The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-6-2025
ISPRS, EARSeL & DGPF Joint Istanbul Workshop “Topographic Mapping from Space” dedicated to Dr. Karsten Jacobsen’s 80th Birthday
29–31 January 2025, Istanbul, Türkiye

Investigation of Impact to Climate Change of Metan Emission of Underground Mines and Thermal Power Plants Using Sentinel-5p TROPOMI Satellite Data from GEE Platform

Nehir Uyar [1], Hakan Akcin [2]

[1] Department of Architecture and Urban Planning, Zonguldak Vocational School, Zonguldak Bülent Ecevit University, 67100 Zonguldak, Türkiye - nehiruyar@beun.edu.tr
[2] Department of Geomatics Engineering, Engineering Faculty, Zonguldak Bulent Ecevit University, 67100 Zonguldak, Türkiye - akcinh@beun.edu.tr

Keywords: Sentinel-5p TROPOMI, Metane (CH_4) Emission, Google Earth Engine, Mining, Climate Change.

Abstract

Emissions from mines are important, but have not been sufficiently characterised to date. Air pollutant emissions from underground mine, and gases from industrial plant sites where large quantities of coal are stored, adversely affect the environment and human health and contribute to climate change. In this study, the emission distribution structure of atmosphere free methane gas from three ventilation systems of the underground production area within the borders of Kilimli district of Zonguldak Hard Coal Basin located in the Northwest region of Turkey and methane outflows in coal storage areas from five thermal power plants in the basin were analysed with Sentinel-5p TROPOMI satellite sensor data from Google Earth Engine (GEE) Platform for the years 2019-2023. For the conversion of TROPOMI sensor values in Mol/m^2 unit to gas outlet flow rate values in m^3/min unit, CH_4 flow rate measurement data from the sensors at the emission outlet points of the Turkish Hard Coal Authority (TTK) were used. $R^2 = 0.5601$ and $r = 0.75$ correlation values were obtained from 13 common observations with a linear regression model. At the underground emission exit points, 5-year average flow rate values of 2.71 m^3/min at Arslan Garden (ASB), 2.77 m^3/min at exit point 140 and 2.79 m^3/min at exit point 52 were calculated with the transformed TROPOMI data. Accordingly, it was determined that an average of 4,346 Million m^3 of methane gas was released into the atmosphere annually and 21,730 Million m^3 of methane gas was released in a total of five years.

1. Introduction

World energy resources are handled in two main groups. Consumable energy resources, which are fossil resources, constitute the first group of energy resources, while renewable energies such as wind and sun constitute the second group of energy resources (World Energy Council Turkiye 2021). Today, although the transition to the second group of clean energy sources is desired, coal and coal industry, one of the first group energy sources, still play an important role in the global economy. As a result, an environmental crisis is occurring due to the increase in greenhouse gas content in the atmosphere in production facilities and industrial areas based on coal mining (Ivanova et al. 2022; Wu et al. 2023).

The impacts of coal mining on society and the environment can occur directly through active mining practices and indirectly after active mining (Malan 2019). In active mining, activities destroy the natural vegetation of the land, disrupting local ecosystems and biodiversity and causing localised climate changes (Rock 2024). Methane gas can be released during the normal operation of a mine, or methane gas can be released in the storage area around industrial facilities where produced coal and waste are stored.

Mine ventilation systems discharge a large amount of particulate matter (dust) and toxic gases into the environment. Significant amounts of methane (CH4), a potent greenhouse gas, are also released. Methane gas emission in the coal is released during coal production and released to the atmosphere through ventilation systems. Since it is lighter than air, it goes directly into the Ozone layer, contributing to global warming and worsening the climate crisis. Methane therefore continues to accumulate in the atmosphere as a result of human activities (Plant et al. 2022) and is responsible for about 30 per cent of the increase in global temperatures (United Nations Environment Programme-UNEP 2021).

However, due to its much greater ability to trap infrared rays compared to carbon dioxide, methane has an atmospheric warming effect 80 times stronger than carbon dioxide over a 20-year period (Xiaoying and Xianbo 2009).

In this study, the effect of methane gas emissions discharged to the atmosphere as a result of active underground mining using ventilation shaft technology in Kilimli district of Zonguldak province and the methane gas emissions released from coal storage areas of coal beneficiation plants and thermal power plants around these mines were investigated with Sentinel-5p TROPOMI satellite images obtained using the GEE platform.

2. Materials and Methods

2.1. Study Area

This study is analysed for the thermal power plants and Turkish Hard Coal Enterprise Karadon (THCEK) underground coal production zones of Kilimli District in the Zonguldak hard coal basin of Turkey, shown in Figure 1. The analysis is focused on three underground production sections operating at deep elevations and the power plant hard coal stockpile area between 2019 and 2023 in the region. Studies in production departments analyzing methane gas emissions, average - 150 m/ - 500 m sea level depths. Coal seam thicknesses vary between 2 m and 3,5 m and the average inclination angle of these coal seams is 30°. An example of the relationship between production panels and wells in the region is given in Figure 2, the distribution of wells and panels in the THCEK production area is given in Figure 3 and the Digital Elevation Model (DEM) showing the relationship of the wells where the emission output is monitored with the tapographical structure is given in Figure 4.

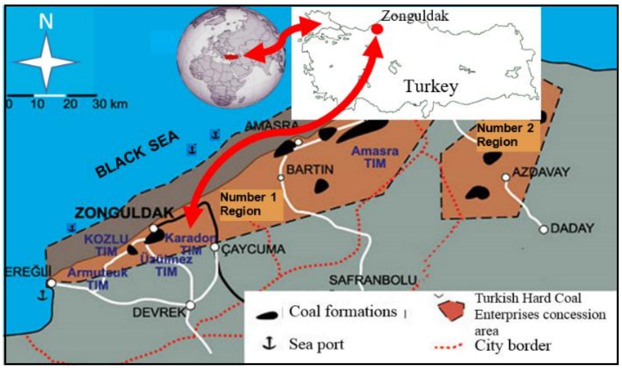

Figure 1. Zonguldak-Kozlu Hard Coal Basin and application area Karadon TIM of the study.

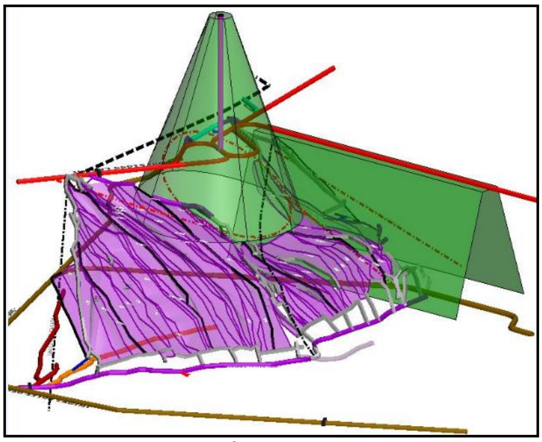

Figure 2. An example of the well and production panel relationship in THCEK.

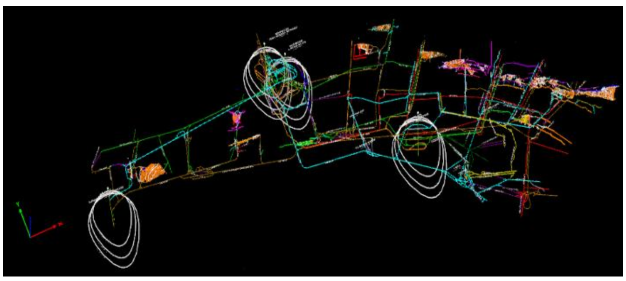

Figure 3. Distribution of wells and panels in the THCEK production area

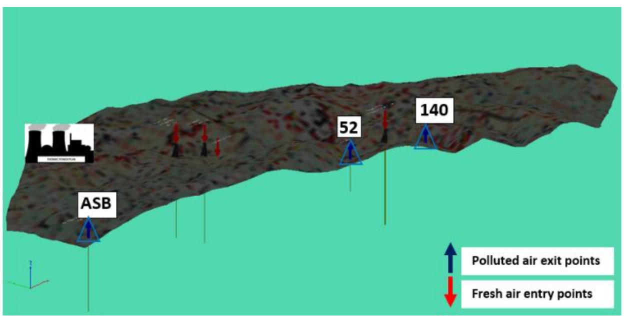

Figure 4. Digital Elevation Model (DEM) showing the relationship of the wells where the emission output.

As of the second half of 2016, there are four coal-fired thermal power plants in the region. Currently, two relatively older plants burn 5500 tons of hard coal per day and stockpile 1,700,000 tons of coal. In the other three new plants, 11000 tons of coal is burned daily and 4,000,000 tons of coal is stockpiled. Figure 5 and 6 shows the view of coal stockpiles and thermal power plants. The raw hard coal production amounts of THCEK between 2019-2023 are shown in Table 1.

Figure 5. Distribution of Hard coal storage areas and Thermal Power Plants in the basin from GEE.

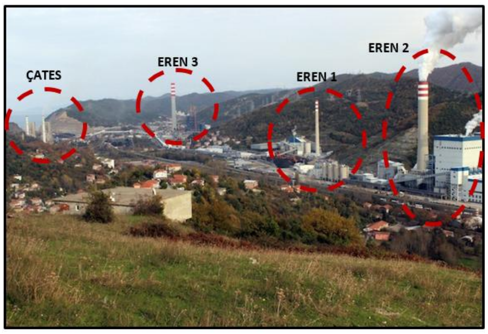

Figure 6. Thermal power plants operating in the basin (Çelikoğlu, 2016).

Year	Raw coal production amount (tone)
2019	465.863
2020	465.001
2021	540.437
2022	537.705
2023	457.922

Table 1. Coal production amounts of THCEK (Turkish Hard Coal Enterprise (THCE) Reports 2020, 2022 and 2023)

2.2 CH4 Monitoring From Sentinel-5p TROPOMI and GEE

Methane gas measurements of THCEK and thermal power plants region between 2019-2023 were obtained with Sentinel-5p TROPOMI satellite sensor. Sentinel-5p is a satellite specifically designed to provide rich data and imagery at the heart of the European Commission's Copernicus programme. Some technical specifications for this sensor are given in Table 2. With the TROPOMI (The TROPOspheric Monitoring Instrument) sensor of the Sentinel-5P (Precursor) satellite, satellite data on air quality can be obtained since 2018. Methane (CH_4) data with a resolution of approximately 1000m were obtained for ASB, wells 140 and 52 and termal power plants surroundings, where methane (CH_4) is discharged to the atmosphere as an emission from underground wells, galleries and hard coal storage areas of the basin using GEE applications. Figure 7 shows the distribution of TROPOMI satellite CH4 observations on the topographic map. The obtained five-year satellite observation data were spatially analysed year by year between 2019 and 2023. The unit of CH4 values as satellite observation data is mol/m^2. A basin retrival model was developed using the ground observation sensor data measured by THCEK at the exit points ASB, 140 and 52 to find the annual and five-year total m^3 of CH4 from the atmosphere directly to the ozone layer.

Specifications	Sentinel-5p
Sensor	The TROPOspheric Monitoring Instrument- TROPOMI
Bands	Ultraviolet, Visible, NIR and SWIR
Spatial Resolution	~ 1000 m Visible in Level 3, 7 km in satellite flight direction and 3.5 km in perpendicular direction in level 2
Spectrum	Ultraviolet 270-320nm Visible 320-500nm, NIR 675-775 nm, SWIR 2305-2385 nm
Operational Time	2017- Cont.
Temporal Resolution	2 day
Orbit	Polar, Sun-synchronous orbit
Orbit altitude	824 km
CH_4 measurement range	min 1285 - max 2405mol/m^2

Table 2. Some technical specifications of Sentinel-5p.

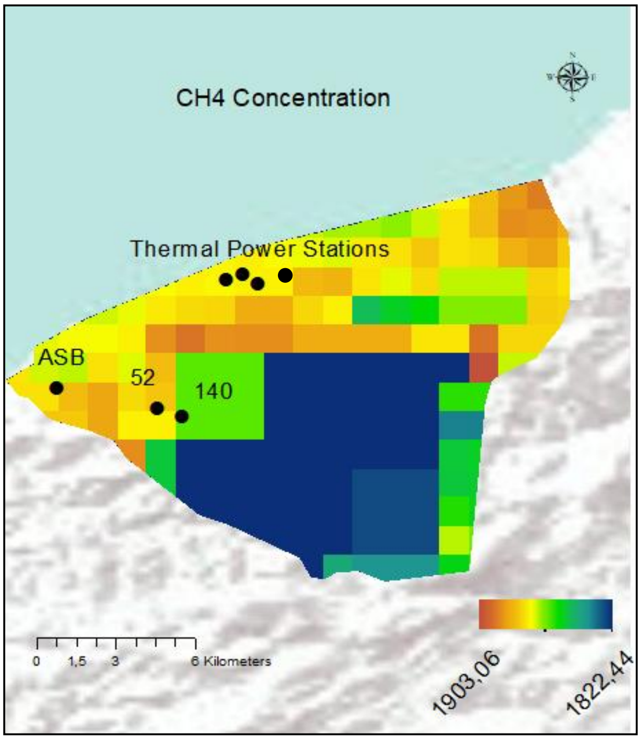

Figure 7. CH4 distribution map in the Zonguldak- Kilimli-Karadon region in the mining wells where CH4 is discharged and in the thermal power plant area where coal is stored between 2019-2023.

Time series graphs of the data measured with the TRAPOMI sensor between 2019 and 2023 are shown in Figures 8, 9 and 10. The reason for the low values of the data in the 2019 and 2020 periods is that this period is the period of the COVID-19 pandemic and the production has decreased significantly. After 2020, the upward trend in the amount of CH4 was evident at all three observation points.

3. Retrieval Method Application

Using the GEE platform, the volumetric amount of CH4 released into the atmosphere was determined by converting the sensor observation data obtained in Sentinel-5p TROPOMI mol/m^2 unit to flow rate values in m3/min unit. This total volume amount was multiplied by the CH_4 density value and the amount of CH_4 in tonnes was calculated. In the conversion process, a regression analysis was performed between the sensor data measured by THCEK at the underground outlet points at ASB, 140 and 52 and TROPOMI measurement data for the same day. $CH_4^{FLOW\ RATE} = a_0 + a_1 * CH_4^{TROPOMI}$ linear regression equation was used with the 13 most compatible common day data. As a result of the transformation, the coefficient of determination $R^2 = 0.5601$ and correlation coefficient $r = 0.75$ were obtained. The graph of the regression analysis is shown in Figure 11. The coefficient a_0 of the linear model ($y=a_0+a_1x$) determined by the regression analysis was obtained as - 205,0100 and the coefficient a_1 was obtained as 0,1106.

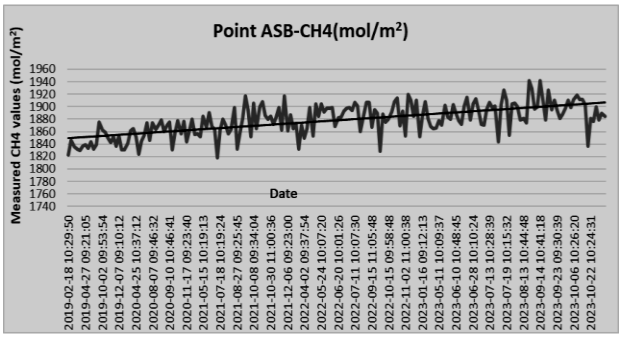

Figure 8. Measured CH_4 values in point ASB

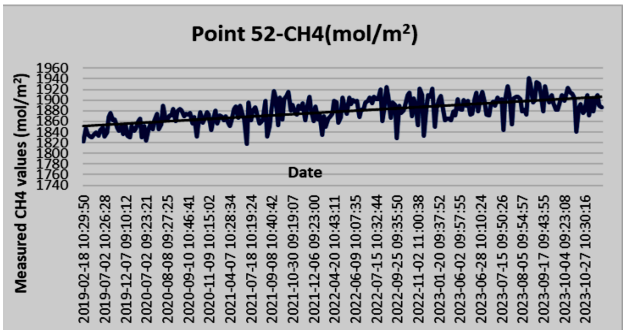

Figure 9. Measured CH_4 values in point 52

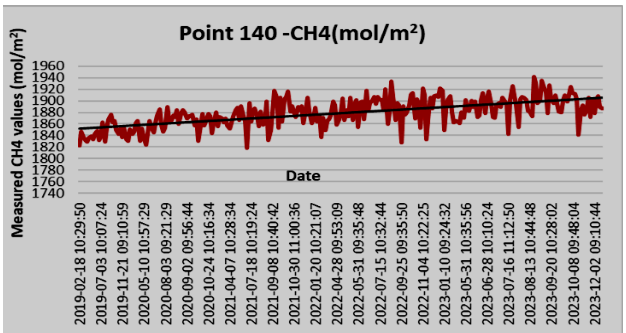

Figure 10. Measured CH_4 values in point 140

The statistical indicators of CH4 data for satellite observations in m^3/min units obtained by retrival from the model equation are presented in Table 3. The annual average values of retrivaled satellite observation data are shown in Table 4 and the graph is shown in Figure 12. There is a significant increase in the flow rate values of these values since the 2019-2020 pandemic period. This situation is consistent with the annual raw hard coal production data given in Table 1.

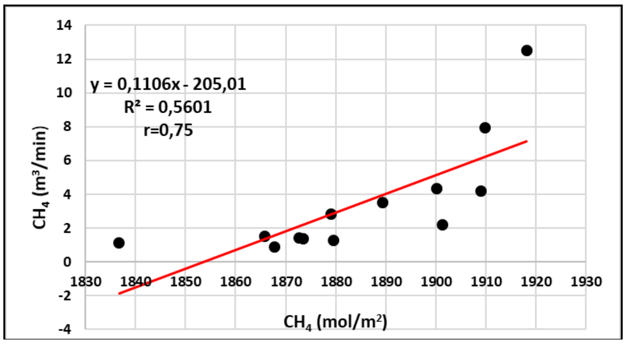

Figure 11. Improved regression model and graph for retrival operations.

Point No	Sample number	Min.	Max.	Average m^3/min	Standard deviation
ASB	192	-3,896	9,775	2,708	±2.855
140	269	-3,896	9,775	2,769	±2.768
52	249	-3,896	9,775	2,786	±1.863

Table 3. Statistical indicators for retrivaled satellite observations.

Years	52	140	ASB
2019	-1,11111	-1,04613	-1,29521
2020	0,959262	0,964239	0,687338
2021	2,610884	2,609924	2,399168
2022	3,490453	3,470026	3,44063
2023	4,46887	4,506833	4,351649

Table 4. Annual average CH_4 flow rate values in m^3/min observed with TROPOMI sensor at emission exit points.

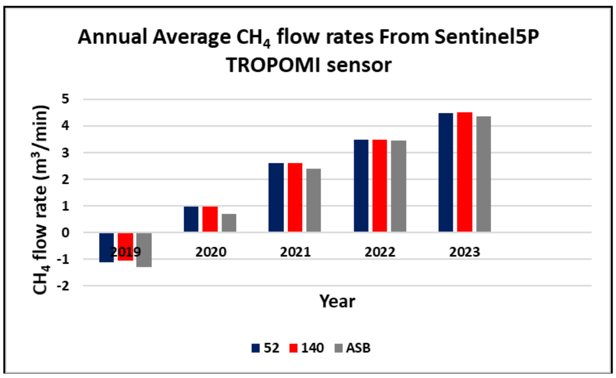

Figure 12. Distribution graph of the average values of CH_4 flow rates by years at the observation points.

According to the values obtained as a result of the conversion of the values measured between 2020 and 2023 as a result of the retrival method application into flow values in m3/min unit, the maps showing the CH4 flow distributions around the well annually and the CH4 distribution in the region in mol/m2 unit are shown in Figure13, 14, 15 and 16.

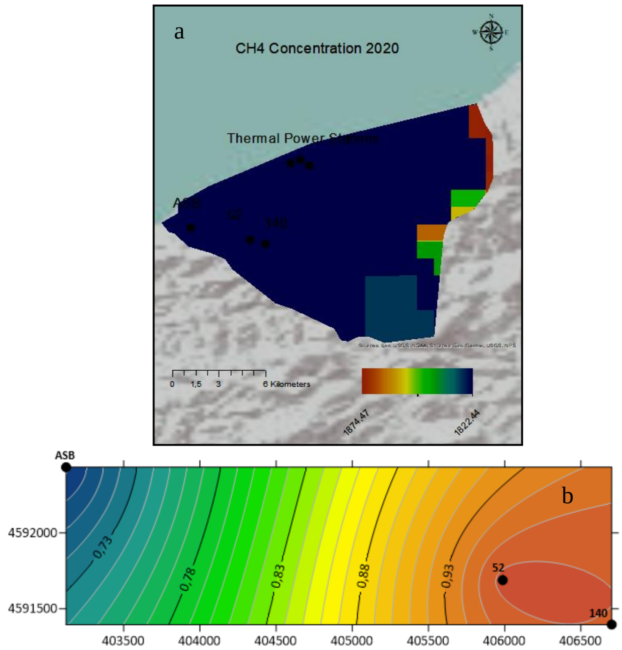

Figure 13. For 2020, a) average methane distribution obtained from satellite observations and b) methane gas distribution map converted into flow values by retrival.

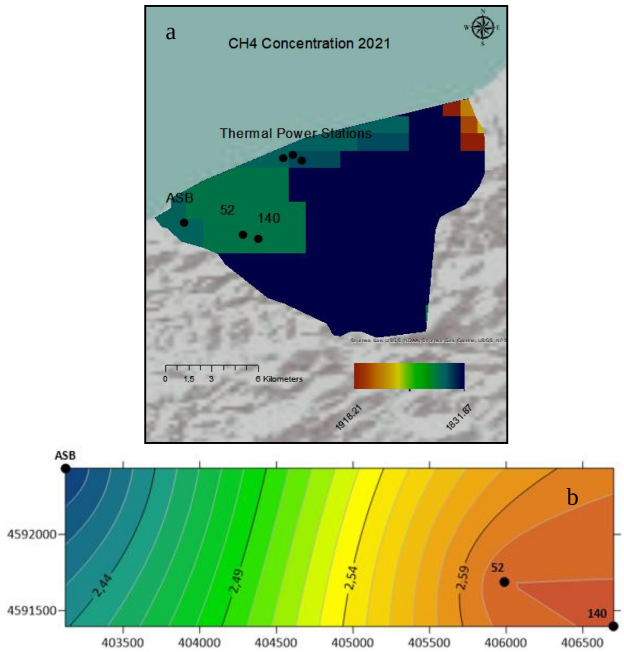

Figure 14. For 2021, a) average methane distribution obtained from satellite observations and b) methane gas distribution map converted into flow values by retrival.

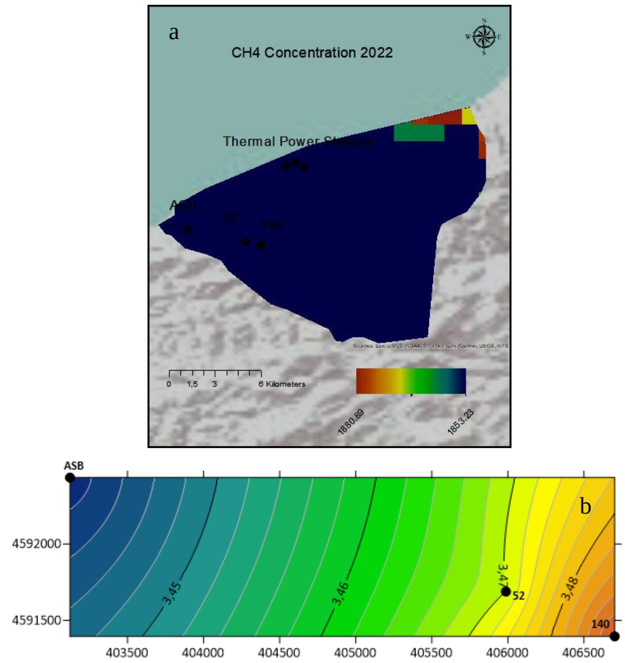

Figure 15. For 2022, a) average methane distribution obtained from satellite observations and b) methane gas distribution map converted into flow values by retrival.

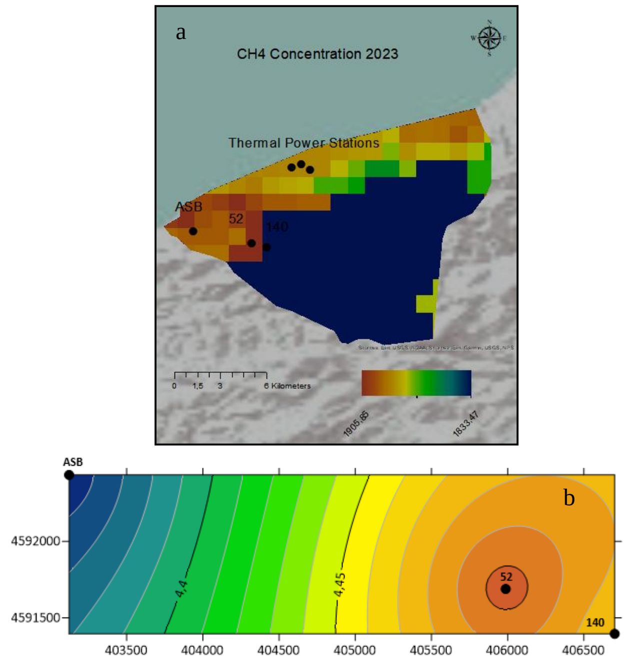

Figure 16. For 2023, a) average methane distribution obtained from satellite observations and b) methane gas distribution map converted into flow values by retrival.

When the averages of TROPOMI CH_4 values obtained in m^3/min units by retrivilisation are considered, the CH_4 values emitted in the atmosphere can be determined in terms of volume and mass according to the emission exit points of these values. For this application, the density of methane, which makes the biggest contribution to global warming, is taken as 0.716 kg/m^3. Annual total volume and annual total methane mass were determined by converting the flow rate values of methane values per minute into annual values. The findings obtained from these calculations are given below.

- For ASB emission exit point: Annual average CH_4 flow rate value is 2,707797 m^3/min; 2,707797*60*24*365= 1424376 m^3= 1,424 Million m^3 annual average methane volume.
- For 140 emission exit points: Annual average CH_4 flow rate value is 2,768517m^3/min; 2,768517*60*24*365= 1455912 m^3= 1,455 Million m^3 annual average methane volume.
- For 52 emission exit points: Annual average CH_4 flow rate value is 2,786140 m^3/min; 2,786140*60*24*365= 1466424 m^3= 1,466 Million m^3 annual average methane volume.

According to these evaluations, the annual average methane volume from all exit points is 4,346 Million m^3 in total. This value was obtained as 21,730 Million m^3 in total for five years. In order to convert the total 5-year methane volume into mass, the methane mass is obtained as 21,730Mm^3*0,000716Tone/m^3= 15558,7 Tonnes by multiplying by the methane density.

Accordingly, it has been determined that uncontrolled release of CH_4 to the atmosphere every year from the ASB, shaft 140 and 52 and the mouth of the gallery together with the underground mine polluted air causes damage to the environmental quality and climate.

4. Conclusions

In mines where the ventilation structure is created with the shaft system, the polluted air waste released by underground production has environmental impacts and negative contributions to climate change. In this study, the methane values in the polluted air released to the atmosphere by aspirator discharge at two shafts and one gallery exit point in the Karodon operation area of Kilimli district of Zonguldak Hard Coal Basin, the only hard coal production region of Turkey, are discussed. In addition, methane gas emissions during the transportation of coal stored in the region of thermal power plants were also examined.

In the application, the observations from the TROPOMI sensor of the Sentinel-5p satellite were obtained through the GEE platform. In the underground production environment, calibration and control processes were carried out by including the sensor measurement values placed at the aspirator outlets.

In the analyses performed based on CH_4 measurement data, a regression model with 75% correlation was created between the values measured in % concentration unit and converted into methane gas flow values at the well exit point and the values measured from the TROPOMI sensor on the same day. With this model, the volume and mass value of methane gas released into the atmosphere in the region for a five-year period between 2019 and 2023 were determined by converting satellite observation data in mol/m^2 to m^3/min flow rate unit. The results are quite high and may lead to environmental and regional climate changes. It has been observed that the annual average value of 21,730Mm^{3}or 15558,7 Tonnes of CH_4 released freely into the atmosphere is at a level that can affect climate change with the greenhouse gas effect it will create.

The results show that urgent measures are needed for the sustainable management of underground mining activities and air pollution control. In particular, it should be taken into account that methane gas accumulates in the atmosphere and is responsible for about 30% of the increase in global temperatures (United Nations Environment Programme (UNEP) 2021; International Energy Agency-IEG 2022). In this regard, it is necessary to improve ventilation systems and develop systems that can control the methane gas released and implement projects to utilize this potential more beneficially.

Acknowledgements

The authors thanks Google Earth Engine for remote sensing data and Turkish Hardcoal Enterprise Karadon Enterprise officials.

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