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Application of Statistical Distributions to PM_{10} Concentrations: Van, Türkiye

PM_{10} Konsantrasyonunun İstatistiksel Dağılımına İlişkin Bir Uygulama: Van, Türkiye

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Abstract

Air pollution is one of the most serious environmental pollution problems that adversely affect human health and the environment. Industrializing and frequent use of low-quality coals for heating purposes and incorrect combustion techniques may cause intense air pollution in the winter season. In the related literature, there are several studies on air quality employing different methods using various air pollutants (carbon monoxide, nitrogen oxides, ground-level ozone, and particle pollution). In this study PM_{10} (concentration of 10 micrometers or smaller size of air pollutants) levels in Van province which is one of the most crowded provinces in Eastern Anatolia, Türkiye. Due to the fuels used for heating in Van, the air quality may be higher than limits set by regulations several times during the year. In this study, PM_10 levels of Van are modeled using lognormal, Weibull, and Gamma distributions. Information and goodness of fit criteria are used to compare their performance. In addition, predictions of exceedances are provided for the PM_{10} concentration higher than given limits. According to the results, the Gamma distribution performed better than the other two distributions in modeling the PM_10 concentrations in Van and predicted the exceedances accurately.

Keywords

Air pollution, lognormal distribution, Türkiye, Van

Öz

Hava kirliliği, insan sağlığını ve çevreyi olumsuz yönde etkileyen en ciddi çevre kirliliği sorunlarından biridir. Sanayileşme ve kalitesiz kömürlerin ısınma amacıyla sıklıkla kullanılması ve yanlış yakma teknikleri kış mevsiminde yoğun hava kirliliğine neden olabilmektedir. İlgili literatürde çeşitli hava kirleticilerine (karbon monoksit, kurşun, nitrojen oksitler, yer seviyesinde ozon ve partikül kirliliği) ait ölçümlerin farklı yöntemler kullanarak modellenmesine ve incelenmesine ilişkin birçok çalışma bulunmaktadır. Bu çalışmada Türkiye'nin Doğu Anadolu bölgesindeki en kalabalık illerden biri olan Van ilindeki PM_10 (10 mikrometreden küçük partikül madde) konsantrasyonu, lognormal, Weibull ve Gamma olasılık fonksiyonları kullanılarak modellenmiştir. Ek olarak, verilen limitlerden daha yüksek PM_10 konsantrasyonu için aşım kestirimleri verilmiştir. Van ilinde ısınma amaçlı kullanılan yakıtlar nedeniyle hava kalitesi yıl içerisinde çeşitli zamanlarda hava kalitesi yönetmelikle belirlenen limitlerinin üzerinde olabilmektedir. Bu sebeple hava kalitesi ile ilgili çalışmalar önem arz etmektedir. Çalışmada kullanılan veri seti, Kasım 2021 ile Mart 2022 tarihleri arasında ölçülen PM_10 konsantrasyonlarını içermektedir. Elde edilen sonuçlara göre Van ili PM_10 konsantrasyonlarının modellenmesinde Gamma dağılımının diğer dağılmlara göre daha bir iyi performans gösterdiği tespit edilmiştir.

Anahtar Kelimeler

Hava kirliliği, lognormal dağılımı, Türkiye, Van

Introduction

Air pollution is one of the most significant causes that adversely affect human health. Air pollution is mostly a problem associated with industrialized areas however, it can also emerge in some areas where low-quality coal or solid fuels (wood, dried dung, etc.) are frequently used for space heating and cooking. Consequently, air quality may fall below safe levels, especially during the winter season in such areas. Moreover, indoor smoke from such fuel combustion produces a large number of health-damaging air pollutants resulting in much higher exposure to air pollutants than from outdoor sources (Mishra, 2003, p. 848). A number of previous studies (Cakmak et al., 2012; Díaz-Robles et al., 2015) have pointed out that exposure to airborne particles may result in adverse health effects such as cancer, cardiovascular and respiratory diseases, infant mortality, and more. Van, is the most crowded province in Eastern Anatolia, Türkiye. In the province of Van such fuels like coal, wood, or dried dung are extensively used since natural gas is not accessible to all parts of the city. Due to the topographic and geographical location of the city, the winter season is harsh, and the city's average temperature is lower than the country's average (Öztürk and Bayram, 2019, p. 1142). Accordingly, air pollutants originating from preferred fuels for heating have a large share in air pollution (Öztürk and Bayram, 2019, p. 1142). Moreover, vehicle traffic also contributes to air pollution levels considering the city has a large population (nearly 1.15 million by 2020).

The first Air Quality Control Regulations in Türkiye date back to the late 1980s. Later an updated regulation is released in 2005 parallel with the directives of the European Union (EU) and considered Environmental Law as well. One of the purposes of this regulation is to inform the public through threshold values of air pollutant levels. Air pollutants generally refer to carbon monoxide, lead, nitrogen oxides, ground-level ozone, particle pollution (also known as particulate matter), and sulfur oxides. Particulate matter (PM) concentration of 10 micrometers or smaller size of air pollutants is called PM_{10} and used in tracking air quality widely. In Türkiye, limits for the annual average PM_{10} concentrations set as 40 $\mu g/m^3$. However, these limits are higher than updated limits set by the world health organization's (WHO) air quality guidelines. Average PM_{10} the concentration of Van in 2021 is measured nearly 2 times above the latest limits set (15 $\mu g/m^3$) by the WHO guidelines. Furthermore, the studies examining the air quality in Van province are quite limited. Recently, Öztürk and Bayram, (2019) investigated the air quality of the Van in their study. According to their work, although the measured sulfur dioxide concentrations remain below the limits set by WHO, PM_{10} concentrations exceeded the limit values several times during the winter period. Although the overall air quality in Van is generally reasonable throughout the year, air quality can significantly decrease during the winter season. When examining the data from the previous year, it is observed that the daily limit for PM_{10} is exceeded 56 times in Van during the winter season. Van Directorate of Environment and Urbanization presented a "Van Province Clean Air Action Plan" aims to establish an air quality assessment and management system for the years 2020-2024, ensure effective implementation of Environmental Legislation, and achieve compliance with EU limit values by reducing air pollution as much as possible. To obtain air quality data accurately, it is considered necessary to set up four additional air quality measurement stations according to this plan since there is only one air quality measurement station in the city. Most importantly, it is also pointed out in the plan the lack of any modeling studies for the Van province and as part of the 5-year development plan, a project is aimed to be carried out in collaboration with the university in the region to prepare an Air Pollution map for Van by 2024.

Various models such as regression analysis, artificial neural networks, and frequency distributions can be used in modeling levels of air pollutants. The approaches used in modeling PM_{10} concentrations can be found in a review presented by Taheri Shahraiyni & Sodoudi (2016). Concentrations of air pollutants can be modeled with different distribution functions as well. Each area may have its own characteristic depending on various factors such as emission levels or meteorological conditions (Plocoste et al., 2020). Consequently, motivated by the reasons mentioned above modeling the distribution of the PM_{10} the concentration of Van province is beneficial in controlling risks arising from air pollutants, which can be harmful to the environment and human health.

Numerous probability distribution functions are employed to model the PM_{10} concentrations in the related literature. Amongst the other distribution functions, the lognormal distribution stands out in modeling air pollutant levels. In addition, the distributions such as the Weibull, Gamma, Rayleigh, and Gumbel are utilized in modeling PM_{10} concentrations in the literature (See in Mijić et al. 2009; Yusof et al. 2010; Plocoste et al. 2020). In this study, the lognormal, Gamma, and Weibull distributions are considered in the modeling PM_{10} concentrations of Van province due to their well-acceptance and satisfactory performances in modeling PM_{10} levels. In estimating the unknown parameters of the Gamma, lognormal, and Weibull distributions, the Maximum Likelihood (ML) estimation method is used. The contributions of the study are given as follows. To the best of the author's knowledge, PM_{10} concentrations of Van province are not modeled using probability distribution functions previously. In addition, this study emphasizes the need for evaluating the air quality in such areas where the use of low-quality (high-sulfur, low-calorie) coals or dry dung fuel is frequent, due to natural gas is not accessible yet or costly to install indoors.

The rest of the study is organized as follows. In section 2, related literature is reviewed. Then, the distributions used in the study are given along with the ML method for estimating parameters of the lognormal, Gamma, and Weibull distributions. In section 4, application results are presented and modeling performances of the Weibull, Gamma, and lognormal distributions are compared. In section 5, the study is finalized with some concluding remarks.

2. Literature

In this section first, some of the studies conducted in Türkiye from different fields concerning air quality are overviewed afterward, the studies employing various distribution functions in modeling particle matter concertation are reviewed.

Although there are fewer studies using probability functions for modeling air pollutants in Türkiye, there are many studies conducted in several regions using different methods. In particular, many descriptive studies concerning air quality exists in the literature. Karademir (2006) conducted a study using the Gaussian dispersion model in Kocaeli which is one of the most industrialized areas in Türkiye. They stated that high levels of sulfur dioxide and nitrogen dioxide are mapped in refineries and the petrochemical industry located nearby. Şahin et al. (2012) investigated the size distribution of airborne particles in İstanbul and concluded that the lowest Mass Median Aerodynamic Diameter values are observed in Avcılar, Beşiktaş, Rasathane areas during the winter. Ozel & Cakmakyapan (2015) estimated a gamma–Poisson process to fit daily PM_{10} concentrations in the Central Anatolia region. They provided yearly and monthly expected PM_{10} concentrations. Dursun & Karaman (2019) carried out a study considering PM_{10} measurements and precipitated dust pollutants emitted from the mixed concrete plant in Van. They stated that when the measured concentrations are compared with the limit values determined in the Industrial Air Pollution Control regulation, it is observed that the measured and calculated concentrations are below the threshold value. Bozdağ et al. (2020) applied machine learning algorithms to model PM_{10} levels in Ankara province, Turkey, concluding that artificial neural networks performed the best. Kahraman (2020) investigated the trends in the PM_{10} and sulfur dioxide data are measured between 2010 and 2019 years with the help of Mann-Kendall and Sen tests. They analyzed annual, seasonal, monthly, and hourly changes in PM_{10} and sulfur dioxide levels and the effect of meteorological conditions on air pollution in the Nevşehir province. Also, the relationship between PM_{10} and sulfur dioxide pollutants with temperature, pressure, wind speed, and relative humidity parameters are examined. Akbulut (2020) modeled the levels of particulate matter and sulfur dioxide using artificial neural networks and regression models for the data measured between 2009-2017. According to their study, the regression method is preferred over the artificial neural networks method. Aktaş (2021) PM_{10}, $PM_{2.5}$ and sulfur dioxide concentrations obtained from eight stations in Ankara province for the period of January-December 2018 are analyzed with the Bayesian ANOVA method.

In addition, some studies that mostly performed a descriptive analysis of air pollutants are overviewed as follows. In a study by Zeydan, (2021) PM_{10} concentrations recorded at all air quality monitoring stations in Türkiye are evaluated according to the limit values in Türkiye's air quality regulations. Koşan et al., (2018) similarly conducted a study for Erzurum province. Yakın & Behçet (2019) prepared an emission inventory of traffic-related air pollutants in Van province and Öztürk & Bayram (2019) presented a detailed investigation of Van provinces air pollutant levels, preferred fuels, and descriptive statistics considering them. In a study by Tayanç et al. (2022), air pollutants are evaluated on a daily, monthly, seasonal, and annual time scale in which they investigated the mechanisms that influence low air quality by using air pollutants data from Konya, Türkiye.

The studies employing various distribution functions are reviewed as follows. Sansuddin et al. (2011) investigated the frequency distribution of PM_{10} concentration in industrial and residential areas. The probability of exceedances and the return period between actual and predicted concentrations based on the threshold limit for PM_{10} concentrations are given using well-known distribution functions in their work. In addition, they also used an autoregressive model for short-term predictions of PM_{10} exceedance. In a study by Todorovic et al. (2015), PM_{10} measurements collected from Belgrade between 2003 and 2013 are modeled using Pearson 5, lognormal and Weibull distributions. According to their results, the Pearson 5 and lognormal distributions described the data best. In addition, they conducted an extreme value analysis for determining the probability of extreme PM_{10} value emergence. Similarly, Perišić et al. (2015) conducted a study for the data obtained in Belgrade to assess the frequency of exceeding daily PM_{10} limits in the European Union (EU) and the US Environmental Protection Agency. In order to fit the data obtained, and estimate the number of exceedances, Pearson 5, lognormal, and Weibull distributions and extreme value distributions are employed in their work. Papanastasiou & Melas (2010) simulated PM_{10} concentrations of Greece using lognormal distribution. They stated that PM_{10} measurements are above EU air quality standards in Volos, Greece. Aleksandropoulou et al. (2012) presented a study that the Weibull and lognormal distributions are fitted to PM_{10} and $PM_{2.50}$ concentration data measured at 15 stations in the urban areas of Athens and Thessaloniki. They stated that according to the analysis results the lognormal distribution is found to best fit to the observed data and in most stations, the theoretical distributions predicted the daily air quality standards exceedances accurately.

Since air pollution can seriously affect daily life in Far East countries, there are many studies conducted in these regions as well. For example, Nur Shaziayani et al. (2020) reviewed previously used methods for PM_{10} levels prediction in Malaysia. They stated that %72 of the studies employed statistical methods for the studies conducted in Malaysia. Gulia et al. (2017) fitted various probability distribution functions for hourly average $PM_{2.5}$ and nitrogen dioxide concentrations at one of the busiest traffic intersections in Delhi. They found the lognormal and log-logistic distribution performed best in describing related air pollutants. Wang et al. (2013) modeled daily PM_{10} the average concentration in Beijing, Shanghai, Guangzhou, Wuhan, and Xi'an, China using the lognormal, Weibull, and Gamma distributions. They stated that even in one of the cleanest cities, Guangzhou's air pollutant levels must be reduced by at least %50 percentage.

3. Method

In this section, the probability distribution functions (pdf) of the lognormal, Weibull, and Gamma distributions are given and parameter estimations are provided.

3.1. The Lognormal Distribution

If a random variable X is log-normally distributed, then $Y = ln(X)$ normally distributed. Consequently, the pdf of the lognormal distribution is given as,

$$f(x;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}}\exp\left\{\frac{-(\log(x)-\mu)^2}{2\sigma^2}\right\}, x > 0$$

if the natural logarithm of X is normally distributed with mean μ and variance σ^2 (see the lognormal distribution from Evans et al., (2001).

3.2. Weibull Distribution

When X is a random variable following the Weibull distribution with shape parameter β and the scale parameter θ the pdf of the Weibull distribution is given as,

$$f(x;\theta,\beta) = \frac{\beta}{\theta^\beta}x^{\beta-1}e^{-(\frac{x}{\theta})^\beta}, x > 0; \theta,\beta > 0.$$

3.3. Gamma Distribution

A random variable following the Gamma distribution with the shape parameter α and the scale γ parameter has the following pdf

$$f(x;\alpha,\gamma) = \frac{1}{\gamma^\alpha\Gamma(\alpha)}x^{\alpha-1}e^{\frac{-x}{\gamma}}, x > 0; \gamma,\alpha > 0.$$

3.4. Parameter Estimation

The ML method is employed in the parameter estimation of the given distributions. Since the estimators of parameters used in this study have already been obtained in previous studies, they will not be given here for brevity, but the ML estimations for the lognormal, Weibull, and Gamma distributions can be seen from the Evans et al., (2001, p. 133), Cohen, (1965, p. 580) and Choi & Wette (1969, p. 684), respectively.

In addition probabilities of PM_{10} concentrations being above the limits are provided, and actual and predicted exceedances are given in the study. The predicted exceedances are obtained by calculating the probability of PM_{10} concentration higher than the threshold value determined by Air Quality Control Regulations in Türkiye. Actual exceedances are simply the ratio of the number of exceedances above the limits. Two limit values are taken into account in the calculation of probabilities. According to the regulation in Türkiye, the limit value determined for the winter season is 90 $\mu g/m^3$. The daily limit is expressed as 50 $\mu g/m^3$. Since the data set used in the study comprises the winter season PM_{10} concentrations, exceedances for both of the limits are provided.

4. Data and Application

In this section, the data set is introduced and the lognormal, Weibull, and Gamma distributions are applied to the PM_{10} concentrations measured in Van. Several well-known criteria including the root mean square error (RMSE), coefficient of determination (R^2), Kolmogorov Smirnov (KS) test and information criteria such as lnL and Akaike information criterion (AIC) are utilized in comparison of performances of the distributions. Matlab R2021 software is used in the analysis.

4.1. Data Set

In this study, the daily average PM_{10} concentration between the dates 1 November 2021 and 31 March 2022 collected by the air quality monitoring station in Van is considered. The data set is publicly accessible on the link provided in the references (Air Quality Monitoring, 2021) and may be shared by the author upon request. There are 7 missing observations in the data. It is preferred to use the data for the last winter season and a part of the fall and spring seasons when the use of energy increased for heating. Descriptive statistics for the PM_{10} concentrations and geographical information of the Van province are provided in Tables 1 and 2, respectively.

Table 1. Descriptive statistics

Descriptive Statistics	
Mean	47.1882
Skewness	0.6013
Kurtosis	2.4595
Variance	535.08

Table 2. Geographical information of the Van province

Latitude	**Longitude**
38.499817	43.378143

Table 3 presents ML estimates of lognormal, Weibull, and Gamma distributions' parameters.

Table 3. ML estimates of the parameters for the lognormal, Weibull, and Gamma distributions

Weibul$(x; \theta, \beta)$	**Lognormal**$(x; \mu, \sigma)$	**Gamma**$(x;\alpha,\gamma)$
53.500	3.728	4.142
2.200	0.513	11.38

Values of evaluating criteria for lognormal, Weibull, and Gamma distributions are provided in Table 4. As is known lower values of the AIC, RMSE, and KS and higher values of KS (p-value),R^2 and lnL criteria indicate a better fit.

Table 4. Modeling performances of the given distributions for the PM_{10} data.

Distribution	**AIC**	**RMSE**	$\mathbf{R^2}$	**KS**	**KS(p-value)**	**Ln*l***
Lognormal	1303.20	0.0316	0.9892	0.0707	0.4423	-649.6
Weibull	1306.97	0.0353	0.9859	0.0767	0.3427	-651.4
Gamma	1302.19	0.0315	0.9893	0.0692	0.4709	-649.09

It can be seen from Table 4 that the Gamma distribution provided the smallest values for the AIC, RMSE, and KS and the largest values for the R^2, KS (p-value), and Lnl. Meaningly the Gamma distribution performed better than the other two distributions in modeling the PM_{10} concentrations of Van province. Furthermore, fitted density plots for the lognormal, Weibull, and Gamma distributions are provided in Figure 1.

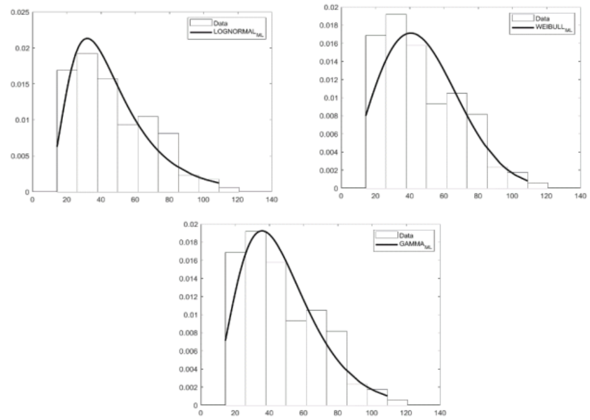

Figure 1. Fitted density plots for the lognormal, Weibull, and Gamma distributions.

Figure 1 shows that the Weibull distribution performs relatively poorly compared to Gamma and lognormal distributions at the peak of the distribution, although it fitted quite satisfactorily for the remaining part of the distribution. In addition, it can be seen lognormal distribution is over fitted slightly at the peak of the distribution. For this reason, the results pointed out in Table 4 are also supported by the plots.

Table 5. Probabilities of exceedances from limit values and predicted, actual values according to them

Limits ($\mu g/m^3$)	**Probability**	**Predicted(day)**	**Actual(day)**	**Difference**
90	0.0517	7.49	8	0.51
50	0.3883	56.30	56	0.30

Exceedance ($P(X > 50)$ and $P(X > 90)$) probabilities from the limits for PM_{10} concentrations are given in Table 5 for the Gamma distribution. In addition, actual and predicted exceedances and the difference between them are provided. As stated by Sansuddin et al. (2011, p.583) exceedances are acceptable, with a difference of less than 1 day. It can be seen from the table for both of the limit values (50 $\mu g/m^3$ and 90 $\mu g/m^3$) differences are less than 1 day. Meaningly, the predictive performance of the Gamma distribution function is satisfactory. When the probability function of PM_{10} is known for the considered area, prediction of the required emission reduction, and the frequency of exceedances from the limit values can be calculated since the governorships of the provinces takes action when long-term or short-term limits are exceeded.

Conclusion

In this study, the lognormal and Weibull and Gamma distributions are considered in modeling PM_{10} concentrations in Van, which is the most crowded city in Eastern Anatolia, Türkiye. In parameter estimation, the ML method is used. The results showed that the Gamma distribution described PM_{10} concentrations in Van better than Weibull and lognormal distributions. However, all of the considered pdf's performed very closely in modeling PM_{10} data. As it was mentioned previously, every region has its special characteristics thus in some cases, the lognormal distribution might not best option for describing air pollutants for the considered region as in this case.

In addition, exceedance probabilities and frequencies are also provided in the previous section. According to air quality assessment and management regulations in Türkiye, it is only allowed to exceed the limit value 35 times in a year however the daily mean PM_{10} concentrations exceeded the daily limits 56 times which is quite above the allowed number of exceedances determined by regulations in Türkiye. Since there is only one air quality measurement station in the city, the data obtained in this study cover an area where natural gas is widely used, considering the location station. It should be emphasized that the number of stations needs to be increased since fuels like coal, wood, or dried dung are extensively used where natural gas is not accessible. Specifically, it is recommended to establish two stations in areas where coal is used as fuel, such as Erciş District, and one station in the vicinity of the industrial zone. These additional stations would provide a more comprehensive and accurate assessment of air quality in the region. As emphasized in the 5-year air action plan by the Van Directorate of Environment and Urbanization, the necessity of modeling studies for preparing an Air Pollution map for Van, the findings of this study will help achieve this goal. Overall, it is known that along with damage to the environment, particulate matter pollution can cause serious health problems such as cancer, heart problems, respiratory diseases, and an increase in infant mortality rates. Hopefully, the study will be useful in controlling the risks arising from air pollutants in the considered region.

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Araştırma ve Yayın Etiği Beyanı

Araştırmacılar verilerin toplanmasında, analizinde ve raporlaştırılmasında her türlü etik ilke ve kurala özen gösterdiklerini beyan ederler.

Yazarların Makaleye Katkı Oranları

Makale tek yazarlı olarak hazırlanmıştır.

Çıkar Beyanı

Makalenin hazırlanmasında herhangi bir çıkar çatışması bulunmamaktadır