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Spatial and Temporal Variability of Atmospheric Methane Concentrations in Bangladesh

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ABSTRACT

We used 2019-2021 TROPOMI satellite observations of atmospheric methane in an analytical inversion to identify methane (CH_4) emissions in Bangladesh from 2019 to 2021. Methane is considered as second most important greenhouse gas (GHG) contributor, with nearly 28 times more potential to global climate change next to carbon dioxide. Monitoring and predicting atmospheric methane concentrations is important in global efforts to mitigate and adapt to climate change. This study made an effort to detect existing concentrations of CH_4 at the atmospheric level of Bangladesh, hot spot identification, and spatial-temporal pattern detection using remote sensing. The study used daily column-averaged dry air column methane mixing ratio (XCH_4) data retrieved from TROPOMI measurements. Weekly/monthly average concentrations were extracted from Sentiniel-5P satellite images. The batch inverse Distance weighting (IDW) interpolation technique was conducted on raw images (excluding October months) to fill in missing values in the images. The emerging hot spot analysis tool (ArcGIS Pro) was applied to the weekly interpolated images to identify statistically significant spatiotemporal hotspots of CH_4 concentrations. Results indicate that the persistent hot spot and intensifying hot spot of methane concentrations are prominent within the Dhaka Division. An intensifying hot spot of CH_4 was found within the Dhaka district, which indicates that it is a hot spot for the study period. Source point detection and real-time monitoring can be more effective in identifying the methane emission reduction mechanism.

INTRODUCTION

Methane (CH_4) is a major precursor of tropospheric ozone and the second-most significant anthropogenic greenhouse gas after carbon dioxide (CO_2). Methane (CH_4) is one of the major greenhouse gases. (Mosier, 1998), having a 30% contribution to global warming, and it is now increasing at a rate unheard of since records were kept in the 1980s (UN Environmental Program, 2021). A recent study (Mar *et al.*, 2022) Provided an overview of methane's impacts on climate, ecosystem, and health. From the analysis, it was found that photochemical reactions of methane (CH_4) in the atmosphere lead to the production of tropospheric ozone (O_3), CO_2, and stratospheric water vapor (strat.H_2O). These produce Greenhouse gases (GHGs) and contribute directly to global warming. Tropospheric ozone(O_3) is produced from methane (CH_4) and is harmful to human health and ecosystems, damaging plants, leading to crop losses, and reducing the ability of the biosphere to store carbon (Mar *et al.*, 2022).

Methane (CH_4) sources are both natural and anthropogenic, including wetlands (where CH_4 is produced via microbial activity), fossil fuels, agriculture (livestock and rice cultivation), waste management (landfills), and fires (Kvalevåg & Myhre, 2013; Saunois *et al.*, 2020). The primary loss mechanism (sink) is atmospheric oxidation: Almost 7% of CH_4 is oxidized in the stratosphere and 88% of CH_4 is oxidized in the troposphere using the hydroxy radical (OH) (Boucher *et al.*, 2009). Notably, human activities can also have an impact on the natural sources of CH_4 emissions (e.g., land use changes can affect CH4 from wetlands). The balance between these diverse sources and sinks determines the atmospheric concentration of CH_4 and its temporal dynamics (i.e., trend, seasonality).

Methane concentrations in the atmosphere have increased significantly from pre-industrial values is about 715 ppb to 1732 ppb in the early 1990s and 1774 ppb in 2005 (Saunois *et al.*, 2016). and the latest value of 1910 ppb from 1 January to 31 March 2021 was found in the atmosphere of Bangladesh (Kozicka *et al.*, 2021). Since the Industrial Revolution, rising human populations have resulted in increasing waste generation, agriculture, and fossil fuel production. About 60% of the methane in the atmosphere today comes from sources that scientists believe are caused by humans, with the remaining coming from sources that existed before humans began dramatically altering the carbon cycle (Borunda, 2019). A study (Manjunath *et al.*, 2014) found that South Asia has a total methane emission rate of 4.7817 Tg/yr, and India (3.3860 Tg/yr), Bangladesh (0.9136 Tg/yr), Pakistan (0.2675 Tg/yr), Sri Lanka (0.1073 Tg/yr), and Nepal (0.1074 Tg/yr).this are the countries with the highest mean methane emissions (Manjunath *et al.*, 2014).

A recent study (Kozicka *et al.*, 2021) explored the spatial and temporal variability of atmospheric methane concentration from 2019 to 2021 in several countries. The study found that the highest mean content of methane in the atmosphere was observed for Bangladesh (1903 ppb) while the lowest for Indonesia (1836 ppb)

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(Kozicka *et al.*, 2021). Methane concentration varies by country for spatial and temporal changes. In Bangladesh, a leading source of methane emissions are inundated rice paddies and other agricultural activities, landfills, urban industrial waste, and leaky natural gas pipelines but efforts are still underway to quantify these emissions and their spatiotemporal patterns. To Scale up this effort to mitigate methane emission measurement of atmospheric methane concentration is necessary in Bangladesh. Frequent mapping of methane content at the global and regional scale is possible using different satellite sensors GOSAT, OCO-2, and MethaneSAT for methane retrieval technique.

Greenhouse Gases observing satellite (GOSAT) uses a Fourier transform spectrometer (FTS) to implement a spectral fitting technique to measure sunlight absorption by methane and other gases in infrared regions but we infer the use of TROPOMI instead of other satellites to observe highly sensitive traces of gas for its high spatial resolution measurements with its wide spectral coverage (Hu *et al.*, 2018; Lorente *et al.*, 2021; Hasekamp *et al.*, 2021). A different study revealed that one of the most available sensors for such purpose, because of high spatial resolution and short revisit time, is the TROPOMI (Tropospheric Monitoring Instrument). TROPOMI employs the differential optical absorption spectroscopy (DOAS) method to measure sunlight reflection and methane absorption in the near-infrared wavelength range. It is placed on the Sentinel-5 Precursor (Sentinel-5P) satellite board, launched in October 2017. Satellite data from Sentinel-5P can be transformed to the column-averaged dry-air mixing ratio of CH4 in the atmosphere at spatial resolution 7 × 7 (to August 2019) and 7 × 5.5 km (from August 2019). This study aims to objectify the methane emission hotspot analysis and characterize spatiotemporal variability from atmospheric methane concentration data from TROPOMI over Bangladesh from 2019 to 2021. We infer methane emission and identify potential hotspots to reduce the increasing methane concentration rate in Bangladesh

MATERIALS AND METHODS

Divisions (State) and Sub-divisions within Bangladesh were selected for the study. In the first step of the analysis, Divisions of Bangladesh were selected based on the huge concentration of methane spotted over Bangladesh with large, frequent emissions over Dhaka that were detected by Paris-based company Kayrros SAS and reported by Bloomberg. Data from Sentinel-5P was used for the analysis. The column-averaged dry-air mixing ratio of CH_4 (in ppb-parts per billion) data for the period from 1 January 2019 to 31 December 2021 was used. The Sentinel-5P imagery from the TROPOMI sensor preprocessed as a Level 3 (L3) product was used. Datasets were downloaded from the image collection "COPERNICUS/S5P/OFFL/L3_CH4" of Google Earth Engine as georeferenced raster files/Mean values of the column-averaged dry-air mixing ratio of CH_4 for 3-year periods was analyzed. Monthly (1-month periods) temporal changes in 9 divisions and 64 sub-divisions of Bangladesh of methane(CH4) concentration based on sentinel-5P data were analyzed. Four Categories were selected to show important insight into the spatial-temporal trend in the study area.

Pattern (classify each location as one of 17 categories of hot spot and cold spot trends that were adopted from ESRI). The Trend Bin category was used to classify each location as having a statistically significant upward or downward trend for hot/cold spot z-scores. (-3: downtrend, 99% confidence; -2: downtrend, 95% confidence; -1: downtrend, 90% confidence, 0: no significant trend; 3: up trend, 99% confident; 2: up trend, 95% confident; 1: up trend, 90% confident), Perc hot was introduced to obtain Percentage of time intervals of a location is being a significant hot spot, After that Mean weekly methane concentrations over the study period were found.

Study Area

The study was conducted in Bangladesh which is located within South Asia. The unit of analysis is division and subdivision Bangladesh. Natural gas, agricultural, livestock farm, Urban landfill waste, and industrial processed waste in the major urban areas are the key contributors to Methane emission.

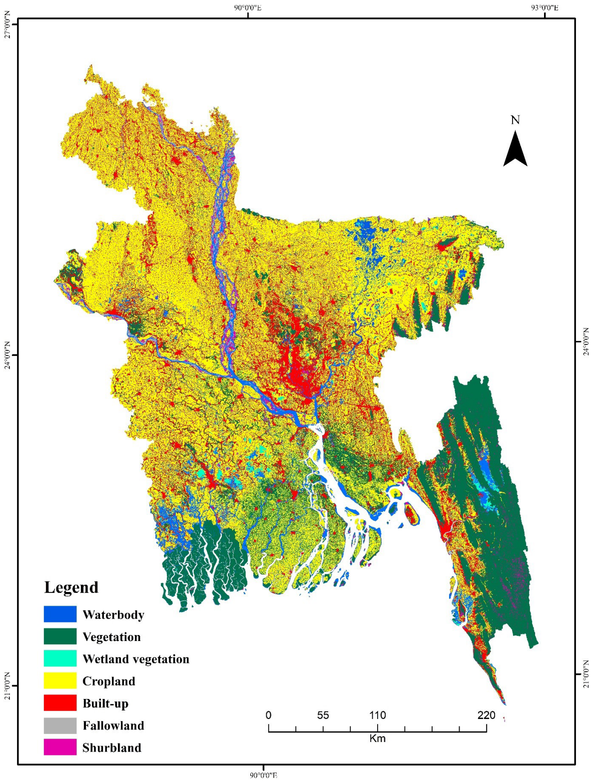

Figure 1: Topographic Map of Study Area Bangladesh

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Image acquisition and processing

The study has covered the period of 2019 to 2021 excluding the monsoon months of May-September due to cloud cover. Datasets were downloaded from the image collection "COPERNICUS/S5P/OFFL/L3_CH4" of Google Earth Engine as georeferenced raster files (in GeoTIFF format file) at spatial resolution 7 × 7 km. The daily column-averaged dry-air column methane mixing ratio (XCH4) data retrieved from TROPOMI measurements available from Google Earth Engine (GEE) for the period of 1 January 2019 to 31 December 2021. For the Methane Retrieval technique, TROPOMI measures the differential optical depth, difference of measured intensity, and reference intensity. The formula for differential optical depth (ΔOD) in the context of TROPOMI's DOAS measurements can be expressed as follows:

$$\text{Differential optical depth } (\Delta OD(\lambda)) = -\ln(I(\lambda)/I0(\lambda))$$

Here, ΔOD(λ) is the differential optical depth at a specific wavelength (λ). Where I(λ) is the measured intensity of light at the wavelength(λ) after passing through the atmosphere.I0(λ) is the intensity of the incident light at the same wavelength λ before passing through the atmosphere. By deriving the (ΔOD) concentration of various atmospheric constituents can be identified. For column concentration measurement the following expression can be stated:

$$\text{Column Concentration} = -\,(\text{Differential Optical Depth})/\sigma$$

$$\text{Column Concentration} = -\,(-\ln(I(\lambda)\,/\,I0(\lambda)))/\sigma$$

Where, σ is the absorption cross-section of methane at a specific wavelength, In the analysis. σ is the standard absorption cross-section of methane used in measurement. The derivation of σ follows the logic that variable wavelengths have certainties associated with ln(I(λ). Hence, the standard column concentration of the atmospheric constituents is inferred from the Differential column depth(ΔOD). In GEE various spatial and temporal operations were used, First the Dataset was imported and filtered. After that, the Dataset was projected to Bangladesh's Co-ordinate reference system (CRS) and Clipped to the study area. A Java Script was developed to streamline the bulk download and process to extract weekly average methane concentrations at a spatial resolution of 7 km. A Python script was developed to conduct batch Inverse Distance Weighting (IDW) interpolation method to raw images to fill in missing values in the images. IDW was applied only to missing pixels to preserve the original pixel values.

Data analysis

In the spatiotemporal statistical analysis, the emerging hotspot analysis from the Space Time Pattern Mining toolbox in ArcGIS Pro was applied to the weekly methane concentrations data (i.e., weekly interpolated images) from 2019 through 2021. The emerging hotspot analysis evaluated spatiotemporal patterns of methane concentrations using a combination of two statistical measures 1) the Getis-Ord Gi* statistic (Harris *et al.*, 2017) to identify hot spots and cold spots of methane concentrations for each week. The Getis-Ord Gi* statistic generated Z scores (Standard deviations) and P values (statistical probabilities) for each bin. For statistically significant positive Gi* statistic z-scores, the Z-score is a more intense cluster of values (hot spot) at a significant level of $p<.05$ (Harris *et al.*, 2017), and 2) the Mann-Kendall trend test to examine how hot spots and cold spots have evolved. In this case, the term 'hot spot' was defined as an area that has a high value of methane concentrations and is surrounded by other areas with high values as well. The steps for running the emerging hotspot analysis from space-time pattern mining tools in ArcGIS Pro were applied to create a space-time cube from the time series of raster imagery data. The Fill Empty Bins Method was applied to create a space-time cube from a multidimensional raster layer tool. Then the space-time neighbors' technique was used to fill the empty bins with the average value of space-time neighbors. The Input Multidimensional Raster Layer was projected using the WGS 1984 World Equidistant Cylindrical projection (WKID 4087). For reprojecting cell size (spatial resolution) was changed for the data as the resultant space-time cube is 1 km. The created space-time cube was used as an input for running the emerging hot spot analysis tool. The fixed distance of 10 km was used for the conceptualization of spatial relationships.

RESULTS AND DISCUSSION

Hot Spot Analysis Result

The statistical measures for Emerging Hot Spot Analysis produced different types of feature classes with variables such as input data and resultant hot spot layer for hot spot analysis Spatial-temporal data trends, z-score, and p-values values were found.

PATTERN: The result category was used to classify each location as one of 17 categories of hot spot and cold spot trends that were adopted from ESRI. As shown in Figure 2 (a), (source "COPERNICUS/S5P/OFFL/L3_CH_4") the persistent hot spot and intensifying hot spot of methane concentrations were prominent within the Dhaka Division. Specifically, the persistent hot spot was found around Dhaka especially in the Narayanganj district adjacent to Dhaka city, the Capital of Bangladesh, which is a hot spot over the study period, while the intensity of clustering was not trending significantly upward or downward over time. An intensifying hot spot of methane was found within the Dhaka district, which indicates that it is a hot spot over the study period and there is a statistically significant increasing trend in the intensity of clustering of high concentrations over the three years. In contrast, there was a large area of cold spots in the southeastern part of the country (e.g., Chittagong Division), which is mainly persistent and intensifying cold spots.

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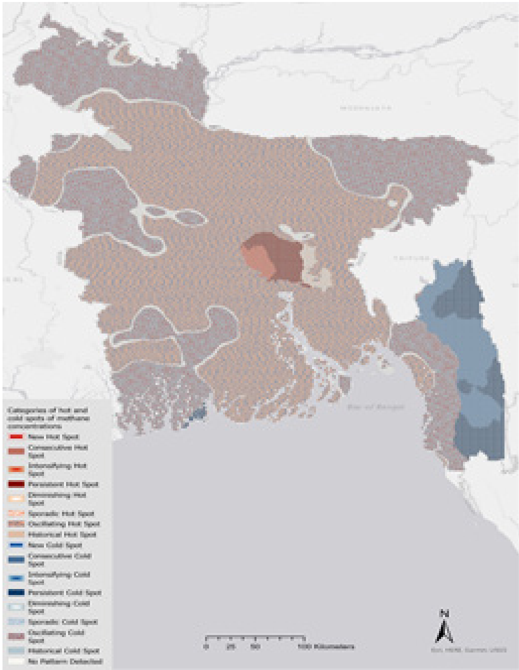

Figure 2 (a): Categories of hot and cold spots of methane concentrations between 2019 and 2021

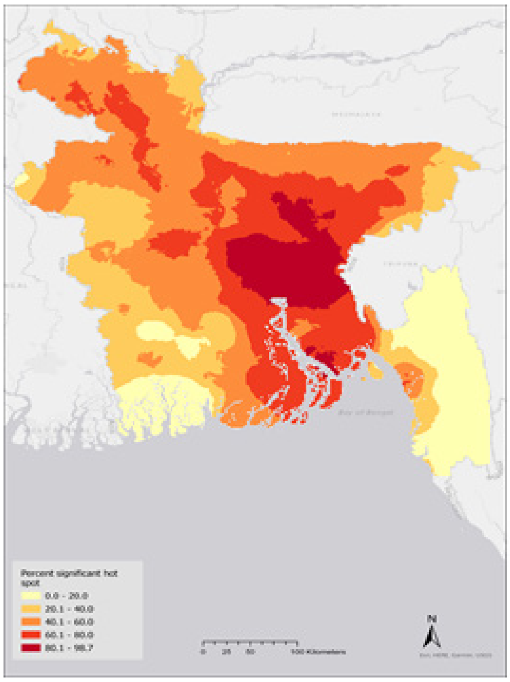

Figure 2 (c): Percent significant hot spots between 2019-2021

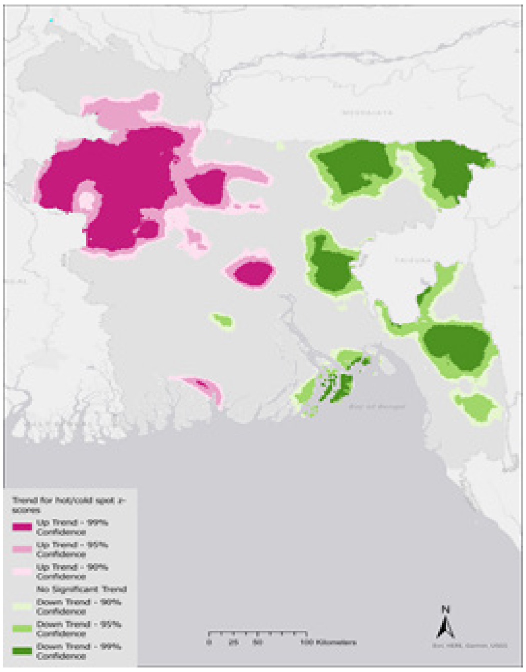

Figure 2 (b): Trends of hot/cold spot z-scores for methane concentrations between 2019 and 2021

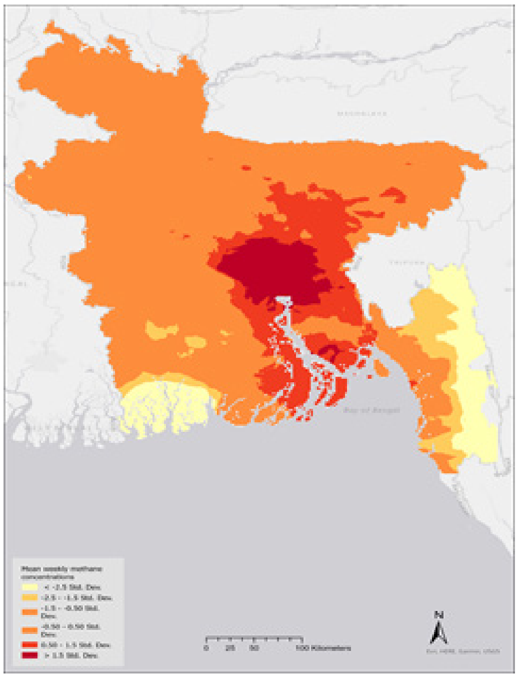

Figure 2 (d): Average weekly methane concentrations between 2019 and 2021

TREND_BIN:. From Figure 2(b), it was found that the Munshiganj and Dhaka districts showed a statistically significant upward trend with 99% confidence. Naogaon, Bogura, Natore, Rajshahi, Pabna and Kushtia districts of Northwestern Corner Division Rajshahi also showed an upward trend. Very few districts of the Rajshahi division showed an upward trend with 95% confidence.

PERC_HOT: Percentage of time intervals of a location being a significant hot spot. As shown in map 2 (c), areas in dark red have been significant hot spots of methane concentration for more than 80 percent of the weeks within the study period from 2019 to 2021. Dhaka, Narayanganj, Munshiganj, Gazipur, Narsingdi, Comilla, Brahmanbaria and Kisoreganj districts have shown significant hot spots for more than 80 percent of the weeks.

MEAN_VALUE: Mean weekly methane concentrations over the study period. Figure 2 (d) illustrated the average

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weekly methane concentrations hot spots spotted in Dhaka, Narayanganj, Munshiganj, and Gazipur districts with standard deviation from 2019-2021.

Figure 3 (a) reflects the average yearly methane concentration in the atmosphere of 8 divisions of Bangladesh. Figure 3 (b) illustrates the average monthly methane concentration for the years 2019, 2020, and 2021 respectively in Bangladesh.

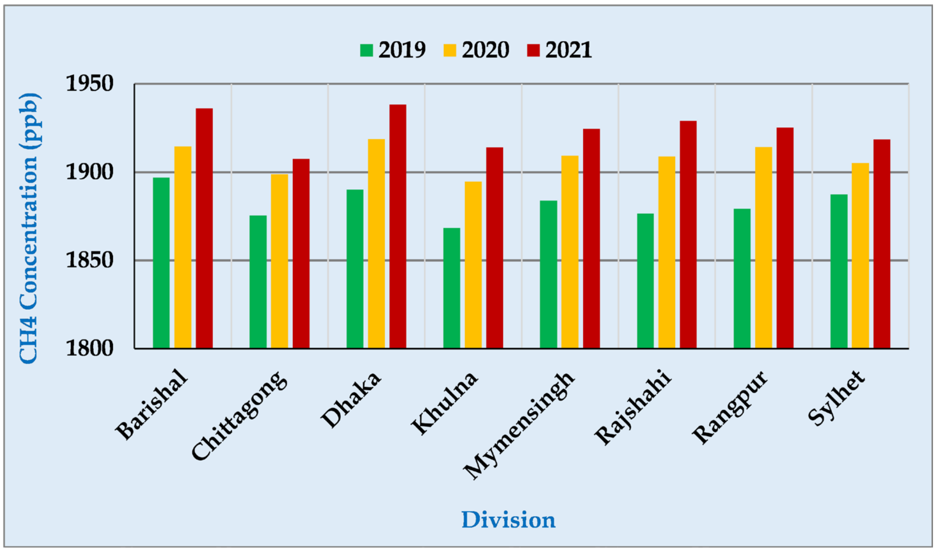

Figure 3 (a): Average yearly Methane Concentration over Bangladesh

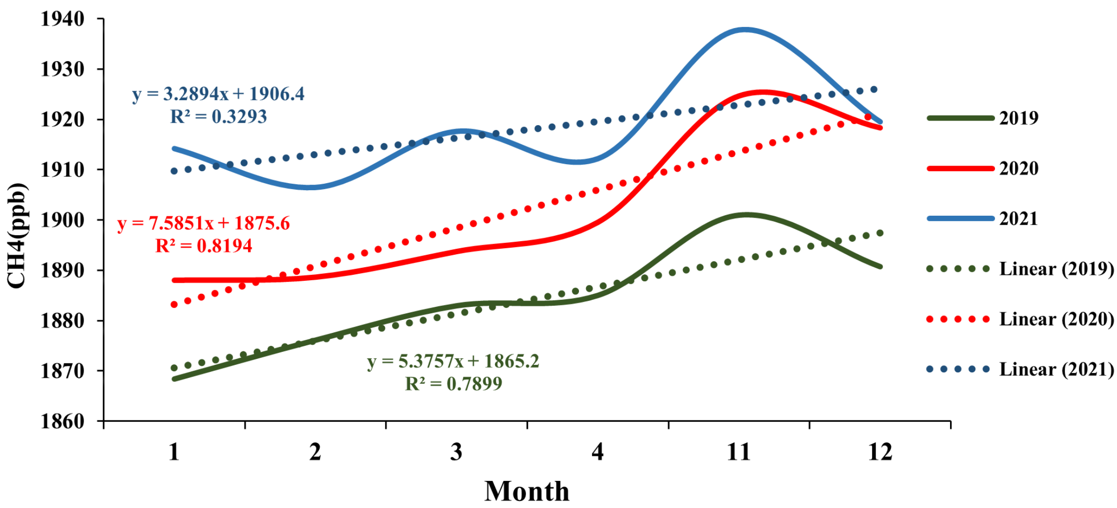

Figure 3 (b): Monthly trend analysis of methane concentration over Bangladesh

Discussion

The study demonstrates the Emerging pattern of Hot Spot Analysis and methane trend pattern as an approach for evaluating and monitoring statistically significant clusters of methane concentration in the atmosphere of Bangladesh. The study reveals that Dhaka, Narayanganj and Munshiganj districts consistently present statistically significant hot spots in Bangladesh. The study found that the yearly average methane concentration is increasing rapidly. During the study period, divisional changes, as well as a long-term increasing trend were observed for the content of methane at the atmospheric level of Bangladesh. All divisions of Bangladesh are characterized by a very similar pattern of changes. In the study, it was observed that the methane concentration is increasing gradually in anthropogenic sources of agriculture, livestock, urban landfills, and industrial waste In the Dhaka division the methane concentration is increasing which represents. Yearly long-term upward trend was observed during the study period and high concentration was found in November and December. Comparing other studies based on Asia, photochemical reactions of methane (CH_4) Produce ozone (O_3), CO_2, and stratospheric water vapor (strat.H_2O). The methane sink mechanism is mandatory, The primary loss mechanism (sink) is atmospheric oxidation: Almost 7% of CH_4 is oxidized in the stratosphere and 88% of CH_4 is oxidized in the troposphere using the hydroxy radical (OH) (Boucher *et al.*, 2009). In our study effect Analysis of different environmental factors on spatiotemporal

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variability Monthly trend analysis Figure 3 (b) of CH_4 Concentration led to an increase in the confidence of measurements than previously determined trends. In our study, we classified each location as one of 17 categories of hot spot and cold spot trends that were adopted from ESRI The Hotspot source denoted northwestern parts of Bangladesh and it was observed there was a large area of cold spots in the southeastern part of the country.

CONCLUSIONS

This study's identification of methane hotspot areas using remote sensing technology analyzing sentinel-5P satellite images was the main purpose of this study but later it will be used to make policy concentration for proper management of methane emission in Bangladesh. Policy for proper management of methane emission will be Location-specific based on emerging methane concentration areas, such as urban areas and industrial areas. Methane emission reduction Policy and strategy can be developed based on this study's findings to identify landfill methane emission rates in urban areas and there will be further studies to develop source points of methane emission and real-time monitoring systems. As well as In future studies it will also improve to identify the point sources and sinks of methane in Bangladesh which is necessary for adaptation and mitigation of climate change in the next future study. Our study only inferred the increasing methane concentration trend but a more detailed future study will be conducted to infer a machine learning (ML) time series fundraising forecasting model to predict future methane concentration trends based on the existing statistically significant hotspots of this study. To predict methane concentrations for the next three to five years on a district level we will employ a time-series forecasting approach using the Prophet library in Python to confidently predict future production. Machine learning (ML) methodologies could help to identify futuristic trends in averaging periods or even individual data points that are sufficiently similar, leading to an increase in the confidence of measurements. This could bring current hot spot analysis of the Munshiganj, Naogaon, Bogura, Natore, Rajshahi, Pabna, and Kushtia districts of Northwestern corner Division Rajshahi and Dhaka districts those showed statistically significant upward trend into an improvement in monitoring and predicting methane concentration at the atmosphere of Bangladesh.

REFERENCES

Borunda, A. (2019). Methane facts and information. In *National Geographic*. https://www.nationalgeographic.com/environment/article/methane.

Boucher, O., FriedlingsteinKozicka, P., Collins, B., & Shine, K. P. (2009). The indirect global warming potential and global temperature change potential are due to methane oxidation. *Environmental Research Letters, 4*(4), 44007. https://iopscience.iop.org/article/10.1088/1748-9326/4/4/044007/meta

Harris, N. L., Goldman, E., Gabris, C., Nordling, J., Minnemeyer, S., Ansari, S., Lippmann, M., Bennett, L., Raad, M., Hansen, M., & Potapov, P. (2017). Using spatial statistics to identify emerging hot spots of forest loss. *Environmental Research Letters, 12*(2). https://doi.org/10.1088/1748-9326/aa5a2f

Hasekamp, O., Lorente, A., Hu, H., Butz, A., aan de Brugh, J., & Jochen Landgraf. (2021). Algorithm Theoretical Baseline Document for Sentinel-5 Precursor Methane Retrieval. *Netherlands Institute for Space Research, 1*(10), 1–67. https://sentinels.copernicus.eu/documents/247904/2476257/Sentinel-5P-TROPOMI-ATBD-Methane-retrieval.pdf.

Hu, H., Landgraf, J., Detmers, R., Borsdorff, T., Aan de Brugh, J., Aben, I., Butz, A., & Hasekamp, O. (2018). Toward global mapping of methane with TROPOMI: First results and inter-satellite comparison to GOSAT. *Geophysical Research Letters, 45*(8), 3682–3689.

Kozicka, K., Gozdowski, D., & Wójcik-Gront, E. (2021). Spatial-Temporal Changes of Methane Content in the Atmosphere for Selected Countries and Regions with High Methane Emission from Rice Cultivation. In *Atmosphere* (Vol. 12, Issue 11). https://doi.org/10.3390/atmos12111382

Kvalevåg, M. M., & Myhre, G. (2013). The effect of carbon-nitrogen coupling on the reduced land carbon sink caused by tropospheric ozone. *Geophysical Research Letters, 40*(12), 3227–3231.

Lorente, A., Borsdorff, T., Butz, A., Hasekamp, O., Schneider, A., Wu, L., Hase, F., Kivi, R., Wunch, D., & Pollard, D. F. (2021). Methane retrieved from TROPOMI: improvement of the data product and validation of the first 2 years of measurements. *Atmospheric Measurement Techniques, 14*(1), 665–684.

Manjunath, K. R., More, R., Chauhan, P., Vyas, A., Panigrahy, S., & Parihar, J. S. (2014). Remote sensing based methane emission inventory Vis-A-Vis rice cultural types of South Asia. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40*(8), 821.

Mar, K. A., Unger, C., Walderdorff, L., & Butler, T. (2022). Beyond CO2 equivalence: The impacts of methane on climate, ecosystems, and health. *Environmental Science and Policy, 134*(January), 127–136. https://doi.org/10.1016/j.envsci.2022.03.027

Mosier, A. R. (1998). Soil processes and global change. *Biology and Fertility of Soils, 27*(3), 221–229.

Saunois, M., Jackson, R. B., Bousquet, P., Poulter, B., & Canadell, J. G. (2016). The growing role of methane in anthropogenic climate change. *Environmental Research Letters, 11*(12), 120207.

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., Houweling, S., & Patra, P. K. (2020). The global methane budget 2000–2017. *Earth*

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System Science Data, 12(3), 1561–1623. https://essd.copernicus.org/articles/12/1561/2020/

UN environmental program. (2021). Methane emissions are driving climate change. In *the UN environmental program*. https://www.unep.org/news-and-stories/story/methane-emissions-are-driving-climate-change-heres-how-reduce-them.

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