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# Forecasting and Seasonal Investigation of $PM_{10}$ Concentration Trend: a Time Series and Trend Analysis Study in Tehran

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## ABSTRACT

In this study, a multitude of statistical tools were used to examine PM10 concentration trends and their seasonal behavior from 2015 to 2021 in Tehran. The results of the integrated analysis have led to a better understanding of current PM10 trends which may be useful for future management policies. The Kruskal – Wallis test indicated the significant impact of atmospheric phenomena on the seasonal fluctuations of $PM_{10}$. The seasonal decomposition of PM10 time series was conducted for better analysis of trends and seasonal oscillations. The seasonal Mann-Kendall test illustrated the significant possibility of a monotonic seasonal trend of PM10 ($p = 0.026$) while showing its negative slope simultaneously (Sen = -1.496). The forecasting procedure of PM10 until 2024 comprised 15 time series models which were validated by means of 8 statistical criteria. The model validation results indicated that ARIMA (0,1,2) was the most satisfactory case for predicting the future trend of PM10. This model estimated the concentration of $PM_{10}$ to reach approximately 79.04 ($\mu g/m^3$) by the end of 2023 with a 95% confidence interval of 51.38 – 107.42 ($\mu g/m^3$). Overall, it was concluded that the use of the aforementioned analytical tools may help decision-makers gain a better insight into future forecasts of ambient airborne particulate matter.

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## INTRODUCTION

As one of the leading causes of premature death and a destructive threat to the environment, air pollution has always been one of the major management challenges for politicians in different parts of the world (Ravishankara et al., 2020; Dedoussi et al., 2020). This issue is of increasing importance in developing countries that are still striving to replace fossil fuels with clean energy and lack adequate infrastructure and additional guidelines for air quality management (Krzyzanovsk and Schwela 1999). In these countries, largely populated megacities which encompass a variety of fixed and mobile emission sources, are more involved in such a problem (Delavar et al., 2019; Dehhaghi and Rashidi et al. 2022). Air quality management approaches make a significant contribution to improving public health and well-being in these cities.

Tehran - the capital of Iran - is one such example, with many industries located in the suburbs, massive traffic congestions, unique geographical and topographic conditions, which pose many complex problems in air quality management (Shahbazi et al., 2016; Hosseini et al., 2016). Therefore, efficient theoretical tools are needed in the field of air quality monitoring.

In order to deal with air pollution, two frameworks are considered, the first being the technical solutions and the second is known as the theoretical framework. The latter is a prerequisite for

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the optimal management of air quality and is very helpful in developing a comprehensive vision as well as strategic plans for the necessary actions required for the mitigation of air pollution. This framework contains a set of models, calculations, and analyses that guide policymakers to proper actions and appropriate decision-making.

One of the important parts of the theoretical framework of air quality management is the prediction of the concentration of air pollutants, which is not only effective in apprising the public but also warning the managers about extreme pollution events.

As a harmful pollutant, PM10 has a serious impact on urban air quality and public health. The management of this pollutant faces many complex issues due to hot-season dust storms, winter boundary layer thinning, and multiple emission sources. (Jaafari et al., 2019; Torkashvand et al., 2021). Such challenges double the need to combine seasonal analysis with powerful integrated forecasting systems.

In the past, different analytical approaches have been used to make interpretations, while statistical models were claimed to provide significant results (Dominici et al., 2003; Daly and Zanetti, 2007; Banerjee et al., 2011). Time series models have been such cases (Modarres and Dehkordi 2005; Mokoena et al., 2019). The integration of specific statistical tools with time series analysis may prove useful as an efficient set to identify the factors affecting pollutant concentration fluctuations.

In this study, trend analysis techniques were used to examine the long-term trend of PM10. In this regard, statistical methods are used to identify the underlying seasonal behaviors of PM10 and their influence on the pollutant concentration trend. Then, using multiple time series models, they were validated by means of statistical tests followed by the determination of the most appropriate model to predict and project the future changes in PM10 concentration.

## MATERIALS AND METHODOLOGY

Geographically located at 35.41°N and 51.25°E, Tehran has an area of 730 km$^2$ and a population of about 13 million people (Amini et al., 2014; Habibi et al., 2017; Hadei et al., 2017; Faridi et al., 2018; Khajavi et al., 2019). Based on municipal divisions, Tehran is divided into 22 districts (Bayat 2019). Its mean altitude above sea level is approximately 1200 meters (Bahari et al., 2014) and there is a height difference of about 700 meters between the highest and lowest point of this city, which elucidates the reason behind the existence of diverse weather conditions in this metropolis (Amini et al., 2014; Habibi 2017). Tehran has a semi-arid and cold climate with continental climate characteristics and a Mediterranean rainfall pattern, with an average annual temperature estimated at about 18°C (Arhami et al., 2018; Yunesian et al., 2019). Tehran is usually sunny with around 2800 hours of sunshine per year and an average of 30% cloudiness, while the predominant wind direction is from west to east and northeast. (Leili et al., 2008; Amini et al., 2014). Tehran experiences the coldest and hottest months of the year in January and July, respectively (Amini et al., 2017). With respect to the temperature range of Tehran, this city has a moderate climate (Khajavi et al., 2019).

Figure 1 shows the map of Tehran and the location of $PM_{10}$ monitoring stations. The study area consists of fifteen air quality control stations that belong to Tehran Air Quality Control Company. The study interval include data extracted from 2015 to 2021. These stations were selected based on the data availability ≥ 75%. Table 1 presents the characteristics of each air quality monitoring station belonging to Tehran Air Quality Control Corporation (TAQCC).

Monitoring of $PM_{10}$ is done at some stations using Environment S.A equipment (MP101M). The measuring method of this device is based on the reduction of the absorption of beta rays (Gauge Monitor). Airborne particles pass through the filter where they settle. In this case, the airborne particulate is measured by emitting beta rays and measuring the amount of radiation passing through the dust spot. The sampling operation interval is set on a daily basis (24 hours)

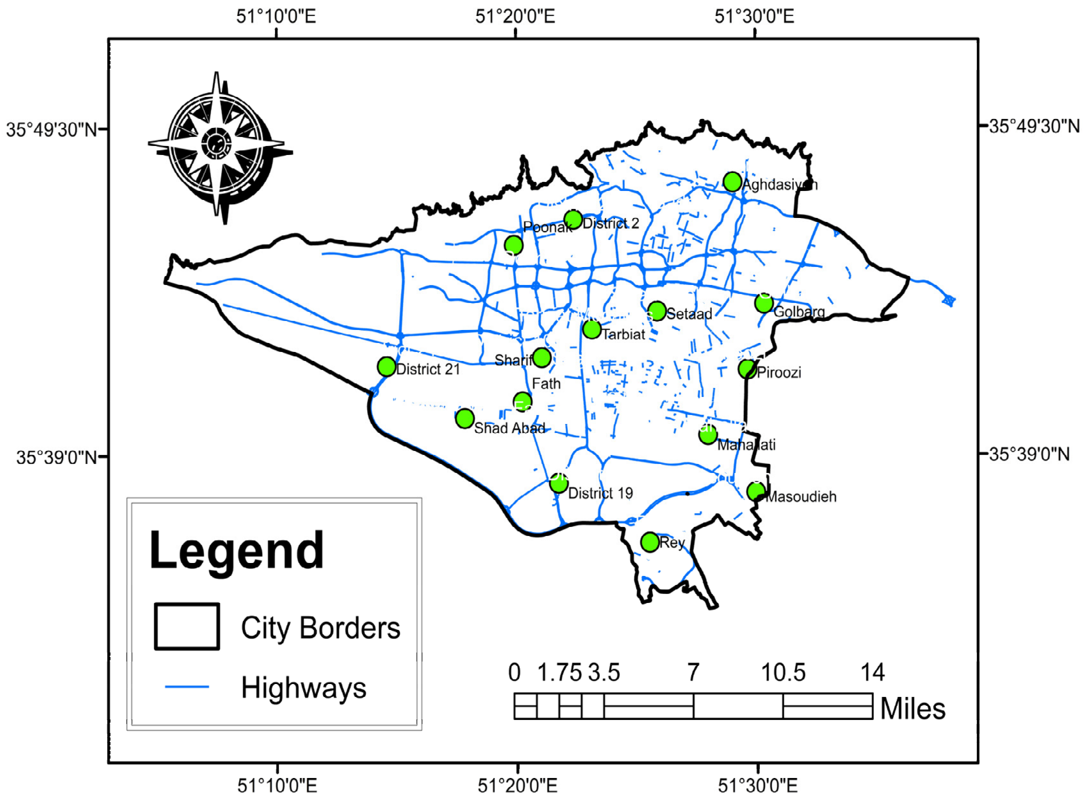

**Fig. 1.** Study area map comprising Tehran city along with its main routes and PM$_{10}$ monitoring stations

**Table 1.** PM$_{10}$ Monitoring stations and their characteristics

| Station name | ID | Latitude | Longitude | PM$_{10}$ sampler | Background |
|---|---|---|---|---|---|
| Aghdasieh | RES1 | 3961415.9 | 543746.72 | Environnement S.A (MP101M) | Residential |
| Poonak | TRS1 | 3957635.3 | 529983.03 | Environnement S.A (MP101M) | Traffic |
| Piroozi | TRS2 | 3950317.1 | 544692.7 | Metone BAM 1020 | Traffic |
| Tarbiat Modarres University | URS1 | 3952685.5 | 534904.76 | Metone BAM 1020 | Urban |
| Setaad Bohran | URS2 | 3953764 | 538996.61 | Environnement S.A (MP101M) | Urban |
| Shad Abad | TRS3 | 3947393.9 | 526910.67 | Metone BAM 1020 | Traffic |
| Sharif University of Technology | URS3 | 3950989.4 | 531747.91 | Metone BAM 1020 | Urban |
| Shahr Rey | INDS | 3940040.1 | 538559.42 | Environnement S.A (MP101M) | Traffic - Industrial |
| Fath | TRS4 | 3948378.3 | 530543.7 | Metone BAM 1020 | Traffic |
| Golbarg | URS4 | 3954232.5 | 545727.55 | Environnement S.A (MP101M) | Urban |
| Mahallati | URS5 | 3946458.8 | 542211.17 | Metone BAM 1020 | Urban |
| Masoudieh | TRS5 | 3943058.4 | 545235.63 | Environnement S.A (MP101M) | Traffic |
| District 2 | RES2 | 3959177.6 | 533726.91 | Environnement S.A (MP101M) | Residential |
| District 19 | URS6 | 3943549.6 | 532822.94 | Metone BAM 1020 | Urban |
| District 21 | TRS6 | 3950455.1 | 521994.24 | Metone BAM 1020 | Traffic |

**Fig. 2.** PM$_{10}$ samplers which are used in air quality stations of TAQCC: (a) Environnemnet S.A (MP101M) and (b) Metone (BAM1020)

and the measurement unit of the device is micrograms per cubic meter. The measurement range is zero to 1000 $\mu g/m^3$ and the minimum detection limit is 6 $\mu g/cm^3$. In other stations, Metone (BAM1020) sampler was used, with a measurement range of 0 - 1000 $\mu g/cm^3$. Figure 2 demonstrates the mentioned sampling devices.

PM$_{10}$ measurement procedure was carried out in accordance with EN 12341:2014 BS. The calibration and maintenance of devices are done regularly by TAQCC staff.

Seasonal decomposition was done to separate the seasonal, trend, and irregular components of the dataset. The seasonal Mann-Kendall trend test was used to assess the possibility of a monotonic trend between seasonal intervals of PM$_{10}$ concentration. The aforementioned analysis was applied to the average PM$_{10}$ concentrations of 15 monitoring stations to achieve an overview of the overall seasonal changes of this pollutant throughout the study domain.

In the case of time series modeling and forecasting, 15 time series models were selected with a 95% confidence interval. The time series model set included: (1) Random walk, (2) random walk with drift, (3) constant mean, (4) linear (5) quadratic trend (6) exponential and (7) S-curve trend, (8) the simple moving average of 2 terms, (9) simple exponential smoothing with alpha, (10) Brown's linear exponential smoothing with alpha, (11) Holt's linear exponential smoothing with alpha, (12) Brown's quadratic exponential smoothing with alpha, (13) ARIMA (1,0,0) with constant, (14) ARIMA (1,1,1), (15) ARIMA (0,0,1) with constant, (16) ARIMA (0,1,2) with constant.

The best-fitted model was chosen to forecast the changes in PM$_{10}$ levels until 2024, which encompasses 2 years of prediction for the average of 15 monitoring stations. Time series modeling and trend analysis were performed using XLSTAT and Statgraphics Centurion.

Each model was tested against eight statistical criteria including (1) RMSE, (2) MAE, (3) MAPE, (4) ME, (5) MPE, (6) AIC, (7) SBIC, and (8) HQC. AIC was considered the main validation criterion, while other statistical validation tools were used to confirm the results.

## RESULTS AND DİSCUSSİON

Figure 3 shows the graphs obtained from the seasonal analysis of $PM_{10}$ concentration trends. The trend-cycle chart shows that $PM_{10}$ experienced a downward trend between 2015 - 2018,

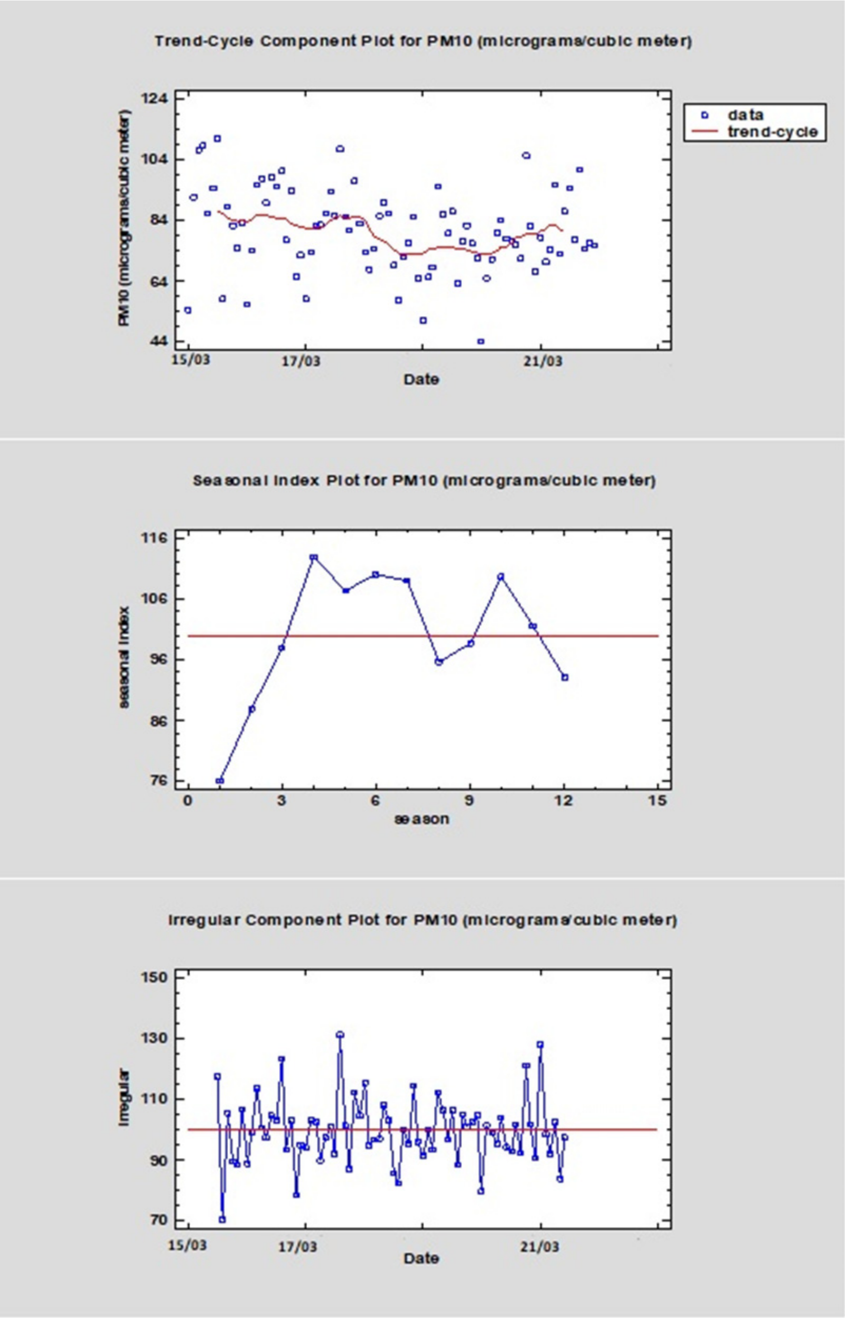

**Fig. 3.** Seasonal decomposition plots of $PM_{10}$ time series data, demonstrating the main trend, seasonal and irregular component of concentration data

contrary to the 2018 - 2021 period, in which an upward trend was observed in the time series. The development of the bus rapid transit system and the planning of low-emission zones over the last decade; may have contributed to the reduction of $PM_{10}$ pollution in urban areas, especially before 2018. On the other hand, aging motor vehicles, population growth, and increasing motor vehicle traffic may have affected the trend from this point onwards.

The seasonal index component indicates the upward trend of $PM_{10}$ seasonal changes from the beginning of the year to June, while there are fluctuations from June to January, from January onwards until the end of the year, the seasonal changes experience a significant downward trend. A decrease is also observed from late summer to late autumn, probably due to the weakening of dust storms in the fall.

The residual plot shows that the random data yielded a homogenous variation throughout the study period and the 7-year time series of $PM_{10}$ concentrations were similarly affected by random factors.

The results obtained from the seasonal Mann-Kendall test indicated that there is a significant monotonic seasonal trend in the time series of $PM_{10}$ concentration ($p = 0.026$), while Sen's slope showed that the slope of the seasonal trend of $PM_{10}$ time series is negative (Sen = -1.496), and a negative trend with a relatively steep slope was observed in consecutive seasons.

The Krusal – Wallis test indicated a significant difference between the ranks of seasonal mean $PM_{10}$ concentrations ($p = 0.0001$). Dunn's post hoc test revealed significant differences in seasonal mean $PM_{10}$ concentrations between all seasons, except between fall and winter, which means that temperature and wind conditions are likely to be the main factors influencing the seasonal variation of this pollutant. Phenomena such as inversion and lower height of the boundary layer may not make a difference between these seasons. This issue may be caused by the increased usage of fossil fuels and their derivatives (such as gasoline and kerosene) in industries located throughout Tehran. On the other hand, the most significant difference was found between spring and summer ($p=7.74\times10^{-6}$), which may underscore the important role of dust storms blowing from the west in summer (Farahani and Arhami 2020).

According to the results of time series model fitting – which is shown in Table 2 - ARIMA (0,1,2) with constant was the best alternative among the studied models for the average $PM_{10}$ concentration time series from 2015 until 2021. Despite the stochastic nature of air pollutant concentrations (which depend on meteorological conditions and several other parameters), the validation criteria seem to be at satisfactory levels (Kumar and Jain 2009). The second fittest model was ARIMA (1,0,0) with constant.

Figure 4 presents the fitness and forecasts of ARIMA (0,1,2) from 2015 to February 2024. While figures indicate a satisfactory fit, the forecasts reveal that the $PM_{10}$ concentration trend may continue steadily, possibly reaching 79.4 ($\mu g/m^3$) until the end of the prediction period. Higher and lower boundaries of the confidence interval were estimated to be 51.38 and 107.42 ($\mu g/m^3$) respectively. These predictions suggest the moderately leaping trend of $PM_{10}$ pollution in the ambient air of Tehran, warning the authorities of its concerning future.

The time series model projections depict an upward $PM_{10}$ trend in the future, allowing the policymakers to achieve an overview of the future of air quality in terms of $PM_{10}$ pollution. The lower bound of the confidence intervals associated with the time series projections indicate that a large decline in $PM_{10}$ by 2024 can be viewed as an equally optimistic scenario, whereas the upper bounds of the ARIMA (0,1,2) confidence interval exemplify a pessimistic scenario to the managers. Therefore, it is necessary to seek solutions for further prevention of urban air pollution based on the results obtained from statistical analyses which are relevant to the past and present.

According to the aforementioned results, it can be said that the authorities can use seasonal decomposition to facilitate the identification of pollution drivers in the months in which the $PM_{10}$ concentration rises. For example, in the investigations of this study, it was observed

**Table 2.** The results of time series models validation for monthly $PM_{10}$ concentrations from 2015 – 2021

| Model | RMSE | MAE | MAPE | ME | MPE | AIC | HQC | SBIC |
|---|---|---|---|---|---|---|---|---|
| Random walk | 16.11 | 12.86 | 16.88 | 0.25 | -1.84 | 5.55 | 5.55 | 5.55 |
| Random walk with drift | 16.21 | 12.84 | 16.88 | -1.71 | -2.17 | 5.59 | 5.60 | 5.62 |
| Constant mean | 13.68 | 10.80 | 14.32 | -5.83 | -3.16 | 5.25 | 5.26 | 5.28 |
| Linear trend | 13.46 | 10.11 | 13.54 | -8.62 | -3.07 | 5.24 | 5.27 | 5.30 |
| Quadratic trend | 13.27 | 10.12 | 13.56 | -3.21 | -2.97 | 5.24 | 5.27 | 5.32 |
| Exponential trend | 13.51 | 10.26 | 13.51 | 1.16 | -1.59 | 5.25 | 5.27 | 5.31 |
| S–curve trend | 13.83 | 10.82 | 14.11 | 1.20 | -1.62 | 5.30 | 5.32 | 5.35 |
| Simple moving average of 2 terms | 14.77 | 11.73 | 15.48 | -0.05 | -2.45 | 5.40 | 5.42 | 5.43 |
| Simple exponential smoothing with alpha | 13.64 | 10.43 | 14.08 | -0.87 | -4.15 | 5.24 | 5.26 | 5.27 |
| Brown's linear exponential smoothing with alpha | 13.83 | 10.59 | 14.28 | -0.69 | -3.85 | 5.27 | 5.29 | 5.30 |
| Holt's linear exponential smoothing with alpha | 13.81 | 10.57 | 13.96 | 1.22 | -1.41 | 5.29 | 5.32 | 5.35 |
| Brown's quadratic exponential smoothing with alpha | 13.97 | 10.81 | 14.46 | -0.01 | -3.03 | 5.29 | 5.31 | 5.32 |
| ARIMA (1,0,0) with constant | 13.14 | 10.02 | 13.27 | 0.07 | -2.80 | 5.20 | 5.22 | 5.28 |
| ARIMA (0,1,1) | 13.29 | 10.18 | 13.57 | -0.54 | -3.57 | 5.19 | 5.21 | 5.22 |
| ARIMA (1,1,1) | 13.13 | 9.92 | 12.92 | 0.78 | -1.81 | 5.19 | 5.22 | 5.25 |
| ARIMA (0,1,2) | 13.09 | 9.88 | 13.08 | -0.39 | -3.31 | 5.19 | 5.21 | 5.24 |

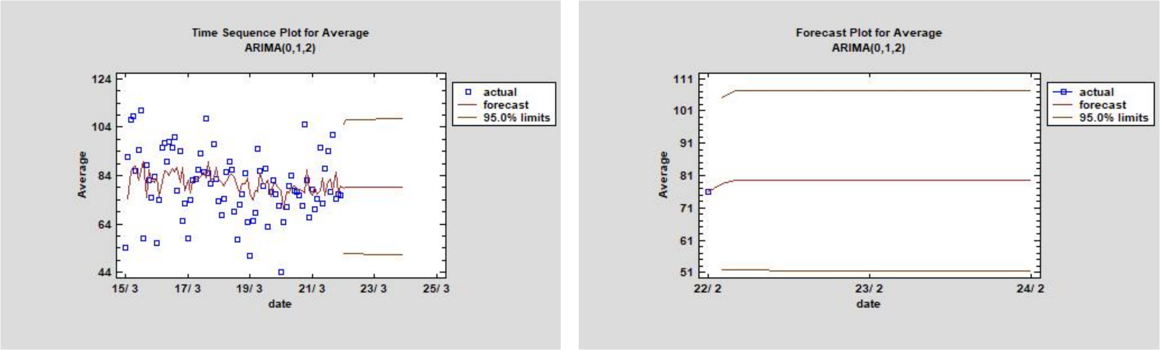

**Fig. 4.** Time series modeling and forecast plots indicating the fit and prediction of ARIMA (0,1,2) as the best-chosen model for $PM_{10}$ ($\mu g/m^3$)

that the concentration of $PM_{10}$ experiences a sharp increase from spring to June and from November to January, pointing at the importance of focusing on the main pollution sources in these two important periods. In the meantime, the Kruskal-Wallis test results emphasize that the authorities should think of solutions for tackling the effects of the climatic factors which influence the peak of $PM_{10}$ levels. By considering the results of this test and the seasonal index chart at the same time, the authorities can consider the thermal inversion in the period from November to December and the prevailing wind in the spring season as important influential events. Moreover, the seasonal Mann-Kendall trend test illustrates that despite the uniformity of the seasonal trend of $PM_{10}$ concentration, the negative slope of $PM_{10}$ concentration can be seen from the beginning to the end of the year. Hence more attention should be paid to the management of $PM_{10}$ in the hot seasons.

## CONCLUSION

The integrated use of time-series modeling and specific trend analysis tools provided a better perspective on the current and future state of this pollutant, linking past and present knowledge to predict future $PM_{10}$ pollution levels. The combination of statistical tools presented in this study focused on seasonal factors influencing in $PM_{10}$ concentration trend, facilitating the identification of reasons behind the probable surge or decline of this pollutant in the future.

In this study, analytical results show the synergistic effect of anthropogenic sources and meteorological conditions on $PM_{10}$, which should be considered in future air quality management plans. The analysis of seasonal trends emphasizes that this problem has existed in the past and likely will continue to emerge in the future, as the seasonal monotonic trends confirm this matter. Stochastic parameters may continue to affect $PM_{10}$ trends to the same extent as they had in the past. The results of time series forecasting indicate that the increase in $PM_{10}$ concentrations is likely to continue until 2024, raising the level of concern over the situation in Tehran unless special attention is paid to the management of this ambient air pollutant. Combining other types of statistical tools with time-series modeling may provide a more granular approach to compelling factors involved in extreme pollution events and sources of potential threats to ambient airborne particulate pollution.

## DECLARATIONS

All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

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## DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

## CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

## AUTHORS CONTRIBUTION

1- Sam Dehhaghi wrote the main manuscript text and conducted the study’s statistical analysis.
2- Hossein Bahiraee: gathered required information regarding the datasets and methodology.
3- Alireza Pardakhti: supervised this study.
4- All authors reviewed the manuscript.

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None

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