Greenpeace Research Laboratories Technical Report

Air Quality Monitoring for SO_2 in Bulgaria: Comparison of diffusion tube monitoring with data from automatic measuring stations in Golemo Selo, Galabovo, Dimitrovgrad and Pernik, October 2025 - February 2026

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1. Introduction

Sulfur dioxide (SO_2) is widely recognised as a hazardous health pollutant for which air quality guidelines have been set by the World Health Organisation (WHO)[1], and air quality standards set by the European Union (EU)[2].

This report describes the results of a four month SO_2 monitoring survey using diffusion tubes (DT), carried out in the vicinity of automatic measuring stations (AMS) at four locations in Bulgaria; Golemo Selo, Galabovo, Dimitrovgrad and Pernik. One or more coal fired power stations (CFPP) are located close to each of the AMS, with other CFPPs in the vicinity. Coal fired power stations (CFPP) are a notable source of SO_2 emissions in Bulgaria[3].

Diffusion tube monitoring is a well recognised[4] method to determine average concentrations of SO_2 in air over timeframes of weeks or months. DTs are not able to provide information on changes in concentration over short timeframes in the way that AMS can. To compare DT and AMS data it is necessary to calculate averages of the time-resolved AMS data that match the time period for which the DTs were deployed. Here, we use a comparison of monthly mean concentrations from both methods as an indication of the reliability of AMS data.

Monitoring was undertaken between October 2025 and February 2026, to enable a comparison between average concentrations obtained using diffusion tube monitoring and SO_2 concentrations reported in the public register of automatic measuring stations for monitoring ambient air quality of the Bulgarian Executive Environmental Agency (ExEA)[5]

2. Materials and Methods

Diffusion Tubes (DTs)

Monitoring for SO_2 was undertaken between October 2025 and February 2026 using DTs prepared and analysed by Gradko Ltd (UK). During this time DTs were deployed by Greenpeace Bulgaria for four

[1] WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, 2021. https://www.who.int/publications/i/item/9789240034228

[2] EU Ambient Air Quality Directive, European Union (EU). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202402881

[3] https://industry.eea.europa.eu/industrial-emissions/dashboards/explore-by-pollutant

[4] Bennett, M., 2017. Air Pollution Monitoring. In Measurement, Instrumentation, and Sensors Handbook: Electromagnetic, Optical, Radiation, Chemical, and Biomedical Measurement (pp. 77-1). CRC Press.

[5] Public register of automatic measuring stations for monitoring ambient air quality, Bulgarian Executive Environmental Agency (ExEA), https://eea.government.bg/kav/

consecutive periods of approximately 1 month each. For each settlement (Golemo Selo, Galabovo, Dimitrovgrad and Pernik), two DT monitoring locations were selected. One location was a suitable location for DT deployment at the closest possible place to the AMS.

Figure 1. "AMS Pernik" (on the right) and DTs location near the AMS (on the street sign)

The second location was somewhat further from the AMS but where public access was limited giving confidence that the measurement would not be disturbed. As it was not possible to locate DTs immediately adjacent to the AMS air intake, this second site also investigated differences in average SO2 concentrations over relatively short distances in the vicinity of the AMS, and differences due to physical structures close to DT locations. For one settlement, Galabovo, the initial location of the DT placed closest to the AMS was enclosed by buildings. It was changed to a less enclosed location for the 4th monitoring period, though the distance from the AMS remained very similar to that for the first 3 periods.

Efforts were made to install all DTs at a similar height to the intake of the nearby AMS; all DTs were located at a height between 2.5-4 m above the ground. Details of DT locations and deployment times are given in Tables 1 and 2.

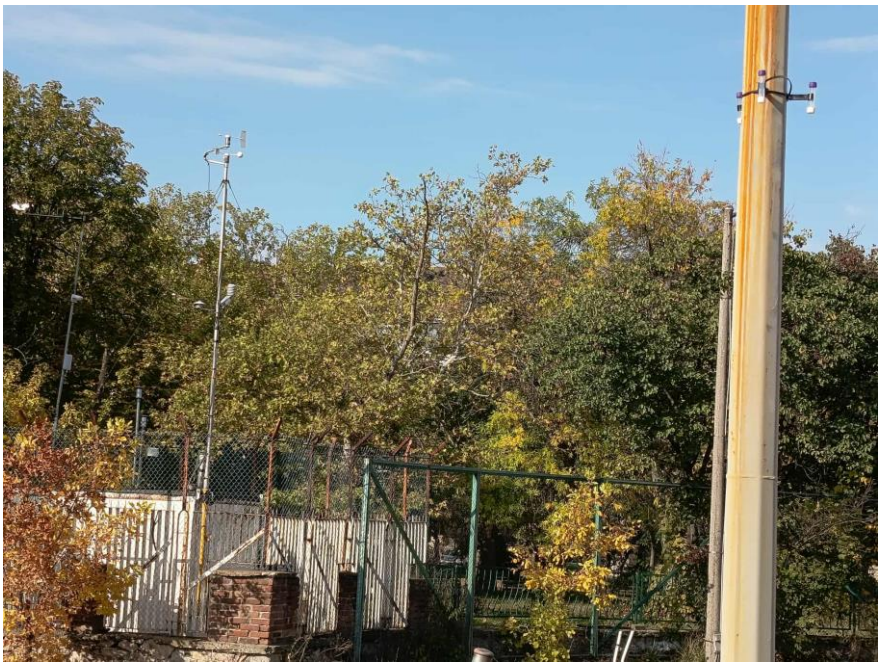


Figure 2. "Dimitrovgrad AMS Rakovski" (to the rear) and DTs located at an adjacent school (top right)

Triplicate DTs were deployed at each location to determine the variability in measured SO_2 concentrations between individual DTs at the same location, and to provide a more accurate measure of SO_2 concentrations. During each monitoring period, 6 field blank DTs were placed at separate locations alongside monitoring DTs for the entire monitoring period.

Figure 3. Example of triplicate DTs near "Dimitrovgrad - AMS Rakovski"

Settlement	Location	Latitude & Longitude	Distance between DT & AMS
Golemo Selo	near AMS	42.292528°N, 23.043389°E	34 m
	school	42.290111°N, 23.041167°E	360 m
Galabovo	near AMS periods 1-3 near AMS period 4	42.146358°N, 25.875634°E 42.146413°N, 25.875074°E	29 m 33 m
	local house	42.147157°N, 25.877167°E	158 m
Dimitrovgrad	near AMS	42.056411°N, 25.593491°E	5 m
	school	42.056488°N, 25.593746°E	27 m
Pernik	near AMS	42.610333°N, 23.032222°E	3 m
	Youth centre rear	42.610889°N, 23.032194°E	62 m

Table 1: Diffusion tube locations in Golemo Selo, Galabovo, Dimitrovgrad and Pernik

(a) Golemo Selo **(b) Galabovo**

(c) Dimitrovgrad **(d) Pernik**

Figure 4. Maps showing the location of the AMS and DT deployment locations for (a) Golemo Selo, (b) Galabovo, (c) Dimitrovgrad, and (d) Pernik. Imagery ©2026 Airbus, Imagery©2026 Airbus, CNES / Airbus, Maxar Technologies, Map data ©2026 (maps a-c); Imagery ©2026 Google, Imagery©2026 Airbus, CNES / Airbus, Maxar Technologies, Map data ©2026 (map d). Images edited by Greenpeace to add locations

Settlement	Location	Period 1	Period 2	Period 3	Period 4
Golemo Selo	near AMS	14/10/2025, 13:45 to 14/11/2025, 12:39	14/11/2025, 12:39 to 14/12/2025, 08:23	14/12/2025, 08:25 to 14/01/2026, 13:08	14/1/2026, 13:09 to 16/2/2026, 13:11
	School	14/10/2025, 12:01 to 14/11/2025, 12:23	14/11/2025, 12:23 to 14/12/2025, 08:06	14/12/2025, 08:10 to 14/01/2026, 12:50	14/1/2026, 12:50 to 16/2/2026, 13:25
Galabovo	near AMS	15/10/2025 11:48 to 14/11/2025, 11:12	14/11/2025 15:12 to 15/12/2025 12:09	15/12/2025 12:09 to 15/01/26 12:56	15/1/2026, 13:20 to 16/2/2026, 12:55
	resident	15/10/2025 17:49 to 13/11/2025, 17:00	14/11/2025 17:24 to 15/12/2025 08:05	15/12/2025 12:41 to 15/01/26 08:05	15/1/2026, 16:12 to 15/2/2026, 12:03
Dimitrovgrad	near AMS	15/10/2025 14:02 to 14/11/2025, 12:15	14/11/2025 12:15 to 15/12/2025 13:49	15/12/2025 13:49 to 15/01/26 15:07	15/1/2026, 15:10 to 16/02/26. 14:42
	School	16/10/2025 10:44 to 14/11/2025, 12:08	14/11/2025 12:08 to 15/12/2025 13:45	15/12/2025 13:45 to 15/01/26 15:03	15/1/2026, 15:03 to 16/2/2026, 14:30
Pernik	near AMS	14/10/2025, 18:11 to 14/11/2025, 13:38	14/11/2025, 13:38 to 14/12/2025, 09:13	14/12/2025, 09:15 to 14/01/2026, 14:04	14/1/2026, 14:04 to 16/2/2026, 10:53
	Youth centre rear	14/10/2025, 18:21 to 14/11/2025, 13:44	14/11/2025, 13:44 to 14/12/2025, 09:22	14/12/2025, 09:24 to 14/01/2026, 14:11	14/1/2026, 14:11 to 16/2/2026, 11:07

Table 2: Diffusion tube monitoring periods for the locations in Golemo Selo, Galabovo, Dimitrovgrad and Pernik

Existing Monitoring Data

Automatic air quality monitoring stations (AMS) operate in each of the four settlements. All monitors report hourly concentrations of SO_2 and other air pollutants. Data for the AMS in Galabovo, Dimitrovgrad and Pernik were downloaded from the public register of automatic measuring stations for monitoring ambient air quality[6]. The AMS at Golemo selo is installed and maintained by the CFPP "Bobob dol". Greenpeace Bulgaria requested data from it under the rules of The Access to Public Information Act and data were received from the Regional Inspectorate of Environment and Water (RIEW) - Sofia. For each AMS, the average SO_2 concentration for a monitoring period was calculated using reported hourly average concentrations during the time that the DT was in place.

[6] Public register of automatic measuring stations for monitoring ambient air quality, Bulgarian Executive Environmental Agency (ExEA). https://eea.government.bg/kav/

Figure 5. "AMS Golemo selo" (front right), Greenpeace team installing the DTs at location near the AMS (bottom left) and CFPP "Bobov dol" (at the back)

3. Results and discussion

Results of the four month DT monitoring survey are summarised in Table 3, together with average SO_2 concentrations reported for each AMS for the equivalent times over which the DTs were deployed. For each settlement, two DTs were installed at different locations; one close to the AMS & the second nearby but somewhat further from the AMS. For each DT, the reported concentrations are averages of 3 triplicates.

Comparisons of the average concentrations for each AMS with the respective DT concentrations are also given in Table 3, showing the extent to which the AMS reported higher (above 100%), or lower (below 100%) average concentrations compared to the DT concentration for the same time period. The further from 100% indicates a greater difference between the AMS and DT values. Where AMS values were below DT values and therefore the AMS:DT ratio was below 100% (Golemo Selo and Galabovo) a lower ratio indicates a larger difference between AMS and DT values. Where AMS values were higher than DT values and therefore the AMS:DT ratio was above 100% (Dimitrovgrad and Pernik) a higher ratio indicates a larger difference between AMS and DT values. Detailed DT data are provided in Appendix 1.

Settlement	DT location	Period 1 (Oct-Nov 2025)			Period 2 (Nov-Dec 2025)			Period 3 Dec 2025-Jan 2026			Period 4 Jan-Feb 2026		
		DT µg/m³	AMS µg/m³	AMS/DT (%)	DT µg/m³	AMS µg/m³	AMS/DT (%)	DT µg/m³	AMS µg/m³	AMS/DT (%)	DT µg/m³	AMS µg/m³	AMS/DT (%)
Golemo Selo	near AMS	55.4	3.15	5.7%	52.7	4.45	8.4%	76.4	8.24	10.8%	26.2	2.30	8.8%
	school	47.9	3.15	6.6%	49.3	4.45	9.0%	67.2	8.24	12.3%	23.3	2.30	9.9%
Galabovo	near AMS	11.0	6.8	62%	17.3	6.6	38%	17.5	7.2	41%	12.5	12.1	97%
	local house	12.5	6.9	55%	16.8	6.6	39%	16.9	7.2	43%	13.7	12.1	89%
Dimitrovgrad	near AMS	4.6	11.4	248%	15.6	21.4	137%	5.9	18.2	309%	13.9	26.3	189%
	school	5.1	11.5	224%	16.8	21.4	128%	6.6	18.2	277%	14.5	26.3	182%
Pernik	near AMS	16.8	25.9	154%	10.8	16.7	155%	19.1	21.7	113%	21.9	30.8	141%
	youth centre rear	16.9	25.9	153%	10.9	16.7	153%	20.4	21.7	106%	20.9	30.8	147%

Table 3: Summary of average SO_2 concentrations (µg/m³) from diffusion tubes (DT), and automatic monitoring station (AMS) reported data, and the ratio of AMS:DT concentrations (%). AMS concentrations are average values calculated for the hours that each individual DT was monitoring at each location

Results for field blanks and laboratory blanks were below detection limits in the majority of cases, including all samples for the last 3 periods. For other cases, the raw DT results were corrected by subtraction of the field or laboratory blank value, whichever was higher.

For each of the 4 settlements, average DT concentrations were similar between the 2 locations across the 4 monitoring periods, with the value for the DT closest to the AMS being between 88-116% of that for the DT at the nearby second location during the same period. These results indicate that average SO_2 concentrations measured using DTs showed little variation over the relatively short distances between the two DT locations in the vicinity of each AMS, providing reassurance that the values for the DTs located closest to each AMS can be expected to provide a reasonable measure of the SO_2 concentration at the AMS location.

Furthermore, for each location and monitoring period, the SO_2 concentrations for each of the individual triplicates were in good agreement, with relative standard deviation (%RSD) below 5% for the majority of triplicate sets, and below 10% in all cases (Table A1). These results provide reassurance of the acceptable reliability of data from individual DTs.

Comparison of SO_2 concentrations from AMS and DT

For two sites, Golemo Selo and Galabovo, the average AMS SO_2 concentrations for all monitoring periods were lower than the equivalent values measured using DTs, to a similar extent for both the DT located close to the AMS and that located somewhat further from the AMS. This was most notable for Golemo Selo where the AMS average concentrations were 5.7% to 10.8% of equivalent values for the DT closest to the AMS (9 to 18 times lower than the DT values). Though to a lesser extent than at Golemo Selo, the AMS average concentrations for Galabovo were also lower than the equivalent DT values, especially for the first 3 periods, during which the AMS average concentrations were 38% to 62% of the equivalent values for the DT located close to the AMS (1.6 to 2.6 times lower than the DT values). See Figures 6 & 7.

During the 4th monitoring period, the AMS average concentrations at Galabovo more closely matched the equivalent DT values. For this monitoring period the location of the DT closest to the AMS at Galabovo was changed to a less enclosed location. However, the relative difference in DT SO_2 concentrations between the two locations remained similar to the relative differences between the two DTs that was seen in the first 3 monitoring periods. The DT closest to the AMS reported a value 91% of the other DT for the 4th monitoring period, compared to between 88%-103% for the previous 3 monitoring periods. These results suggest that the location change for the 4th period did not have a notable effect on the comparison between DT and AMS reported concentrations.

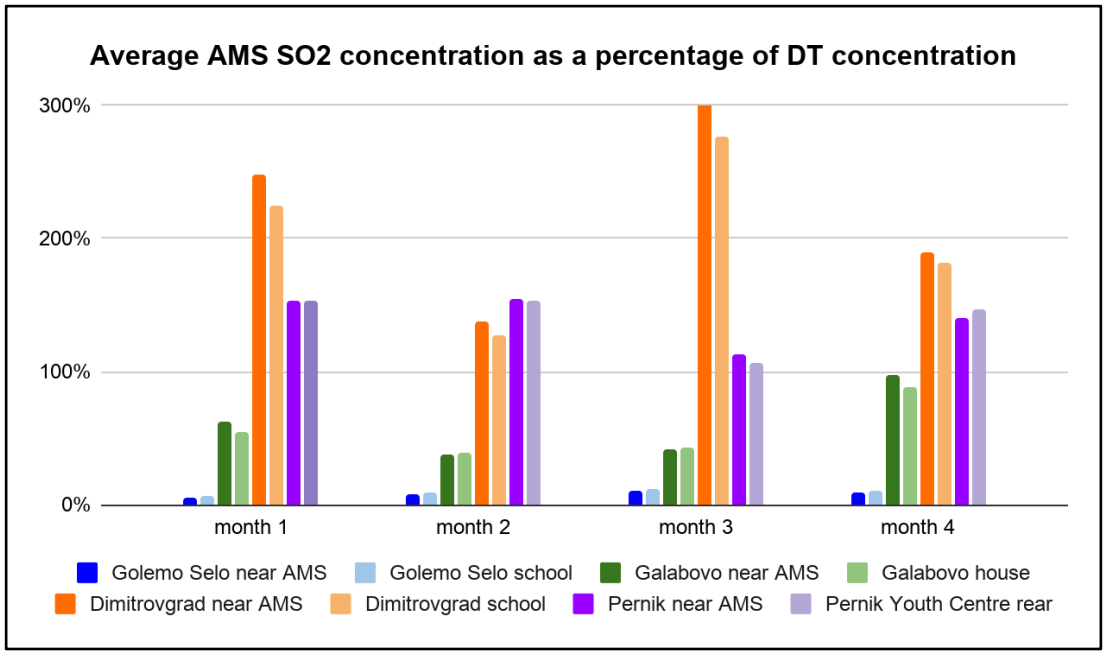
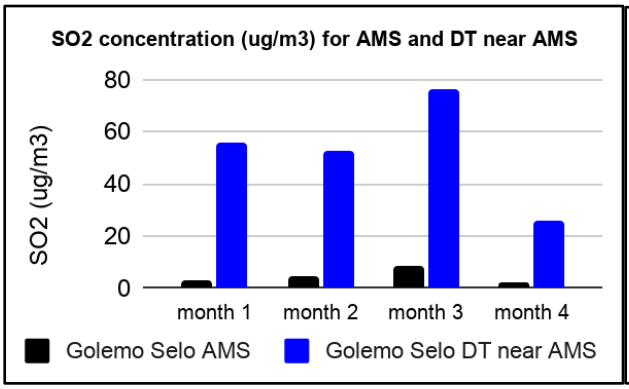
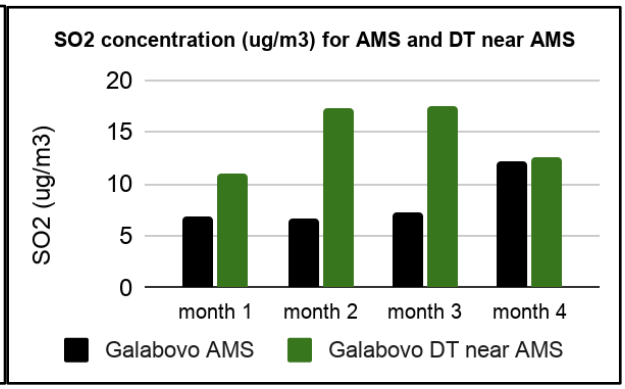


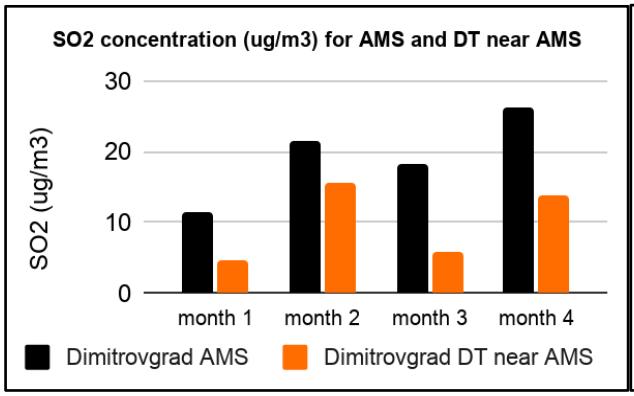
Figure 6. Average SO_2 concentration calculated from reported AMS data, as percentage of the concentration measured using diffusion tubes, for 4 consecutive periods between October 2025 and February 2026



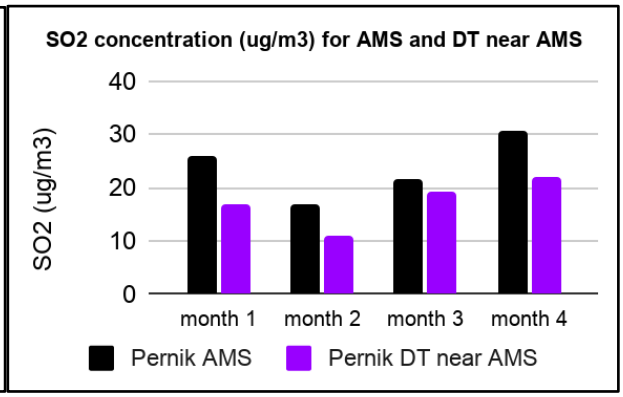
(a) Golemo Selo: AMS 9-18 times *lower* than DT values



(b) Galabovo: AMS 1.6-2.6 times *lower* than DT value



(c) Dimitrovgrad: AMS 1.4-3.1 times *higher* than DT values



(d) Pernik: AMS 1.1-1.6 times *higher* than DT values

Figure 7. Average SO_2 concentrations (µg/m^3) calculated from reported AMS data and measured using diffusion tubes (DT) located near the AMS, for 4 consecutive periods between October 2025 and February 2026; (a) Golemo Selo, (b) Galabovo, (c) Dimitrovgrad, and (d) Pernik

In contrast, for Dimitrovgrad and Pernik the average AMS SO_2 concentrations for all monitoring periods were higher than the equivalent values measured using DTs. As for Golemo Selo and Galabovo, the difference between AMS and DT values were similar for both the DT located close to the AMS and that located somewhat further from the AMS. For Dimitrovgrad, the AMS average concentrations were between 137% and 309% of the DT located close to the AMS (1.4 to 3.1 times higher than the DT values), compared to between 113% and 155% for Pernik (1.1 to 1.6 times higher than the DT values).

This analysis of differences between DT and AMS values compares average concentrations for each monitoring period. For all 4 sites, AMS data are reported as hourly average concentrations, from which average concentrations were calculated for the times that DT were deployed. The hourly average SO_2 concentrations from all four AMS show considerable variability over hourly timeframes, with occasions when hourly average concentrations are far higher than the monthly average, though typically lasting for only a few hours. This short timeframe variability was seen for those AMS for which the average SO_2

concentrations were notably lower than the DT values during the monitoring periods (Golemo Selo and Galabovo), as well as those AMS which reported higher average SO_2 concentrations than the equivalent DT values (Dimitrovgrad and Pernik). This is consistent with the differences between average AMS and DT values not being due to short term variability in SO_2 concentrations at some locations.

This study investigated whether AMS reported SO_2 concentrations agree with DT monitored values. The results question if data published for AMS at the four locations in Bulgaria are sufficiently accurate. An in-depth investigation into the reasons for the observed discrepancies between DT and AMS measurements was beyond the scope of this work. The results of AMS instrument calibrations provided by the Bulgarian Executive Environmental Agency were reviewed. These indicate that a system of instrument calibrations is operated at the Dimitrovgrad, Pernik and Galabovo AMS sites. The SO_2 calibration gases used in the provided reports were between 100-700 ppb (~260-1830 µg/m^3) in Dimitrovgrad, 50-800 ppb (~130-2100 µg/m^3) in Galabovo and 50-400 ppb (~130-1050 µg/m^3) in Pernik, much higher than average ambient conditions. Zero calibrations were also included in the reports, but only at Galabovo and Pernik, not Dimitrovgrad. Calibration information included uncertainty values for Dimitrovgrad and Galabovo, which were below 4% of the respective calibration concentration. Notably higher percentage differences were seen between AMS and DT measurements in this study. Consistent use of zero calibrations and calibration gas concentrations close to average ambient concentrations may improve AMS instrument performance for determining long-term average concentrations.

4. Conclusions

This four month SO_2 monitoring survey using diffusion tubes (DT) at Golemo Selo, Galabovo, Dimitrovgrad and Pernik highlights notable differences between average SO_2 concentrations determined using DTs and those calculated from hourly average data reported for automatic measuring stations (AMS), with AMS values being lower at some locations and higher at others. Particularly large differences were seen at Golemo Selo, where AMS data provided average concentrations typically more than 10 times lower than those determined by DTs for the same period. Consistency across the triplicate DT data used in the comparison with AMS data supports the widely recognised reliability of DT monitoring for ambient SO_2 concentrations.

The study highlights concerns about the reliability of published SO_2 concentrations from some AMS in Bulgaria and the need to investigate quality control/quality assurance (QC/QA) processes used to validate data from AMS in Bulgaria, including regular calibration of each AMS and calibration gas concentrations used, as well as regular network intercalibrations between individual monitors.

Appendix 1: Details of triplicate diffusion tube SO_2 concentrations at each location between October 2025 to February 2026

Settlement	DT location	Period 1 (Oct-Nov 2025)		Period 2 (Nov-Dec 2025)		Period 3 (Dec 2025-Jan 2026)		Period 4 (Jan-Feb 2026)	
		range (µg/m³)	%RSD	range (µg/m³)	%RSD	range (µg/m³)	%RSD	range (µg/m³)	%RSD
Golemo Selo	near AMS	52.91-56.98	3.95%	51.95-53.54	1.53%	75.14-78.58	2.45%	25.55-26.75	2.32%
	School	47.25-48.60	1.43%	47.38-50.33	3.42%	66.12-68.25	1.59%	23.05-23.64	1.28%
Galabovo	near AMS	10.26-11.4	5.78%	17.01-17.87	2.70%	17.07-18.15	3.36%	12.15-13.27	5.09%
	resident	12.03-12.87	3.39%	15.62-18.05	7.23%	16.77-16.98	0.64%	13.35-14.36	4.08%
Dimitrovgrad	near AMS	4.36-4.8	4.85%	15.17-16.04	2.79%	5.61-6.16	4.68%	12.15-13.27	4.89%
	School	5.04-5.19	2.00%	16.27-17.35	3.24%	6.45-6.72	2.06%	14.35-14.55	0.73%
Pernik	near AMS	15.92-17.73	5.40%	10.11-11.93	9.40%	18.41-19.72	3.49%	21.67-22.19	1.30%
	Youth centre rear	16.62-17.11	1.57%	10.27-11.29	5.23%	20.23-20.61	0.98%	20.77-21.10	0.79%

Table A1. Range (µg/m³) and relative standard deviation (RSD, %) for SO_2 concentrations for DT triplicates at each location and monitoring period