

Air Pollution from Transport Sector: Evaluation of Emissions in Yozgat Province

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ABSTRACT

In this study, vehicle-related emissions in Yozgat province were quantified and their impacts on air quality were analyzed. Emission calculations were performed based on traffic density and vehicle categories using data obtained from the General Directorate of Highways, and the resulting estimates were compared with data from the National Air Quality Monitoring Network. Within the scope of the study, road transport-related emissions of CO, NO_x, VOC, and PM in Yozgat province were calculated according to road segments and vehicle types, revealing that emission levels exhibit spatial variations depending on traffic intensity and route characteristics. The findings indicate that gasoline-powered vehicles contribute more significantly to CO and VOC emissions, whereas diesel-powered light commercial vehicles and buses are the primary sources of NO_x and PM emissions. Consequently, promoting the use of alternative fuels and improving public transportation systems are recommended in order to reduce vehicle-related pollution.

Ulaşım Sektöründen Kaynaklanan Hava Kirliliği: Yozgat İlinde Emisyonların Değerlendirilmesi

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Sorumlu Yazar

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Anahtar Kelimeler

Hava kalitesi

İçten yanmalı motorlar

Emisyonlar

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ÖZ

Bu çalışmada, Yozgat ilindeki araç kaynaklı emisyonlar belirlenmiş ve bunların hava kalitesi üzerindeki etkileri analiz edilmiştir. Emisyon hesaplamaları, Karayolları Genel Müdürlüğü verileri kullanılarak trafik yoğunluğu ve araç türlerine göre yapılmış ve elde edilen değerler Ulusal Hava Kalitesi İzleme Ağı verileriyle karşılaştırılmıştır. Çalışma kapsamında, Yozgat ilinde karayolu taşımacılığında kaynaklanan CO, NO_x, VOC ve PM emisyonları yol kesimi ve araç türü bazında hesaplanmış; emisyonların trafik yoğunluğu ve güzergâh özelliklerine bağlı olarak mekânsal farklılıklar gösterdiği belirlenmiştir. Benzinli araçların CO ve VOC emisyonlarının yüksek olduğu, dizel hafif ticari araçlar ve otobüslerin ise NO_x ve PM emisyonlarının daha yüksek olduğu tespit edilmiştir. Sonuç olarak, araç kaynaklı kirliliği azaltmak için alternatif yakıtların kullanımının teşvik edilmesi ve toplu taşıma sistemlerinin iyileştirilmesi önerilmektedir.

1. INTRODUCTION

Air pollution has become an increasingly serious environmental problem at both global and local scales due to increasing industrialization, urbanization, and the use of fossil fuels. Especially in large cities with high traffic density, air pollutants emitted from various sources pose serious threats to public health and the environment [1,2]. Pollutants such as PM, NO_x, and ozone cause health problems like respiratory diseases and heart conditions while also increasing the risk of premature death. Air pollution not only affects public health but also reduces agricultural production, damages ecosystems, and contributes to climate change. This situation has made it imperative to take measures to monitor and improve air quality [3,4].

Air pollution in Turkey is a critical issue, particularly in large cities and industrial areas. In provinces with high traffic density, exhaust emissions and fossil fuel use are among the main factors negatively affecting air quality. The National Air Quality Monitoring Network (UHKIA), established by the Ministry of Environment, Urbanization, and Climate Change, serves as a crucial tool for monitoring air quality nationwide and implementing necessary measures [5,6]. Based on the data obtained from this network, measures such as industrial emission control, traffic regulations, and the promotion of renewable energy sources are being implemented. However, even in regions with relatively low air pollution compared to major industrial centers, traffic-related emissions, fossil fuel use, and field burning have the potential to negatively impact air quality. Therefore, measures taken at the local level in different regions of Turkey must be supported by sustainable environmental policies [7,8].

Table 1. Literature review

Authors	Methodology	City/area	Common highlighted elements	Conclusion
Cuci & Polat [9] (2015)	Use of emission factors and activity data	Gaziantep	Traffic density, industrial zones	NO _x emissions below the limit values; organized industrial zone and city center are high pollution zones
Yakın & Behçet [10] (2019)	Emission inventory according to EMEP/EEA guidelines	Van	Fuel consumption and traffic impacts	CO: 442.78 tons/year, NO _x : 83.01 tons/year. Fossil fuel use increases air pollution.
Behçet & Yakın [11] (2020)	Emission inventory (CO, NO _x , PM, VOC)	Malatya	Alternative fuels and reducing vehicle density	CO: 768.22 tons/year, NO _x : 153.73 tons/year. Alternative fuel use is recommended.
Yakın [12] (2022)	Vehicle counts and emission calculations	Ağrı	Use of alternative energy sources	CO: 455.24 tons/year. Promotion of electric vehicles is recommended.
Çetin et al. [13] (2025)	EMEP/EEA 2023 Tier-1 emission inventory; Annual Average Daily Traffic data from the General Directorate of Highways; fuel distribution statistics from the Turkish Statistical Institute	Turkey (state highways; provincial level)	Temporal variation of road transportation-related emissions, contribution rates by vehicle types, and spatial concentration of emissions	It was determined that emissions originating from road transportation have increased over the years, with heavy-duty vehicles dominating NO _x and PM emissions, while passenger cars are the primary contributors to CO emissions. The Tier-1 approach provides a suitable basis for emission assessments at the provincial level.
Zhu et al. [14] (2025)	Field measurements; entropy-weighted evaluation method; VOC composition and reactivity analysis	An industrial city in the North China Plain	Sector-specific VOC emissions, chemical composition, and ozone and secondary aerosol formation potential	It was revealed that industrial VOC emissions exhibit significant differences across sectors, and that the petrochemical and pharmaceutical sectors are particularly critical in terms of air quality and health risks.
İbik & Öztürk [15] (2025)	IPCC Tier-1 method; long-term transportation activity and fuel consumption data	Ankara	Temporal variation of road transportation-related CO ₂ emissions and the influence of fuel types	It was determined that road transportation-related CO ₂ emissions have increased rapidly, and that diesel-fueled vehicles play a decisive role in total emissions. Investments in public transportation and integrated transportation policies are recommended for emission reduction.

An examination of the studies presented in Table 1 shows that road transportation–related emissions in Turkey have been assessed across different cities and regions using various methodologies. In the study conducted in Gaziantep, the impacts of traffic density and industrial areas on air quality were emphasized [9], while emission inventory studies carried out in Van and Malatya revealed the decisive roles of fuel consumption, vehicle type distribution, and traffic activities on emissions [10,11]. In the study focusing on Ağrı province, calculations based on vehicle counts indicated the prominence of passenger car–related CO emissions [12]. A recent nationwide study demonstrated that emissions originating from road transportation exhibit pronounced spatial variations at the provincial level and that heavy-duty vehicles dominate NO_x and PM emissions [13]. Research conducted specifically for Ankara also shows that road transportation–related CO₂ emissions have exhibited a rapid increasing trend over time and that diesel vehicles account for a high share of total emissions [15].

While the existing literature has predominantly focused on metropolitan areas, industrially intensive regions, or major transportation corridors, it is noteworthy that detailed road emission inventory studies targeting medium-sized provinces with relatively lower traffic volumes remain limited. Unlike previous studies conducted in provinces such as Gaziantep, Van, Malatya, Ankara, and Ağrı, this study addresses road transportation–related emissions in a medium-sized province such as Yozgat, rather than in large metropolitan areas characterized by high traffic volumes and industrial intensity, and examines emissions in detail on the basis of road segments and vehicle types; in this respect, it provides a complementary contribution to the existing literature in Turkey from both spatial and methodological perspectives. Accordingly, the primary objective of this study is to determine CO, NO_x, VOC, and PM emissions originating from road transportation in Yozgat province and to reveal the relationship between these emissions and traffic intensity. For this purpose, emissions were calculated on the basis of road segments and vehicle types using traffic volume data obtained from the General Directorate of Highways, and the EMEP/EEA 2023 Tier-1 emission factors were adopted in the calculations. Within the scope of the findings, CO, NO_x, VOC, and PM emissions originating from road transportation in Yozgat province were calculated according to road segments and vehicle types, and daily emission values for each road segment were obtained in tabular and graphical form. It is considered that the dataset and calculation approach developed within the framework of this study can be used in further analyses aimed at evaluating road transportation–related emissions at the provincial scale.

2. METHOD

In this study, CO, NO_x, VOC and PM emissions were calculated by taking into account the average traffic volume data on KGM state roads of Yozgat province for the year 2023 and the distribution of motor vehicles registered in Yozgat province according to their types. The calculations were carried out using the emission factors published by EEA and the values obtained were compared with the emission data of Yozgat province for the year 2023 in the UHKIA data bank. In this way, it is aimed to evaluate the impacts of vehicle emissions on the existing air quality in the region.

The road network of Yozgat province varies according to surface types and has a total network length of 1179.2 kilometers. Of this network, 1106.9 kilometers consist of asphalt roads, of which 402.4 kilometers are classified as asphalt concrete and 704.5 kilometers as surface coating. Provincial roads have a larger share than state roads with a length of 671.3 kilometers. Paved roads are 12 kilometers in total, while stabilized and dirt roads are almost non-existent. However, the total length of other roads is 59.3 kilometers and is concentrated especially on provincial roads [16]. Considering these data, Yozgat province is a province where the road infrastructure is largely composed of asphalt roads and the road quality is at a high level due to its location in the middle intersection points of Turkey [16,17].

The map presented in Figure 1 shows the highway network of Yozgat province and the connections between the districts. When the map is examined, it is seen that there are main arteries providing road transportation between different districts of the province. Yozgat province center is an important center of transportation within the province and consists of Akdağmadeni, Aydıncık, Boğazlıyan, Çandır, Çayıralan, Çekerek, Kadışehri, Saraykent, Sarıkaya, Sorgun, Şefaati, Yenifakılı, Yerköy districts [16,17].

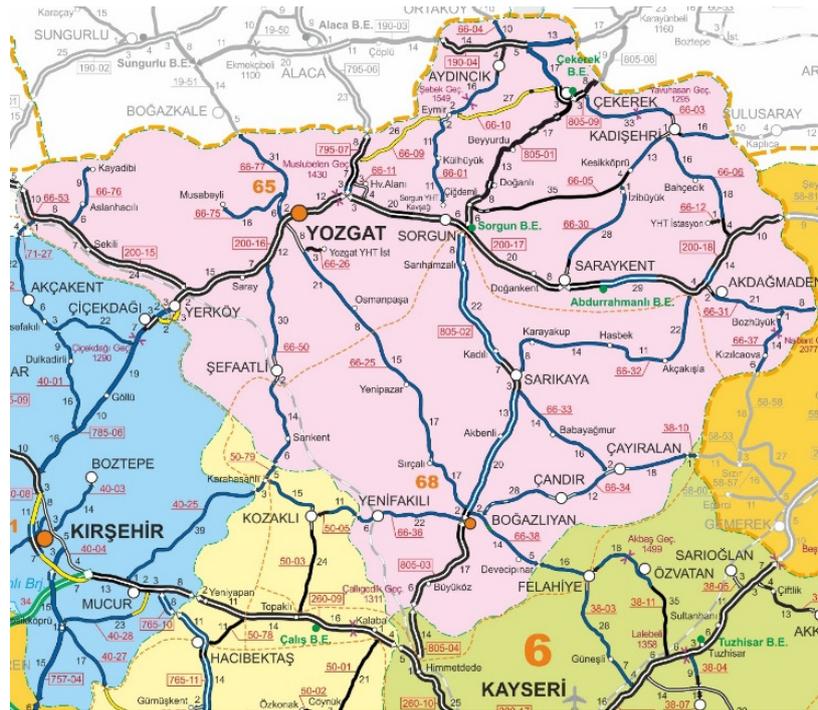


Figure 1. Highways map of Yozgat province [16]

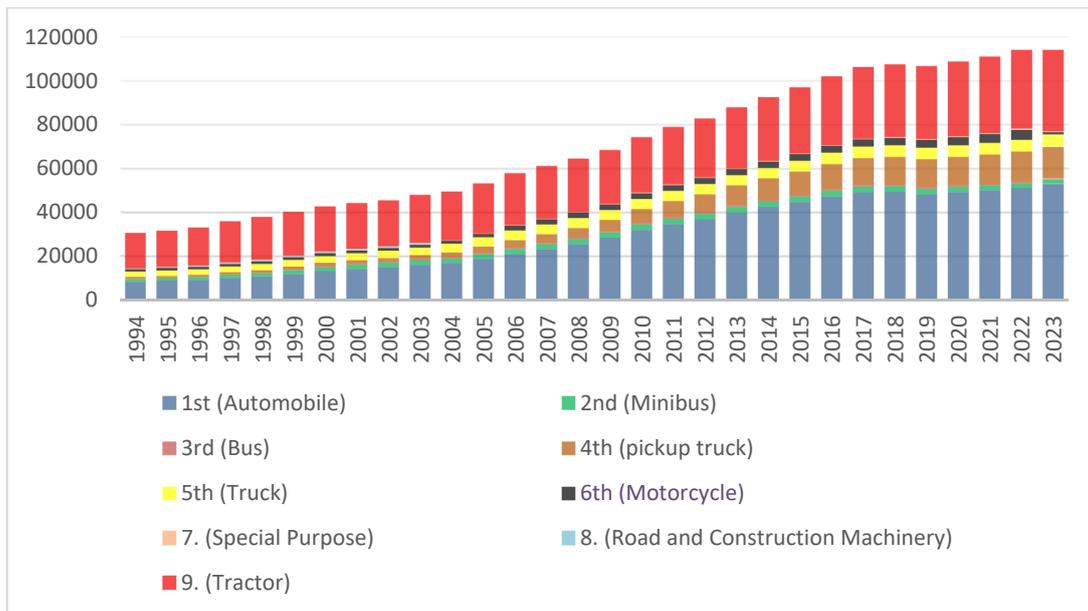


Figure 2. Number of motor vehicles of Yozgat province by vehicle types for the years 1994-2023 [18]

The graph shows the change in the number of motor vehicles in Yozgat between 1994-2023. When the data is analyzed, it is observed that different types of vehicles tend to increase numerically over time. Although it is seen that the automobile category has a significant share over the years, the number of tractors has also increased over time. The number of commercial and freight vehicles such as minibuses, buses, trucks and pickup trucks has also been on an upward trend, albeit fluctuating in certain years. It is also observed that the number of motorcycles has been increasing especially since 2010s [18].

An analysis of the graph for special-purpose vehicles, motor vehicles manufactured to carry people or goods for special purposes and used for special purposes such as fire brigade, lifeguard, funeral, radio, cinema, television, library, research vehicles and towing, transporting or lifting broken or damaged vehicles, shows that the share of such vehicles in the total number of vehicles is lower compared to other categories [18].

Table 2. Number of vehicles registered in Yozgat province in 2023 according to vehicle types [18]

Automobile	Minibus	Bus	Pickup truck	Truck	Motorcycle	Special purpose	Tractor
52936	2074	562	14336	5528	1111	407	37140

The number of vehicles registered in Yozgat province in 2023 according to vehicle types is presented in Table 2. When the data are analyzed, it is seen that automobiles and tractors have the largest share in the total number of vehicles. Light commercial vehicles and trucks also have a significant share, showing the role of freight transportation and commercial activities in urban and intercity transportation. The share of motorcycles and special purpose vehicles in the total number of vehicles is relatively lower [18].

Based on the total numbers of passenger cars (52.936), motorcycles (1.111), and light commercial vehicles (minibus: 2,074; pickup: 14.336) reported in Table 2, the composition of the light-duty vehicle fleet in Yozgat was derived. The share of motorcycles within the light-duty vehicle fleet was determined to be 1,58%. The remaining passenger cars were distributed according to fuel type based on the Turkish Statistical Institute (TURKSTAT) 2023 vehicle fuel-type proportions (33% gasoline, 48,2% diesel, and 18,5% LPG); LPG-fueled vehicles were assumed to have emission characteristics similar to gasoline vehicles and were therefore included in the gasoline category. Vehicles in the Diesel Light Commercial group were determined by considering the proportional distribution of diesel passenger cars according to TURKSTAT fuel statistics and the number of minibuses (diesel light commercial vehicles) reported in Table 2. The numbers of buses, trucks, and truck–trailer combinations were directly taken from the annual average daily traffic (AADT) values presented in Table 6, and separate emission factors were applied for each vehicle category. No fuel-type differentiation was made for these groups, and all buses, trucks, and truck–trailer combinations were assumed to be diesel-powered.

In the emission calculations, based on the updated data provided in the EMEP/EEA 2023 guidelines, the Tier 1 method relies on the product of the vehicle-category-specific emission factor for each pollutant (g pollutant/kg fuel) and the typical fuel consumption (g fuel/km). Within this approach, total emissions are obtained by multiplying the emission values per kilometer by the number of vehicles and the length of the relevant road segment, thereby extrapolating emissions to the regional scale [19,20].

$$E_{i,j} = EF_{i,j} \times A_j \times FC_j \tag{1}$$

In Equation (1) [9,15], $E_{i,j}$ denotes the emission of pollutant i for vehicle type j (g), $EF_{i,j}$ represents the emission factor (g/km), A refers to vehicle activity (km), and $FC_{i,j}$ indicates the fuel consumption per kilometer (g fuel/km).

$$A_j = N_j \times L \tag{2}$$

$$FC_j = sf_{c_{j,m}} \tag{3}$$

In the calculation of $E_{i,j}$, the parameter A_j used in Equation (2) represents the daily number of vehicles N_j and the length of the road segment L (km). The parameter FC_j is calculated in Equation (3) using the specific fuel consumption per kilometer, $sf_{c_{j,m}}$ defined according to vehicle type and fuel type [20].

Table 3. Emission factors by vehicle type and fuel type [20]

Vehicle type / Fuel	CO (g/kg fuel)	NO _x (g/kg fuel)	VOC (g/kg fuel)	PM (g/kg fuel)
Gasoline passenger car	48,36	3,98	7,75	0,02
Diesel passenger car	2,41	11,77	0,51	0,78
Gasoline light commercial vehicle	118,70	5,93	7,42	0,02
Diesel light commercial vehicle	6,81	13,48	1,23	1,22
Heavy-duty vehicle (diesel) / bus	6,10	25,95	0,90	0,55
Motorcycle (gasoline)	244,88	7,23	92,74	0,51

The Tier 1 emission factors presented in Table 3, expressed as grams of emissions per kilogram of fuel by vehicle type and fuel category, were compiled from the average values reported in Tables 3-5 (for CO and VOC) and 3-6 (for NO_x and PM) of the EMEP/EEA 2023 guidelines. For the Tier 1 methodology, these values represent European fleet averages and provide an appropriate baseline for the Turkish vehicle fleet [20].

Table 4. Fuel consumption per kilometer by vehicle category [20]

Vehicle type / Fuel	Fuel consumption (g fuel/km)
Gasoline passenger car	61,9
Diesel passenger car	56,8
Gasoline light commercial vehicle	72,5
Diesel light commercial vehicle	79,0
Heavy-duty vehicle (diesel) / bus	216,8
Motorcycle (gasoline)	27,7

The typical fuel consumption values per kilometer by vehicle category presented in Table 4 were obtained from Table 3-15 of the EMEP/EEA 2023 guidelines.

Table 5. Emissions per kilometer by vehicle type [20]

Vehicle type	CO (g/km)	NO _x (g/km)	VOC (g/km)	PM (g/km)
Gasoline passenger car	2,99	0,25	0,48	0,0012
Diesel passenger car	0,14	0,67	0,029	0,044
Gasoline light commercial vehicle	8,61	0,43	0,54	0,0015
Diesel light commercial vehicle	0,54	1,06	0,097	0,096
Heavy-duty vehicle (diesel) / bus	1,32	5,63	0,20	0,119
Motorcycle (gasoline)	6,78	0,20	2,57	0,014

The per-kilometer emission values presented in Table 5 represent the emissions per kilometer (g/km) calculated using the formula given in Equation 1, obtained from the product of the values reported in Table 3 and Table 4 [20].

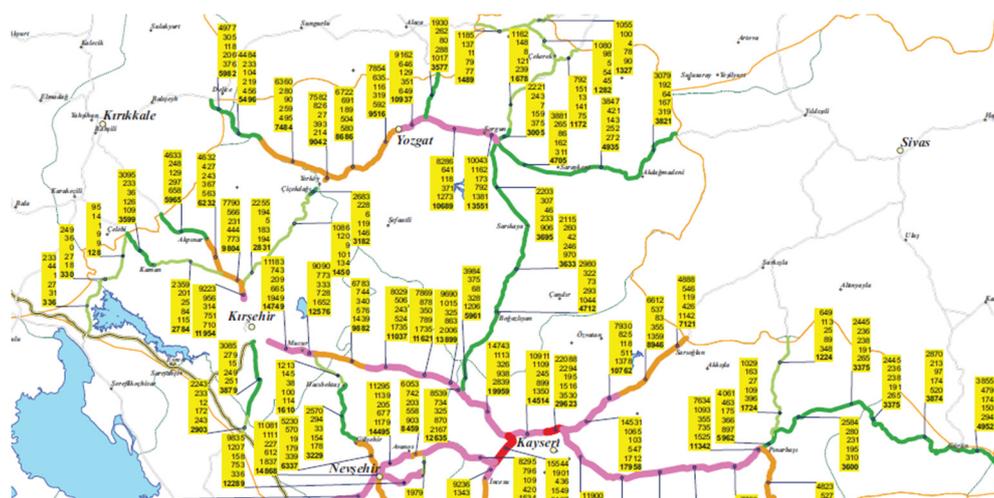


Figure 3. Highways Yozgat province traffic volume map [16]

Highways Yozgat province traffic volume map and vehicle density in the region are presented in Figure 3. The map shows that traffic flow in Yozgat is concentrated on certain routes. It is seen that especially the main roads providing intercity connections have high traffic volume, the highest traffic volume is realized on the Yozgat-Akdağmadeni route, especially on the section coded 200-17/2 with 10,043 vehicles per day, and the route with the lowest traffic volume is the Yozgat-Şefahtli road coded 805-09/0 with only 792 vehicle crossings per day, which is a very low density compared to other routes [16].

Table 6. KGM Yozgat province state roads average traffic values [16]

KKNO/ Slice	Road Name	Length	Vehicle Count Type	Automobile YOGT Vehicle/ Day	Medium Commercial Vehicle	Bus YOGT Vehicle/D ay	Truck YOGT Vehicle/ Day	Truck + Trailer Tow Truck + Semi-trailer YOGT Vehicle/Day
190-04/1	Yozgat-Kırıkkale	19	Forecast	1185	137	11	79	77
190-04/2	Yozgat-Kırıkkale	13	Forecast	1055	100	4	78	90
200-15/1	Yozgat-Çekerek	18	Otss3	4484	233	104	219	456
200-15/2	Yozgat-Çekerek	31	Forecast	6360	280	90	259	495
200-16/1	Yozgat-Sorgun				RAW ROADS			
200-16/2	Yozgat-Sorgun	2	Forecast	7582	826	27	393	214
200-16/3	Yozgat-Sorgun	22	Forecast	6722	691	189	504	580
200-16/4	Yozgat-Sorgun	14	Otss3	7854	635	116	319	592
200-16/5	Yozgat-Sorgun	12	Otss3	9162	646	129	351	649
200-17/1	Yozgat-Akdağmadeni	23	Otss3	8286	641	118	371	1273
200-17/2	Yozgat-Akdağmadeni	6	Forecast	10043	1162	173	792	1381
200-17/3	Yozgat-Akdağmadeni	28	Otss3	3881	265	86	162	311
200-18/1	Yozgat-Sefaati	33	Forecast	3847	421	143	252	272
200-18/2	Yozgat-Sefaati	24	Otss3	3079	192	64	167	319
795-07/0	Yozgat-Sefaati	18	Otss1	1930	262	80	288	1017
805-01/1	Yozgat-Sefaati	20	Forecast	1080	98	5	54	45
805-01/2	Yozgat-Sefaati	17	G.Traf	1162	148	8	121	239
805-01/3	Yozgat-Sefaati	20	Otss1	1162	148	8	121	239
805-01/4	Yozgat-Sefaati	7	Forecast	2221	243	7	159	375
805-02/1	Yozgat-Sefaati	37	Otss1	2203	307	46	233	906
805-02/2	Yozgat-Sefaati	36	Forecast	2115	260	42	246	970
805-02/3	Yozgat-Sefaati	2	Forecast	2980	322	73	293	1044
805-03/0	Yozgat-Sefaati	23	G.Traf	3984	375	68	328	1026
805-09/0	Yozgat-Sefaati	11	Otss1	792	151	13	141	75

Table 6 presents the AADT values recorded by the General Directorate of Highways for state roads in Yozgat province, disaggregated by road segment and vehicle type. The counting types reported in the table refer to different traffic measurement and estimation methods employed by the General Directorate of Highways. OTSS3 represents data based on continuous automatic vehicle counting and classification measurements conducted throughout the year using magnetic loop detectors. OTSS1 refers to automatic traffic measurements carried out for limited periods using portable counting equipment. Forecast data indicate estimated AADT values calculated for road segments where direct measurements are not available, based on traffic data from previous years and measurements from nearby segments. G.Traf (Route Traffic) denotes traffic volumes determined using data obtained from road segments with similar traffic characteristics [16].

Equation 3 [19,21] was used to calculate the emission values in kg/day according to the vehicle density during the day for Yozgat province highways given in Table 6.

$$\text{Emisyon (kg/gün)} = \text{Araç Sayısı} \times \text{Emisyon Faktörü (g/km)} \times \text{Uzunluk (km)} \times 10^{-3} \quad (3)$$

Based on these calculations, daily emission amounts were determined for each road section depending on the vehicle density and the emission distribution was analyzed in detail. The data obtained were used to evaluate the effect of traffic volume on air pollution by revealing the emission differences between road routes. Thus, the current situation of vehicle emissions in Yozgat province has been revealed on scientific basis and comparative evaluations have been made in the following analyzes.

3. FINDINGS AND DISCUSSION

The traffic density on the state roads of Yozgat province according to different vehicle types is given in Table 6. Considering the traffic volume, it is seen that especially the roads providing intercity connections have higher vehicle density compared to other routes. This shows that emission levels may vary depending on the road type and frequency of use. In this context, emission calculations for each road are given in Table 7. The data in Table 7 provides a detailed breakdown of emissions calculated on a daily basis by vehicle type.

Table 7. Emission calculations for Yozgat province road

KKNO	Road name	Length(km)	Vehicle type	Number	CO (kg/day)	NOx (kg/day)	VOC (kg/day)	PM (kg/day)
190-04/1	Yozgat-Kırıkkale	19	Gasoline Cars	740	59.44	4.22	8.86	0.0253
			Diesel Light Comm.	579	1.65	7.48	0.352	0.506
			Bus	11	0.276	1.18	0.0418	0.0249
			Truck	79	1.98	8.45	0.300	0.179
			Truck + trailer	77	1.93	8.23	0.293	0.174
Total Emission					65.28	29.56	9.847	0.909
190-04/2	Yozgat-Kırıkkale	13	Gasoline Cars	659	37.16	2.64	5.55	0.0158
			Diesel Light Comm.	531	1.05	4.69	0.221	0.317
			Bus	4	0.069	0.293	0.0104	0.0062
			Truck	78	1.32	5.62	0.199	0.119
			Truck + trailer	90	1.55	6.59	0.234	0.139
Total Emission					41.14	19.84	6.214	0.597
200-15/1	Yozgat-Çekerek	18	Gasoline Cars	2794	251.46	17.85	37.52	0.107
			Diesel Light Comm.	2183	5.95	26.72	1.26	1.80
			Bus	104	2.47	10.54	0.374	0.222
			Truck	219	5.21	22.22	0.788	0.469
			Truck + trailer	456	10.84	46.23	1.64	0.977
Total Emission					275.93	123.56	41.58	3.58
200-15/2	Yozgat-Çekerek	31	Gasoline Cars	3963	522.71	37.12	78.01	0.222
			Diesel Light Comm.	3097	14.57	65.40	3.08	4.41
			Bus	90	3.68	15.70	0.558	0.332
			Truck	259	10.60	45.20	1.60	0.954
			Truck + trailer	495	20.26	86.36	3.07	1.83
Total Emission					571.82	249.78	86.32	7.75
200-16/2	Yozgat-Sorgun	2	Gasoline Cars	4719	44.48	3.16	6.64	0.0189
			Diesel Light Comm.	3687	1.11	4.97	0.234	0.335
			Bus	27	0.071	0.304	0.0108	0.0064
			Truck	393	1.04	4.43	0.157	0.0935
			Truck + trailer	214	0.565	2.41	0.0856	0.0510
Total Emission					47.27	15.28	7.13	0.504
200-16/3	Yozgat-Sorgun	22	Gasoline Cars	4185	367.02	26.06	54.77	0.156
			Diesel Light Comm.	3270	10.95	49.15	2.32	3.32
			Bus	189	5.49	23.40	0.831	0.495
			Truck	504	14.65	62.46	2.22	1.32
			Truck + trailer	580	16.84	71.80	2.55	1.52
Total Emission					414.95	232.87	62.68	6.81
200-16/4	Yozgat-Sorgun	14	Gasoline Cars	4889	343.95	24.43	51.34	0.146
			Diesel Light Comm.	3820	8.05	36.14	1.70	2.44
			Bus	116	2.14	9.14	0.325	0.193
			Truck	319	5.90	25.15	0.892	0.531
			Truck + trailer	592	10.94	46.65	1.66	0.987
Total Emission					370.98	141.51	55.93	4.30
200-16/5	Yozgat-Sorgun	12	Gasoline Cars	5704	402.04	28.55	60.00	0.171
			Diesel Light Comm.	4458	8.03	36.07	1.70	2.43
			Bus	129	2.04	8.71	0.310	0.184
			Truck	351	5.56	23.71	0.842	0.501
			Truck + trailer	649	10.28	43.82	1.56	0.927
Total Emission					427.95	140.86	64.41	4.21

Table 7. Continued

200-17/1	Yozgat- Akdağmaden	23	Gasoline Cars	5157	541.49	38.45	80.81	0.230
			Diesel Light Comm.	4030	13.91	62.47	2.94	4.21
			Bus	118	3.58	15.27	0.542	0.323
			Truck	371	11.26	48.00	1.70	1.01
			Truck + trailer	1273	38.63	164.68	5.85	3.48
Total Emission				608.87	328.87	91.82	9.26	
200-17/2	Yozgat- Akdağmaden	6	Gasoline Cars	6251	220.08	15.63	32.85	0.0935
			Diesel Light Comm.	4886	4.41	19.80	0.933	1.34
			Bus	173	1.37	5.84	0.208	0.124
			Truck	792	6.27	26.75	0.950	0.565
			Truck + trailer	1381	10.94	46.64	1.66	0.986
Total Emission				243.07	114.66	36.60	3.11	
200-17/3	Yozgat- Akdağmaden	28	Gasoline Cars	2415	284.25	20.18	42.42	0.121
			Diesel Light Comm.	1888	7.93	35.61	1.68	2.40
			Bus	86	3.18	13.56	0.482	0.286
			Truck	162	5.99	25.54	0.907	0.540
			Truck + trailer	311	11.51	49.06	1.74	1.04
Total Emission				312.86	143.95	47.23	4.39	
200-18/1	Yozgat- Şefaati	33	Gasoline Cars	2395	394.68	28.03	58.91	0.168
			Diesel Light Comm.	1872	9.76	43.82	2.06	2.95
			Bus	143	6.23	26.56	0.944	0.561
			Truck	252	10.98	46.81	1.66	0.989
			Truck + trailer	272	11.85	50.51	1.79	1.07
Total Emission				433.50	195.73	65.36	5.74	
200-18/2	Yozgat- Şefaati	24	Gasoline Cars	1916	252.91	17.96	37.74	0.107
			Diesel Light Comm.	1498	5.39	24.21	1.14	1.63
			Bus	64	2.03	8.65	0.307	0.183
			Truck	167	5.29	22.56	0.801	0.477
			Truck + trailer	319	10.11	43.10	1.53	0.912
Total Emission				275.73	116.48	41.53	3.30	
795-07/0	Yozgat- Şefaati	18	Gasoline Cars	1201	151.34	10.75	22.59	0.0643
			Diesel Light Comm.	939	2.57	11.53	0.543	0.777
			Bus	80	1.90	8.10	0.288	0.171
			Truck	288	6.84	29.18	1.04	0.617
			Truck + trailer	1017	24.15	102.97	3.66	2.18
Total Emission				186.80	162.53	28.13	3.81	
805-01/1	Yozgat- Şefaati	20	Gasoline Cars	672	70.79	5.03	10.57	0.0301
			Diesel Light Comm.	525	1.58	7.08	0.333	0.477
			Bus	5	0.132	0.563	0.0200	0.0119
			Truck	54	1.43	6.08	0.216	0.128
			Truck + trailer	45	1.19	5.07	0.180	0.107
Total Emission				75.11	23.81	11.31	0.754	
805-01/2	Yozgat- Şefaati	17	Gasoline Cars	723	64.88	4.61	9.68	0.0276
			Diesel Light Comm.	565	1.63	7.32	0.345	0.494
			Bus	8	0.180	0.766	0.0272	0.0162
			Truck	121	2.73	11.64	0.414	0.246
			Truck + trailer	239	5.39	22.98	0.816	0.485
Total Emission				74.81	47.31	11.22	1.27	
805-01/3	Yozgat- Şefaati	20	Gasoline Cars	723	76.33	5.42	11.39	0.0324
			Diesel Light Comm.	565	1.92	8.61	0.406	0.581
			Bus	8	0.211	0.901	0.0320	0.0190
			Truck	121	3.19	13.62	0.484	0.288
			Truck + trailer	239	6.31	26.91	0.956	0.569
Total Emission				87.96	55.46	13.28	1.49	

Table 7. Continued

805-01/4	Yozgat-Şefaati	7	Gasoline Cars	1382	60.87	4.32	9.08	0.0259
			Diesel Light Comm.	1080	1.13	5.09	0.240	0.343
			Bus	7	0.065	0.276	0.0098	0.0058
			Truck	159	1.47	6.27	0.223	0.132
			Truck + trailer	375	3.47	14.79	0.525	0.312
Total Emission				67.00	30.74	10.08	0.819	
805-02/1	Yozgat-Şefaati	37	Gasoline Cars	1371	280.96	19.95	41.93	0.119
			Diesel Light Comm.	1072	5.89	26.44	1.25	1.78
			Bus	46	2.24	9.56	0.340	0.202
			Truck	233	11.39	48.56	1.72	1.03
			Truck + trailer	906	44.27	188.74	6.70	3.99
Total Emission				344.75	293.25	51.94	7.12	
805-02/2	Yozgat-Şefaati	36	Gasoline Cars	1316	254.04	18.04	37.92	0.108
			Diesel Light Comm.	1029	5.55	24.92	1.17	1.68
			Bus	42	2.00	8.52	0.302	0.180
			Truck	246	11.70	49.88	1.77	1.05
			Truck + trailer	970	46.11	196.58	6.98	4.15
Total Emission				319.40	297.94	48.14	7.17	
805-02/3	Yozgat-Şefaati	2	Gasoline Cars	1855	15.62	1.11	2.33	0.00663
			Diesel Light Comm.	1450	0.44	1.96	0.0923	0.132
			Bus	73	0.193	0.823	0.0292	0.0174
			Truck	293	0.774	3.30	0.117	0.0697
			Truck + trailer	1044	2.76	11.76	0.418	0.249
Total Emission				19.79	18.96	2.99	0.475	
805-03/0	Yozgat-Şefaati	23	Gasoline Cars	2479	233.56	16.58	34.85	0.0992
			Diesel Light Comm.	1938	6.69	30.03	1.41	2.02
			Bus	68	2.07	8.81	0.313	0.186
			Truck	328	9.96	42.48	1.51	0.898
			Truck + trailer	1026	31.14	132.76	4.72	2.81
Total Emission				283.42	230.66	42.80	6.01	
805-09/0	Yozgat-Şefaati	11	Gasoline Cars	493	25.49	1.81	3.80	0.0108
			Diesel Light Comm.	385	0.79	3.56	0.168	0.240
			Bus	13	0.189	0.805	0.0286	0.0170
			Truck	141	2.05	8.73	0.310	0.184
			Truck + trailer	75	1.09	4.64	0.165	0.098
Total Emission				29.60	19.55	4.47	0.550	

An examination of Table 7 indicates that emissions originating from road transportation in Yozgat province vary by vehicle type and route. The table data reveal that gasoline passenger cars exhibit higher emission levels, particularly for CO and VOC, compared to other vehicle categories. This finding should be interpreted in conjunction with the relatively high share of gasoline vehicles within the total vehicle fleet.

In contrast, diesel light commercial vehicles, buses, and heavy-duty vehicles are observed to make more pronounced contributions in terms of NO_x and PM emissions. In particular, routes with intensive use of trucks and truck-trailer combinations exhibit increased NO_x and PM emission levels. Although heavy-duty vehicles constitute a relatively smaller proportion of the total vehicle fleet, their high per-vehicle emission factors account for this outcome. A route-based assessment indicates that total emission amounts increase along the Yozgat-Akdağmadeni, Yozgat-Çekerek, and Yozgat-Sorgun roads, where traffic intensity is relatively high. Conversely, emission levels remain more limited on road segments with lower daily traffic volumes. These findings demonstrate that emission magnitudes are directly associated with vehicle type distribution, road length, and traffic volume.

Air pollution poses a significant threat to the environment and public health, particularly due to emissions originating from road transportation [22,23]. Pollutants such as CO, NO_x, VOCs, and PM released from road transport accumulate in the atmosphere and adversely affect air quality [24]. These pollutants lead to respiratory and cardiovascular diseases, cause ecosystem degradation, and contribute to global climate change in the long term. In this context, the accurate calculation of vehicle emissions plays a critical role in identifying strategies to improve air quality [25-27]. In this study, emissions originating from vehicles in Yozgat province were calculated and compared with NCCIH data. The emission data used in the study were evaluated according to traffic intensity and vehicle types, and the emission amounts generated by each

vehicle group were analyzed in detail. This analysis, prepared using data from the General Directorate of Highways, demonstrates the impact of vehicle emissions on air quality even in medium-sized cities such as Yozgat.

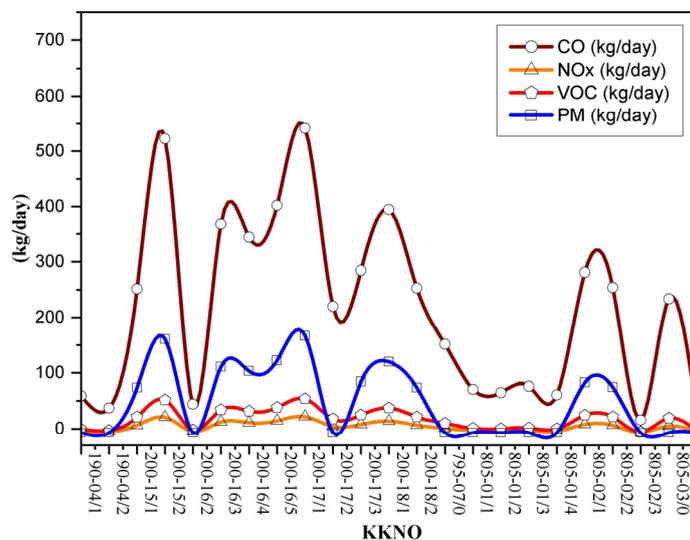


Figure 4. Emission graph of gasoline cars for Yozgat province roads

An examination of Figure 4 indicates that among the emissions originating from gasoline passenger cars, CO exhibits higher values compared to other pollutants. CO emissions display a fluctuating distribution along the road segments, while VOC emissions follow a trend similar to that of CO but remain at lower levels. The highest CO emission values are observed on the road segments corresponding to the Yozgat–Akdağmadeni and Yozgat–Çekerek routes. In contrast, NO_x and PM emissions remain low across all routes, with only limited variation.

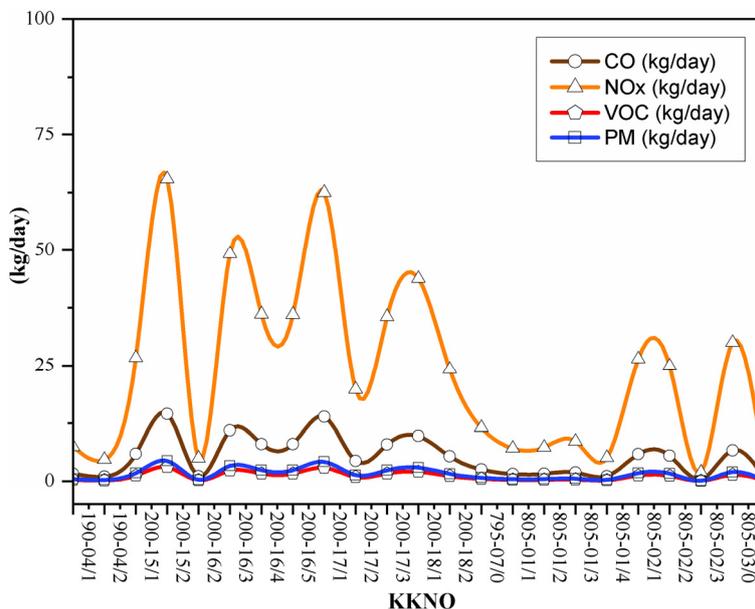


Figure 5. Emission graph of diesel light commercial vehicles for Yozgat province roads

An examination of Figure 5 shows that among the emissions originating from diesel light commercial vehicles, NO_x emissions exhibit higher values compared to the other pollutants. NO_x emissions display pronounced fluctuations along the road segments, reaching peak levels on certain routes. CO and VOC emissions remain at lower levels relative to NO_x, while PM emissions are limited across all road segments. The highest CO and NO_x emission values are concentrated on the road segments corresponding to the Yozgat–Akdağmadeni and Yozgat–Çekerek routes.

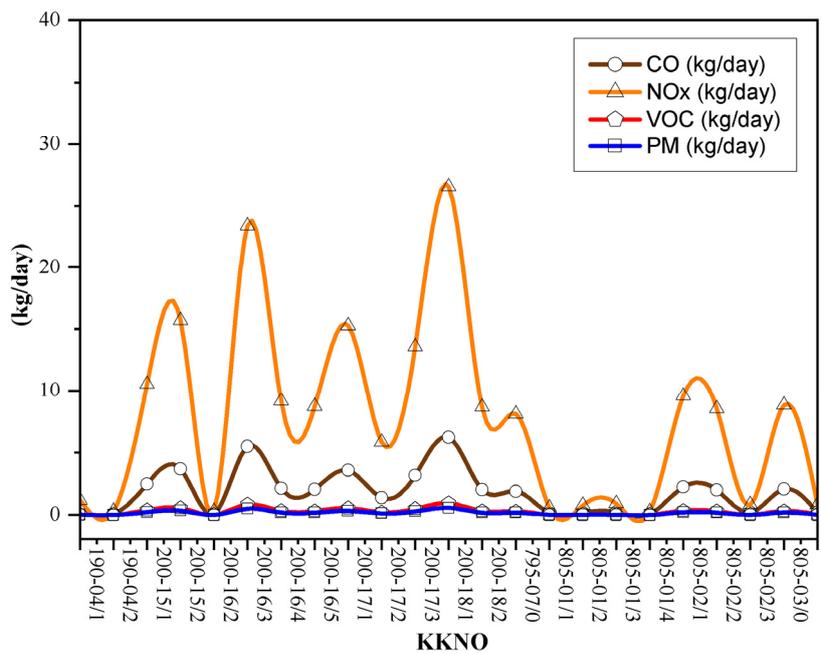


Figure 6. Emission graph of bus vehicles for Yozgat province roads

An examination of Figure 6 indicates that among the emissions originating from buses, NO_x emissions exhibit higher values compared to the other pollutants. NO_x emissions show a fluctuating distribution along the road segments, with pronounced peaks observed on certain segments. CO emissions remain at lower levels relative to NO_x, while VOC and PM emissions are limited across all routes.

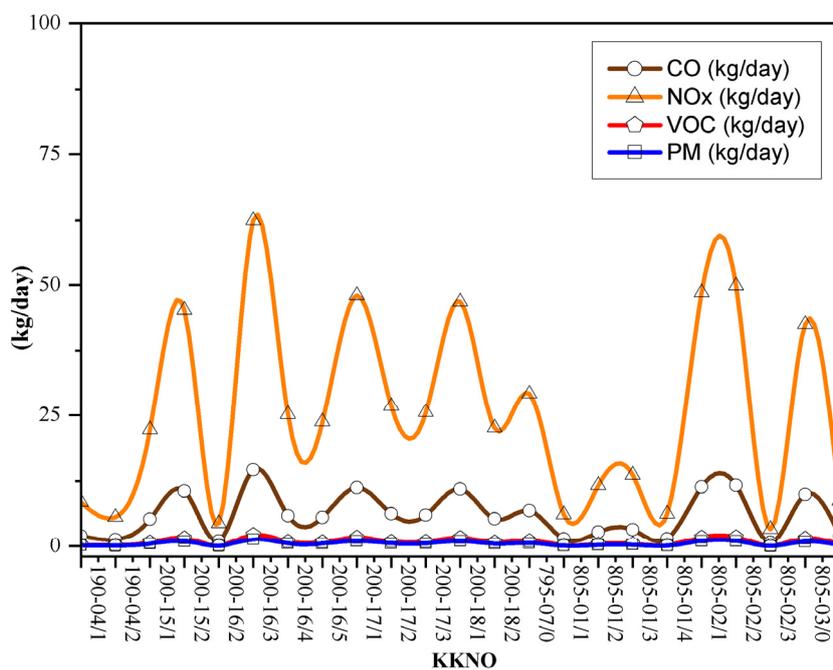


Figure 7. Truck emission graph for Yozgat province roads

An evaluation of the emission distribution for trucks in Figure 7 shows that NO_x emissions vary over a wider range than the other pollutants across the graph. NO_x values exhibit sharp increases on certain road segments, which are clearly represented as distinct peaks in the figure. CO emissions remain within a narrower range compared to NO_x, while VOC and PM emissions stay at low levels across all road segments. This emission pattern indicates that certain routes with intensified truck traffic stand out in terms of NO_x emissions.

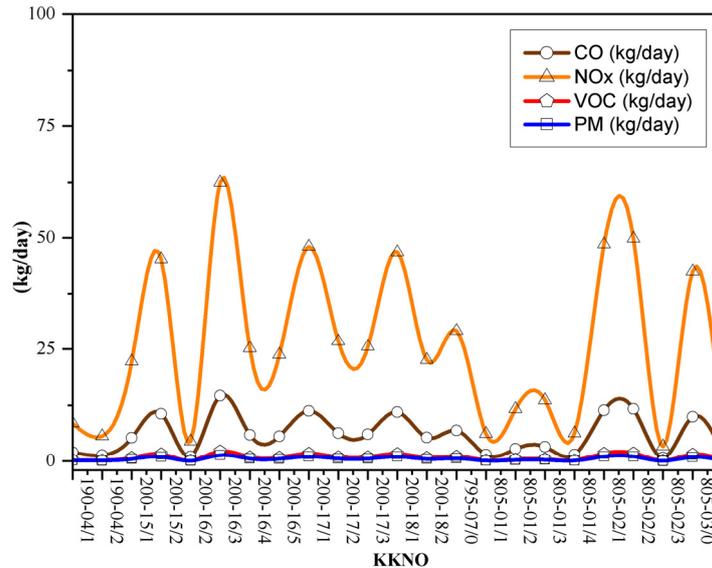
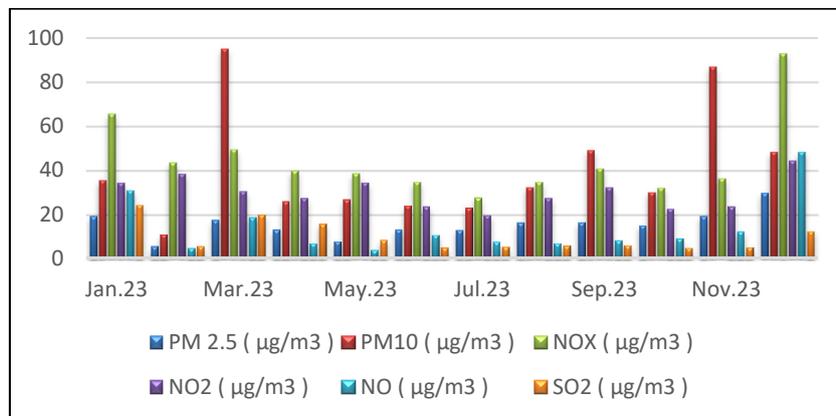
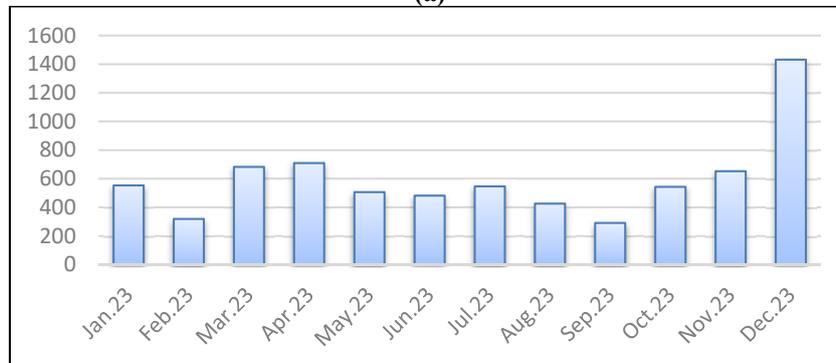


Figure 8. Truck + trailer emission graph for Yozgat province roads

An examination of the emission distribution for trucks and truck–trailer combinations in Figure 8 shows that NO_x emissions form pronounced peak values across the graph. NO_x emissions exhibit abrupt increases on certain road segments, represented by distinctly higher levels compared to the other pollutants. CO emissions remain at lower levels than NO_x but follow a similar fluctuating pattern, while VOC and PM emissions are confined within a narrow range along all road segments. The overall distribution indicates that emission levels increase markedly on specific segments where truck and truck–trailer traffic is concentrated.



(a)



(b)

Figure 9. Change in emissions (a) and CO₂ (µg/m³) emissions (b) according to months in NHKIA Yozgat Province in 2023

According to the general emission data for the year 2023 presented in Figure 9, PM and NO_x emissions show a significant increase in winter months. While VOC emissions increase in summer months, CO emissions follow a relatively balanced course throughout the year. PM emissions reach their highest levels especially during the cold months, while they decrease in other periods of the year. NO_x emissions fluctuate throughout the year, with an increasing and decreasing trend in certain periods.

The emission data calculated according to vehicle types presented in Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8 reveal the effect of vehicle-derived air pollutants on air quality in Yozgat province. In these graphs, it is determined that especially CO, NO_x, VOC and PM emissions vary depending on different vehicle types. Heavy vehicles (trucks and trailers/trailers) are found to produce high levels of NO_x and PM, while gasoline cars produce high levels of CO and VOC emissions. Diesel light commercial vehicles have a significant contribution in terms of both NO_x and PM emissions, and buses have a significant contribution, especially in NO_x emissions.

When the general emission data for the year 2023 presented in Figure 9 is analyzed, the share of vehicle-based emissions calculated in the study in total air pollutants can be determined. According to the NCCIA data, it is seen that emissions from vehicles make a significant contribution to the total air pollutants. In particular, vehicles have a dominant share in CO and NO_x emissions, while other sources play an important role in PM and VOC emissions. Vehicle emissions calculations show that a large portion of NO_x emissions, in particular, come from motor vehicles. However, when PM emissions are evaluated, it is seen that emissions from vehicles constitute only a certain portion of the total PM load, while the remaining part may be caused by industrial activities, fossil fuel use for heating, agricultural activities and naturally occurring dust emission [28,29].

This comparison shows that air pollution is not limited to vehicular emissions, but industry, heating, agriculture and other environmental factors in the region also have a significant impact on air quality. However, reducing emissions from the transportation sector requires measures to be taken, especially to reduce CO and NO_x levels.

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, CO, NO_x, VOC, and PM emissions originating from road transportation in Yozgat province were calculated on the basis of road segments and vehicle types using traffic volume data obtained from the General Directorate of Highways and Tier 1 emission factors provided in the EMEP/EEA 2023 guidelines. While the existing literature predominantly focuses on metropolitan areas and industrially intensive regions, this study differs by presenting a detailed emission inventory for a medium-sized province. In addition, evaluating emissions not only in terms of total amounts but also by disaggregating them according to routes and vehicle types enables a clearer representation of the spatial distribution of traffic-related air pollution at the regional scale.

The main results of the study can be summarized as follows:

- I. It was determined that CO, NO_x, VOC, and PM emissions originating from road transportation in Yozgat province exhibit pronounced differences depending on vehicle type and road segment.
- II. Gasoline passenger cars were found to be prominent contributors in terms of CO and VOC emissions, whereas diesel light commercial vehicles, buses, and heavy-duty vehicles contribute more substantially to NO_x and PM emissions.
- III. Total emission amounts were observed to increase along the Yozgat–Akdağmadeni, Yozgat–Çekerek, and Yozgat–Sorgun routes, where traffic volume is relatively high, while emission levels remained more limited on road segments with lower traffic intensity.
- IV. The spatial distribution of emissions was found to be directly related to road length and daily vehicle counts.
- V. The emission graphs prepared by vehicle type support the quantitative findings presented in Table 7 and reveal pronounced fluctuations and peak values, particularly for CO and NO_x emissions.
- VI. The comparison with NHQMN data indicates that vehicle-related emissions constitute a significant share of the overall air pollution burden, especially in terms of CO and NO_x components.

Based on the findings obtained in this study, future research aimed at a more detailed assessment of emissions originating from road transportation in Yozgat province should move beyond this approach based on fixed emission factors and instead evaluate emissions using more comprehensive datasets that include variables such as vehicle counts, speed distributions, fuel types, and vehicle age. In particular, the application of Tier 2 or Tier 3 methodologies that incorporate real-time traffic measurements conducted at the road-segment level and consider fleet characteristics may reveal the spatial and temporal variation of vehicle-related emissions in a more detailed manner.

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