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Toward Sustainable Air Pollution Management in Isfahan: Strategic and Foresight-Oriented Policy Planning for a Major Industrial Metropolis in Iran

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Abstract

This study provides an integrated assessment of air pollution in Isfahan, Iran, by the integration of spatial emission inventory data, meteorology, and monthly AQI distributions for 15 municipal zones. Seasonal spikes in the pollution during winter are determined to be mainly attributed to increased fuel burning and atmospheric stagnation. Source analysis of emissions reveals that mobile sources emit the largest share of the CO and NO□, while stationary sources emit SO_2 and PM concentrations.

Besides descriptive analysis, the research incorporates cost–benefit analysis of the selected mitigation alternatives, including industrial desulfurization, carburetor motorcycle replacement, and retrofitting of the public transport. The most effective but lowest-cost intervention was replacement of carburetor motorcycles, with a benefit–cost ratio of over 1.6. SWOT analysis also identified significant institutional and infrastructural abilities, as well as governance problems and insufficient funds as areas of weakness. The results suggest the need for targeted, multisectoral policies that are both economically and operationally viable. The combined approach presented here enables decision-making in favor of effective and locally implementable air quality interventions.

1. Introduction

Urban air pollution has emerged as one of the most significant 21st-century environmental and public health problems[1–5]. The World Health Organization (WHO) assesses that over 90% of the world's population breathes polluted air with high concentrations of pollutants, particularly in low- and middle-income countries [6]. In Iran, air pollution results in thousands of premature deaths annually and creates huge socio-economic costs for urban populations[7].

Isfahan, the capital city of the central region of Iran, is one of the most industrialized and densely populated cities of Iran. The city suffers from ongoing air pollution caused by a combination of heavy motor traffic, the use of fossil fuels, and the presence of large-scale industrial complexes such as steel, cement, and petrochemical plant factories. Previous studies have indicated that concentrations of principal air pollutants — including nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), and carbon monoxide (CO) — consistently exceed country and international standards in Isfahan [8–12]

Several attempts have been made to measure and quantify air pollution in Isfahan and other major Iranian cities. For example, [13]studied the health impacts of PM_{10} in Isfahan and concluded that long-term exposure significantly increases respiratory and cardiovascular mortality. [10]applied receptor modeling techniques to identify the major sources of $PM_{2.5}$ and highlighted the dominant role of mobile sources. However, most existing studies have been either time-series or chemical analysis without the spatially explicit modeling of pollutant dispersion[14].

The spatial distribution of air pollutants represents a critical but at times de-emphasized dimension of urban air quality management.[15] Geographic Information System (GIS)-informed approaches have proved to be valuable in pollution hotspots mapping, assessing the exposure of the population, and

informing targeted mitigation policy. The integration of emission inventory with dispersion mapping in this regard is a major method of urban environmental planning[16].

Therefore, the objectives of the present study are:

(1) To analyze spatial and temporal distribution of major air pollutants in Isfahan according to AQI and emission inventory;

(2) To calculate and estimate contributions of stationary and mobile sources to ambient pollution levels;

(3) To determine the economic viability of selected measures for reducing pollution by cost–benefit analysis

(4) To examine the institutional and strategic air quality governance environment using a SWOT analysis; and

(5) To develop evidence-based recommendations for cost-effective and integrated air pollution management in Isfahan.

By bringing together empirical evidence with spatial modeling methods, this research fills an important literature gap and offers a scalable framework to other urban regions facing similar environmental challenges.

2. Materials and Methods

2.1 Study Area

Isfahan is a major industrial and urban city in the middle of Iran with a population of more than two million and a semi-arid climate. It experiences marked seasonal variations in air pollution, which can be explained primarily by its bowl-shaped topography, traffic density, and adjacency to huge industrial complexes such as steel mills and refineries[15]. The research focused on the 15 municipal districts of Isfahan with spatial boundaries defined by the 2024 Emission Inventory Project. The base map of Iran was used as a reference with Isfahan province outlined (see Fig. 1)

2.2 Air Quality and Emission Data

Data on air pollutant concentrations were obtained from the Isfahan Department of Environment’s fixed monitoring stations for the year 2024. Four primary pollutants were analyzed:

- Carbon Monoxide (CO)
- Nitrogen Oxides (NO_x)
- Sulfur Dioxide (SO_2)
- Particulate Matter (PM_{10}/$PM_{2.5}$)

Monthly and seasonal AQI maps were used to assess temporal and spatial variations across districts. Additionally, pollutant-specific emission rates were extracted from the emission inventory database, which categorized sources into mobile, stationary, and area-based emissions.

2.3 Meteorological Parameters

Meteorological data were collected from three synoptic stations: Isfahan (central), East Isfahan (airport), and Kaboutarabad. Monthly values for temperature, precipitation, relative humidity, wind speed, and sunshine hours. These variables were used to interpret the atmospheric dynamics influencing pollutant dispersion and accumulation during different seasons.

2.4 Spatial and GIS Analysis

All spatial analyses were conducted using ArcGIS 10.x software. Pollutant concentration maps, emission source overlays, and zoning layers were integrated to identify hotspots and population exposure patterns.

2.5 Cost–Benefit Analysis (CBA)

To assess the economic feasibility of mitigation strategies, a simplified cost–benefit framework was employed. Three major interventions were selected:

(1) installation of SO_2 scrubbers in industrial facilities,

(2) replacement of carbureted motorcycles with cleaner alternatives, and

(3) CNG conversion of public buses.

Cost data were sourced from national transport and energy reports, while benefit estimates were based on avoided health costs using WHO exposure-response functions.

2.6 SWOT Analysis

A structured SWOT (Strengths–Weaknesses–Opportunities–Threats) framework was applied to evaluate the institutional, technical, and policy environment for air quality management in Isfahan. The analysis was informed by national policy documents, municipal reports, stakeholder interviews, and expert judgment

3. Results

The spatial and temporal pattern of air pollution in Isfahan reveals clear seasonal variations and source-dependent trends in the 15 municipal districts of the city. The integration of emission inventory data and Air Quality Index (AQI) maps confirms that pollutant levels were considerably greater during colder months and reduced progressively throughout summer. This is consistent with atmospheric inversion conditions, reduced boundary layer elevations, and increased fuel combustion during winter (Table 1).

Monthly AQI maps show that during January and December, the air quality ranges in most of the districts were in the "Unhealthy for Sensitive Groups" or poorer. Districts such as Rahanān and Kaaveh persistently recorded the poorest air quality, with daily AQI values for $PM_{2.5}$ and NO_2 being frequently exceeded. On the other hand, Bahonar and Farshadi districts were comparatively cleaner throughout the year, the likely reason being lower traffic density and greater green cover(Table 2). As can be observed from Fig. 3, the quality of air was significantly worse during winter months for nearly all districts, most notably Bahman and Dey..

Figure. Monthly Average AQI across Isfahan Districts

Table 1
Monthly Air Quality Status in Isfahan

Month	Clean Days	Good Days	Unhealthy for Sensitive Groups	Unhealthy for All	Notes
Farvardin (Mar–Apr)	0	23	8	0	Rahanan had the worst air (18 bad days)
Ordibehesht (Apr–May)	0	23	8	0	Bahonar best (24 good days)
Khordad (May–Jun)	0	20	11	0	Enqelab worst (19 unhealthy days)
Shahrivar (Aug–Sep)	0	22	8	1	Rahanan had 13 bad days
Mehr (Sep–Oct)	4	26	4	0	Farshadi: 4 clean days; Rahanan worst
Aban (Oct–Nov)	3	21	5	1	Rahanan had 16 bad days
Azar (Nov–Dec)	3	7	12	7	Kaaveh had 15 days unhealthy
Dey (Dec–Jan)	3	10	13	4	Rahanan again worst air quality
Bahman (Jan–Feb)	8	13	6	3	Farshadi: best with 12 clean days

The distribution per pollutant shows that carbon monoxide (CO) and nitrogen oxides (NO□) are released predominantly by mobile sources — namely private cars and carburetor motorcycles. This agrees with emission inventory data, where mobile sources accounted for over 80% of CO and NO□ emissions (Table 3). Meanwhile, sulfur dioxide (SO_2) and particulate matter (PM) were largely attributed to stationary sources, such as industrial combustion processes and fossil-fuel-fired power plants.

A primary result is the disconnect between emission sources and exposure hotspots. While heavy industry is located on the outskirts (e.g., Zob Ahan and refinery), wind direction and topographic trapping consistently transport pollutants to central and southern neighborhoods, which are most densely populated. This presents an environmental justice concern: lower-emission neighborhoods can still experience disproportionate health effects from ambient pollution transfer.

Table 2
Annual sulfur dioxide (SO_2) emissions from major stationary sources in Isfahan

Source Type	Facility Name	Annual SO_2 Emissions (tons/year)
Power Plant	Shahid Montazeri	0.09
Power Plant	Isfahan Islam-Abad Plant	0.07
Petrochemical Refinery	Isfahan Oil Refinery	327.00
Steel Industry	Mobarakeh Steel Company	113.00
Steel Industry	Esfahan Steel Co. (Zob Ahan)	37.74

These findings are also supported by the meteorological analysis of synoptic station data (Tables 5), which shows that during winter months, winds were slower, relative humidity was higher, and atmospheric stability conditions favored pollutant accumulation. Thermal inversions contributed to the trapping of pollutants vertically in the area around ground level.

Studies such as [15] have shown that coupling weather forecasting with air quality modeling has the potential to significantly enhance pollution prediction and control strategies.

At the policy level, this analysis underscores the imperative of differentiated policy by type of pollutant and by district. Since vehicle controls can be most effective in traffic-congested urban centers, industrial controls to limit emissions must be facility-specific to target SO_2 and PM burdens[17–19].

Table 3
Estimated annual emissions of carbon monoxide (CO) by vehicle type in Isfahan

Vehicle Type	Annual CO Emissions (tons/year)
Passenger Vehicles	2,700
Motorcycles	1,450
Diesel Trucks	980
Buses	310

A combined spatial overlay of all four pollutants (NO_2, SO_2, CO, and $PM_{2.5}$) identified Districts 3, 4, and 9 as critical pollution hotspots in Isfahan (Table 4).

Table 4
Contribution of Different Emission Sources to Air Pollution in Isfahan (%)

Pollutant	Mobile Sources	Stationary Fuel Combustion	Industrial Processes	Waste & Evaporation	Total (%)
CO	96.42%	1.83%	0.88%	0.87%	100%
NO□	82.64%	11.58%	3.76%	2.02%	100%
SO_2	13.96%	68.90%	14.33%	2.81%	100%
PM (TSP)	29.55%	50.95%	18.78%	0.72%	100%
VOC	38.04%	15.17%	0.90%	45.89%	100%

Table 5
Monthly Climatic Data in Isfahan City

Month	Avg. Temp (°C)	Max Wind Speed (km/h)	Precipitation (mm)	Rel. Humidity (%)	Sunshine Hours
Farvardin	15.3	38	17.6	32	221
Ordibehesht	21.0	41	3.4	26	297
Khordad	27.2	36	0.0	20	334
Tir	30.7	34	0.0	16	368
Mordad	29.8	32	0.0	17	346
Shahrivar	26.1	31	0.2	21	327
Mehr	20.2	36	0.0	27	291
Aban	13.9	39	2.8	34	228
Azar	8.6	41	5.6	41	190
Dey	4.1	37	9.2	48	162
Bahman	7.3	35	6.1	45	184
Esfand	11.5	33	3.9	36	201

Cost–Benefit Analysis of Air Pollution Reduction Strategies in Isfahan

Controlling air pollution in large cities is not only technically feasible but also economically feasible. To ascertain the effectiveness and cost of three possible interventions to control air pollution in Isfahan, i.e.,

industrial SO_2 filtration, substitution of carburetor motorcycles, and fitting diesel public buses with cleaner fuels, a cost–benefit analysis (CBA) was conducted.

The first policy is the installation of flue gas desulfurization (FGD) machinery in big industrial units such as thermal power plants and steel mills. High upfront capital expense—around USD 4 million per facility—is the price of this action, though it can reduce SO_2 emissions significantly, which are known to produce respiratory illness and acid deposition. Based on conventional emission reduction rates and WHO models of health harm, the cost advantages due to avoided hospitalization, morbidity, and mortality are estimated at more than USD 1.2 million annually per plant. With additional saving on environmental degradation and ecosystem protection, the payback period has been estimated to be less than four years[20–22].

The second strategy is focused on replacing old, carbureted motorbikes with a disproportionate share of mobile-source CO and hydrocarbon emissions. The cost of replacing one unit with electric or new four-stroke motorbikes is around USD 900. For five years of productive life, net gain per motorbike considering the savings of cost in terms of health and emissions is USD 250 or more. If scaled up to 10,000 units (a realistic urban target), the program would be valued at USD 9 million and present social and health returns of over USD 15 million. The derived benefit–cost ratio (BCR) of over 1.6 makes this strategy highly desirable, particularly for high traffic density urban areas with marginalized communities.

The third option addresses public transport emissions through the retrofitting of diesel buses with compressed natural gas (CNG). This offers significant reductions in PM and NO emissions but is economically less attractive. With an estimated cost of approximately USD 12,000 per bus and modest resultant benefits in health terms (~ USD 8,000 per vehicle over five years), the BCR is set at between 0.6 and 0.9. In addition, the viability hinges upon long-term maintenance, fuel costs, and fleet operational rates. The measure thus needs government subsidy or foreign assistance to be economically viable.

Finally, the cost–benefit analysis shows that each of the three measures has the ability to yield reduction in pollution, but that the motorcycle replacement program is the most financially rewarding, followed by industrial SO_2 control. Fleet conversion for the public is important to sustainability in the long term but less financially attractive without targeted subsidies. These findings are a quantitative justification for choosing priorities for interventions for future air quality action plans in Isfahan.

SWOT Analysis of Air Quality Management in Isfahan

This section evaluates the strategic landscape of urban air pollution control in Isfahan using a SWOT (Strengths, Weaknesses, Opportunities, Threats) framework. It aims to support evidence-based planning for sustainable interventions.

Strengths

Item	Description
Established monitoring network	Continuous data collection from fixed and mobile AQI stations enables tracking and trend analysis.
Emission inventory completed	A full-scale, GIS-based emissions inventory provides spatial decision support.
Municipal technical capacity	Isfahan Municipality and Department of Environment have trained staff and active departments in pollution control.
Public awareness campaigns	Seasonal media warnings and school-based educational programs exist, especially in winter months.

Weaknesses

Item	Description
Low enforcement capacity	Weak regulation of industrial emissions and non-compliant mobile sources.
High number of old vehicles	Over 40% of motorcycles are carbureted and lack catalytic converters.
Outdated industrial tech	Steel and refinery sectors use legacy systems without effective SO_2/PM scrubbers.
Fragmented governance	Multiple stakeholders (DoE, municipality, traffic police) with overlapping authority and weak coordination.

Opportunities

Item	Description
Green transport incentives	National EV subsidies and pilot e-bus projects can be expanded.
Private sector participation	Public–private partnerships (PPPs) in air quality solutions (monitoring, mobility).
Smart city integration	Use of IoT sensors and air quality apps can enhance public engagement and real-time alerts.
Access to environmental funds	Opportunities from international donors or Green Climate Fund for pilot interventions.

Threats

Item	Description
Climate change impacts	Higher temperatures and extended droughts worsen dust and secondary pollutant formation.
Urban sprawl without planning	Encroachment of industry near residential zones increases exposure risks.
Resistance from industry lobby	Implementation of stricter emission standards may face opposition from influential industrial actors.
Economic constraints	Limited municipal budgets reduce ability to implement transformative strategies.

The SWOT analysis indicates that while Isfahan possesses foundational tools for air quality management — such as technical capacity and data infrastructure — key barriers such as regulatory enforcement and stakeholder coordination must be addressed. Strategic investments in electrified transport, real-time monitoring, and inter-agency governance could convert latent opportunities into measurable air quality gains.

4. Discussion

4.1. Spatial and Seasonal Variability of Air Pollution

The results of the present study demonstrate substantial spatial and seasonal variability in air quality across Isfahan's 15 municipal districts, with poorer air quality generally observed during the colder months. This pattern is consistent with previous investigations in Isfahan that have identified elevated particulate matter concentrations during cold periods. For example, a study examining $PM_{2.5}$ concentrations between 2014 and 2019 reported higher concentrations during October, November, December, and January, with elevated pollution levels across the northern, northwestern, southern, and central parts of the city. Similarly, Hajizadeh et al[15] documented substantial temporal and spatial variability in traffic-related pollutants in Isfahan, demonstrating the importance of considering both monitoring location and temporal patterns when assessing urban air pollution. These findings collectively support the need for seasonally differentiated air quality management rather than relying exclusively on annual averages.

The deterioration in air quality during winter can plausibly be associated with reduced atmospheric mixing, lower boundary-layer heights, and changes in emissions related to fuel combustion and energy demand. Under stable atmospheric conditions, pollutants emitted from traffic and stationary sources may accumulate near the ground, increasing the likelihood of elevated ambient concentrations. Nevertheless, the magnitude and seasonal direction of these effects may differ among pollutants because their sources, atmospheric lifetimes, and chemical transformation processes are not identical. Consequently, the wintertime deterioration observed in the present study should be interpreted in

conjunction with pollutant-specific concentration data and meteorological observations rather than being attributed to a single mechanism.

Importantly, not all previous findings for Isfahan indicate the same seasonal pattern. Jadidi et al.[23] reported higher $PM_{2.5}$ concentrations during warmer months in their assessment of six monitoring stations in 2016, although their study also identified substantial spatial variation and elevated concentrations in central parts of the city. This difference does not necessarily contradict the present findings. The studies cover different years, monitoring configurations, and analytical approaches, and their conclusions may also depend on whether they examine individual pollutants, $PM_{2.5}$ concentrations, or composite air quality indicators. Seasonal differences in dust resuspension, atmospheric chemistry, and local emission conditions may further contribute to the observed variability. Accordingly, the comparison suggests that air quality management in Isfahan should be based on multi-year, pollutant-specific analysis instead of assuming that all pollutants consistently reach their highest concentrations in the same season.

The spatial differences observed among municipal districts further indicate that citywide air quality indicators may conceal localized pollution burdens. Identifying districts with comparatively poor air quality can help authorities prioritize monitoring, traffic management, and public health communication. However, district-level differences should be interpreted in relation to the monitoring coverage and the spatial resolution of the underlying data. In particular, identifying a pollution hotspot does not, by itself, establish which source caused the observed concentrations or quantify the exposure experienced by individual residents.

4.2. Emission Sources and Implications for Urban Exposure

The emission inventory in the present study indicates that mobile sources are the predominant contributors to CO and NO□ emissions, accounting for 96.42% and 82.64% of the respective totals. In contrast, stationary fuel combustion accounts for 68.90% of estimated SO_2 emissions and 50.95% of total suspended particulate matter (TSP) emissions. These findings highlight the pollutant-specific nature of emission sources and support the use of differentiated control strategies. Measures targeting road traffic are particularly relevant to pollutants dominated by mobile-source emissions, whereas industrial combustion and other stationary sources require interventions tailored to their fuel use, emission characteristics, and control technologies.

The importance of traffic-related pollution in Isfahan is supported by previous research. Hajizadeh et al. [15] investigated the spatial and temporal patterns of traffic-related pollutants and their potential health effects, while Soleimani et al. [18] estimated the economic burden of air pollution attributable to motor vehicles in the city. The latter study estimated annual economic costs averaging approximately USD 51.7 million using the value-of-a-statistical-life approach and USD 11.5 million using the value-of-life-years approach. Although these estimates address the economic consequences of traffic-related pollution rather than the emission shares reported in the present study, they provide complementary

evidence that vehicle emissions constitute an important target for urban air quality policy. Taken together, these studies support prioritizing transport-related interventions while recognizing that the most appropriate intervention depends on the pollutant, the affected population, and the expected reduction in ambient exposure.

The substantial contribution of stationary sources to SO_2 and TSP emissions also emphasizes the importance of industrial emission management. A transport-focused strategy alone would not adequately address pollutants for which industrial combustion and industrial processes account for substantial emission shares. Facility-specific emission controls, improved combustion efficiency, fuel-quality improvements, and effective particulate and sulfur-control technologies may therefore be necessary alongside vehicle-related measures. The relative priority of these interventions should be determined using the magnitude of emissions, the achievable reduction, implementation costs, and the resulting changes in ambient concentrations and health risks.

A further implication concerns the relationship between emission sources and the spatial distribution of air pollution. The present study identifies spatial differences in air quality and reports major industrial sources around the wider urban area. Nevertheless, an emission inventory and a spatial overlay cannot independently demonstrate that emissions from a particular industrial facility are transported to a specific residential district. Establishing that relationship requires additional evidence, such as dispersion modelling, source apportionment, or analysis of wind direction and pollutant concentrations over time. The spatial patterns observed here therefore provide a basis for identifying areas requiring further investigation and for improving geographically targeted monitoring. Such an approach would help distinguish areas with high emissions from areas experiencing high ambient concentrations and population exposure.

4.3. Economic Prioritization of Air Pollution Control Measures

The cost–benefit analysis in the present study extends the assessment beyond identifying emission sources by comparing three potential interventions: industrial SO_2 control, replacement of carbureted motorcycles, and conversion of public buses to compressed natural gas. According to the study's estimates, motorcycle replacement offers the most favorable benefit–cost ratio, exceeding 1.6, whereas the economic performance of bus conversion is less favorable under the assumptions applied. This comparison is important because the intervention with the greatest potential emission reduction is not necessarily the one that delivers the greatest economic return per unit of expenditure. Economic prioritization requires consideration of implementation costs alongside avoided health impacts and other benefits.

These findings are consistent with the broader evidence that the economic justification for air pollution control depends on the intervention, pollutant, exposure–response relationship, and valuation method. A systematic review of 104 studies evaluating the costs and health and economic impacts of air pollution control strategies found that approximately 70% reported benefits exceeding implementation costs. The

review also emphasized the importance of accounting for uncertainty, equity, and the range of benefits included in economic evaluations. This evidence supports the use of cost–benefit analysis as a decision-support tool, while cautioning against treating benefit–cost ratios as universal values transferable between cities without considering local conditions.

Research in Isfahan also demonstrates the substantial economic implications of traffic-related air pollution. Soleimani et al. [18] quantified the economic costs associated with vehicle-related pollution, while Amoushahi et al.[8] estimated the health and economic burden associated with ambient $PM_{2.5}$ exposure. Although these studies do not evaluate precisely the same intervention scenarios as the present analysis, they provide local evidence that the health consequences of air pollution have an economic dimension relevant to policy decisions. The present study contributes to this literature by comparing selected mitigation options rather than estimating the overall burden alone.

The relative attractiveness of motorcycle replacement in the present analysis should nevertheless be interpreted within the boundaries of the evaluated scenarios. Its estimated benefit–cost ratio reflects the intervention costs, assumed emission reductions, valuation of avoided health effects, and time horizon used in the analysis. Differences in vehicle age, baseline emissions, replacement technology, utilization, and the pollutants included in the health assessment could alter the resulting ratio. The estimates should therefore be understood as decision-support evidence for the scenarios assessed, rather than as a universal ranking of transport interventions. Similarly, the lower estimated benefit–cost ratio for bus conversion does not necessarily imply that public transport modernization lacks environmental or social value; its overall benefits may extend beyond those captured by the economic indicators included in the analysis.

From a policy perspective, the results favor evaluating interventions through a common and transparent economic framework. Decision-makers should compare the expected reductions in emissions and health burdens, capital and operating costs, implementation feasibility, and distribution of benefits across population groups. Where the underlying assumptions and cost categories are comparable, this framework can help identify measures that offer favorable economic returns while ensuring that interventions with important health or environmental benefits are not excluded solely because their monetized benefits are lower over a limited evaluation period.

4.4. Governance Challenges and Policy Implications

The SWOT assessment identifies institutional coordination, regulatory enforcement, technical capacity, financing, and opportunities for cleaner transport as relevant considerations for air quality management in Isfahan. These factors are consistent with the broader literature, which emphasizes that effective air pollution control requires more than identifying emission sources or selecting technically feasible interventions. Implementation depends on the capacity of responsible institutions, coordination among transport and environmental authorities, the availability of financial resources, and the continuity of monitoring and enforcement.

The implications of the present findings are particularly relevant because the dominant sources differ by pollutant. A single citywide intervention is unlikely to address the full range of emission sources identified in the inventory. Transport policies should therefore be coordinated with industrial emission controls and seasonal management measures. Spatially targeted interventions may improve the efficiency of resource allocation, provided that the prioritization of districts is supported by sufficiently resolved and representative air quality data. Likewise, winter response measures should be informed by meteorological conditions and pollutant-specific observations rather than by season alone.

The SWOT findings also highlight the importance of translating technical assessments into implementable policy. Monitoring networks and emission inventories can support priority setting, but their value depends on regular data updating, public accessibility, and the use of results in enforcement and planning decisions. Coordination between environmental authorities, municipalities, traffic-management agencies, and industrial operators could improve the consistency of measures and reduce the risk of fragmented implementation. Public communication is also important, particularly during high-pollution episodes, when timely and accessible information can help vulnerable groups make informed decisions.

The present study combines spatial air quality assessment, emission inventory analysis, economic evaluation, and strategic assessment within a single decision-support framework. Its main contribution is therefore not that any one method is entirely new, but that the results of several complementary analyses are brought together to inform locally relevant management priorities. The findings suggest that air quality planning in Isfahan should integrate pollutant-specific source control, spatially informed monitoring, seasonal response planning, and transparent economic evaluation. Further work combining multi-year monitoring data with dispersion modelling and more detailed exposure assessment would strengthen the evidence base for evaluating how particular interventions may improve air quality in specific districts.

Overall, the results support an integrated approach to urban air pollution management in which interventions are selected according to the pollutant being addressed, the contribution of relevant sources, the spatial distribution of ambient pollution, and the economic and institutional conditions for implementation. This approach can help Isfahan move beyond generalized pollution-control measures toward a more targeted and evidence-informed strategy.

4. Conclusion

This study demonstrated that the air pollution pattern in Isfahan is characterized both by seasonal meteorological conditions as well as by unequal spatial distribution of the sources of emissions. Even though mobile sources are big emitters of CO and NO□ in the city center, huge industrial sources at the periphery remain big sources of SO_2 as well as PM load.

To support policymaking based on evidence, the research had a cost–benefit analysis of three emission-reducing strategies. The most economic among these was found to be the replacement of aged

motorcycles, then industrial SO_2 filtration. While public transport retrofitting had limited economic value, it is a valuable long-term investment in health and equity.

Besides, a SWOT analysis revealed significant strengths of already available monitoring infrastructure and trained technical personnel. Institutional fragmentation, enforcement limits, and budget constraints are significant challenges. The presence of latent opportunities — green transport incentives, international climate funds, and smart city integration — provides a platform for policy innovation.

In conclusion, a successful air quality strategy in Isfahan will have to be balanced: technologically sound, economically effective, and institutionally integrated. This study offers a framework that bridges data-driven diagnostics and strategic planning tools, to enable both short-term response and long-term environmental management.

5. Policy Recommendations

Based on the findings of this study, the following policy recommendations are proposed:

1. Localized Emission Controls

Implement Low Emission Zones (LEZ) in districts with the highest levels of NO_2 and CO, especially during peak traffic hours. Promote the use of electric vehicles and enforce stricter emission standards for taxis and motorcycles.

2. Industrial Regulation and Relocation

Introduce emissions caps for SO_2 and $PM_{2.5}$ in major industrial facilities, particularly in Districts 7 and 9. Evaluate long-term feasibility of relocating or modernizing heavy industries located within close proximity to residential zones.

3. Seasonal Pollution Management

Enact seasonal pollution control strategies during winter months, such as limiting industrial output on high-pollution days and incentivizing work-from-home policies to reduce traffic volume during inversion events.

4. Real-Time Monitoring and Public Access

Expand the air quality monitoring network and ensure real-time public access to pollution data via online platforms and mobile applications.

5. Integrated Urban Planning

Consider spatial pollution patterns in future land use and transportation planning. Avoid new residential developments in high-exposure zones and prioritize green buffers around industrial

complexes.

6. Health Risk Communication

Increase awareness through public health campaigns about the health risks of air pollution, particularly for vulnerable populations such as children, the elderly, and individuals with respiratory conditions.

These recommendations are intended to guide policymakers in designing evidence-based, geographically-informed interventions that improve air quality and public health in Isfahan and similar urban environments.

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Figures

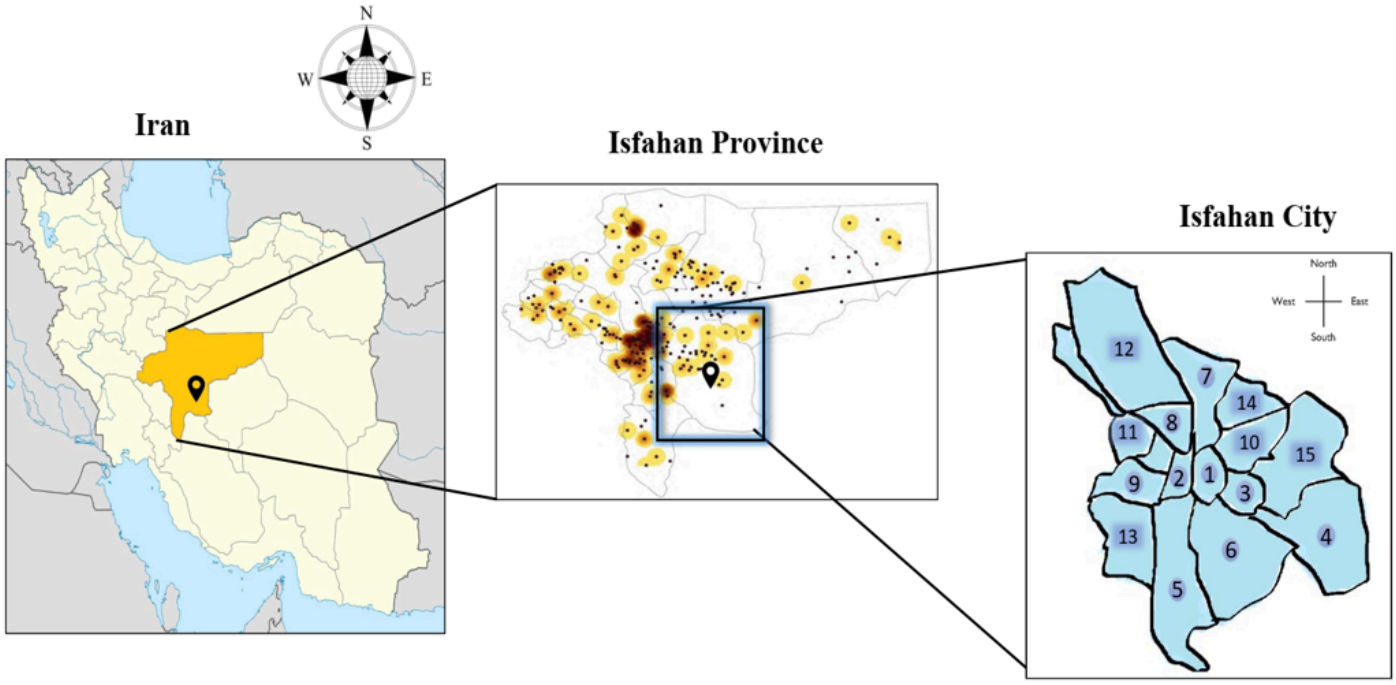


Figure 1

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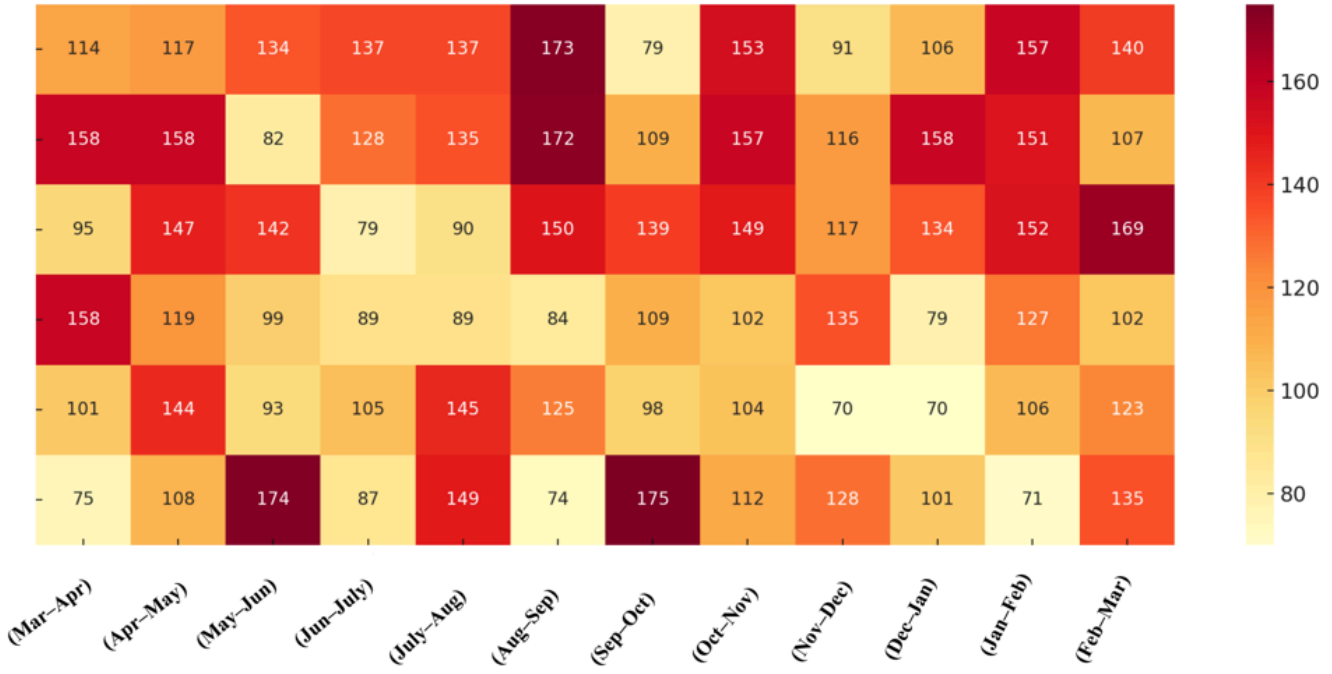


Figure 2

Monthly Average AQI across Isfahan Districts

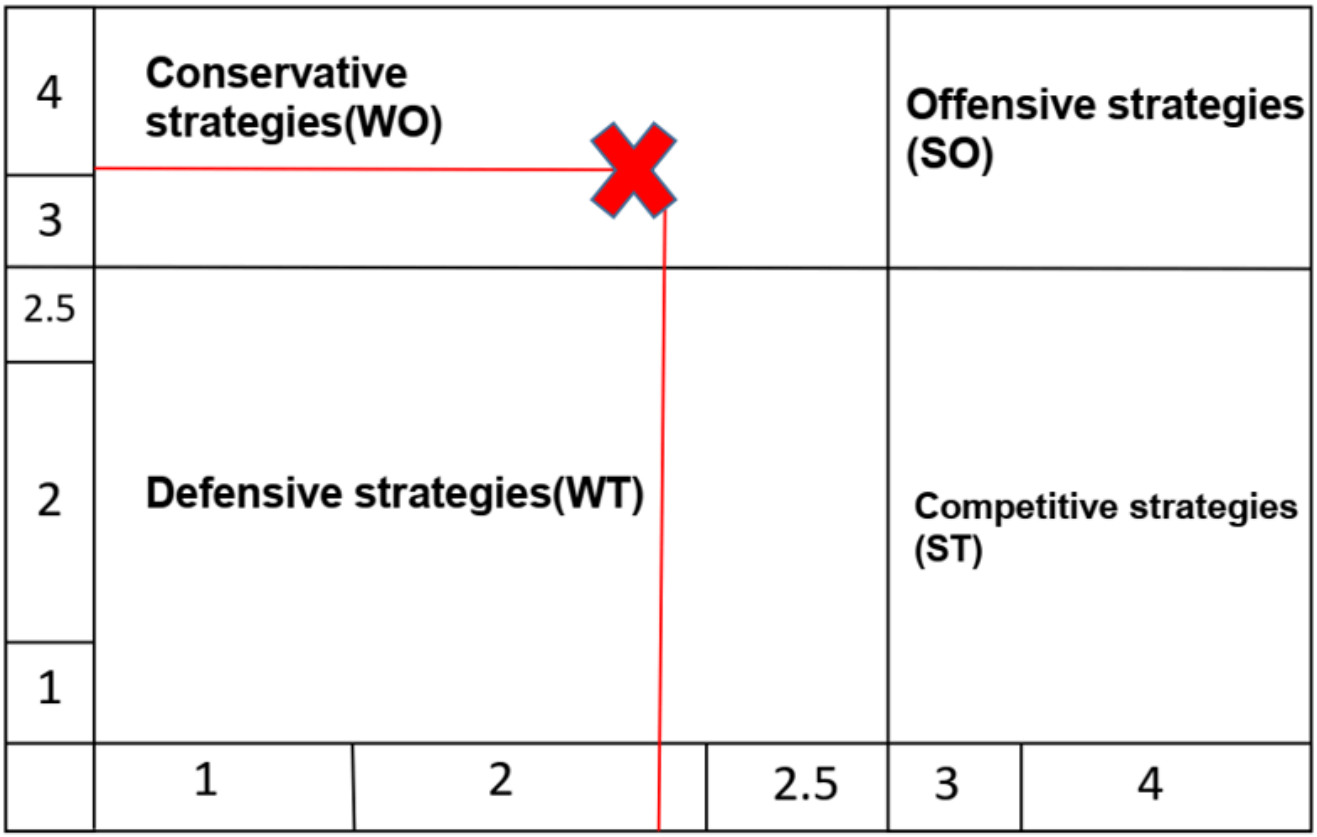


Figure 3

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