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Leveraging Geospatial Technology For Spatiotemporal Analysis Of Air Quality

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ABSTRACT:

Swidden agriculture, locally known as Jhum cultivation, is a prevalent traditional slash-and-burn farming method in the region. This practice, involving seasonal land clearing and burning, particularly between February and March, leads to significant environmental and societal consequences, causing seasonal increases in air pollution in an otherwise 'clean and green' state. The state of Mizoram imposes yearly, a strict and specific timeframe for swidden agriculture burning to take place. The study addresses a notable gap in existing literature concerning the environmental ramifications of swidden agriculture within the Mizoram context. The methodology employed geospatial technology, specifically Sentinel 5P TROPOMI and Landsat 8 OLI datasets, to meticulously evaluate the repercussions of periodic land burning on ambient air pollution levels. Google Earth Engine (GEE) and QGIS were extensively utilised for processing and thematic map creation, primarily leveraging Level 3 Offline (OFFL) Near-Real Time products from Sentinel 5P. The study's objectives are to highlight the utility of active remote sensing in air quality monitoring, assessing the effects of seasonal burning, determining links between swidden agriculture and air quality changes. The analysis focused on data from February to March 2023. The findings reveal a marked escalation in the atmospheric concentrations of hazardous pollutants, including formaldehyde (HCHO), carbon monoxide (CO), and nitrogen dioxide (NO₂), directly coinciding with the peak seasonal burning period of Jhum cultivation from February to March 2023. In contrast, aerosol (UVAI), methane (CH₄), and sulfur dioxide (SO₂) showed minimal or negligible changes in emission levels, or data was inconclusive due to technical limitations for CH₄. Interestingly, tropospheric ozone (O₃) exhibited a slight dip during this period. This research reinforces the importance of integrating satellite-derived data with terrestrial observations for a more active approach to air quality surveillance. The implications of this study are wide-ranging, extending beyond Mizoram to other areas where swidden agriculture is still practiced.

Keywords: Swidden agriculture, Geospatial technology, Air pollution, Mizoram, Satellite monitoring

1. INTRODUCTION

Slash and burn agriculture is a traditional and long-standing method of farming that was widely practiced extensively around the world, particularly common in and around the tropical areas. As a technique, it involves cutting and burning crops and other vegetation to create a swidden field which is left to dry off. These dried off fields are then burned to leave a patch of land nutritionally rich for the subsequent round of crops. Such land clearing and burning has been practiced for thousands of years with its origins traced back to the Neolithic Revolution, approximately 12,000 years ago. It allowed for the cultivation of crops in areas where dense vegetation would otherwise make it impossible to plant. More sustainable agricultural practices have not proliferated to Mizoram to completely replace Jhum cultivation.

In terms of atmospheric effects, the primary substances released during this process are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), all of which are potent greenhouse gases contributing to global warming. The burning of biomass leads to the release of particulate matter and volatile organic compounds (VOCs), which can contribute to haze and have health implications for local populations. Additionally, the destruction of vegetation releases carbon stored in the plant biomass back into the atmosphere, exacerbating the greenhouse effect. This practice also emits various nitrogen oxides (NO_x), which are precursors to ground-level ozone, a harmful air pollutant.

2. JHUM CULTIVATION IN MIZORAM

According to the Mizoram Government's land use statistics of 2019-20, out of 2040.52 hectares of land reported for Land utilization Statistics, 18.51 hectares of land were utilized for Jhum cultivation. This utilization rose to 19.08 hectares in 2020-21.

Table 1: Total Cropped Area and Jhum Land utilization of Mizoram in 2019 and 2020.

Source: Statistical Handbook of Mizoram, 2022

Particulars	2019-20	2020-21
	Area (thousand hectares)	
Total Cropped Area	202.52	200.84
Jhum land	18.51	19.08
Proportion of Jhum land to Total Cropped Area	9.13%	9.50%

Direct comparison between Total Cropped Area, which includes all areas sown for agricultural use throughout the year, and Jhum land shows that a staggering 9.13% of Total Cropped Area constituted land used for Jhum cultivation in 2019-20. This rose by 0.37% in 2020-21 despite the State Government's efforts at minimizing Jhum cultivation methods over the years. (Table 1).

Table 2: Yearly Jhum Land Area utilization of Mizoram from 1998 to 2007

Source: Statistical Abstract, Department of Agriculture, 2003 adapted from R. Kavita Rao (2012)

Year	Jhum Land Area
1998-99	46,634
1999-00	36,285
2000-01	35,798
2001-02	40,306
2002-03	41,356
2003-04	43,447
2005-06	40,100
2006-07	41,465

Table 2.1: District-wise proportion of households to Jhum cultivators in 2004

Source: Statistical Abstract, Department of Agriculture, 2003 adapted from R. Kavita Rao (2012)

District	No. of Households	No. of Jhum Cultivators	% of Jhum Cultivator Families
Aizawl	49,596	15,806	32
Mamit	10,034	6,149	61
Kolasib	12,712	7,930	62
Lunglei	24,550	13,295	54
Siaha	17,009	12,541	74
Champhai	20,038	12,394	62
Serchhip	8,947	4,737	53
Lawngtlai	11,757	5,343	45
Total	1,54,643	78,195	51

Total Jhum land showed a slight increasing trend from 1998 to 2007 with widely fluctuating Jhum land utilization over the years (Table 2). District-wise statistics taken in 2004 showed a relatively high proportion of Jhum cultivators as compared to the total number of households in each district of Mizoram (8 districts at the time). Aizawl district having a major portion of urban area compared to other districts had the lowest proportion of Jhum Cultivators (Table 2.1) (R Kavita Rao, 2012).

3. OBJECTIVES

The objectives of this research paper may be highlighted as -

- To highlight the utility of active remote sensing in air quality monitoring.
- To assess the effects of yearly seasonal burning of land for Swidden Agriculture over the state of Mizoram.
- To determine the links between Swidden agriculture with air quality changes.
- To complement existing literature on air quality studies over the AOI.

4. STUDY AREA AND BACKGROUND

Mizoram, a small landlocked northeastern state in India, was established on February 20, 1987. Aizawl serves as its capital city. Encompassing an area of around 21,087 square kilometers (Economic Survey, 2012-13), Mizoram possesses predominantly hilly terrain with substantial forest cover, accounting for over 85.41% of its total area (according to the FSI, 2019). The state shares borders with Tripura, Assam and Manipur. It shares international boundaries with Bangladesh to the southwest and Myanmar to the east. Mizoram's economy is primarily agrarian, with traditional farming practices like slash-and-burn (jhum) or shifting cultivation being prevalent. Slash and burn agriculture, has been the dominant agricultural practice in Mizoram for many years. Yearly, as the Rabi season ends, farmers and cultivators in the State would slash their croplands of all vegetation and be left for a while to allow the slashed vegetation to be dried up after which these dried up vegetation would be burned to clear the land for future cultivation before the arrival of the northeast monsoon rains. As such, this leads to high increase in air pollution seasonally every year in the otherwise 'clean and green' state of Mizoram. Studies regarding the linkage between slash and burn agriculture and air pollution and its associated impacts have not been done extensively in literature.

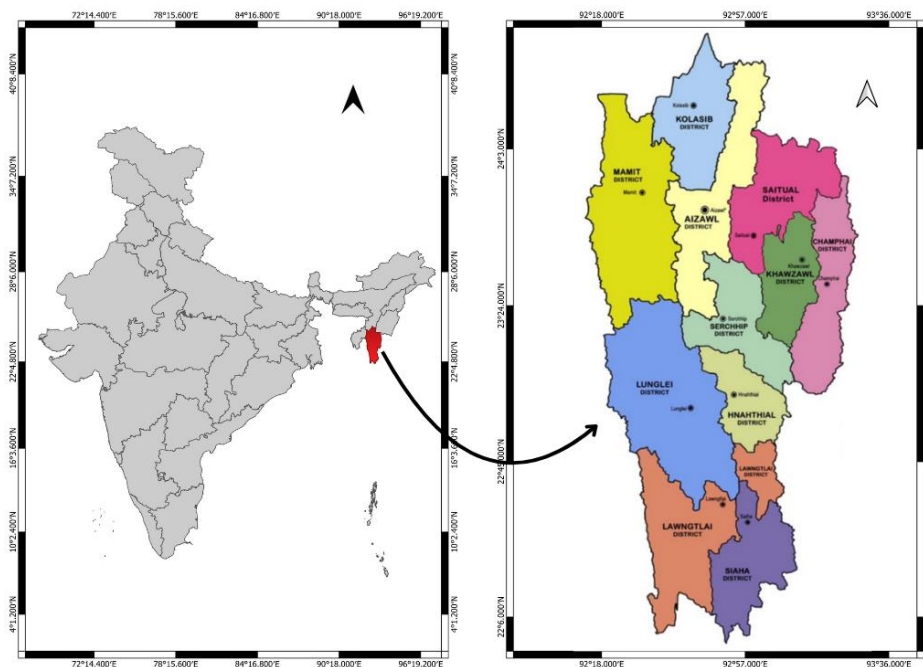


Figure 1: Location of Study Area

The Government of Mizoram, through its Magistracy, prohibits citizens from undertaking all Jhum cultivation related burning of land after 13th March to 15th March typically. This order, promulgated through the respective District Magistrates of all Districts of Mizoram as their capacities as Chairmen, District Fire Prevention Committee by invoking Section 144 of the CrPC, 1971 (Act II of 1973) follows strict compliance by citizens. This is beneficial for undertaking research related to this field as a set timeframe is allowed to exist where a before-after comparative study is made much easier and more accurate to undertake. This order was also in place during the research period throughout the whole of Mizoram.

In terms of Air Quality Index (AQI) over Mizoram, high seasonality can be observed where a significant degree of seasonality is evident, indicating that Mizoram's air quality notably deteriorates as winter progresses. Such is substantiated by AQI monitoring stations across the state. Figure 3 shows the averaged monthly AQI scores from all 19 air quality monitoring stations located across Mizoram for the year 2022.

While fluctuations in air quality can be influenced by various factors, the notable correlation between increases in AQI during the peak burning season of Jhum cultivation and decreases in AQI just before and after the implementation of statewide planned prohibitory orders raises specific inquiries into the extent of their correlation.

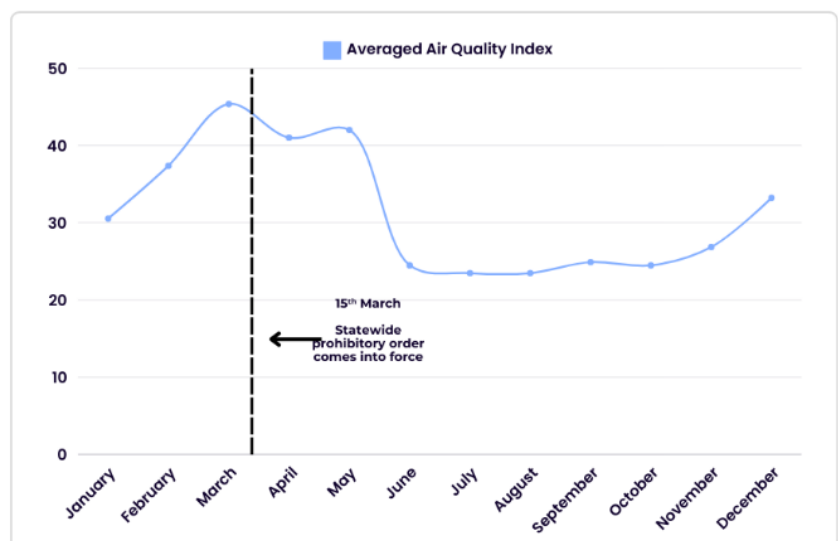


Figure 2: Averaged Air Quality Index of all State Pollution Control Board Monitoring Stations throughout Mizoram in 2022.
Source: Statistical Handbook of Mizoram, 2022, Directorate of Economics and Statistics, Government of Mizoram

In view of all these factors and observations, the specific study area of Mizoram has been chosen as the study area. Although a direct and detailed observation and analysis of Jhum cultivation and its effects is not the purview of this paper, such shall nonetheless be discussed. The forested fallow is slashed and cleared during December to January by farmers in Mizoram. The burning of slash is done in March (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA), 2015). Rice planting primarily occurs from April to mid-May following the onset of the first rains. Farmers often cultivate both early and late maturing varieties of rice on the same land, resulting in two distinct harvest periods: one between July and August, and the other from October to November.

Incidence of accidental forest fires have been observed to be significantly higher during the Swidden burning period throughout the year for all recorded areas in the history of Mizoram. Although no specific statistic on the number of burning specifically as a result of Swidden agriculture exists, it is expected to be high. Although it is acknowledged that many other causes and factors exist that contribute to forest fires, and, that correlation does not necessarily equate to causation, the figure below (Figure 3) shows a multiline graph of all fire statistics from 2012 to 2021 in Mizoram

which shows a significant incidence of forest fires during February to March for each recorded year which corresponds to the burning period of Jhum cultivation.

Increase in forest fires correspond to increases(worsening) of AQI over Mizoram shown in Figure 3. It may be noted that these forest fire incidents do not include the controlled burning of land for Jhum cultivation processes. They only include forest fire incidents that occur due

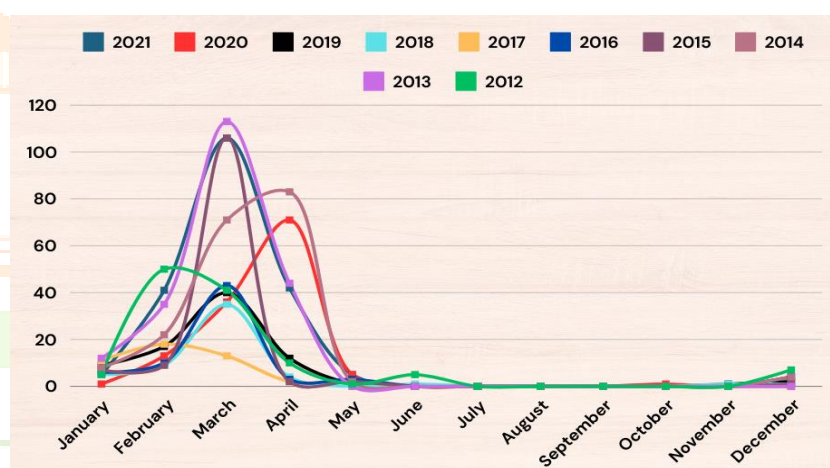


Figure 3: Monthly forest fire related incidents in Mizoram between 2012 to 2021.

Source: Fire and Emergency Services Department, Government of Mizoram

to other reasons and those caused by accidental uncontrolled forest fires from Jhum cultivation related activities.

One of the most immediate consequences of Jhum cultivation is the emission of particulate matter (PM) into the atmosphere. Particulate matter with a diameter of 10 micrometers or less, commonly referred to as PM₁₀, poses a significant risk to various life forms and serves as a key sign of air contamination. The presence of PM₁₀ in the atmosphere can lead to respiratory issues, cardiovascular diseases, and other health problems in humans, while also impacting wildlife and vegetation. PM₁₀ poses serious health risks when inhaled, as they can penetrate deep into the lungs, causing respiratory problems and exacerbating existing conditions such as asthma and bronchitis. (Fang and Chang 2010; Koulouri et al. 2008; Kulshrestha et al. 2009; Li et al. 2014; WHO 2016). The combustion of vegetation during Jhum cultivation releases a cocktail of gases, including methane (CH₄), carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde (HCHO), volatile organic compounds (VOCs), and sulfur dioxide (SO₂). NO_x and VOCs can react in the presence of sunlight to form

ground-level ozone (O₃), a highly reactive oxidant and a major component of smog. Tropospheric ozone, formed through this process, poses significant health risks, particularly for vulnerable populations, and can also damage crops and other vegetation. It may be important to note that PM₁₀ values is shown to be declining in Europe and USA, whereas in most Asian countries' values are still critical, especially in India and China (Balakrishnan et al., 2019).

It may be mentioned that no concrete medical data and disease burden profile of Mizoram exists in public access repositories at present. However, general accepted consensus in Mizoram states that respiratory illnesses are among the most prominent illnesses in Mizoram. In light of this, and with the added context of correlation between smoke from wildfires and AQI changes, it may be further established that wildfires, or, in this context, Swidden agriculture burning in Mizoram directly leads to higher respiratory illnesses in Mizoram. However, this requires further study.

5. METHODOLOGY

Sentinel 5P TROPOMI and Landsat 8 OLI Collection 2 Level 2 data was used extensively. Basemaps with shapefiles were prepared, and digitized using Landsat 9 OLI data, utilising the Remotior Sensis Python package within Semi-Automatic Classification Plugin ver. 8.2.2 in QGIS. Landsat 9 OLI optical imagery was just used for best accuracy and for easy reference and thus, does not contribute majorly to the final maps. Shapefile of the study area, Mizoram, was obtained from secondary sources and farther refined to account for inaccuracies and outdated data. Other preprocessing such as radiometric correction or doppler terrain correction was not performed. QGIS 3.28.11 and SNAP ver. 9 were used in tandem with each other for various aspects of the process.

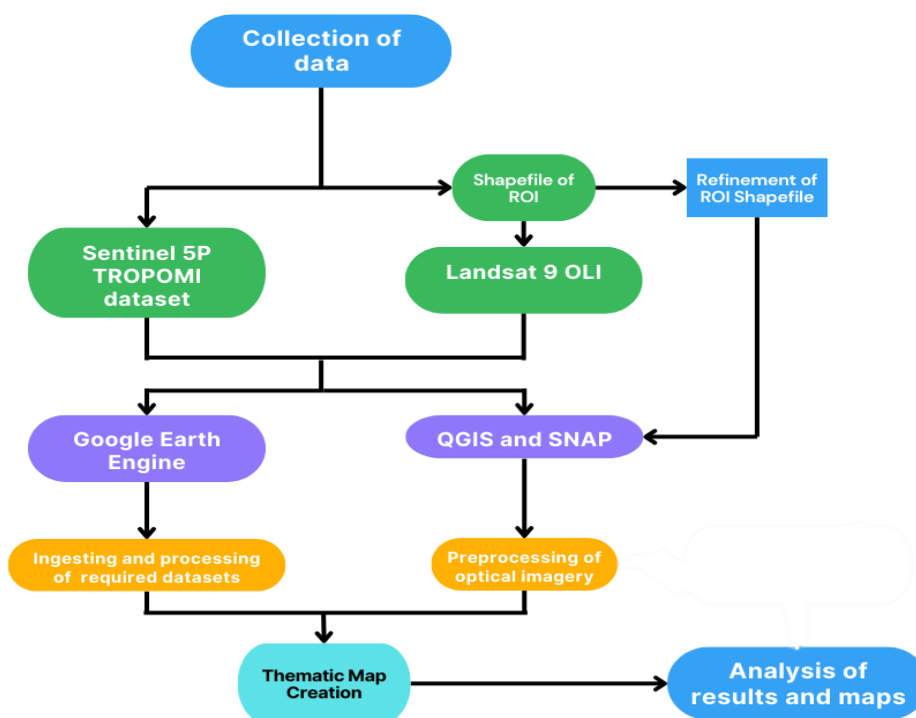


Figure 4: Flowchart showing research methodology

With regards to Sentinel 5P TROPOMI data, Google Earth Engine (GEE) was extensively used to process and export GeoTIFF file for further thematic map creation and symbology. Datasets were provided by the European Union/ESA/Copernicus through GEE. All processing which was ultimately used for all resultant maps and analysis were based on Level 3 Offline (OFFL) Near-Real Time products. Land Use/Land Cover map of Mizoram was generated in GEE using the Dynamic World 10m near-real-time (NRT) dataset based on unsupervised classification method after which symbologies and layouts were further created in QGIS.

All GIS & RS related data were based on a temporal period between February, 2023 to March, 2023. Other secondary sources of data include Government websites, datasets, public repositories, and other similar sources. All assessments and understandings of the end outcomes were carried out via careful visual examination, guaranteeing the precision and dependability of the findings. A flow chart of the methodology adapted in this paper has been put forward below. All datasets produced through Google Earth Engine(GEE) were done so through its native JavaScript API code integration. GeoTIFF files and graphs were also generated natively in GEE. Although GEE derived datasets were mostly based on tropospheric column sampling, data points corresponding to Aizawl (92.71602171527309, 23.733685708787384), Lawngtlai (92.8980765041029, 22.530945368113265), Kolasib (92.67687954220635, 24.22782298403602), and Champhai (93.33522156493495, 23.468631509967697) were taken and presented to provide for much needed context to supplement maps for the Carbon Monoxide dataset. This was achieved through the feature function in GEE. A reducer was applied to sample the data to the first pixels corresponding to the geographical points using ee.Reducer.first() at a native resolution scale of 7000 with a maxPixels limiter of 1e9.

Table 3: GEE datasets used and their particulars

Pollutant	Data	Band Name	Unit	Resolution
Nitrogen Dioxide	NRTI/L3_NO2	NO2_column_number_density	mol/m ²	1113.2 meters
Carbon Monoxide (CO)	NRTI/L3_CO	CO_column_number_density	mol/m ²	1113.2 meters
Formaldehyde (HCHO)	NRTI/L3_HCHO	tropospheric_HCHO_column_number_density	mol/m ²	1113.2 meters
Methane (CH4)	OFFL/L3_CH4 (Bias Corrected)	CH4_column_volume_mixing_ratio_dry_air	Mol fraction (ppm)	1113.2 meters
Sulfur Dioxide (SO2)	NRTI/L3_SO2	SO2_column_number_density	mol/m ²	1113.2 meters
Tropospheric Ozone (O3)	OFFL/L3_O3_TCL	ozone_tropospheric_mixing_ratio	mol/m ²	1113.2 meters

6. RESULTS

Per-pollutant processing results and their analysis shall be put forward in this section and shall include all the pollutants listed under Table 3.

6.1 Carbon Monoxide (CO)

Carbon monoxide (CO) holds significance as a trace gas in the atmosphere, crucial for understanding tropospheric chemistry. The primary origins of CO include the combustion of fossil fuels, biomass burning, and the atmospheric oxidation of methane and other hydrocarbons. While fossil fuel combustion predominantly contributes to CO levels in northern mid-latitudes, the oxidation of isoprene and biomass burning assumes a pivotal role in tropical regions. The series map shown alongside (Figure 5) shows the spatiotemporal extent of carbon monoxide per 4-day averaged time period from February to March, 2023. It can be observed that there is a rise in CO level from 20th February, with its peak at around 16th March, after which it recedes towards normal (optimal) levels. This coincides with the Swidden agriculture burning period. The CO content overall appears to subside after around 9 days post the enactment of the prohibitory order.

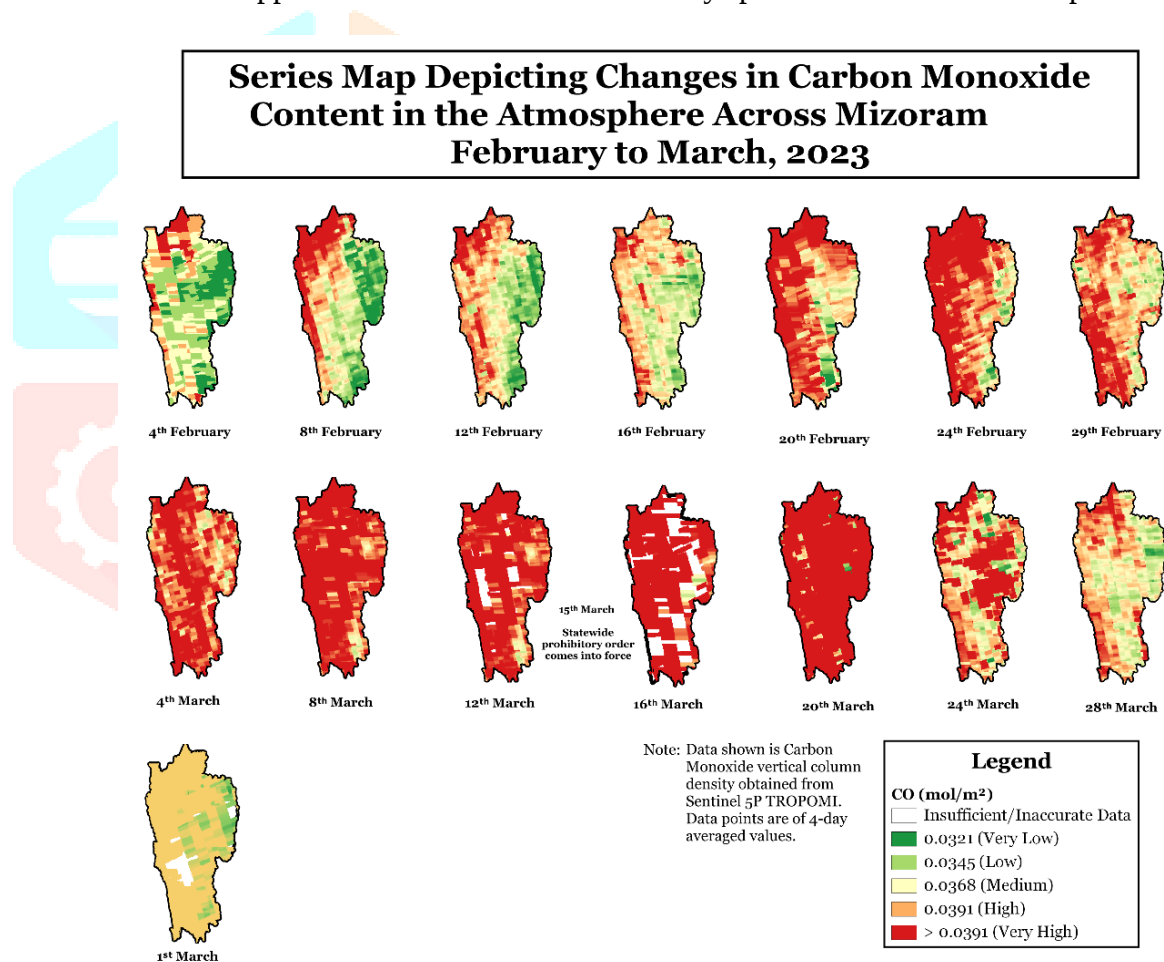


Figure 5: Series map showing CO content over Mizoram between February to March, 2023

Table 4: Pollutant count across 4 settlement areas during 4th February, 15th and 31st March, 2023

Place	Pollutant Count		
	4 th February, 2023	15 th March, 2023	31 st March, 2023
Aizawl	0.0365	0.0555	0.0405
Lawngtlai	0.0319	0.0604	0.0432
Kolasib	0.0442	0.1057	0.0421
Champhai	0.0318	0.0500	0.0369

6.2 FORMALDEHYDE (HCHO)

The figure (Figure 6) alongside provides tropospheric Formaldehyde observations over Mizoram during February to March, 2023. It can be observed that most areas in Mizoram show relatively high HCHO levels during the study period, with its southern extent having the maximum level of HCHO across clusters. The graph below (figure 7) shows a significant spike in HCHO levels to a peak of around 0.00075 at 15th March, 2023 and a dip to almost 0.0 on 22nd March, 2023. The series map shown below (Figure 8) clearly shows the spatiotemporal extent of HCHO per 4-day averaged time period from February to March, 2023. The statewide increase in HCHO levels during the Swidden agriculture burning period can be clearly observed here. This coincides with the period of Swidden agriculture burning period.

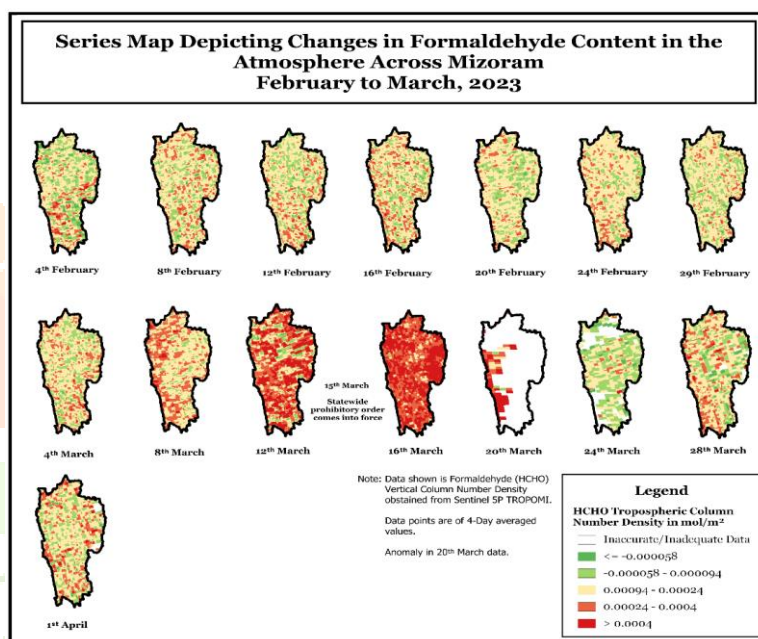


Figure 6: Map showing averaged HCHO content over Mizoram between February to March, 2023.

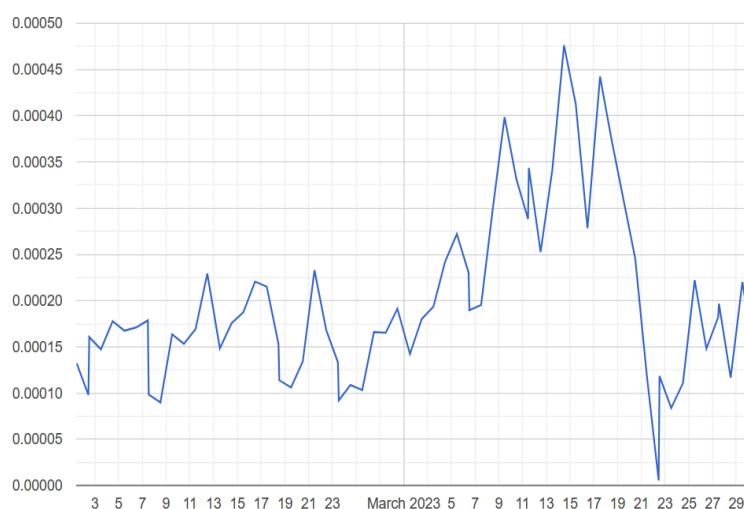


Figure 7: Graph showing HCHO content over Mizoram between February to March, 2023

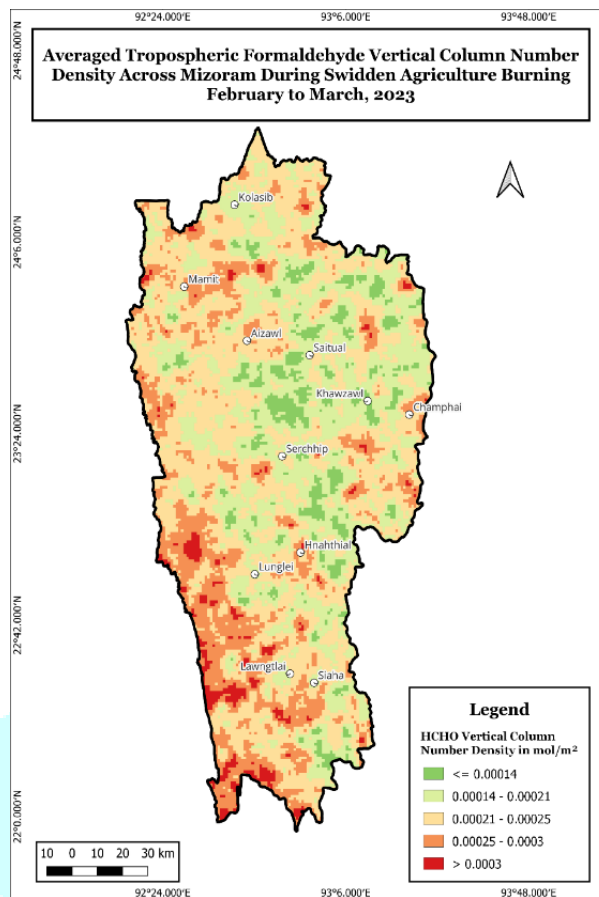


Figure 8: Series map showing HCHO content over Mizoram between February to March, 2023.

6.3 METHANE (CH₄)

Methane (CH₄) ranks second only to carbon dioxide (CO₂) as the primary driver of the human-induced greenhouse effect. Figure 9 shows the temporal extent of CH₄ content in the atmosphere. No significant increase or decrease in the CH₄ content of the atmosphere over the study area has been observed. This could be due to the incomplete combustion of the burned crops and forests but also due to the acknowledged technical inaccuracies with regards to the dataset. The graph below has been generated using interpolated values and thus, may not offer good accuracy. Figure 10 shows the Methane content over the atmosphere during the study period. The data is not substantial enough to provide any conclusions as a result of the aforementioned technical issues. Thus, large swaths of data gaps can be observed over Mizoram even when taking averaged values from 1st February to 15th March.

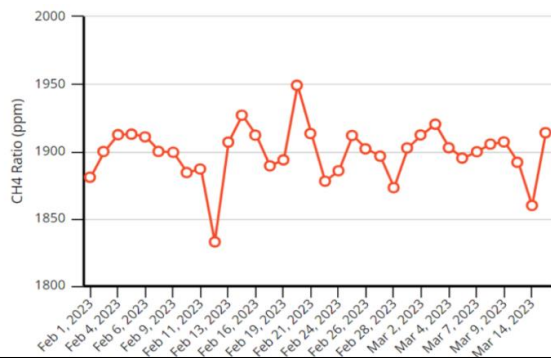


Figure 9: Graph showing averaged bias-corrected Methane (CH₄) dry air column volume mixing content over Mizoram between February and March, 2023.

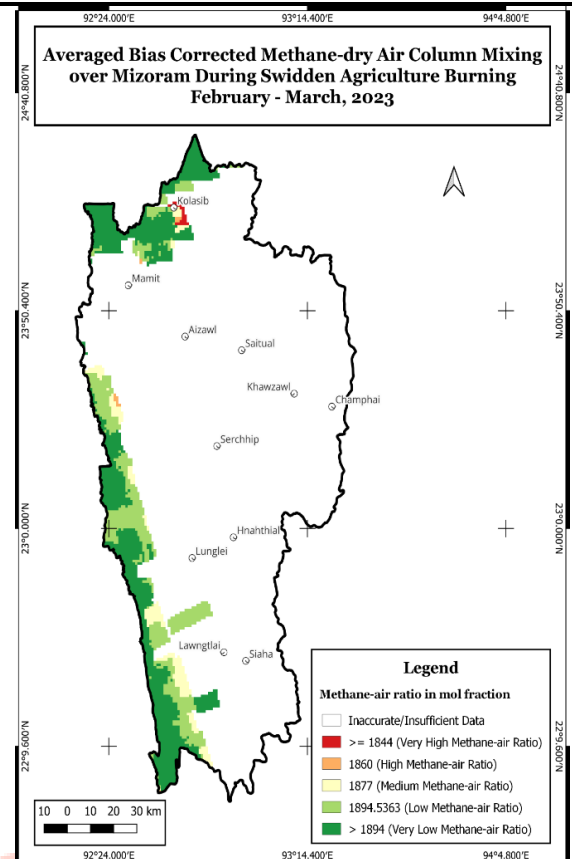


Figure 10: Map showing averaged CH₄ content over Mizoram between February to March, 2023.

6.4 NITROGEN DIOXIDE

Nitrogen oxides (NO₂ and NO) are significant trace gases found in Earth's atmosphere, existing in both the troposphere and the stratosphere. Figure 11 below provides NO₂ spatial observations over Mizoram during February to March, 2023. It can be observed that most areas within the study area have low NO₂ content with only some patches of land having particularly high NO₂ content.

Figure 12 below provides temporal extent of NO₂ observations over Mizoram during February to March, 2023. A sharp increase in the NO₂ content can be observed from around 11th March to 15th March after which there is an abrupt dip. This coincides with the period of Swidden agriculture burning period.

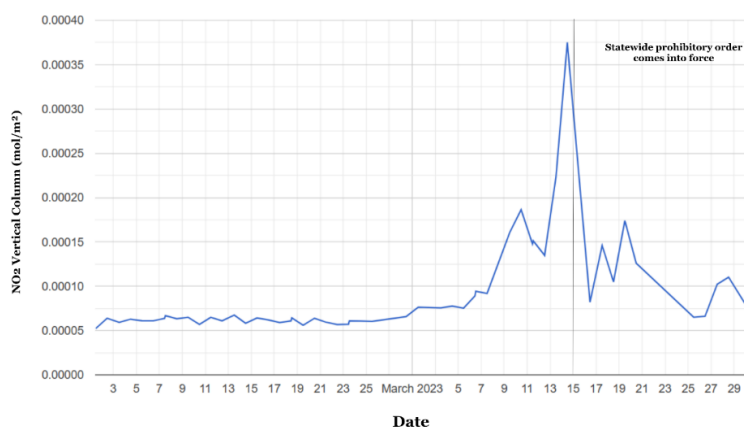


Figure 12: Graph showing NO₂ content over Mizoram between February to March, 2023.

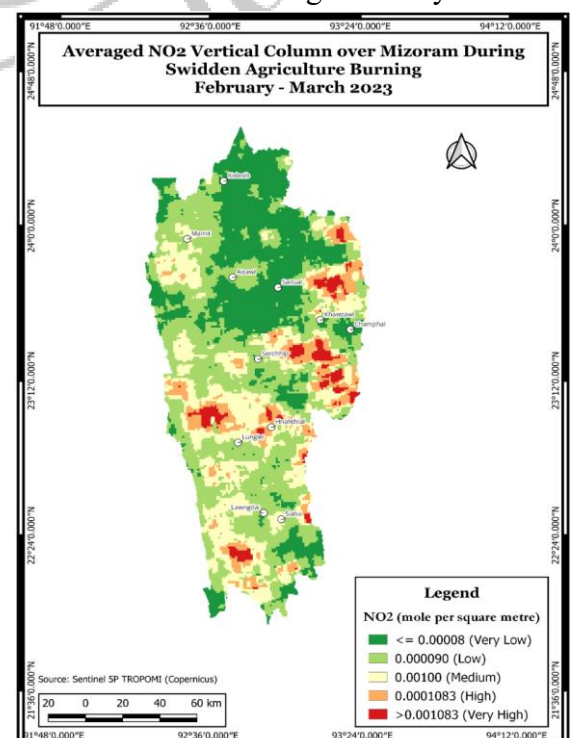


Figure 11: Map showing NO₂ content over Mizoram between February to March, 2023.

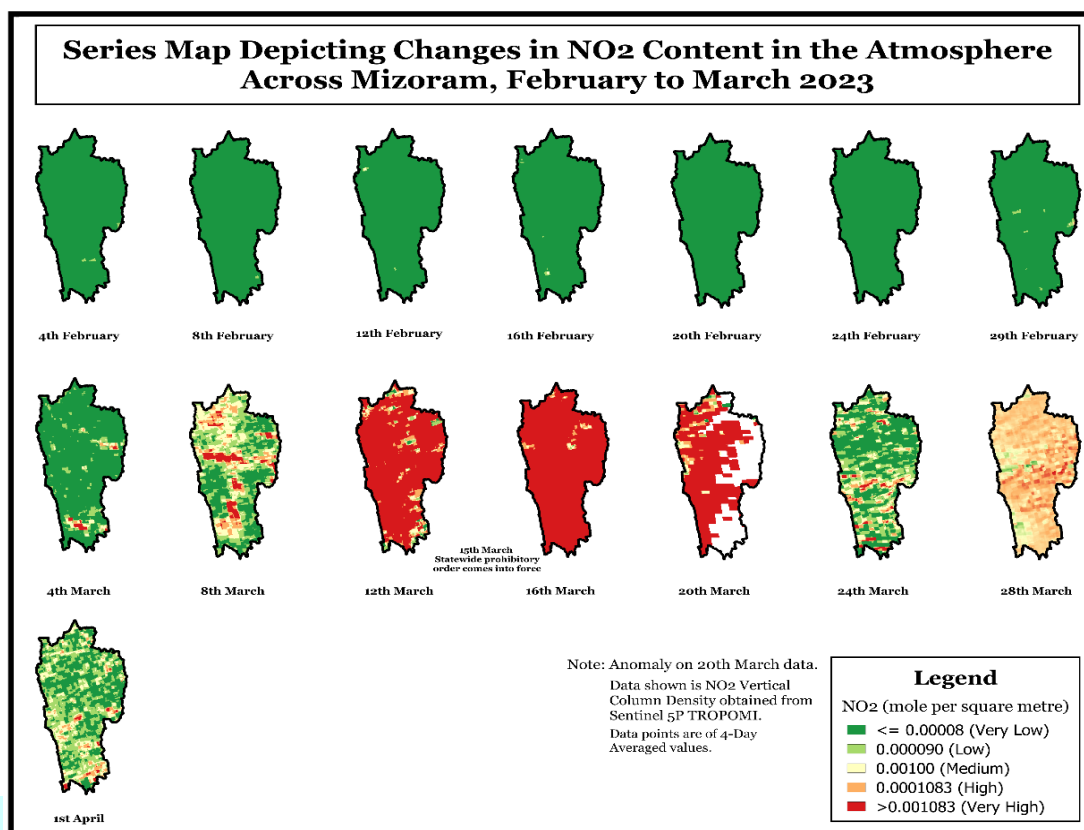


Figure 13: Series map showing NO₂ content over Mizoram between February to March, 2023.

The series map (Figure 13) shows the spatiotemporal extent of NO₂ per 4-day averaged time period from February to March, 2023. The statewide increase in NO₂ levels during the Swidden agriculture burning period can be clearly observed here with a low range at 0.00008 between 4th February to 20th February throughout Mizoram. NO₂ content peaks on 12th March and 16th March – the peak (before 15th March) hours where land burning takes place. This coincides with the period of Swidden agriculture burning period. It is evident from the series map that NO₂ content in the atmosphere scatters and dissipates relatively quickly.

6.5 SULPHUR DIOXIDE (SO₂)

Sulfur dioxide (SO₂) infiltrates the Earth's atmosphere through natural as well as human-induced activities, exerting chemical influence both locally and globally, with impacts ranging from short-term pollution to climate effects. Figure 14 shows the SO₂ temporal observations over Mizoram during February to March, 2023. In general, it can be observed that SO₂ levels within the area fluctuate with a comparatively sustained slight rise after 15th March, 2023. This coincides with the period of Swidden agriculture burning period.

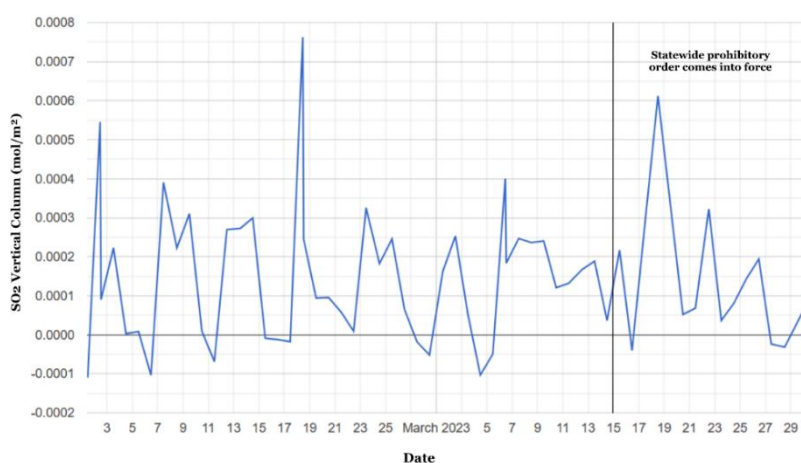
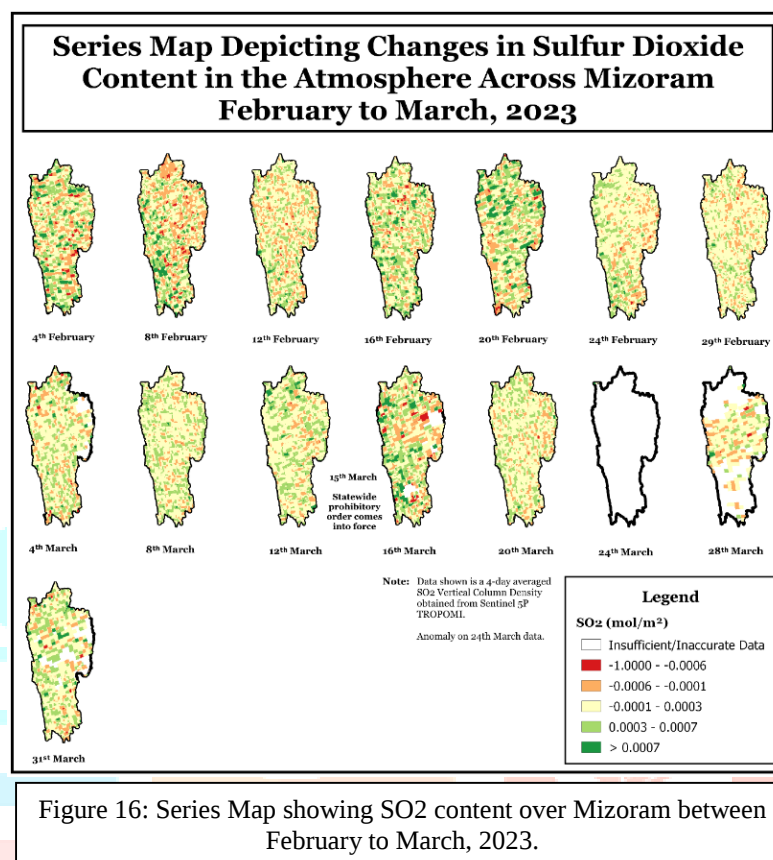


Figure 14: Graph showing SO₂ content over Mizoram between February to March, 2023

However, the observed increases are not substantial.

Figure 15 alongside shows the averaged SO_2 spatial observation over Mizoram during February to March, 2023. Clustered areas of high SO_2 content can be found in the study area. These hotspots may be due to specific increase in burning of crops over or near the area over the near-two month study period. Figure 16 shows the



spatiotemporal extent of SO_2 per 4-day averaged time period from February to March, 2023. Although no significant increase in aerosol levels can be observed during peak burning period, patches of higher concentrations can be observed during 16th March period. This coincides with the period of Swidden agriculture burning period. Note the data gap on 24th March and the partial data gap on 28th March.

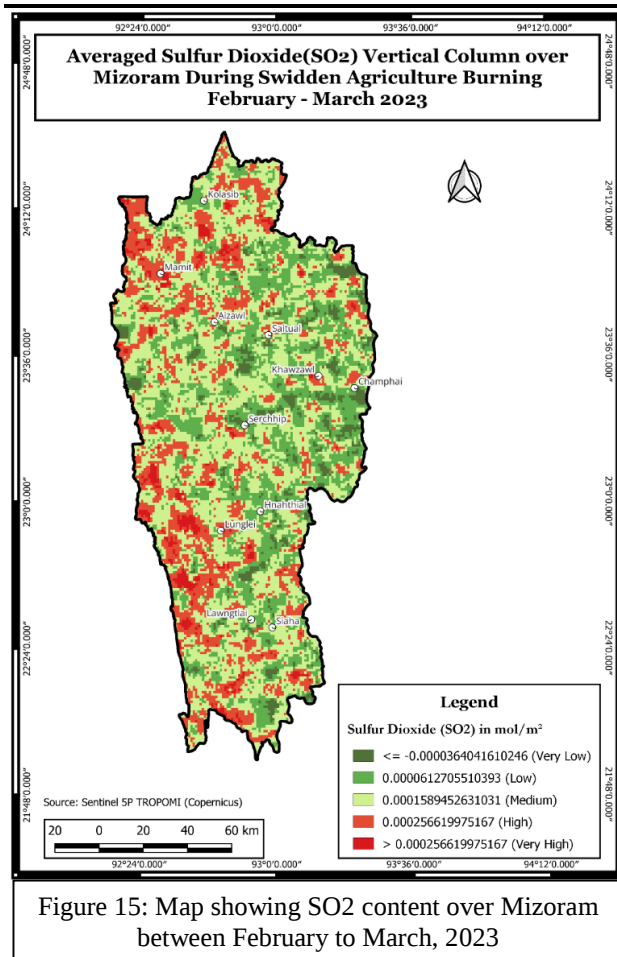


Figure 15: Map showing SO₂ content over Mizoram between February to March, 2023

6.6 TROPOSPHERIC OZONE (O₃)

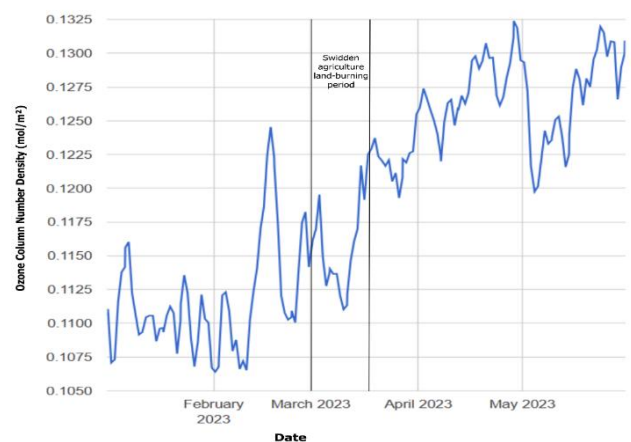


Figure 17: Graph showing Ozone content over Mizoram between February to March, 2023.

Figure 17 alongside shows the O₃ temporal observations over Mizoram during February to March, 2023. Of note for this measurement is that tropospheric O₃ rises constantly as the winter wanes off. However, a slight dip in the O₃ content can be observed during the Swidden agriculture period. It may be noted that this period is not a strict set of dates for land burning to take place and thus, it may only be interpreted as a peak burning period. Overall, the tropospheric ozone over the study area shows a generally increasing trend over the study period.

7. CONCLUSION

Slash and burn agriculture, although being a highly prominent subject not just for the state of Mizoram but also for the whole world where it is practiced, still holds very less wealth of literature for the area of interest. This paper aims to contribute to the gap in literature and provide for a useful and accurate literature with regards to case studies on Swidden Agriculture and its effects in Mizoram. Formaldehyde, Carbon Monoxide, and Nitrogen Dioxide showed the most increase in emissions over the study area during the period of study while Methane and Sulfur Dioxide show little to negligible change in their emission levels. This could be due to gaps in data collection because of technical difficulties with the Landsat 9 OLI platform. Of note is the dip in tropospheric ozone content during peak Swidden agriculture burning which may be attributed to the burning. It may be noted that even just an observation of an increase in one substance can lead to long-standing health impacts for the local population and as such, further scientific research, discourse and discussions are needed to throw light upon the extent of damage Swidden agriculture has caused.

8. LIMITATIONS

The present study is not without its limitations, which should be considered when interpreting the findings. The dearth of prior research on similar subject over the study area alongwith the lack of statistical data may restrict the ability to contextualize and compare the current findings with established knowledge in the field. Technical issues have also played a role in shaping the limitations of this study. Despite concerted efforts to address bugs, glitches, and errors encountered during the research process, several technical challenges remain unresolved.

9. FUTURE RESEARCH SCOPE

A more nuanced and technical analysis of all relevant data, especially those of the Sentinel 5P data may be performed. More advanced Google Earth Engine (GEE) scripts may be employed to derive more useful and detailed data regarding the subject matter. Furthermore, ground-level quantitative and qualitative surveys of all stakeholders may be performed in Mizoram to further enhance analysis of the Jhum cultivation effects. Health related metrics of Mizoram may be further integrated into the study to provide conclusive evidence that Swidden agriculture does indeed cause negative health impacts.

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