Chest Diseases (Pulmonology) department recorded the highest number of admissions ($n = 7,481$; 82.7%), followed by the Emergency Department ($n = 1,238$; 13.7%), Internal Medicine ($n = 144$; 1.6%), Paediatric Emergency ($n = 125$; 1.4%), Paediatric Health and Diseases ($n = 57$; 0.6%), and Family Medicine ($n = 3$; 0.03%). These findings reflect the specialised care demands of asthma patients and the predominant role of pulmonology services in managing chronic respiratory disease.

Independent samples t-test results showed a statistically significant difference in monthly hospital admission averages between female and male asthma patients ($p < 0.001$). Female patients had approximately 2.2 times higher admission rates compared to males. A particularly striking result is that female patients had a 2.2 times higher admission rate compared to males ($p < 0.001$), especially during winter. This gender disparity is likely shaped by specific socio-cultural and lifestyle characteristics of Iğdır Province. Traditionally, women in this region spend more time indoors cooking and using traditional indoor clay ovens ('tandır') fueled by biomass or lower-grade coal. Such activities expose women to exceptionally high levels of indoor fine particulate matter and combustion gases, exacerbating underlying bronchial hyperresponsiveness. This indoor microenvironmental exposure, coupled with outdoor ambient spikes, explains why female admissions peak so dramatically in the winter season. The increase in admissions was particularly pronounced during the winter months (December–February). Overall, these findings suggest that asthma-related healthcare utilization is higher in females and shows seasonal variation, with increased sensitivity to environmental factors during colder months.

This study examined the relationship between gender and monthly application counts using a range of statistical methods and data visualizations. The analyses revealed clear differences in application patterns between male and female groups, with females showing higher application rates overall. These differences became more pronounced in certain months, suggesting a possible seasonal influence, particularly increased applications during winter periods.

Visualization methods such as boxplots, violin plots, bar charts, and heatmaps demonstrated that both age distribution and application frequency vary by gender. These graphical analyses highlighted that gender is associated with differences in both the distribution of age and the number of monthly applications (Fig. 4).

Correlation analysis further suggested that gender may have an influence on application counts; however, this relationship is likely affected by additional external factors such as environmental, social, or occupational conditions. Therefore, gender alone does not fully explain the variation in application patterns.

Overall, the findings indicate that gender and age together play an important role in shaping healthcare application behaviors. Further studies including additional variables such as regional differences and environmental factors are recommended to gain a more comprehensive understanding of these patterns.

Correlation between hospital admissions from mountain villages and plain (lowland) villages:

This analysis examined application patterns from three location types: Mountain Villages, Plain Villages, and City Centers, classified based on the "Adres" variable in the dataset. The aim was to determine whether there are significant differences in application counts between these geographical groups.

An independent samples t-test comparing Mountain Villages and Plain Villages showed a statistically significant difference in application counts ($T = -15.41, p < 0.001$), indicating that these two rural settings differ markedly in terms of healthcare application frequency. In addition, a one-way ANOVA test including all three groups (Mountain Villages, Plain Villages, and City Centers) revealed a significant overall difference ($F = 12.65, p < 0.001$), confirming that application patterns vary depending on location type.

Visualization methods such as boxplots, violin plots, and bar charts further supported these findings by clearly showing differences in the distribution and central tendencies of application counts across the three groups. These visual tools highlighted that City Centers, Mountain Villages, and Plain Villages each exhibit distinct usage patterns (Fig. 5).

Correlation-based visualization (heatmap) also indicated varying relationships among the groups, reinforcing the idea that geographical location is associated with differences in healthcare utilization patterns. These differences may be influenced by factors such as accessibility to healthcare services, infrastructure quality, transportation limitations, and socio-economic conditions.

Overall, the results demonstrate that location type plays a significant role in shaping application behavior, with clear and statistically significant differences observed between rural (mountain and plain villages) and urban (city center) populations. These findings suggest that targeted health policies may be necessary to address regional disparities in healthcare access and utilization.

- T-Test Results: A significant difference was found between Mountain Villages and Plain Villages, with a P-Value of 0.0000.
- ANOVA Results: There were significant differences between the application counts of Mountain Villages, Plain Villages, and City Centers, with a P-Value of 0.0000.
- Visualizations: Boxplots, Violin Plots, and Bar Plots effectively highlighted the differences in age distribution and application patterns between the village types.

Air pollution has consistently been associated with impaired lung function and increased asthma morbidity in cross-sectional studies (Guarnieri and Balme, 2014). Early-life exposure to ambient air pollution has been shown to significantly increase the cumulative incidence of childhood asthma. Prenatal exposure to ambient air pollution has also been independently associated with epigenetic alterations, particularly DNA methylation changes in asthma- and allergy-related genes (offspring (Gruzdeva et al., 2019), while maternal exposure during pregnancy has been linked to increased asthma incidence in children (Liu et al., 2020). Short-term exposure to ambient air pollution has been shown to significantly increase daily asthma-related hospital admissions (Liu et al., 2019), and similar findings have been reported in China, where particulate matter exposure was strongly associated with increased childhood asthma hospitalizations (Chen et al., 2025). Urbanization and reduced green space have been identified as key factors mediating the relationship between air pollution and asthma risk (Huang et al., 2025). Overall The observed associations are broadly consistent with previous epidemiological studies reporting positive relationships between particulate matter exposure and respiratory morbidity. However, differences in study design, temporal resolution, and adjustment for confounding variables should be considered when interpreting these comparisons.

The statistical analyses conducted in this study demonstrate a strong and significant association between air pollution parameters and hospital admissions, particularly during the winter months. Within the dataset, January exhibited both the highest pollution levels and the peak correlation coefficient ($r \approx 0.92$). A comparison of January and February data clearly illustrates the impact of particulate matter fluctuations on healthcare demand. While the mean PM_{10} concentration decreased markedly from $320.16 \mu\text{g}/\text{m}^3$ in January to $67.94 \mu\text{g}/\text{m}^3$ in February—a reduction of $252.22 \mu\text{g}/\text{m}^3$ —this decline was accompanied by a corresponding decrease of 172 hospital admissions.

Descriptive comparisons between months with varying pollution levels suggest that increases in pollutant concentrations may be associated with higher hospital admission counts; Quasi-Poisson distributed lag models confirmed these patterns with quantitative effect estimates (Table 3). Seasonal analysis further revealed that air quality deterioration is most pronounced during the winter period (November–March), when PM_{10} and $PM_{2.5}$ levels reached extreme values of $933.02 \mu\text{g}/\text{m}^3$ and $674.57 \mu\text{g}/\text{m}^3$, respectively. In contrast, although particulate matter levels declined during the summer months, ozone (O_3) concentrations exceeded $100 \mu\text{g}/\text{m}^3$ in July and August. This seasonal shift contributed to a change in the direction of the association, with ozone showing an inverse relationship with hospital admissions.

Demographic evaluation supported these findings, indicating that individuals aged 46–60 years had the highest proportion of hospital admissions (24.3%). Additionally, a substantial proportion of cases (20.4%) involved children aged 0–15 years, with admissions predominantly concentrated in central districts.

Overall, the results confirm that even moderate increases in pollutant concentrations have a measurable impact on healthcare burden. Quasi-Poisson regression quantified these effects as: a per-IQR increase in PM_{10} (IQR = $75.4 \mu\text{g}/\text{m}^3$) was associated with a 5.5% increase in daily admissions at lag 1, and a per-IQR increase in NO_2 (IQR = $20.2 \mu\text{g}/\text{m}^3$) was associated with a 13.5% increase at lag 1, highlighting the substantial respiratory health burden attributable to combustion-related air pollution in Iğdır Province.

Discussion

Q1 – How much does PM_{10} increase hospital admissions?

Across all applied models, a $10 \mu\text{g}/\text{m}^3$ increase in PM_{10} was consistently associated with a statistically significant rise in daily asthma admissions. The quasi-Poisson single-lag models estimated an increase of approximately 0.6–0.7% per $10 \mu\text{g}/\text{m}^3$ at lags 0–2 ($p < 0.05$), consistent with findings reported in highly polluted urban settings (Zheng et al., 2015). The DLNM analysis identified a stronger non-linear effect peaking at lag 2, while the DLM cumulative estimate indicated an approximately 0.8% increase over 0–5 days. The consistency of findings across multiple modelling approaches strengthens the robustness of the observed association between PM_{10} exposure and asthma-related admissions.

Q2 – Does the effect appear on the same day or 1–3 days later?

The lag-response pattern was generally consistent across models. Significant effects emerged on the same day of exposure (lag 0), peaked at lag 1–2, and diminished to non-significance after lag 3. Both the DLM Almon polynomial and DLNM analyses identified lag 2 as the period of maximum effect. This temporal pattern is biologically plausible, as PM_{10} exposure may induce oxidative stress and neutrophilic airway inflammation that clinically manifests within 24–48 hours, resulting in increased emergency hospital admissions during the following days (Brunekreef and Holgate, 2002; Weinmayr et al., 2009).

Q3 – Does the association persist after controlling for seasonality?

Yes. Seasonal adjustment using Fourier terms in quasi-Poisson and DLM models, as well as penalised splines in GAM analyses, consistently demonstrated significant associations between PM_{10} and asthma admissions. These findings suggest that the observed relationship is not solely attributable to shared winter seasonality. Partial residual analysis additionally demonstrated a significant positive association between PM_{10} concentrations and seasonally adjusted admission residuals ($r = 0.34$, $p < 0.001$), indicating that short-term fluctuations in PM_{10} independently contributed to variations in daily admission counts beyond the general seasonal trend. Temperature and humidity data were unavailable; therefore, direct meteorological adjustment could not be performed, which remains an important limitation of the study. Nevertheless, the consistency of findings across multiple modelling strategies, including Fourier-based models, spline-based GAMs, constrained polynomial DLMs, and DLNM cross-basis analyses, provides convergent evidence supporting an independent pollutant-related association.

Conclusion

This study evaluated the relationship between asthma-related hospitalizations and environmental, demographic, and geographical factors using a daily time-series framework in Iğdır. Asthma admissions demonstrated marked seasonal variation, with higher hospitalization rates observed during winter periods characterized by elevated concentrations of particulate matter and combustion-related air pollutants. Distributed lag analyses identified significant short-term associations between asthma admissions and several pollutants, particularly NO_2 , NO , PM_{10} , $PM_{2.5}$, and NO , while O_3 exhibited an inverse seasonal pattern.

Demographic and geographical analyses further indicated that hospitalization patterns differed according to age, gender, healthcare service utilization, and residential region. Higher admission rates were observed among females, middle-aged individuals, and urban populations, suggesting that both environmental exposure and socio-geographical factors may contribute to asthma-related healthcare utilization.

Overall, the findings suggest that short-term increases in air pollution are associated with increased asthma-related hospital admissions in Iğdır. Although the ecological design and lack of individual-level exposure and meteorological adjustment limit causal interpretation, the consistency of findings across multiple statistical approaches supports the robustness of the observed associations. These results highlight the potential importance of air quality monitoring and public health strategies aimed at reducing pollution-related respiratory health burdens.

Declarations

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Author Contributions: All authors contributed to the study conception and design. The planning, implementation, manuscript writing, and hospital data collection processes were carried out by AA. The planning, implementation, and methodology of the study were contributed by SK. Data analysis and manuscript writing were performed by IP. All authors read and approved the final manuscript.

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Data Availability: The authors do not have permission to share the hospitalization data.

Ethical Approval and Consent to Participate: The hospitalization data used in this study were reviewed and approved by the Iğdır University Ethics Committee (Decision No: 8/6, April 24, 2024). The study was conducted in accordance with the principles of the Declaration of Helsinki and relevant national regulations. As the study was based on anonymized hospital records, individual informed consent was not required.

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Figures

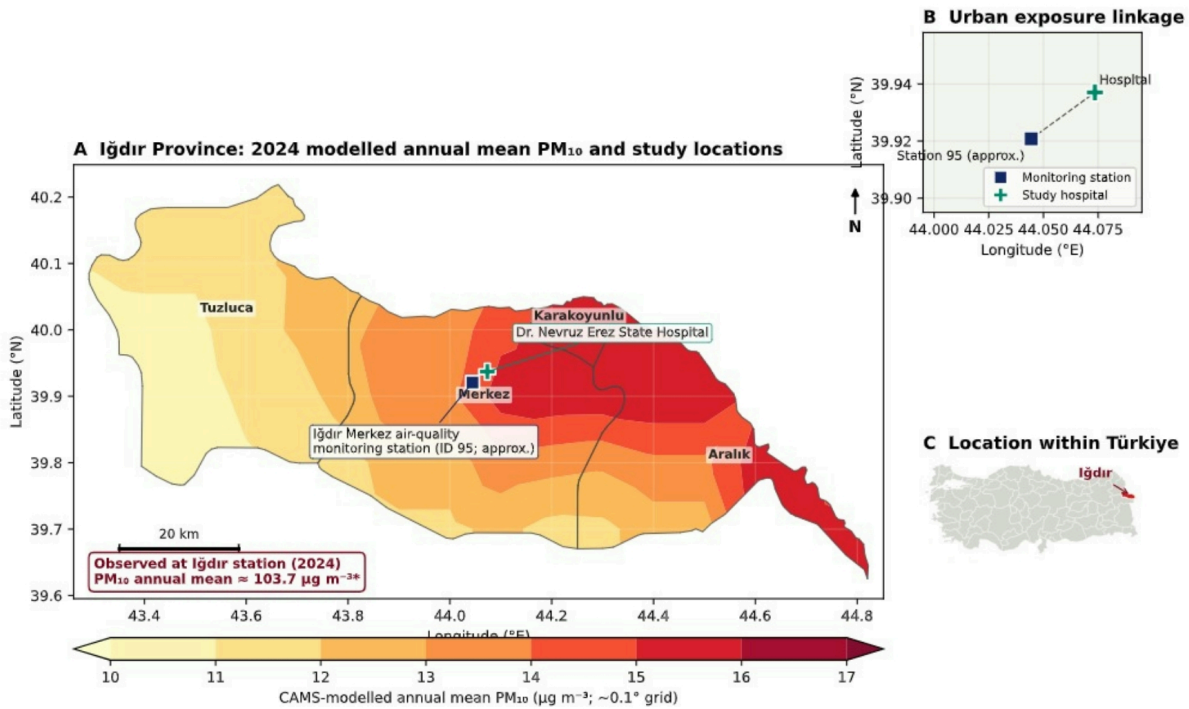


Figure 1

Study-area and regional air-pollution context for Iğdır Province, Türkiye, in 2024. Panel A shows CAMS-modelled annual mean PM₁₀ at approximately 0.1° resolution, district boundaries, the national monitoring station and Dr. Nevruz Erez State Hospital; Panel B enlarges the urban linkage; Panel C locates Iğdır within Türkiye. The mapped CAMS field represents coarse regional background, not patient-level exposure. The monitoring-station symbol is approximate pending operator-verified coordinates. Boundary source: GADM 4.1; pollution source: CAMS European Air Quality Reanalysis; CRS: WGS 84 (EPSG:4326).

Monthly asthma-related hospital encounters, Iğdır, 2024

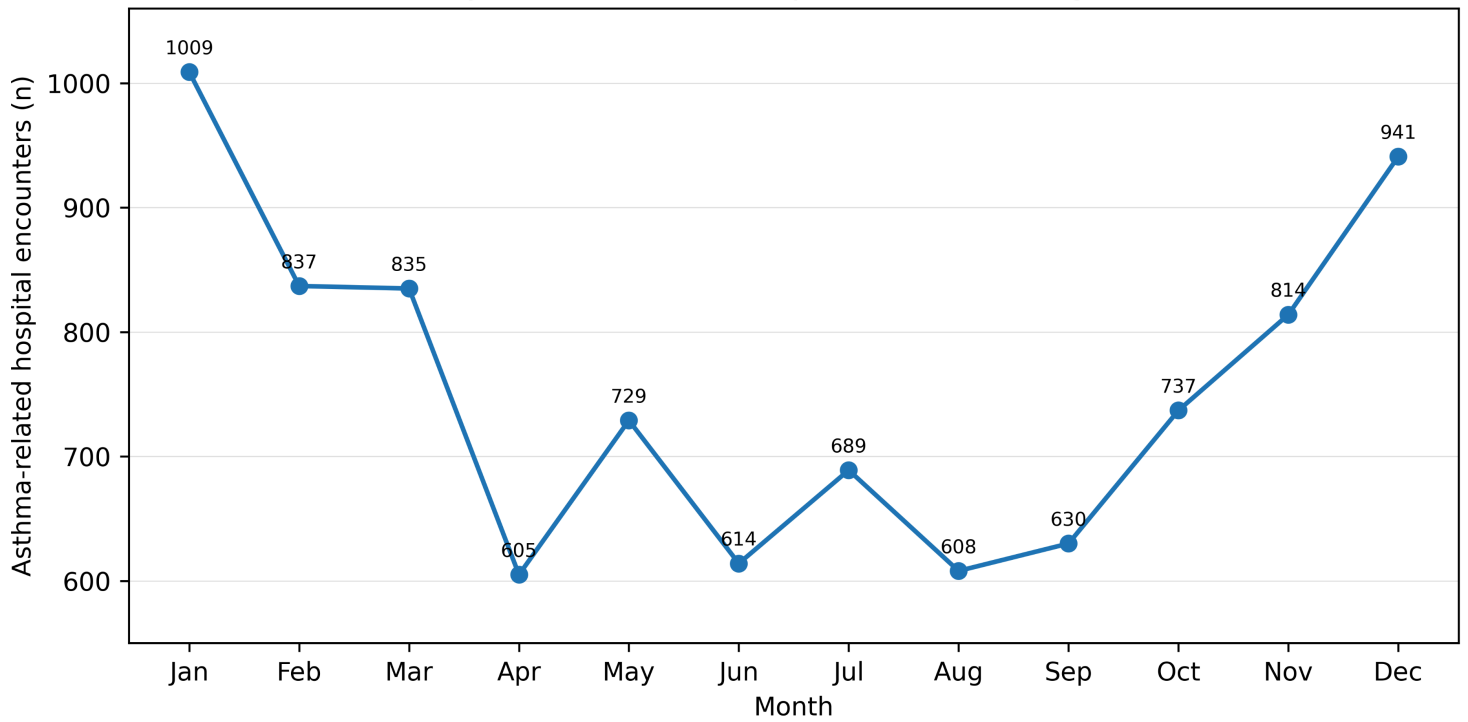


Figure 2

Monthly asthma-related hospital encounter counts in Iğdır during 2024. Values are those reported in Table 1.

Age Distribution

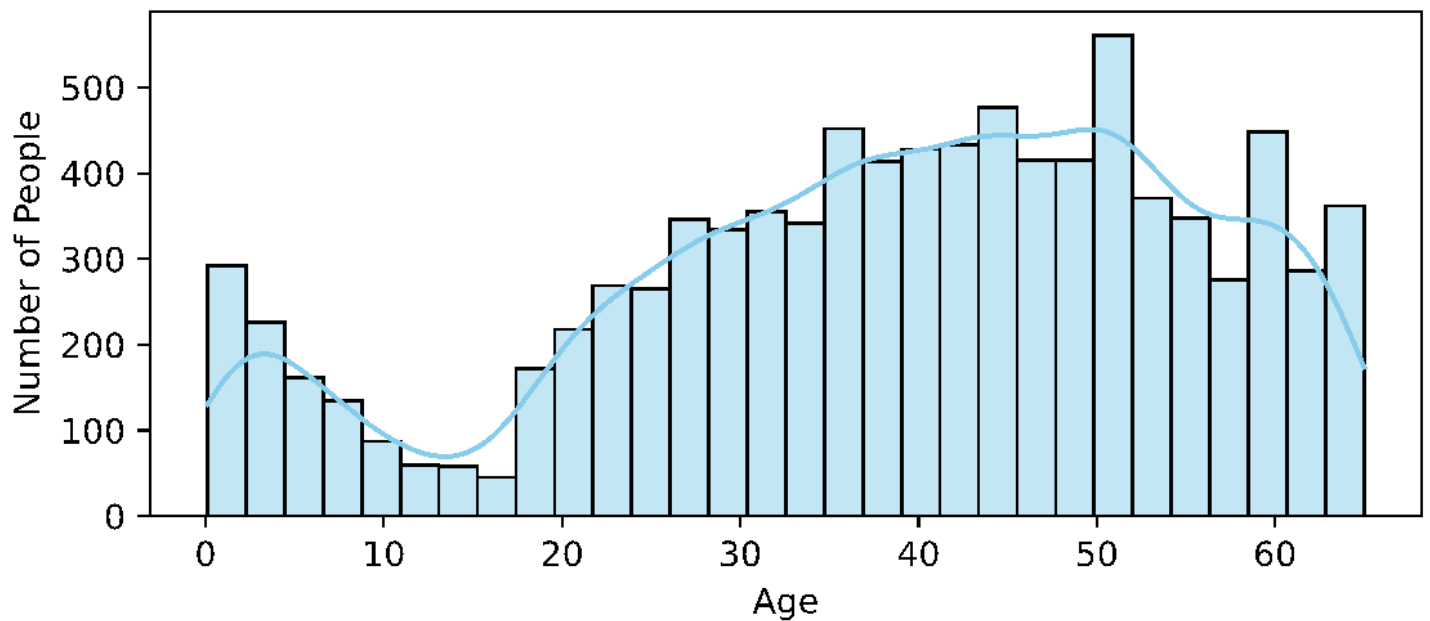


Figure 3

Distribution of Asthma Admissions by Age Group, Iğdır Province 2024

Effect of Gender on Application Count (Violin Plot)

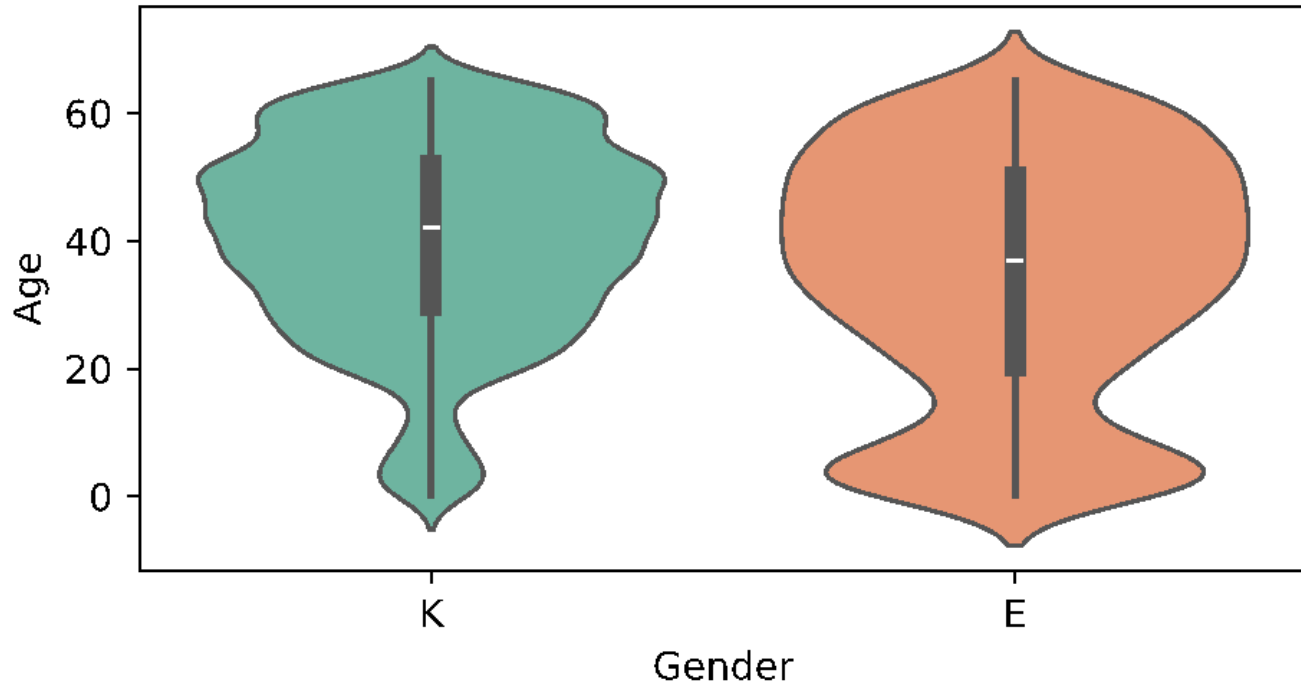


Figure 4

Monthly Asthma Admission Counts by Sex, Iğdır Province 2024

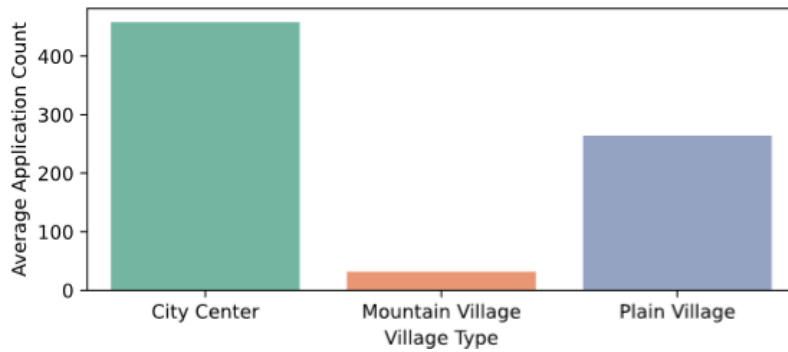


Figure 5

Monthly Asthma Admission Counts by Place of Residence, Iğdır Province 2024