FORECASTING AIR POLLUTION RATES VIA HARMONIC REGRESSION METHOD IN COLD WEATHER CONDITIONS: A CASE STUDY OF ERZURUM CITY, TÜRKIYE

BALIBEY, M.

Department of Strategy, General Directorate of State Hydraulic Works, Republic of Türkiye Ministry of Agriculture and Forestry, Ankara, Türkiye
(e-mail: mstblby@hotmail.com)

(Received 28th Nov 2023; accepted 27th Feb 2024)

Abstract. In this study, daily particulate matter (PM_{10}) of Erzurum province for the period 2010:01-2022:12 is converted to monthly averages and investigated by using periodogram-based time series metodology. Periodicities are investigated in the data obtained from five observation stations and predictions for future years are made with the harmonic regression model by using these periodic components. Predictions about future air pollution values are obtained by harmonic regression method in addition to known time series methods. Considering that all periodic and seasonal effects are included in air pollution data, and it will be seen that the proposed harmonic regression model, which obtained from the data (the period 2010:01-2022:12) implicitly captures the effects of other factors and meaningful predictions can be made for the future. Using these periodic components, predictions about the coming months are made with the harmonic regression model, and the 6, 12 and 80 month cycles are found to be statistically significant. Periodicity of 80 months is found to be significant, however, corresponding cycle is observed to be insignificant in harmonic regression model. Using the significant cycles in the harmonic regression, the predicted values are calculated and the remeaning 9 months of 2023 have been forecasted according to the forecast equation obtained by the harmonic regression in the work.
Keywords: *periodicity, time series analysis, periodograms, particulate matter*

Introduction

In addition to the conveniences brought by urbanization, the increase in air pollution and the prevalence of diseases have disadvantageous effects on human life. Migration to small cities is becoming typical, places where industrialization is low, and the quality of life is high in terms of health. In this context, analysis and measurement methods for air pollution are developing. According to the threshold values announced on the website of the Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye and the National Air Quality Index, EPA, Air Quality Index is expressed as good between 0-50, moderate between 51-100, sensitive between 101-260, “unhealthy between 261-400, bad between 401-520 and dangerous over 521 micrograms/cubic meter” (Ege Temiz Hava Müdürlüğü, n.d.). It is very important for the quality of life to use efficient methods for analysis and forecasts in terms of high accuracy rates in making future plans and monitoring air quality within normal limits. While the World Health Organization (WHO) recommends 50 micrograms/cubic meter per day as limit values of particulate meter (PM_{10}), the annual average value is 20 micrograms/cubic meter (WHO, 2018). According to "Air Quality Assessment and Management Regulation" published by the Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye on 9.9.2013, the daily limit value can be exceeded a maximum of 35 times in a year (Mevzuat Bilgi Sistemi, 2008).

In this context, with the increase in industrialization and emission values, the density of particulate matter in the air also increases. To ensure the symmetry between the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

relevant regulations and limitations, the Paris Climate Agreement has been signed by the countries of the world. The density of particulate matter in the air, which is one of the natural consequences of industrialization and emission values, is also guaranteed by the countries of the world with the Paris Climate Agreement, and in terms of emission reduction, and it is induced that "developed countries should maintain their absolute emission reduction targets; and that developing countries raise their emission reduction targets and adopt new, increased targets that will cover the entire economy over time, in accordance with their different national conditions" (Türkiye Cumhuriyeti, 2021).

Air pollution is an important problem in environmental pollution, which is seen with different situations such as air, water and soil pollution. The pollution rates caused by the long-term presence of pollutants in the air in the atmosphere have affected and killed more than four million people every year in regions where people live over 90% (WHO, 2020). Particulate matter ($PM_{2.5}$ and PM_{10}) is the most dangerous fraction of aerosol pollutants due to the risks of inhalation, so exposure to particulate matter has been shown to cause respiratory and circulatory diseases in sources (Polichetti et al., 2009; Kim et al., 2015; Zeydan, 2021). It has been stated that particulate matter also causes diseases of the brain and nervous system (Chew et al., 2020). In addition to its effects on human health, it changes the structure of the earth's components by mixing with the structure of ecosystems with wet and dry sedimentation. It affects the rate of photosynthesis by accumulating in the leaves of green organisms in nature (Rai, 2016). Measuring sulfur dioxide (SO_2) and particulate matter (Total Suspended Particle), which are pollutants that change the natural composition of the air and give it the characteristics of polluted air, has been found sufficient by the World Health Organization to decide the level of pollution and has been recommended to all countries of the world. The rates of ($PM_{2.5}$) and other pollutants were examined and their effects on human health, such as lung and breast cancer, were compared between men and women (Hasegawa et al., 2021). Therefore, their analysis is very important in terms of keeping the effects of these pollutants under control and taking rapid precautions.

Since the studies focus on geographical data, it has become clear that there is a need to make theoretical examinations of the particulate matter data obtained by researchers.

Doğan and Kitapçıoğlu (2007), conducted a study on air pollution values in 2007 and evaluated the winter air pollution between 1989 and 2004 in İzmir province, Türkiye. Although the mentioned studies can be found in the literature, theoretical ones were also conducted using similar methods to this study. Therefore, the harmonic regression model was considered by using the periodic components obtained by the periodograms. This regression model is considered to be more suitable for making predictions in data containing periodic components because it takes into account periodic fluctuations in the data (Akdi et al., 2020). Okkaoğlu et al. (2020), aimed to investigate the daily Particulate Matter (PM_{10}) periodicity of London between 2014-2018 and to reveal the hidden periodic structure of the data by using the periodogram-based unit root test to check the stationarity of the data examined. As a result, it was found that London has five different cycle periods, namely 7 days, 25 days, 6 months, one year, and 15 months. Akdi et al. (2021), aimed to investigate the monthly amount of particulate matter ($PM_{2.5}$) in Paris between January 2000 and December 2019 was examined using a periodogram-based time series methodology, and as a result of unit root test based on pediograms modeling the ($PM_{2.5}$) values, it was concluded that the data examined had 1-year and 20-year periods, so harmonic regression was used as an alternative to the Box-Jenkins methodology. Since harmonic regression shows a better performance in both in-sample and out-of-sample forecasts, it can be considered as a strong alternative to models and forecast time series with a periodic structure.

Balibey (2023) examined monthly average PM_{10} values for the period 2010:01-2020:12 measured for 2023 Izmir province, the periodicity in the data obtained from seven observation stations was investigated, and predictions for the coming months were made with the harmonic regression model using these periodic components. These predictions were compared with the actual values of 2021, and the deviation rates of the results obtained with the selected harmonic regression model method were determined, and the reliability of the harmonic regression model method was tested. The method ı use in the work, successfully captures and accounts for periodicities that might otherwise be confused with seasonality within an alternative methodology. The main objective of this study is to search the periodic components and fit a harmonic regression model by using the periodic components obtained by periodogram based methodology for monthly PM_{10} values of Erzurum. The fact that it is conducted by using the periodic components in a province with cold weather conditions such as Erzurum is an important element in terms of the originality and the other objectives of the study.

Methodology

Periodograms are often used to investigate latent periodicity in stationary time series. Therefore, first of all, the series under study must be stationary. Although there are many methods for the stationarity of any time series in the literature, the Augmented Dickey Fuller (ADF) test, which was developed based on the asymptotic distribution of least squares estimators of parameters, stands out.

Periodograms are obtained by trigonometric transformations of the series. When it comes to periodic functions, the first thing that comes to mind is trigonometric functions. Therefore, accepting that e_ts are random variables with the same distribution independent of each other with expected value 0, variance σ^2, consider a model in the form of

$$Y_t = \mu + R\, cos(wt + \phi) + e_t, t = 1,2, \ldots, n \qquad \text{(Eq.1)}$$

Here, μ, R, ϕ and w terms refer to expected value, amplitude, phase, and frequency respectively (considered the general model of a sinusoid, given in the equation one). These parameters need to be estimated. When selected as w_k, $w_k = 2\pi k/n$ are Fourier frequencies. Considering $A = R\, cos(\phi)$ and $B = R\, sin(\phi)$ from properties of the cosine function, this model can be written as:

$$Y_t = \mu + A\, cos(w_k t) + B\, sin(w_k t) + e_t, t = 1,2, \ldots, n \qquad \text{(Eq.2)}$$

According to this model, the least squares estimators of the parameters are
$\hat{\mu} = \bar{Y}_n$, $a_k = \frac{2}{n}\sum_{t=1}^{n}(Y_t - \bar{Y}_n)\, cos(w_k t)$ and $b_k = \frac{2}{n}\sum_{t=1}^{n}(Y_t - \bar{Y}_n)\, sin(w_k t)$

Here, a_k and b_k are the Fourier coefficients. From the characteristics of trigonometric functions, it is clear that

$$\sum_{t=1}^{n} cos(w_k t) = \sum_{t=1}^{n} sin(w_k t) = 0 \qquad \text{(Eq.3)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

In other words, Fourier frequencies are invariant with respect to the mean. With the help of Fourier coefficients, Periodogram (periodogram ordinate) of time series in w_k frequency is calculated as follows:

$$I_n(w_k) = \frac{n}{2}(a_k^2 + b_k^2) \quad \text{(Eq.4)}$$

On the other hand, to show spectral density function of $f(w_k)$ series, if $\{Y_1, Y_2, \ldots, Y_n\}$ time series is stable, then while $n \to \infty$, it is $I_n(w_k)/f(w_k) \xrightarrow{D} \chi_2^2$ (Fuller, 1996; Wei, 2006). Here, $\xrightarrow{D}$ refers to convergence in distribution.

Periodograms are often used to investigate latent periodicities in series. In *equation (2)* if $H_0: a = b = 0$ is rejected the data contains periodic component. Although standard F test seems to be used to test this hypothesis, it is not significant because w_k frequencies are unknown (Wei, 2006). For the testing of this hypothesis,

$$V = I_n(w_{(1)}) \left[\sum_{k=1}^{m} I_n(w_k) \right]^{-1} \quad \text{(Eq.5)}$$

test statistics have been defined (Wei, 2006). Here, $I_n(w_{(1)})$ shows the maximum periodogram value, and m shows the full value ($m = [n/2]$) of $n/2$ number. Also, under the hypothesis, $H_0: a = b = 0$ (Wei, 2006);

$$P(V > c_\alpha) = \alpha \cong m(1 - c_\alpha)^{m-1} \quad \text{(Eq.6)}$$

here c_α shows the critical value (at α significance level). Using this equation, critical values are calculated as follows:

$$c_\alpha = 1 - (\alpha/m)^{1/(m-1)} \quad \text{(Eq.7)}$$

If the value of V statistic is greater than the critical value ($V > c_\alpha$), $H_0: a = b = 0$ hypothesis is rejected, and it is concluded that the series contains a periodic component. The method is also used to determine other periodicities in the series by expressing this statistic in a slightly different way. For this,

$$V_i = I_n(w_{(i)}) \left[\sum_{k=1}^{m} I_n(w_k) - \sum_{k=1}^{i-1} I_n(w_{(k)}) \right]^{-1} \quad \text{(Eq.8)}$$

statistics are defined. Again, if the value of this statistic is greater than the critical value, the corresponding period is significant. Here $I_n(w_{(i)})$ shows i the largest periodogram value.

If then, periodic components (let's say p_1 and p_2) are detected in the series, a harmonic regression model in the form of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

$$Y_t = \mu_1 + A_1 \cos\left(\frac{2\pi t}{p_1}\right) + B_1 \sin\left(\frac{2\pi t}{p_1}\right) + B_2 \sin\left(\frac{2\pi t}{p_2}\right) + B_2 \sin\left(\frac{2\pi t}{p_2}\right) + e_t, t = 1,2,\dots,n \quad \text{(Eq.9)}$$

is considered. This regression model is considered to be more suitable for making predictions, because the periodic components have been inserted into the data. On the other hand, because the series is stationary, the standard t test can be used for parameter estimates. The raw date is downloaded and reported on the official website of the Republic of Türkiye Ministry of Environment, Urbanization and Climate Change (National Air Quality Monitoring Network, n.d.).

Analysis and Findings

In this section, Predictions will be made for the coming years by considering the monthly average PM_{10} measurements of Erzurum province for the period 2010:01-2023:03. In addition, possible periodic components that may occur in the data will be examined, and predictive values will be calculated with the harmonic regression model to be obtained using these periodic components, if any. The data used in the study were obtained by compiling and arranging the data of five observation stations (Aziziye, Erzurum, Palandoken, Pasinler and Taşhan) announced to the public on the website of the Ministry of Environment, Urbanization and Climate Change. The data at the observation stations were taken on a daily basis and the missing observations were substituted and evaluated by taking the average of the two days (previous and next). Stationarity is the most important assumption to make predictions in time series. When we look at the graphs of the time series (*Figure 1*) and autocorrelation function (ACF) given in *Figure 2* and partial autocorrelation function (ACF) in *Figure 3* of the series, a periodic structure draws attention. However, it is necessary to examine whether the length of this periodicity or a seasonal periodicity.

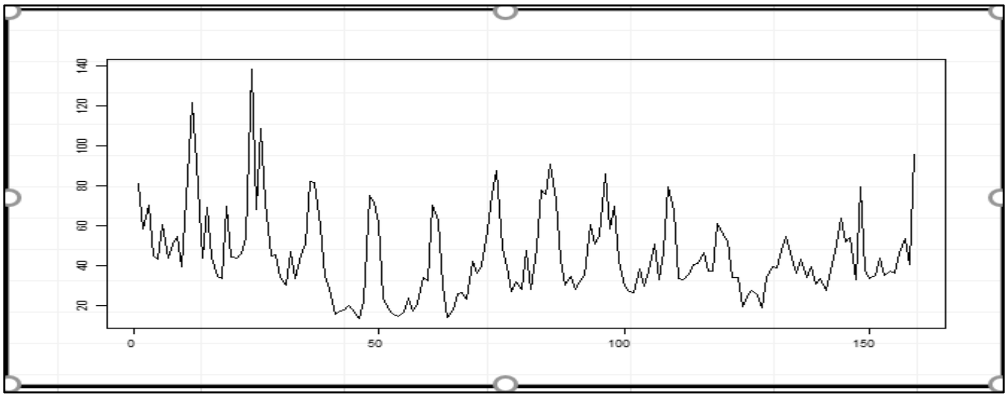

Figure 1. *Time Series "Monthly PM10 Values for 2010:01-2023:03"*

When the results given in *Tables 1 and 2* are evaluated, it is observed that the series is not stationary, and the first-order difference series is stationary. Considering the possible periodicities in the series, the stationarity of the series was also tested by periodogram-based unit root test method.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

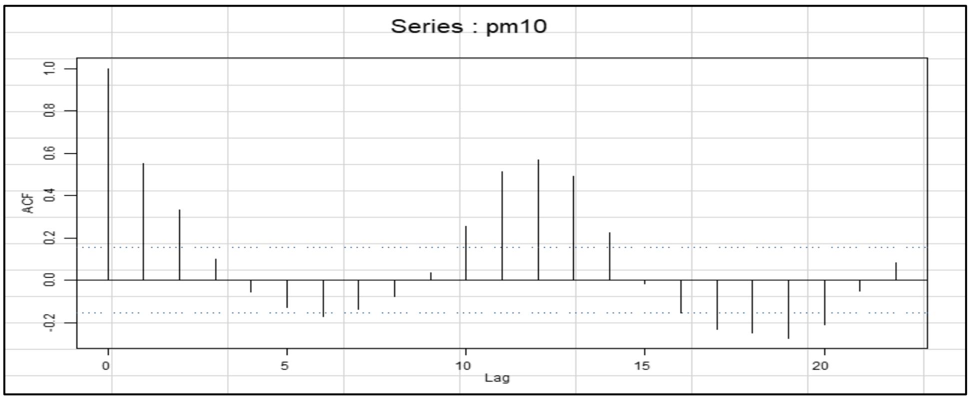

Figure 2. *ACF (Autocorrelation Function) "Monthly PM10 Values for 2010:01-2023:03"*

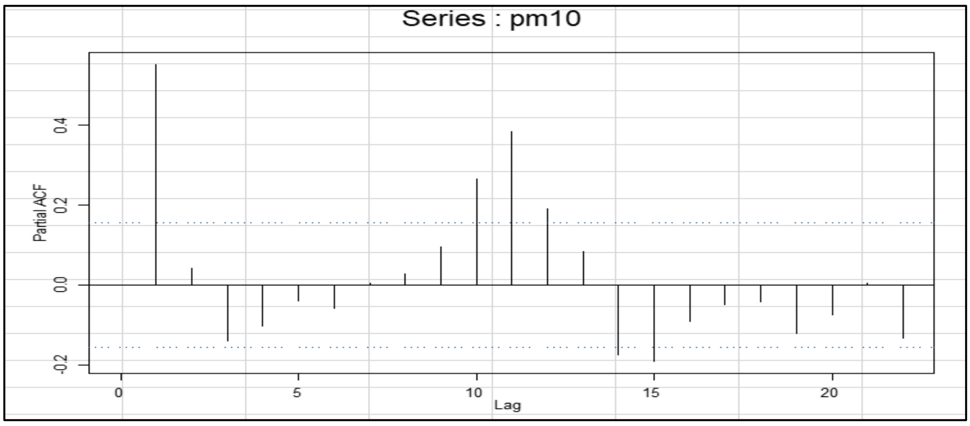

Figure 3. *PACF (Partial Autocorrelation Function) "Monthly PM10 Values for 2010:01-2023:03"*

Table 1. *2010:01-2023:03 Period Monthly PM10 Values (ADF Unit Root Test Results, First Differences)*

		t-Statistic	**Prob. ***
Augmented Dickey-Fuller test statistic		-1.852.685	0.3539
Test critical values:	1% level	-3.475.819	
	5% level	-2.881.400	
	10% level	-2.577.439	

Table 2. *2010:01-2023:03 Period Monthly PM10 Values (ADF Unit Root Test Results)*

		t-Statistic	**Prob. ***
Augmented Dickey-Fuller test statistic		-3.728.527	0.0046
Test critical values:	1% level	-3.476.143	
	5% level	-2.881.541	
	10% level	-2.577.514	

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

According to the standard ADF unit root test results, the series is not stationary. However, considering the possible periodicities in the series, the value of the periodogram-based test statistic given in *Eq. (5)* is $t_n(w_1) = 0.16178$ (calculated here as $I_n(w_1) = 2540.22$ and $\hat{\sigma}_n^2 = 236.8801$), this value is less than the critical value of 5% (0.178). In other words, $t_n(w_1) = 0.16178 < 0.178496 = c_{0.05}$, and we can say that the series is static at the 5% significance level. The difference in ADF and periodogram-based unit root test results is thought to be due to the periodic structure of the series. Having said that the series is stationary, we can investigate the possible periodic components in the series. For this, the values in *Equations (8) and (9)* are calculated and given in *Table 3*.

Table 3. *Periodic Components in PM_{10} Measurement Values*

i	$I_n(w_{(i)})$	V_i	Period	5% Critical value	Result
1	24013.06	0.3240	12.231	0.08916	Significant
2	11518.84	0.2299	79.5	-	Significant
3	6442.32	0.1669	11.357	-	Significant
4	4207.56	0.1309	6.115	-	Significant
5	3008.46	0.1077	5.889	-	Significant

When the values of this *Table 3* are examined, it is seen that a period of 80 months is significant along with the 6 and 12-month periods in the series (calculated here as $\sum_{k=1}^{m} I_n(w_k) = 74112.736$).

The 6 and 12-month periods here correspond to seasonal periods. Using these results, the harmonic regression model given in *Equation (10)* was taken into account, and the results are given below. *Equation (10),* when written as $p_1 = 12, p_2 = 6, p_3 = 80$ and $t = 1,2,\ldots,159$,

$$X_t = \mu + A_1 \cos\left(\frac{2\pi t}{12}\right) + B_1 \sin\left(\frac{2\pi t}{12}\right) + A_2 \cos\left(\frac{2\pi t}{6}\right) + B_2 \sin\left(\frac{2\pi t}{6}\right) + A_3 \cos\left(\frac{2\pi t}{80}\right) + B_3 \sin\left(\frac{2\pi t}{80}\right) + e_t \quad \text{(Eq.10)}$$

Results are presented in *Table 4*.

Table 4. *Harmonic Regression Results*

Parameter Estimates					
Parameter Standard					
Variable	**DF**	**Estimate**	**Error**	**t-Value**	**Pr > |t|**
Intercept	1	45.42144	1.13842	39.90	<.0001
A1	1	16.89615	1.61492	10.46	<.0001
B1	1	6.58206	1.60566	4.10	<.0001
A2	1	4.23009	1.60954	2.63	0,0095
B2	1	6.63607	1.61008	4.12	<.0001
A3	1	5.96669	1.61583	3.69	0.0003
B3	1	10.08246	1.60418	6.29	<.0001

According to the table values, it is observed that all parameters are significant. Accordingly, regarding the PM_{10} values which are the important indicators for air pollution in Erzurum province,

$$\hat{X}_t = 45.42 + 16.90\,cos\left(\frac{2\pi t}{12}\right) + 6.58\,sin\left(\frac{2\pi t}{12}\right) + 4.32\,cos\left(\frac{2\pi t}{6}\right) + 6.63\,sin\left(\frac{2\pi t}{6}\right) + 5.97\,cos\left(\frac{2\pi t}{80}\right) + 10.08\,sin\left(\frac{2\pi t}{80}\right) \qquad (*)$$

an estimation equation was created.

However, by adding the prediction values obtained to the actual observation values for the period 2010:01-2023:03, the time series chart of the relationship to the PM_{10} values between 2010-2023 is given in *Figure 4* above. Although the projections behave in accordance with the overall structure of the series, it is observed that the initially high rates have decreased over the years. There may be different reasons for this. The low air pollution rates for Erzurum can be attributed to climatic conditions. However, it should be expected that there are other reasons for the increase observed over the years. The widespread use of natural gas instead of previously used fossil fuels in cold climate conditions is the most reasonable justification for this. However, it is noteworthy that there has been a significant decrease in the population of Erzurum province over the years. Since the increasing population will affect the increasing use of fossil fuels and the increasing use of automobiles, the population can also be cited as a justification for the decrease rates.

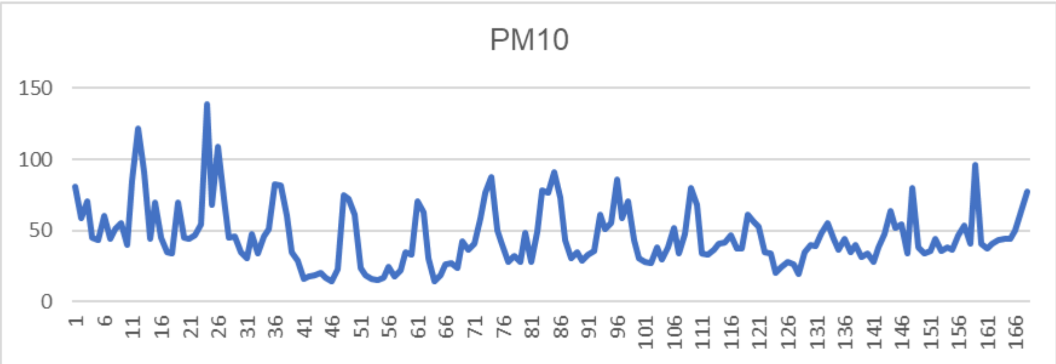

Figure 4. *Predicted PM10 Values for of 2010:01-2023:03*

The forecast values calculated for the remaining months of 2023 (April-2023-December 2023) are calculated according to the forecast model equation given (*) and tabulated in *Table 5* below.

Table 5. *Forecast values for 2023*

2023:04	2023:05	2023:06	2023:07	2023:08	2023:09	2023:10	2023:11	2023:11
40.7367	37.2349	40.3134	43.5541	43.6460	43.8930	50.1653	63.5471	77.3947

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

Discussion

Studies conducted with similar methods were taken into account, but it is seen that they were not carried out in a province with severe climatic conditions such as Erzurum. For these reasons, in order to fill the gap in the literature, the particulate matter data of Erzurum, which was selected among the 30 provinces with metropolitan status in Türkiye due to its harsh climatic conditions, were obtained and arranged, brought to the stage to be analyzed in the program, and the results were obtained.

In terms of theoretical analysis of the study, when the time series contains components such as unit roots, it must be made stationary by removing unit roots that do not meet the stationarity requirement. First, Box and Jenkins (1976) suggested that series contain seasonal unit roots, and therefore series are not stationary. The works of Fuller (1976), Dickey and Fuller (1981), Dickey et al. (1984) and Hylleberg et al. (1990) have made important contributions to the literature by conducting important studies on seasonal variability.

Periodogram-based unit root test was proposed by Akdi and Dikkey (1998) and hidden periodicities were searched using periodograms in data. It was also noted that the status and periodicity of a univariate series are controlled by periodograms (Akdi and Dickey, 1998). Among standard time series tools, frequency domain-based testing has an advantage. In frequency domain-based tests that are seasonally robust, the mean constant and error term are indicated as an estimated variance value $\hat{\boldsymbol{\sigma}}^{2}$. The constancy property of the mean means that periodograms eliminate any deterministic tendencies in the series. Periodograms obtained by trigonometric transformation also take into account possible periodicities (such as cycles) in series. Another advantage is that these tests do not contain models. It does not need delay selection, and the only parameter that needs to be estimated is the variance of the error term. Finally, in periodogram-based unit root testing, the power can be calculated analytically, while in traditional time series analysis, the strength of the tests is not precise (Akdi et al., 2010).

Standard techniques such as the Dickey-Fuller unit root test and extensions are used to determine whether a sequence has a unit root property. In the analysis, without the trend and crossover components, $\boldsymbol{\alpha_1}$ and the t-value obtained by estimation of the *Equation* (**) is compared with the critical values obtained from the simulations by Dickey and Fuller (1979). Basically, it is in the form of

$$\Delta X_t = \alpha_1 X_{t-1} + \zeta_t \qquad (**)$$

Akdi et al. (2019), examined the periodic components of the monthly average crude oil and natural gas prices for the period 2004:01-2018:12, and the cycles in the exchange rates of the Turkish economy for the period 2013:1-2018:12 (5 working days) were tried to be determined using periodograms. Balıbey and Akdi (2019), have taken into account the closing value of the Turkish Lira against the Dollar in 2019 (X_t) and Euro closing value (Y_t). The stability of daily exchange rates was tested by standard unit root tests. In the study on COVID-19 conducted by Akdi et al. (2023), where an important method based on harmonic regression is the focus, the latest periodic structure of daily infected cases was determined, and Türkiye's infected case was analyzed using periodogram-based methodology. As a result, it was concluded that there are cycles of 4, 5 and 62 days in Türkiye's daily new cases. Okkaoğlu et al. (2020), used daily Particulate Matter (PM_{10}) data to investigate periodicity of London between 2014-2018 and as a result, they found that London has five different cycles, namely 7 days, 25 days, 6 months, 12, and 15

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

months. Later Akdi et al. (2021), use monthly amount of particulate matter ($PM_{2.5}$) to investigate periodic components for Paris from 2000:01 to 2019:12 based on the periodogram based analysis they observe 12- and 20-months periods.

In this study, the data set and periods differ from Okkaoğlu et al. (2020) and Akdi et al. (2021) works. The monthly mean PM_{10} values for the period 2010:01-2023:03 measured for Erzurum province are examined. The data set consists of the monthly average (PM_{10}) variable for the period from January 1, 2010 to March 3, 2023. Time series data is gathered from 5 weather stations (Aziziye, Erzurum, Palandoken, Pasinler and Taşhan) which are located at different parts of Erzurum (National Air Quality Monitoring Network, n.d.). The location of these stations can be found in the official website of the Republic of Türkiye Ministry of Environment, Urbanization and Climate Change (National Air Quality Monitoring Network, n.d.). These time series are averaged to form the daily average data. The data at the observation stations are taken on a daily basis and the missing observations are substituted and evaluated by taking the average of the two days (previous and next). Stationarity is the most important assumption to make predictions in time series. As a result, 6-, 12- and 80-month periods are obtained significantly in the data. Besides, the series is stationary, the standard t test can be used for parameter estimates. Using these periodic components, predictions for the coming months are made with the harmonic regression model, and the prediction values for the remaining 9 months of 2023 are obtained, and the significance of the model is also tested (April-2023-December 2023) (*Table 5*). As can be seen, successful results are obtained from the harmonic model by using periodic components.

Considering the graphs of the data, the decrease in the pollution rates in the air pollution data measured in Erzurum is remarkable. The reason for this may be the climatic conditions of Erzurum province, as well as the infrastructure works carried out by the local units on air pollution. In the study, the usual seasonal periods of 6 and 12 months are obtained. The 80 months period is observed to be significant, but the effect of the 80 months period is insignificant in the harmonic regression. This result also reveals the importance of the work as well.

Conclusion

In this context, the model obtained in the study conducted to fill the gap in the literature regarding this kind of climate conditions in metropolitan cities in Türkiye. Obtaining a sub-period of 80 months in addition to the seasonal periods of 6 and 12 months, which correspond to the standard seasonal periods, reveals the importance of the study.

This model can be used by policy makers, academics and researchers working in the field to make reliable predictions for the coming years.

Data availability. The data supporting reported results can be found free of charge via https://sim.csb.gov.tr/STN/STN_Report/StationDataDownloadNew, which is official government site (Republic of Türkiye Ministry of Environment, Urbanization and Climate change) and provide details regarding where, publicly archived datasets analyzed during the study.

Funding Declaration. No funds, grants, or other support was received.

Declaration of interests. I declare that there is no known competing financial interests or personal relationships that could have appeared to influence the work reported in my paper.

REFERENCES

[1] Akdi, Y., Dickey, D. A. (1998): Periodograms of Unit Root Time Series: Distributions and Tests. – Commun. Statist-Theory Meth. 27(1): 69-87.

[2] Akdi, Y., Kalafatcılar, K. M., Özcan, K. M. (2010): Application of periodogram-based cointegration test for the analysis of the services and goods sector inflations. – International Econometric Review (IER) 2(1): 3-10.

[3] Akdi, Y., Balıbey, M., Kayış, A. (2019): Petrol ve Doğalgaz Fiyatlarındaki Periyodik Dalgalanmalar. – Firat University Journal of Social Sciences 29(2): 217-325. DOI: 10.18069/firatsbed.559747.

[4] Akdi, Y., Gölveren, E., Okkaoğlu, Y. (2020): Daily electrical energy consumption: Periodicity, harmonic regression method and forecasting. – Energy 191: 116524.

[5] Akdi, Y., Gölveren, E., Ünlü, K. D., Yücel, M. E. (2021): Modeling and Forecasting of monthly (PM2.5) emission of Paris by periodogram-based time series methodology. – Environ Monit Assess 193: 622. https://doi.org/10.1007/s10661-021-09399-y.

[6] Akdi, Y., Emre Karamanoğlu, Y., Ünlü, K. D., Baş, C. (2023): Identifying the cycles in COVID-19 infection: The case of Turkey. – Journal of Applied Statistics 50(11-12): 2360-2372.

[7] Balibey, M. (2023): Air Pollution Study for Izmir: A Time Series Approach. – Prof. Dursun Kose, Ph. D., pp. 178-192.

[8] Balıbey, M., Akdi, Y. (2019): Döviz Kurlarında Periyodik Dalgalanmalar. – Atatürk University Journal of Institute of Social Sciences 23(1): 123-131.

[9] Box, G. E. P., Jenkins, G. M. (1976): Time Series Analysis: Forecasting and Control. – Revised ed. San Francisco: Holden-Day. [Google Scholar].

[10] Chew, S., Kolosowska, N., Saveleva, L., Malm, T., Kanninen, K. M. (2020): Impairment of mitochondrial function by particulate matter: Implications for the brain. – Neurochemistry International 135: 104694.

[11] Dickey, D. A., Fuller, W. A. (1979): Distribution of the estimators for autoregressive time series with a unit root. – Journal of the American Statistical Association 74(366a): 427-431.

[12] Dickey, D. A., Fuller, W. A. (1981): Likelihood ratio statistics for autoregressive time series with a unit root. – Econometrica: Journal of the Econometric Society, pp. 1057-1072.

[13] Dickey, D. A., Hasza, D. P., Fuller, W. A. (1984): Testing for unit roots in seasonal time series. – Journal of the American Statistical Association 79(386): 355-367.

[14] Doğan, F., Kitapçıoğlu, G. (2007): İzmir ilinde hava kirliliğinin yıllar itibariyle karşılaştırılması. – Ege Medical Journal 46(3): 129-133.

[15] Ege Temiz Hava Müdürlüğü (n.d.): Hava kalitesi indeksi. – Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye, retrieved September 4, 2023 from https://egethm.csb.gov.tr/hava-kalitesi-indeksi-i-87403.

[16] Fuller, W. A. (1996): Introduction to statistical time series. – Wiley, 728p.

[17] Hasegawa, K., Tsukahara, T., Nomiyama, T. (2021): Association between Air Pollutants and Cancer Incidence Rates in Japan: An Ecological Study. – Med. Sci. Forum 4: 15. DOI: 10.3390/ECERPH-3-09054.

[18] Hylleberg, S., Engle, R. F., Granger, C. W., Yoo, B. S. (1990): Seasonal integration and cointegration. – Journal of Econometrics 44(1-2): 215-238.

[19] Kim, Y. O., Park, S., Nam, B. H., Park, J. M., Kim, D. G., Yoon, J. H. (2015): Roseovarius scapharcae sp. nov., isolated from ark shell Scapharca broughtonii. – International Journal of Systematic and Evolutionary Microbiology 65(Pt_12): 4695-4700.

[20] Mevzuat Bilgi Sistemi (2008): Hava Kalitesi Değerlendirme ve Yönetimi Yönetmeliği. – Presidency of The Republic of Türkiye, retrieved: September 4, 2023 from https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=12188&MevzuatTur=7&MevzuatTertip=5.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828

[21] National Air Quality Monitoring Network (n.d.): Station data download. – Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye, retrieved August 31, 2023 from https://sim.csb.gov.tr/STN/STN_Report/StationDataDownloadNew.

[22] Okkaoğlu, Y., Akdi, Y., Ünlü, K. D. (2020): Daily PM10, Periodicity, and Harmonic Regression Model: The case of London. – Atmospheric Environment 238: 117755.

[23] Polichetti, G., Cocco, S., Spinali, A., Trimarco, V., Nunziata, A. (2009): Effects of particulate matter (PM10, PM2.5, and PM1) on the cardiovascular system. – Toxicology 261: 1-8.

[24] Rai, P. K. (2016): Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring. – Ecotoxicology and Environmental Safety 129: 120-136.

[25] Türkiye Cumhuriyeti (2021): Paris Anlaşması. – Republic of Türkiye Ministry of Foreign Affairs, retrieved September 4, 2023 from https://www.mfa.gov.tr/paris-anlasmasi.tr.mfa.

[26] Wei, W. W. S. (2006): Time series analysis: Univariate and multivariate methods. – Pearson Education.

[27] WHO (2018): Ambient (outdoor) air pollution. – World Health Organization, https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (Date of access: 5 March 2020).

[28] WHO (2020): Air Pollution. – World Health Organization, https://www.who.int/health-topics/air-pollution#tab=tab_2 (Date of access: 5 March 2020).

[29] Zeydan, Ö. (2021): 2019 Yılında Türkiye’deki Partikül Madde (PM10) Kirliliğinin Değerlendirilmesi. – Journal of the Institute of Science and Technology 11(1): 106-118.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2202_18171828