Research Journal of Agricultural Science, 58 (3), 2026; ISSN: 2668-926X;

http://doi.org/10.59463/RJAS.2026.3.03

TEMPORAL VARIATION OF SELECTED AIR QUALITY INDICATORS IN BUDAPEST, HUNGARY

Bushra ANSARI[1], Bayar TEGSHJARGAL[1], Thipphaphone SYSAVATH[1], Liliana TÖRÖK[1], Zs. TÖRÖK[1]

[1]John Wesley Theological College, Department of Environmental Security, Budapest, Danko Street, No. 11, 1086, Hungary

Corresponding author: torokliliana@yahoo.com

Abstract. *Budapest's air quality—essential for public well-being, ecological balance, and economic stability—has been analysed in the context of the semester projects conducted by students from the John Wesley Theological College under the auspices of the Department of Environmental Security. The authors of this study collected data from the AccuWeather platform over a 16-month period, between September 2024 and September 2026. The results show that Fine Particulate Matter ($PM_{2.5}$) concentrations ranged from 5 to 51 µg/m³, with a mean of 15.07 µg/m³ and a median of 10 µg/m³. Particulate Matter (PM_{10}) concentrations ranged from 6 to 69 µg/m³, with a mean of 24.44 µg/m³. Nitrogen dioxide (NO_2) concentrations ranged from 6.9 to 59 µg/m³, with a mean of 28.97 µg/m³. Ozone (O_3) concentrations ranged from 5 to 71 µg/m³, with a mean of 38.56 µg/m³. Sulphur dioxide (SO_2) ranged from 1 to 8 µg/m³, with a mean of 3 µg/m³. Carbon monoxide (CO) concentrations ranged from 127 to 585 µg/m³, with a mean of 226.68 µg/m³. Overall air quality ranged from Harmful to Healthy to Good. Particulate matter, NO_2 and SO_2 reached their highest values in autumn, at the start of the heating season, while O_3 was highest in summer. Mean $PM_{2.5}$, PM_{10} and NO_2 concentrations exceeded the World Health Organisation (WHO) 2021 long-term guideline levels, while SO_2 and CO remained well below them, which agrees with the long-term decline in sulphur emissions reported in earlier Hungarian studies. These results suggest that pollutants linked to traffic and residential heating remain the main air quality concern in Budapest.*

Keywords: *air quality, Budapest, particulate matter, nitrogen dioxide, ozone, sulphur dioxide, carbon monoxide, AccuWeather*

INTRODUCTION

Budapest, the capital of Hungary, is situated in the Carpathian Basin. The Danube divides the hilly Buda side from the flat Pest side, and this varied setting, together with the urban heat island, shapes the local climate of the city (TÓTH-RONKAY et al., 2015). The air quality of Budapest is determined mainly by local residential heating and traffic emissions combined with the meteorological conditions (Ferenczi and Bozó, 2017). Persistent wintertime high-pressure situations can lead to smog episodes, while ozone levels are elevated in summer (TÓTH-RONKAY et al., 2015).

For over 150 years, the Hungarian Meteorological Service (***, 2020) has organized, coordinated, and implemented the monitoring and forecasting of weather conditions and air quality in Hungary (LOVAS et al. 2006; FERENCZI & BOZÓ, 2017; FERENCZI et al. 2021). The observations and research covered a wide range of parameters, from aerosols to gaseous substances and particulate matter (SALMA et al., 1998, 2000, 2004).

Furthermore, studies concerning the impact of—and the response to—biotic and abiotic environmental factors have been frequently addressed (CHEN et al., 2023, 2024; FERENCZI et al., 2021; FERENCZI and BOZÓ, 2017; KONDOR, 2018; SZABÓ et al 2023; SIPOS et. al., 2012; SEPSI et al., 2015;). In addition to these, there are studies focused on improving methodology, defining thresholds, and modelling long-term spatial and temporal projections (ALATAWNEH et al., 2026; HAVASI and ZLATEV, 2002; KOVÁCS et al. 2021; LEELŐSSY et al., 2017; LOVAS et al., 2006;

STEIB et al., 2008; TORDAI and MÉSZÁROS, 2025), as well as the sources and geographical origin of some pollutants (PERRONE et al, 2018) and health and environmental benefits resulting from effective managerial decisions to reduce pollution (AUNAN et al., 1998)

The present study focuses on the six so-called classical air pollutants: particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and carbon monoxide (CO).

MATERIAL AND METHODS

Study Design

Data collection began as part of a semester project at John Wesley Theological College, Budapest. The study carried out during September 2024 until September 2026. Six air pollutants were chosen for observation: fine particulate matter ($PM_{2.5}$), particulate matter (PM_{10}), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), and carbon monoxide (CO). Air quality data were obtained from the AccuWeather online service. For each observation, the reported $PM_{2.5}$, PM_{10}, NO_2, O_3, SO_2, and CO concentrations were given in µg/m³ (units of data source) using the units specified therein.

Data analysis

The selected parameters were used to study changes in reported concentrations of air pollutants over the course of the study period. Due to combined datasets collected by two members of the research team independently and the difference in the time frame: the first dataset was collected weekly from 29 September 2025 to 9 February 2026, observations were made every Monday (usually between 13:00 and 14:00 Central European local time); the second dataset were taken irregularly between September 2024 and September 2026 (usually in the evening or nighttime), for the statistical analysis, the mean value of the concentration of the parameters recorded in the database was used.

Descriptive statistics (minimum, maximum, mean, and median) of each pollutant concentration were calculated from the dataset. For the purpose of analysing the selected parameters over the years, the analysis was based on median values—rather than the mean—due to the more accurate representation provided by the median.

Recorded values were also examined to see if there are temporal variations in selected air quality indicators. Since the observations were made online (via an internet weather site) rather than directly measured with research-operated monitoring equipment, the results are reported as air quality values at the times of data collection.

RESULTS AND DISCUSSION

Urban air quality is influenced by emission sources, meteorological conditions and the transport of pollutants between regions (FERENCZI and BOZÓ, 2017). Examining how the concentrations of air pollutants change over time can therefore help to describe the conditions experienced within a city.

Temporal variations in the monitored air quality indicators (PM2.5, PM10, NO2, O3, SO2, and CO) in Budapest reveal distinct seasonal patterns and year-over-year fluctuations. Fine particulate matter concentrations showed synchronized temporal trends. As shown in Figure 1, the lowest recorded concentration occurred in September 2026 (5 µg/m³), peaking the same year but in January at 51 µg/m³.

Research Journal of Agricultural Science, 58 (3), 2026; ISSN: 2668-926X;
http://doi.org/10.59463/RJAS.2026.3.03

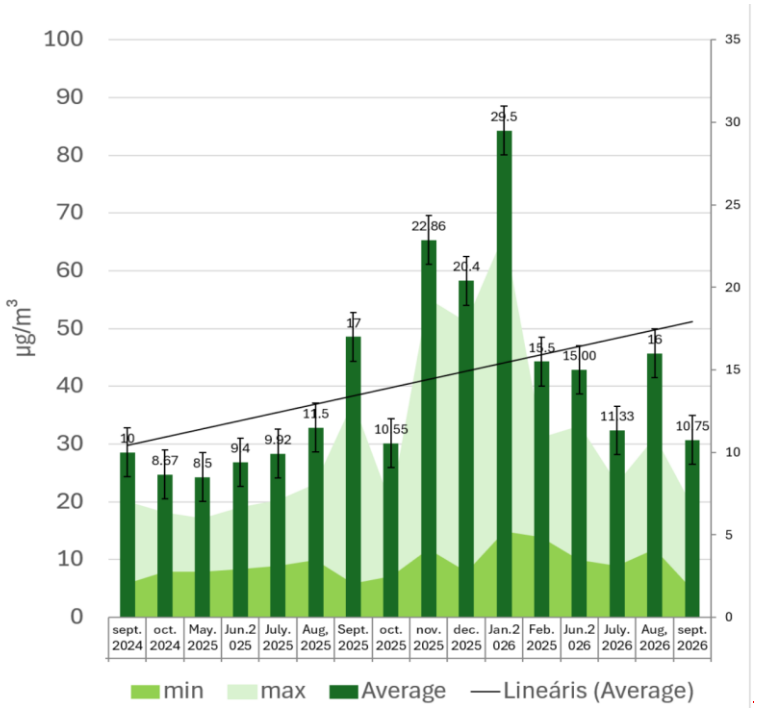


Figure 1. Trend of particulate matter (PM 2.5 (µg/m³))

During the summer season, concentrations of fine particles reached their lowest level—likely due in part to the fact that, during this period, large companies typically go on break, and city life—with the exception of the central tourist area—seems to slow down.

Previous studies have shown that, despite efforts to reduce the concentration of particulate matter in the atmosphere, the number exceedances of the threshold value (50 µg/m^3) continues to be higher than the standards mandated by EU regulations (FERENCZI et al, 2021).

Currently, PM10 concentrations reached a baseline low of 6 µg/m³ in October 2025 before climbing to a highest concentration of 69 µg/m³ in May 2026 (Figure 2).

Research Journal of Agricultural Science, 58 (3), 2026; ISSN: 2668-926X;
http://doi.org/10.59463/RJAS.2026.3.03

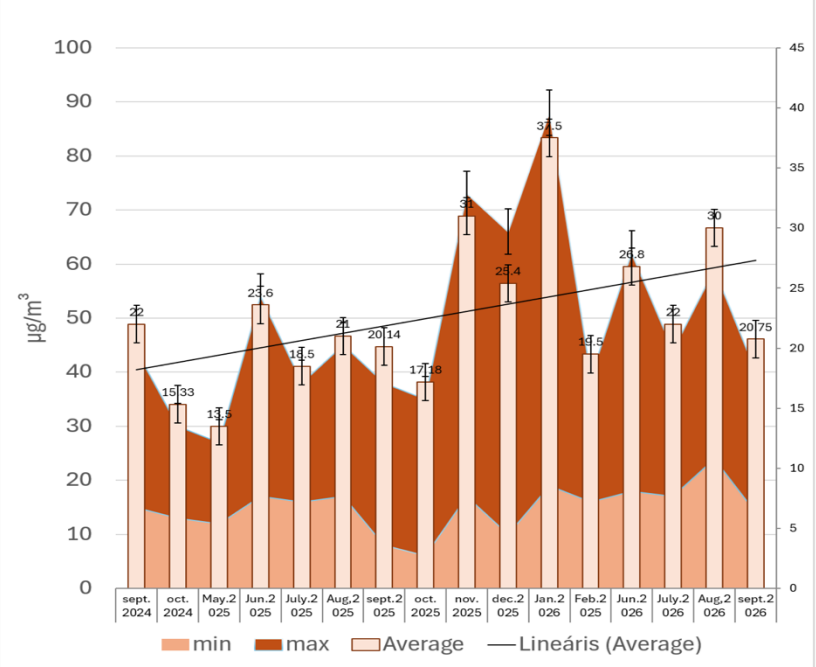


Figure 2. Trend of particulate matter (PM_{10} (µg/m³))

Studies conducted between 2006 and 2010 have shown that PM10 concentrations exceed the limit value, primarily during the winter and autumn (FERENCZI, 2013).

Gaseous pollutants displayed highly variable seasonal dynamics. Nitrogen dioxide (NO_2) monthly averages ranged from a minimum of 6.9 µg/m³ (October 2025) to a primary peak of 68 µg/m³ (May 2026) (Figure 3).

Research Journal of Agricultural Science, 58 (3), 2026; ISSN: 2668-926X;
http://doi.org/10.59463/RJAS.2026.3.03

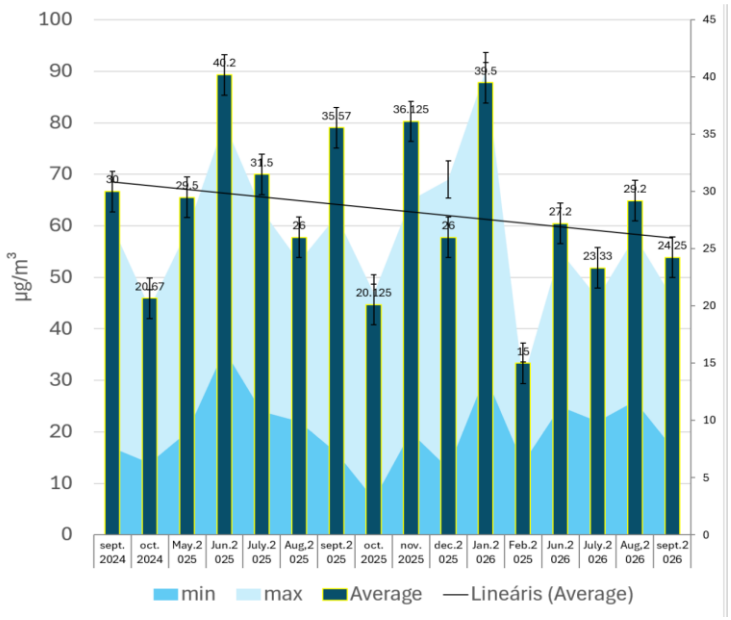


Figure 3. Trend of Nitrogen dioxide (NO_2 (µg/m³))

During the recorded period, the O_3 Fig.4) concentration varied between 5 µg/m³ (November 2025 to January 2026) and 71 µg/m³ (August 226).

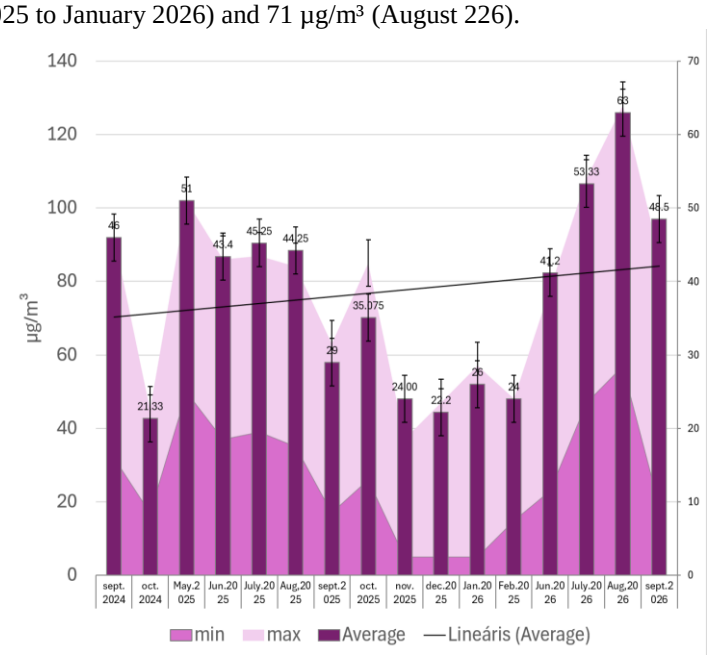


Figure 4. Trend of Ozone (O_3 (µg/m³))

Upon analysing the historical data provided by BOZÓ and BARANKA (1996) analysed the measurements of the urban monitoring network together with dispersion modelling, the authors observed that sulphur dioxide concentrations were higher in winter than in summer and showed a slight decline in the first half of the 1990s.

Nowadays, sulphur dioxide (SO_2) concentration remained low (1 to 8µg/m³) (Figure 5).

When comparing our findings with the historical study by BOZÓ and BARANKA (1996), a notable downward shift in sulphur dioxide concentrations is evident. While historical monitoring and dispersion modelling in the mid-1990s showed higher SO_2 levels during winter periods driven by high sulphur solid and liquid fuel usage, our current observations indicate that SO_2 concentrations remain consistently low (ranging between 1 and 8µg/m³, with an overall mean of 3µg/m³). This significant decrease aligns with broader long-term emission reductions resulting from modern industrial transitions, cleaner residential heating alternatives, and strict fuel quality regulations implemented in Hungary over the past few decades.

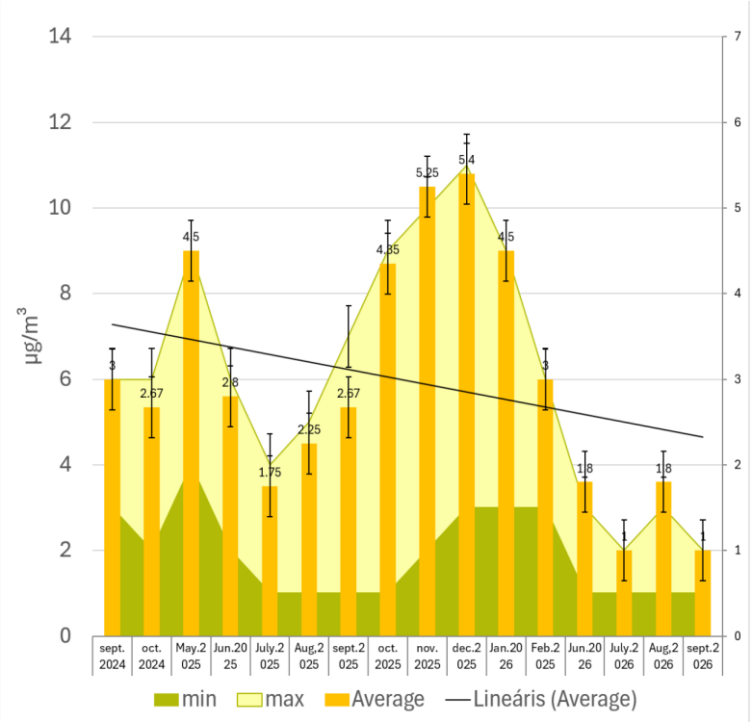


Figure 5. Trend of Sulfur Dioxide (SO_2 (µg/m³))

Carbon monoxide (CO) exhibited distinct episodic tracking. The distinct episodic tracking and sharp winter peaks observed in carbon monoxide concentration (reaching up to 585µg/m³ in January) are primarily driven by a combination of increased anthropogenic emissions and unfavourable meteorological conditions. During the colder month, vehicular traffic emissions combine with residential heating activities. Simultaneously, frequent winter temperature inversions and low atmospheric mixing heights in the Carpathian Basin trap

pollutants near the surface preventing proper dispersion and causing short-term accumulation spikes.

During the recorded period, the CO (Fig.6) concentration varied between 127 µg/m³ (September 2025) and 585 (January 2026) µg/m³.

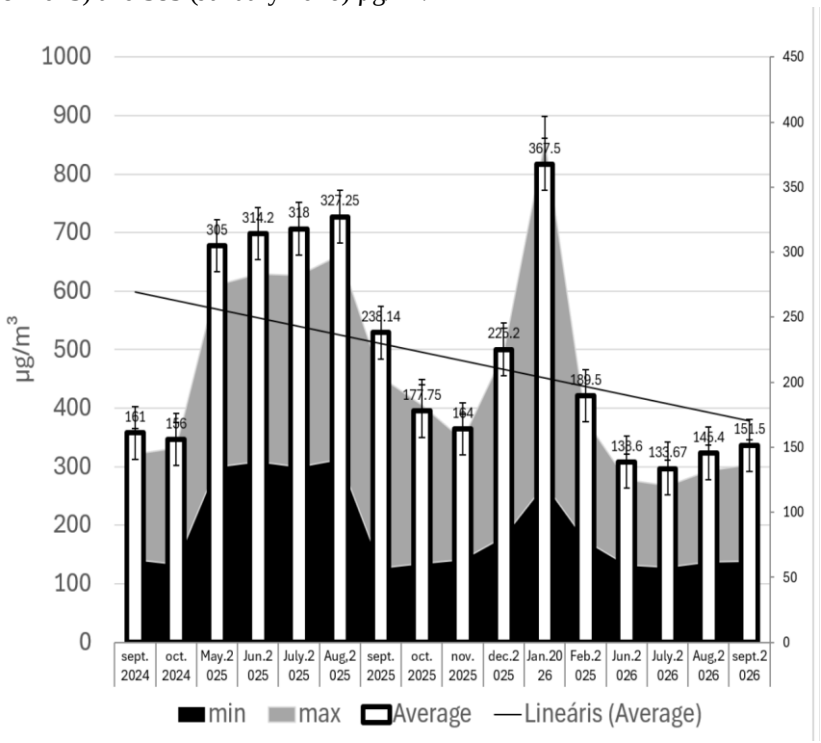


Figure 6. Trend of Carbon Monoxide (CO (µg/m³))

A direct year-over-year comparison between September 2025 and September 2026 reveals contrasting directional shifts among parameters. While mean concentrations offer a general overview of seasonal pollution patterns, analysing the median values provides a more robust and realistic depiction of typical ambient air quality by mitigating the impact of temporary episodic spikes, such as severe winter heating peaks or localized traffic surges.

Over the 16-month study period, the overall median concentration (Table 1) recorded for $PM_{2.5}$ was 12µg/m³ (compared to mean of 15.02µg/m³) in 2025, with a slowly increase in 2026. The $PM_{10,}$ had a median of 20µg/m³ (compared to a mean of 22.24µg/m³) following in this case also an increase in 2026. These lower median baseline values demonstrate that, for the majority of the observation period, particulate pollution levels remained substantially below the elevated mean averages driven by autumn and winter maxima.

The evaluating median trends across gaseous indicators (NO_2, SO_2,) ensures a clearer representation of typical background levels, confirming short-term seasonal or episodic spikes do not distort the long-term spatial and temporal evaluation of Budapest's air quality.

The pattern is different in case of O_3 in which case the median is higher than mean (average) in 2026 and both median and average have much lower values for CO in 2025 compare with 2026.

Table 1

Comparative representation of median and mean (average) for air quality parameters in 2025 and 2026

	PM 2.5 (µg/m³)		PM10 (µg/m³)		NO2 (µg/m³)		O 3(µg/m³)		SO2 (µg/m³)		CO (µg/m³)	
	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average
2025	12	15.02	20	22.24	31	30.67	33.55	33.55	3.5	3.78	242	239.28
2026	14	16.78	23.5	27.73	27.5	29.19	45.5	41.04	2	2.15	147	190.08

CONCLUSIONS

During a period of nearly 2 years, involving the weekly collection of concentrations of pollutants currently monitored in Budapest, a clear difference was observed in the behaviour of the pollutants.

The particulate matters and nitrogen dioxide representing the primary pollutants of concern.

The sulphur dioxide being under EU and World Health Organization limits.

The carbon monoxide having a decreasing trend during the investigated period and ozone a stronger summer seasonality. The findings indicate a clear seasonal dependency, particularly in the colder periods.

These findings offer critical insights into the localized air-quality dynamics established by the monitoring data. However, given that the data was retrieved from an online platform with asynchronous data collection intervals, the conclusions should be treated as illustrative of broad trends rather than a continuous baseline monitoring of air-quality in Budapest. Supplementing the dataset with high-frequency, uniform monitoring, with meteorological datasets and emission inventories, would allow for a more definitive validation of these seasonal trends and their underlying drivers.

ACKNOWLEDGEMENTS

The authors sincerely thank everyone who contributed to the data collection and supported the completion of this research.

BIBLIOGRAPHY

ALATAWNEH, A., AL-LAMI, A., TÖRÖK, Á., (2026), Long-term spatial and temporal projections of road transport emissions: The case study of Budapest, Cities, 175: 107132, 10.1016/j.cities.2026.107132

AUNAN, K., PATZAY, G., ASBJØRN AAHEIMA, H., SEIP, H.M., (1998), Health and environmental benefits from air pollution reductions in Hungary, The Science of the Total Environment 212: 245-268

BARANKA, GY., BOZO L., (1995), Urban air quality evaluation in Budapest, Transactions on Ecology and the Environment, 6: 83-90, WIT Press, www.witpress.com, ISSN 1743-3541

BOZO, L., BARANKA, G., (1996) Air quality modeling over Budapest, Transactions on Ecology and the Environment, 8: 31-36, WIT Press, www.witpress.com, ISSN 1743-3541

CHEN, H., KARDOS, L., GYEVIKI MÁRTA, HROTKÓ, K., SZABÓ, VERONIKA, SÜTÖRINÉ DIÓSZEGI, MAGDOLNA, (2023) Evaluating the capability of woody plants to capture atmospheric heavy metals in Budapest, Journal of Central European Green Innovation, 11(1): 67–81. DOI: 10.33038/jcegi.3359

CHEN, H., KARDOS, L., CHEN, H., SZABÓ VERONIKA, (2024), Investigating physiological responses and fine particulate matter retention of urban trees in Budapest, City and Environment Interactions, 24: 100182, https://doi.org/10.1016/j.cacint.2024.100182

FERENCZI, ZITA, (2013) Predictability analysis of the $PM_{2.5}$ and PM_{10} concentration in Budapest Időjárás, Quarterly Journal of the Hungarian Meteorological Service 117 (4): 359-375, http://www.met.hu/Journal-Idojaras.php

FERENCZI, ZITA, LABANCZ, KRISZTINA, STEIB, R., (2014), Development of a Numerical Prediction Model System for the Assessment of Air Quality in Budapest, ch. 65: 401-405. IN: Steyn, D., Mathur, R., (eds), Air Pollution Modeling and its Application XXIII, Springer Proceeedings in Complexity, DOI: 10.1007/978-3-319-04379-1_65

FERENCZI, ZITA, BOZÓ, L., (2017), Effect of the long-range transport on the air quality of greater Budapest area, Int. J. Environment and Pollution, 62(2/3/4): 407-415,

FERENCZI, ZITA, IMRE, KORNÉLIA, LAKATOS, MÓNIKA, MOLNÁR, ÁGNES, BOZÓ, L., HOMOLYA, EMESE, GELENCSÉR, A., (2021), Long-term Characterization of Urban PM10 in Hungary, Aerosol and Air Quality Research, 21 (10): 210048, https://doi.org/10.4209/aaqr.210048

HAVASI, AGNES, ZLATEV, Z., (2002), Trends of Hungarian air pollution levels on a long time-scale, Atmospheric Environment 36: 4145–4156

KONDOR, BOGLÁRKA, (2018), A Budapesten mért főbb légszennyező anyagok tér-és időbeli eloszlásának vizsgálata 2003 és 2014 között (Analysis of the spatial and temporal distribution of the main air polluters in Budapest from 2003 until 2014), LÉGKÖR 63:8-10

KOVÁCS, A., LEELŐSSY, Á., TETTAMANTI, T., ESZTERGÁR-KISS, D., MÉSZÁROS, R., LAGZI, I., (2021), Coupling traffic originated urban air pollution estimation with an atmospheric chemistry model, Urban Climate, 37:100868, 10.1016/j.uclim.2021.100868

LEELŐSSY, Á., LAGZI, I., MÉSZÁROS, R., (2017), Spatial and temporal pattern of pollutants dispersed in the atmosphere from the Budapest Chemical Works industrial site, Időjárás, Quarterly Journal of the Hungarian Meteorological Service 112 (2): 101-115, http://www.met.hu/Journal-Idojaras.php

LOVAS, R., PATVARCZKI, J., KACSUK, P., LAGZI, I., TURÁNYI, T., KULLMANN, L., HASZPRA, L., MÉSZÁROS, R., HORÁNYI, A., BENCSURA, A., LENDVAY, GY., (2006), http://www.fz-juelich.de/nic-series/volume33, IN: G.R. Joubert, W.E. Nagel, F.J. Peters, O. Plata, P. Tirado, E. Zapata (Eds), Parallel Computing:Current & Future Issues of High-End Computing, Proceedings of the International Conference ParCo 2005, NIC Series, 33: 121-128, ISBN 3-00-017352-8

PERRONE, M.G., VRATOLIS, S., GEORGIEVA, E., TÖRÖK, S., ŠEGA, K., VELEVA, B., OSÁN, J., BEŠLIĆ, I., KERTÉSZ, Z., PERNIGOTTI, D., ELEFTHERIADIS, K., BELIS, C.A., (2018), Sources and geographic origin of particulate matter in urban areas of the Danube macro-region: The cases of Zagreb (Croatia), Budapest (Hungary) and Sofia (Bulgaria Science of the Total Environment 619–620: 1515–1529, https://doi.org/10.1016/j.scitotenv.2017.11.092

SALMA, I., MAENHAUT, W., ZEMPLÉN-PAPP, ÉVA, BOBVOS, J., (1998), Trends of Hungarian air pollution levels on a long time-scale, Microchemical Journal 58: 291–305

SALMA, I., WILLY MAENHAUT, W., DUBTSOV, S., ZEMPLÉN-PAPP, ÉVA, ZARAY, GY., (2000), Impact of phase out of leaded gasoline on the air quality in Budapest, Microchemical Journal 67: 127-133

SALMA, I., CHI, X., MAENHAUT, W., (2004), Elemental and organic carbon in urban canyon and background environments in Budapest, Hungary, Atmospheric Environment 38: 27–36, doi:10.1016/j.atmosenv.2003.09.047

SEPSI, PANNA, SÁRKÖZI, EDIT, HROTKÓ, K., KARDOS, L., (2015), Monitoring of air pollution in Budapest, Hungary using tree leaf samples - preliminary results, AgroLife Scientific Journal, 4(1): 161-164, ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

SIPOS, P., KOVÁCS KIS, VIKTÓRIA, MÁRTON, E., TIBOR NÉMETH, T., MAY, Z., SZALAI, Z., (2012), Lead and zinc in the suspended particulate matter and settled dust in Budapest, Hungary, Eur. Chem. Bull. 1(11): 449-454

SZABÓ, V., CHEN, H., HROTKÓ, K., KOHUT, I., (2023). Investigation of Dust Deposition in Vegetation Period as an Ecological Service on Urban Trees in Budapest—A Case Study. Pollutants 3: 507–520. https://doi.org/10.3390/pollutants3040035

STEIB, R., LABANCZ, KRISZTINA, FERENCZI, ZITA, ALFÖLDY, B., (2008). Airport (Budapest Ferihegy – Hungary) air quality analysis using the EDMS modeling system. Part I. Model development and testing, Időjárás, Quarterly Journal of the Hungarian Meteorological Service 112 (2): 99-112, http://www.met.hu/Journal-Idojaras.php

TORDAI, Á., V., MÉSZÁROS, R., (2025), Street-Level Urban Air Quality Patterns: Insights from a Comprehensive Mobile Measurement Campaign in Budapest, EMS Annual Meeting 2025, Ljubljana, Slovenia, 7–12 Sep 2025, EMS2025-430, https://doi.org/10.5194/ems2025-430, 2025.

TÓTH-RONKAY, MÁRIA, BAJOR, Z., BÁRÁNY, ANNAMÁRIA, FÖLDVÁRI, G., GÖRFÖL, T., HALPERN, B., LEÉL-ŐSSY, SZ., MÉSZÁROS, R., PÉNTEK, A.L., TÓTH, B., TÓTH, Z., VÖRÖS, JUDIT, (2015), Budapest, IN: J. G. Kelcey (ed.), Vertebrates and Invertebrates of European Cities: Selected Non-Avian Fauna, DOI 10.1007/978-1-4939-1698-6_2

***, 2020, 150 years Hungarian Meteorological Service, European Mereorological Society (EMS), accessed 21.10. 2026, https://www.emetsoc.org/