Journal of Air Pollution and Health (Spring 2022); 7(2): 121-130

Original Article

Available online at http://japh.tums.ac.ir

Impacts of subway development on air pollution and vegetation in Tabriz and Shiraz, Iran

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ARTICLE INFORMATION

Article Chronology:
Received 27 February 2022
Revised 27 April 2022
Accepted 25 May 2022
Published 29 June 2022

Keywords:
Air pollution; Subway; Vegetation ; Tabriz; Shiraz

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ABSTRACT

Introduction: Presently, air pollution is viewed as a critical environmental challenge that has deleterious effects on human health and ecosystems. The subway system is extensively developed in numerous countries with the objective of minimizing traffic congestion and pollutant emissions. The aim of the present study is to explore the impact of metro activities on air pollution and, subsequently, urban vegetation inside the two metropolises of Tabriz and Shiraz in comparison to prior years.

Materials and methods: To assess air quality before and after the establishment of the metro, we collected average data for Particulate Matters less than 2.5 µm ($PM_{2.5}$), Particulate Matters less than 10 µm (PM_{10}), SO_2, NO_2, O_3, and CO, as well as the Air Quality Index (AQI), retrieved from monitoring stations in Tabriz and Shiraz between 2014 and 2019. We used the average of the Normalized Difference Vegetation Index (NDVI) calculated by the Landsat 8 satellite in the second phase in order to numerically determine the status of urban vegetation across two timeframes.

Results: Preliminary evidence revealed that the average concentration of pollutants in Tabriz, excluding NO_2, fell after the launch of the metro system in 2016. Simultaneously, several pollutants, including O_3, NO_2, and $PM_{2.5}$, and consequently the AQI, increased following the subway's establishment in Shiraz in 2017. Moreover, it was observed that decreasing emissions in Tabriz amplified vegetation, whereas reducing air quality in Shiraz lowered the NDVI values.

Conclusion: Although it appears that the metro's operation improved environmental conditions in Tabriz, a similar outcome was not evident in Shiraz. Therefore, it is suggested that future studies consider meteorological variables whenever addressing the metro's efficiency.

Introduction

As a result of increased economic growth and urbanization, air pollution has already become a major environmental concern [1]. Any material that is discharged into the atmosphere and causes damage to public health or ecosystems is characterized as a pollutant [2]. The repercussions of air pollution include cardiovascular disease, neuropsychiatric disorders, dermatological

Please cite this article as: Kaviani Rad A, Naghipour A. Impacts of subway development on air pollution and vegetation in Tabriz and Shiraz, Iran. Journal of Air Pollution and Health.2022;7(2): 121-130.

illnesses, and cancers [3]. Additionally, polluted air has a profound influence on animals and may lead to physiological changes in plants, resulting in a reduction in growth and yield. This crisis has the potential to inflict significant damage on emerging economies. Iran ranks 23rd in terms of global air pollution and faces a number of environmental challenges [4]. It has adopted a set of laws to combat air pollution, especially in urban zones. The Iranian government adopted a strategy to address air quality in Tehran, the capital of the country, in 2000 [5]. However, the program has not attained the expected outcome, and air pollution continues to have a negative impact on public health. According to a study, when CO levels of pollution rose, the frequency of hospitalized patients in Tehran increased [6]. Similarly, PM_{10} was a remarkable factor in driving the number of asthma patients hospitalized in Shiraz hospitals [7]. In Shiraz, there was a statistically significant relationship between Coronary Artery Disease (CAD) and NO_2, CO, and Particulate Matters less than 10 µm (PM_{10}) [8]. It was revealed that when $PM_{2.5}$ and PM_{10} concentrations in Mashhad were enhanced by 10 µg/m^3, the relative rates of mortality increased by 0.4% and 0.3%, respectively (95% confidence interval) [9]. Another study found that increasing $PM_{2.5}$ and PM_{10} levels in Iran increased hospitalizations for cardiovascular and respiratory disorders by 0.7% (95% CI, 0.6%-0.9%) [10].

Considering exhaust emissions are a major source of air pollution [1], strategies have been undertaken to restrict automobile activity. In some cities in China, it has been revealed that automobile purchase limitation rules have substantially lowered the increase in average PM_{10} levels [11]. Along with implementing restrictive traffic laws, it is necessary to consider the development of public transport services [1]. Environmental problems may be solved by measures such as modernizing the public transit system [12]. The metro is one of the most technologically advanced vehicles in the network, utilized in a wide variety of countries. The global length of subway lines reached 16,419 km in 2020, providing an effective solution to challenges like heavy traffic [13]. Urban metro transportation may significantly contribute to air pollution reduction and play a key role in promoting sustainable urban development [2, 14]. From 2008 to 2016, an investigation in Beijing, China, demonstrated that constructing subway lines might improve air quality by approximately 2% [15]. Another research showed that the development of a metro system in Nanjing, China, reduced $PM_{2.5}$ and CO levels in regions close to the network by 3.39%, resulting in the prevention of of between 300214 and 443498 people from premature deaths in 2014-2018 [16]. According to Chinese researchers, intercity trains in China reduced average CO emissions on nearby roads and highways by 4.3% between 2015 and 2016 [17]. Between 2013 and 2018, an air quality assessment in 29 Chinese cities recognized that the addition of new subway stations decreased the average $PM_{2.5}$ level by an average of 18 µg/m^3 [18]. Furthermore, it has been reported that switching taxicabs to the subway system would assist in a long-term reduction in air pollution [19].

However, one study concluded that although the metro system's operation may actually reduce CO, it has no direct influence on concentrations of $PM_{2.5}$ [20]. Although CO concentrations decreased in areas near the subway in the first year after it launched in Changsha, China, there was no evidence that the metro had an impact on

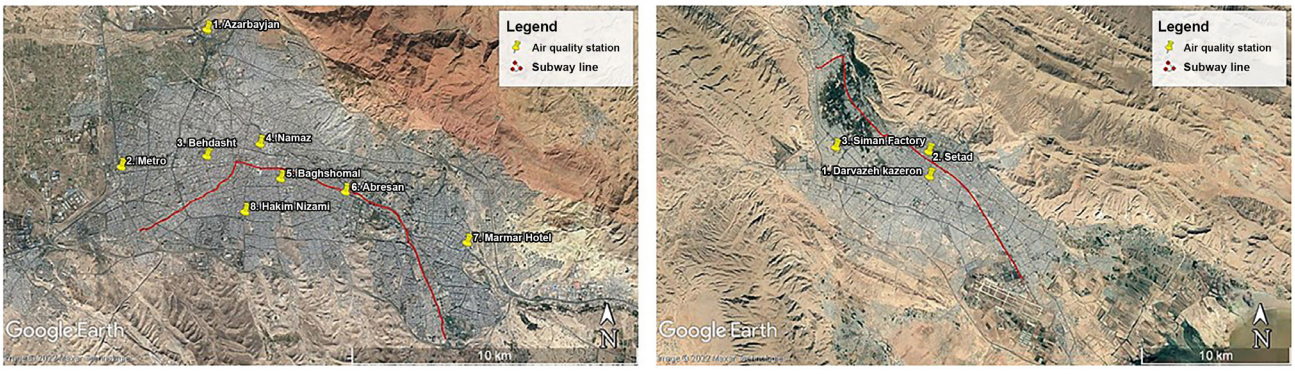
PM and O_3 drops [21]. Though the installation of London's new public transport system lowered NO_2 and O_3 concentrations by 63% and 29%, respectively, at some monitoring sites, it was demonstrated that these reductions were minimal all across the city. Public transportation by itself was inefficient in improving the air quality [22]. In addition, it was found that developing installed public transit networks is practically unattainable to ameliorate air quality in metropolitan cities across the United States [23]. Accordingly, given the conflicting findings, the question of whether an investment in the subway is successful at mitigating air pollution emerges. The metro systems in Tabriz and Shiraz were officially launched in 2016 and 2017, respectively, and since no study has been carried out on the impacts of subway operation on air pollution and urban vegetative cover in Tabriz and Shiraz, this study explores the metro's efficiency in reducing air pollution and urban vegetation in these two cities in 2014–2019 and 2015–2019.

Materials and methods

Case study

Tabriz, located at 38° 4' N and 46° 25' E, has an area of about 324 km² and is situated between 1350 and 1550 meters above sea level. Tabriz is the most populated city in northern Iran, with a population of 1,559,000 people. Besides that, Tabriz is a significant industrial hub, predominantly in equipment and machinery companies. As a result, this city is known as a favorable location for air pollutants accumulation (Fig. 1a).

Shiraz, situated at 29° 36' N and 52° 33' E and covering an area of around 217 km², is located at an elevation of 1486 meters above sea level in the hilly Zagros region of Fars province (Fig. 1b). Although there are traffic congestion issues in this city, favorable weather makes it an attractive option for tourists. Economically, Shiraz is highly dependent on industry and agriculture. However, in 2019, there were only 16 days of extreme air pollution.



(a) (b)

Fig. 1. Locations of the air pollutions sensors in the cities

Data

The Iranian air quality monitoring system collects data on $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO daily at 11 a.m. Moreover, the system gives an Air Pollution Index (AQI) based on the highest level of a contaminant that has been recorded. The AQI value rises in direct proportion to the quantity of air pollutants. As a baseline, this analysis used the average data from all sensors in Tabriz (January 2014–December 2019) and Shiraz (January 2015–December 2019). Tabriz has eight stations, and Shiraz has three (Fig. 1).

The Normalized Difference Vegetation Index (NDVI) is a well-known and extensively applied indicator for statistically quantifying vegetation and assessing plant health. It is calculated using the process by which a plant reflects light at particular wavelengths. For photosynthesis, the chlorophyll inside the leaf absorbs radiant energy (wavelengths 400–700 nm). Various wavelengths of visible light absorbed and reflected by satellite sensors are used in remote sensing operations. Satellite software automatically converts input observation data to the NDVI value using a formula. The NDVI scale ranges from -1 to 1, comprising values close to -1 for water, rocky areas, sand, and snow. Shrubs, grasses, or aged plants are between 0.2 and 0.5, and dense vegetation cover during peak growth periods is responsible for the 0.6-0.9 value. The Landsat 8 L1 satellite database was used to retrieve average NDVI data for the period 2014–2019 (available at https://apps.sentinel-hub.com/eo-browser).

Results and discussion

According to preliminary findings from the Tabriz research, CO pollutants decreased in 2014–2016 but increased significantly in 2017–2019. At the same time, the average CO level in 2019 was lower than it was in 2014 and 2015. The average O_3 concentration reached 22 ppm in 2019, after a relatively stable rise between 2016 and 2018. NO_2 showed a significant drop pattern from 2017 to 2019, after an increasing trend from 2014 to 2016. From 2014 to 2019, SO_2 had a substantially declining trend. PM_{10} levels decreased significantly during this survey period. However, $PM_{2.5}$ levels decreased only slightly. Consequently, the AQI showed an overall decreasing trend (Fig. 2). Also, according to Table 1, the mean of all pollutants except NO_2 decreased between 2017 and 2019 (following the metro's launch) compared to 2014 to 2016 (prior to the metro's establishment), which is probably attributable to the subway's effectiveness in lowering pollution levels.

According to insights gained from the Shiraz survey, CO pollutants were reduced in 2015–2016 while they remained relatively unchanged in 2017–2018. However, the average CO level was significantly lower in 2019 than in previous years. O_3 and NO_2 demonstrated a highly dramatic rise in their mean values. Simultaneously, SO_2 levels have been declining during 2015-2016. PM_{10} levels decreased during the study period, whereas $PM_{2.5}$ levels rose dramatically. Furthermore, the AQI showed an upward trend (Fig. 3). As shown in Table 1, only the average of CO, SO_2, and PM_{10} decreased between 2017 and 2019 (following the subway's launch) and 2014–2016 (previous to the metro's establishment), demonstrating that the metro has not been effective in alleviating air pollution in Shiraz.

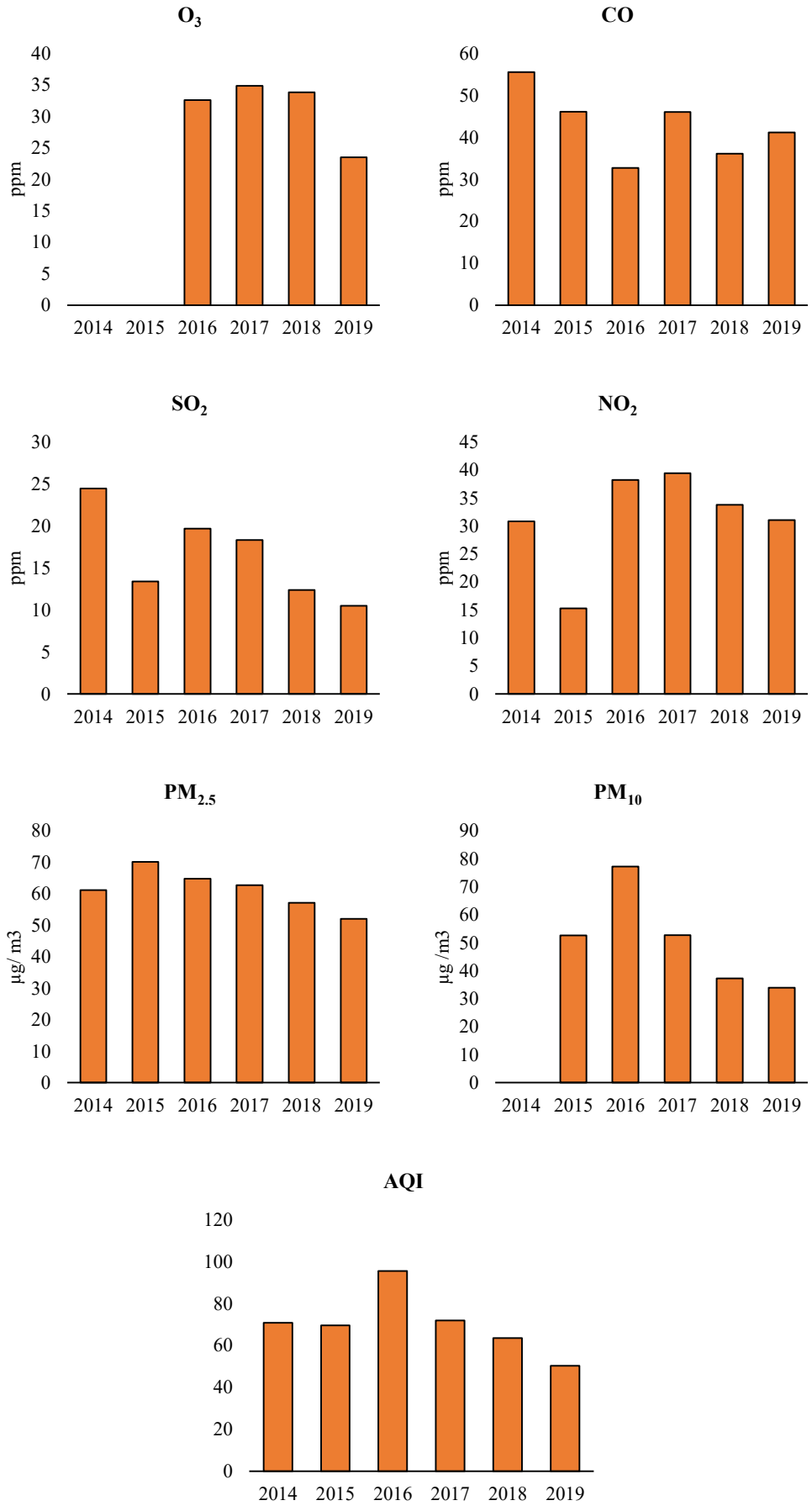


Fig. 2. Changes in air pollutants in Tabriz during 2014-2019

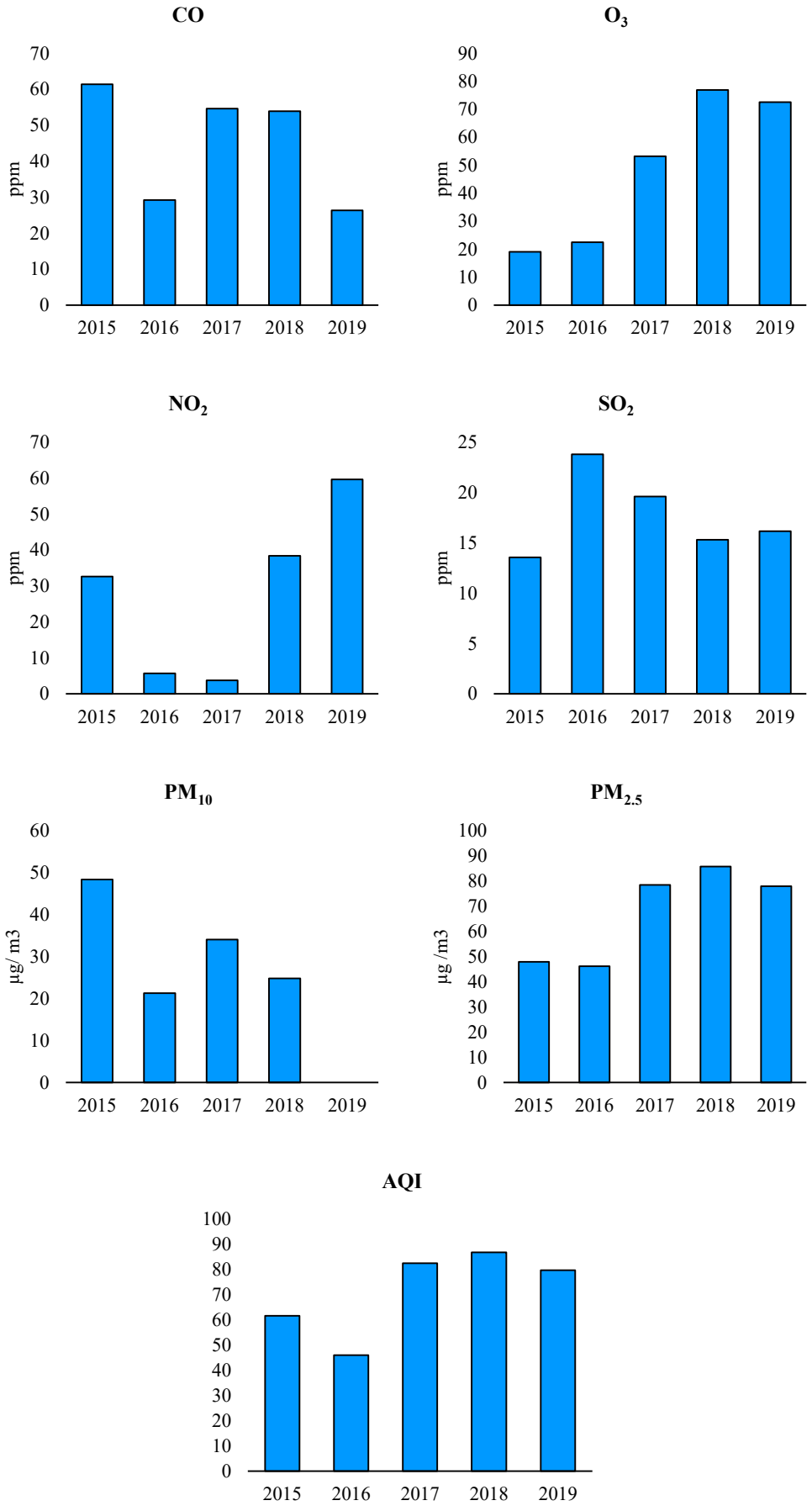


Fig. 3. Changes in air pollutants in Shiraz during 2015-2019

Table 1. Comparison of pollutant emissions before and after the subway's establishment

Tabriz							
Period	**AQI**	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**NO_2**	**O_3**	**CO**
2014-2016	78.54	65.33	64.88	19.18	28.1	32.57	44.77
2017-2019	61.84	57.24	41.26	13.74	34.74	30.70	41.09
Change (%)	-21.27	-12.39	-36.41	-28.37	+23.62	-5.75	-8.22
Shiraz							
Period	**AQI**	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**NO_2**	**O_3**	**CO**
2015-2016	53.87	46.99	34.82	18.65	19.11	20.79	45.29
2017-2019	83.07	80.69	29.40	17.00	33.9	67.52	44.95
Change (%)	+54.20	+71.71	-15.57	-8.85	+77.39	+324	-0.76

The results of the NDVI calculation for the period 2017–2019 (value=0.061127) compared to the time prior to the metro's operation (value=0.059642) revealed that metro activity in Tabriz led to a 2.5% growth in urban vegetation, which is probably related to improved air quality. This assessment in Shiraz indicated that the NDVI declined by approximately 46% between 2017 and 2019 (value=0.082251) and the time before the subway's opening (value=0.151839), which might be attributed to increasing pollution levels in the timeframe after the subway's operation. Potentially, a variety of factors may have an impact on air quality and, subsequently, the environment. In this context, it was reported that the emergence of the COVID-19 pandemic in 2020 changed the emission pattern of air pollutants in most Iranian cities [24, 25]. Additionally, dynamic environmental parameters such as temperature, relative humidity, wind speed, and air pressure have a direct effect on the accumulation of pollutants, either lowering or increasing them. Reducing air pollution consists of the following components: (i) developing devices that use less carbon fuels; (ii) traffic management and promoting the use of public transport services; and (iii) upgrading rail transportation infrastructure [26]. All of the above strategies must be addressed in order to combat air pollution, which is a worldwide concern that contributes to global warming [27].

Conclusion

Air pollution is increasingly known as one of the significant damaging environmental repercussions of urbanization and industrialization in recent decades, with the power to hurt public health and ecosystems. Governments have adopted strategies to mitigate air pollution in urban areas, including

lowering fossil fuel usage and developing the subway system. Iran's rail transport services have tremendously increased in recent years, as five of the country's metropolises already have urban metro networks. Numerous empirical studies conducted worldwide have explored the short- and long-term effects of subway activities on air pollution, so this investigation attempted to demonstrate this consequence through monitoring pollutant emissions in Tabriz and Shiraz in 2014–2019 and 2015–2019. The evidence revealed that the average PM, SO_2, O_3, and CO levels in Tabriz were reduced after the launch of the metro system in 2016, highlighting the metro's effectiveness in improving the quality of air. In Shiraz, on the other hand, the AQI increased by approximately 54% after the start of metro operation in 2017.

Moreover, the NDVI index calculation indicated a 2.5% growth in vegetation in Tabriz and a 46% loss in NDVI in Shiraz, which is probably attributable to the cities' corresponding increases and decreases in air quality. Despite the same conclusions as previous studies on the effects of the subway on air pollution, this study cannot prove such impacts in Tabriz and Shiraz since air quality is affected by a variety of factors. As a result, the study was carried out purely on the basis of available evidence. Considering that a combination of environmental factors influences the status of urban vegetation and the emission of air pollutants, it is recommended that future studies consider statistics on traffic and manufactory greenhouse gas emissions, as well as meteorological variables such as temperature, relative humidity, wind speed, wind direction, air pressure, and solar radiation.

Financial supports

The current study received no external funding.

Competing interests

The authors declare that they have no conflicting interests.

Acknowledgements

The authors would like to express their respect and appreciation to Shiraz University and Kermanshah University of Medical Sciences for providing research facilities.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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