Air pollution in rural India: Analysis of satellite NO_2 measurements

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Overview

India is a country with more than 67% of its population (947 million) residing in rural areas and 33% in urban areas (472 million) as of 2020. Therefore, health of the people living in rural India is very important for its future development plans, economy, and growth. Here, we analyse the rural air quality using satellite measurements of NO_2 in India, as the sources of NO_2 are well-connected to the industrial and economic uplift of a nation. Our analyses for the rural regions show distinct seasonal changes with the highest value (2.0×10^{15} molecules per cm²) in winter and the lowest in monsoon (1.5×10^{15} molecules per cm²) seasons. About 41% of the total NO_2 pollution in India is from its rural sources, but 59% of the urban sources were focused in the past studies. In addition, around 45% of the rural NO_2 pollution is due to road transport, whereas more than 90% of it in urban India comes from the power sector. Our assessment shows that the NO_2 exposure in rural regions is as serious as that in urban areas, indicating the need for more effective reduction of population exposure and protection of public health. Henceforth, this study reveals that rural India is gradually getting polluted from its nearby regions as well as from the new sources within. Therefore it is the right time to take action for protecting the health of our large rural community.

Data and Methods

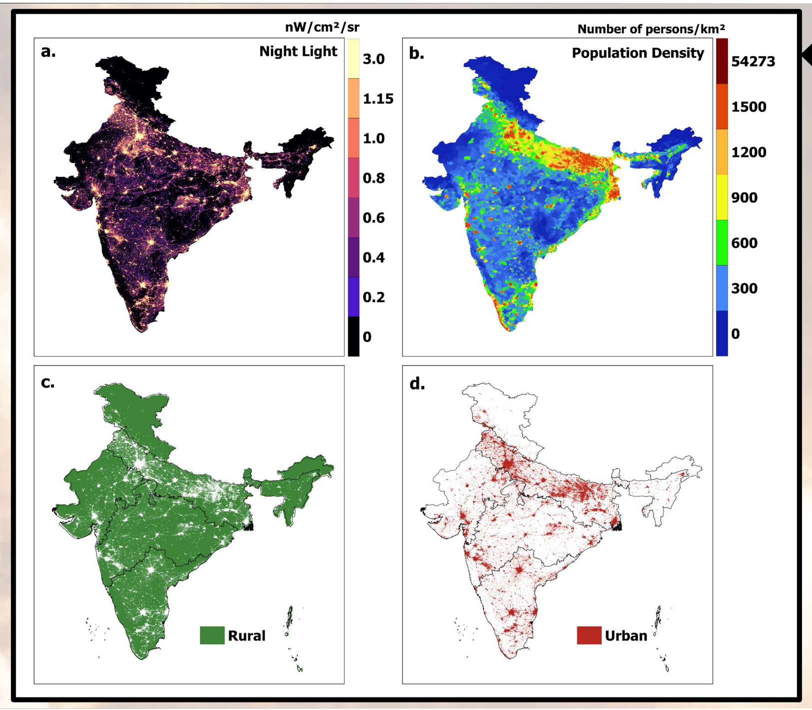

Figure 1. (a) VIIRS nightlight during 2020 over India. (b) Projected population density (number of person/km²) for 2020 based on the counts consistent with national census and population registers. c) Rural regions and d) Urban regions in India as delineated using the nightlight and population density data.

Delineating Rural areas
- VIIRS Nightlight[1]
- Population Density[2]

NO_2 data[3]
- TROPOMI (2019–2021)
- MERGED (1997–2019): GOME (1996–2003), SCIAMACHY (2002–2012) & GOME-2 (2007–2020)
- OMI (2005–2014)

Assessment of temporal changes in NO_2
- Spatio-temporal evolution
- Interannual variation
- Trend detection

Impact assessment of changes in NO_2
- Population exposure

Emission Inventory
- Power sector
- Agriculture
- Refinery
- Road transport
- Iron and steel

Sources of NO_2

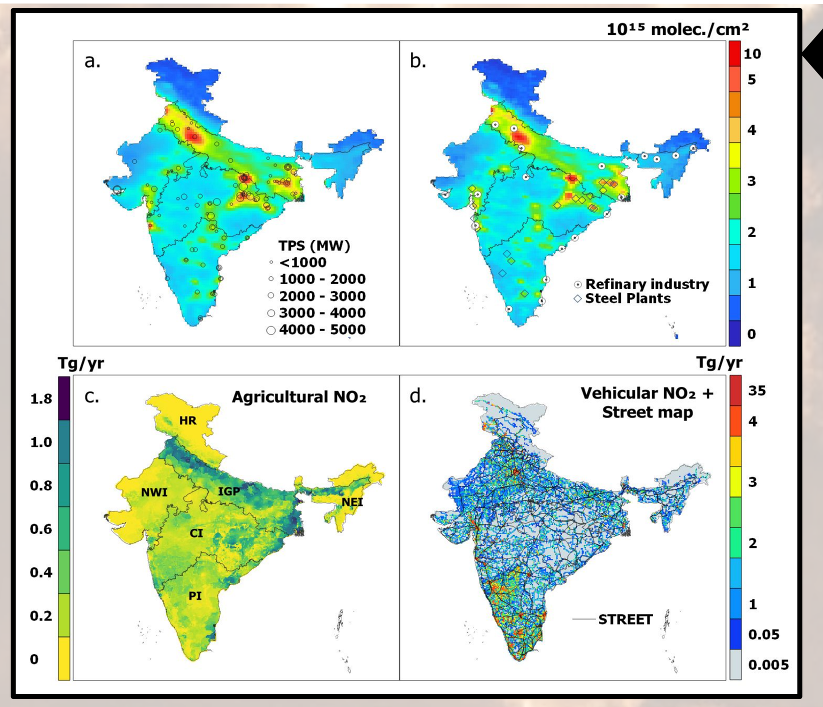

Figure 2. (a) Average annual NO_2 column as analysed using the merged satellite data (1997–2019), overlaid with the location of thermal power plants with their installed capacity. (b) Average annual NO_2 column from the OMI measurements from 2005 to 2014. (c) Agricultural NO_2 emissions as analysed from EDGARv6.1 (1970–2018) over different regions in India. (d) NO_2 column from road transport as analysed using EDGARv6.1 for the same period overlaid with the street map of National Highways in India. The regions marked are IGP (Indo Gangetic Plain), CI (Central India), NWI (North West India), PI (Peninsular India), HR (Hilly Region) and NEI (North East India).

- Power plants, steel plants and refineries are among the major point sources of NO_2 emissions, particularly in the hotspot region of IGP with high NO_2 (2–10 × 10^{15} molec./cm²).
- The transport sector emissions from EDGAR inventory indicate high NO_2 (> 4Tg/yr) over national, state highways and major urban agglomerations.
- Highest emissions from the agricultural sources are observed in IGP (> 0.6 Tg/yr) and NEI (> 0.4 Tg/yr) and CI (0.2–0.6 Tg/yr).

Results and Discussion

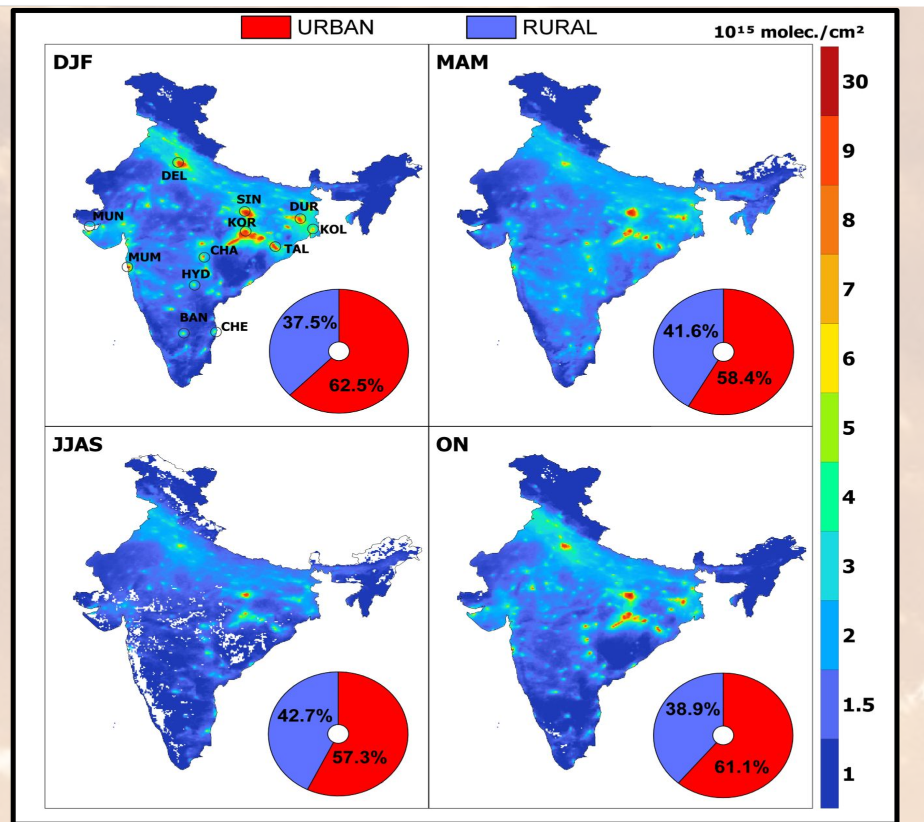

Figure 3. NO_2 column mass density in different seasons using TROPOMI data for the period 2018–2021. The cities marked on the map are Delhi (DEL), Singrauli (SIN), Korba (KOR), Talcher (TAL), Durgapur (DUR), Kolkata (KOL), Mumbai (MUM), Mundra (MUN), Chandrapur (CHA), Hyderabad (HYD), Bangalore (BAN) and Chennai (CHE).

- Winters show highest NO_2 concentration in Rural India (37.5%). Monsoon shows the lowest NO_2 in Rural India (42.7%)
- Hotspot regions: Delhi, Singrauli, Durgapur and Korba due to the presence of power plants, oil refineries, steel plants, vehicular emissions and other industries.[4]

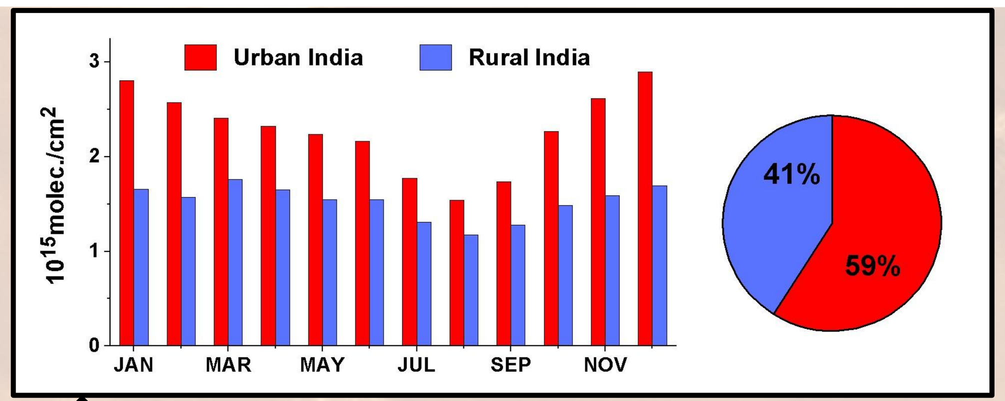

Figure 4. Monthly averaged NO_2 vertical column over urban and rural India as analysed from the TROPOMI data for the period 2018–2021 and (right) the percentage of NO_2 from both regions to the total NO_2 pollution in India. The months are marked with the first three letters (e.g. JAN for January).

- **In rural regions:**
  NO_2 decreases from **January to February** (1.7–1.5 × 10^{15} molec./cm²)
  Lowest value in Monsoon (August) : 1.2 × 10^{15} molec./cm² due to washout of pollutants from the atmosphere.
- Increases in **March** (1.8 × 10^{15} molec./cm²) due to agricultural emissions after harvesting of Rabi crops like wheat, maize, lentils, linseed.
  September to December (1.3–1.7 × 10^{15} molec./cm²)with harvest of rice, maize, millet and pulses, where rise during October–November is attributed to **stubble burning after the Kharif** harvesting period.[5]
- **Rural areas: 41% of India's NO_2 pollution,** urban areas : 59% contribution are mostly focused.

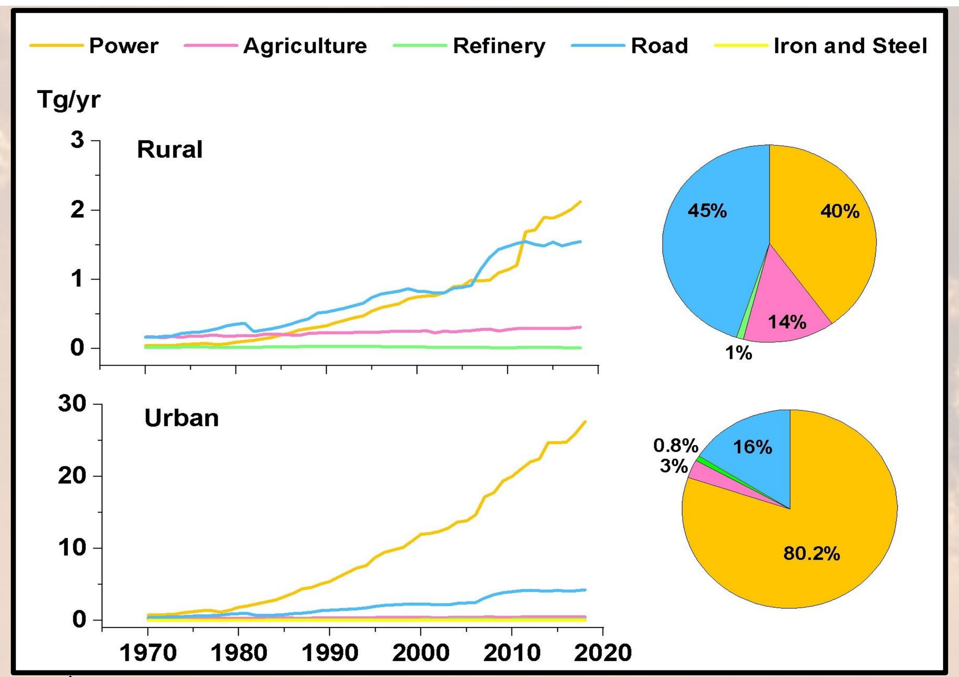

Figure 5. Temporal evolution of NO_2 from different sources as in the EDGAR emission inventory for the rural and urban India from 1970 to 2018.

- **Emissions in rural India:**
  Road Transport = 45%
  Power sector = 40%
  Agriculture = 14%
  Refinery = 1%
- A gradual increase is observed in rural pollution from 1970 to 1982, followed by a steep rise afterwards in the **road transport and power sector,** whereas **agriculture emissions** remain unchanged throughout.

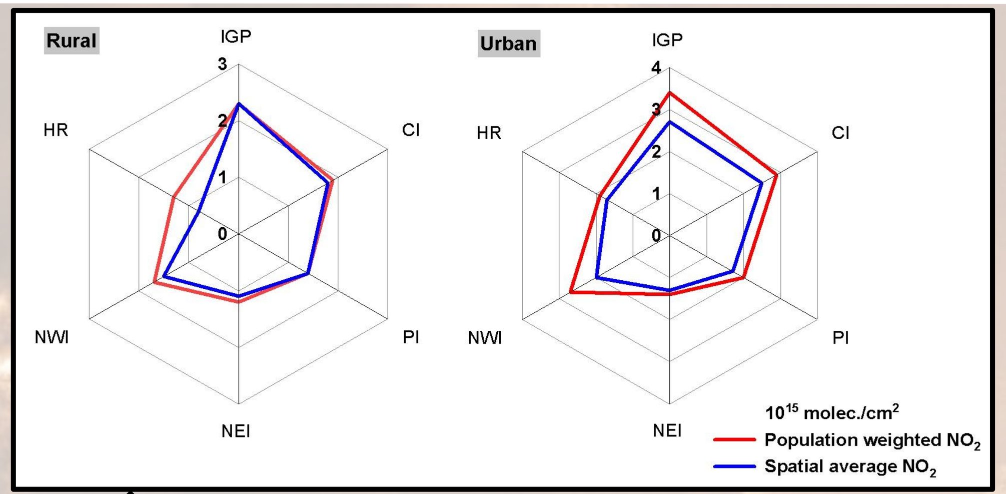

Figure 6. Population-weighted NO_2 exposure in the rural and urban regions of India as observed from TROPOMI for the period 2018–2021. The blue lines represent spatial average NO_2 and the red lines represent population-weighted NO_2.

- The population-weighted exposure :

  rural IGP = 2.3 × 10^{15}molec./cm²
  urban IGP = 3.4 × 10^{15}molec./cm², followed by
  rural CI = 1.9 × 10^{15}molec./cm²
  urban CI = 2.9 × 10^{15}molec./cm²

Takeaway points:

1. Population weighted exposure (PWE) of NO_2 ≥ spatial average column indicates high exposure to people residing in an area.
2. Regions with higher PWE need to be given priority while formulating policies and norms.

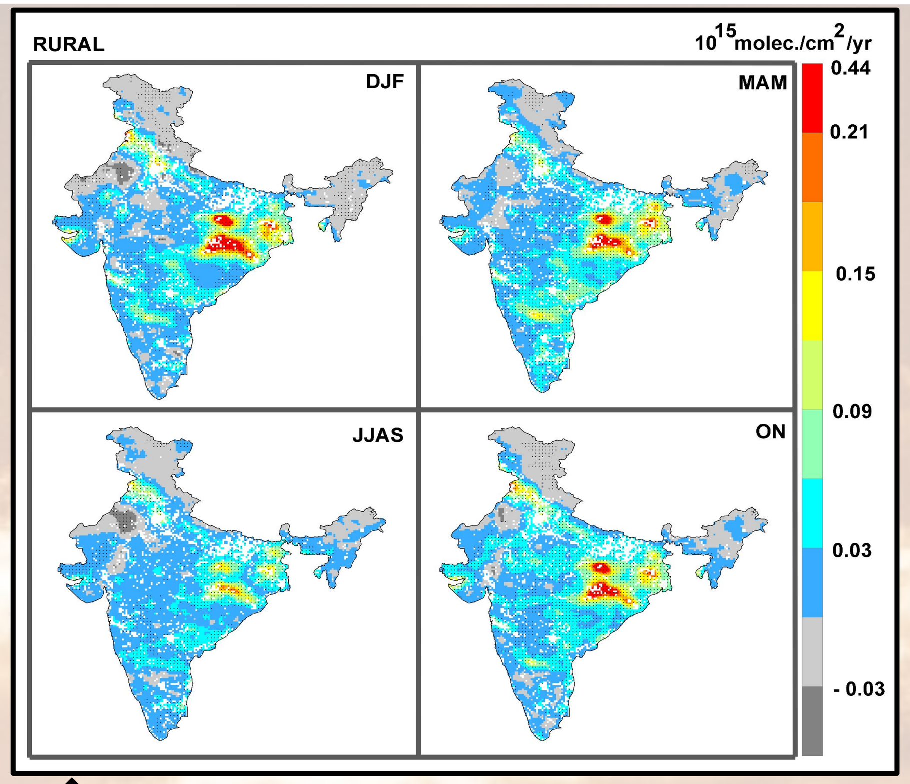

Figure 7. Seasonal trends in NO_2 over the rural India as estimated from the yearly averaged merged satellite data for the period 1997–2019. The hatched regions represent statistical significance and all trends are statistically significant at 95% CI.

- High seasonal trend over rural areas :

During winter, pre-monsoon and post monsoon = 0.03 × 10^{15}molec./cm²/yr

- Low seasonal trend over rural areas :

During monsoon= 0.02 × 10^{15}molec./cm²/yr

- Highest positive trend (0.44 × 10^{15} molec./cm²/yr) over regions closely associated with clusters of thermal power plants and steel plants.

Conclusion and Policy interventions

We observe that air pollution in non-urban (rural) areas of India is just as detrimental and severe as it is in urban areas. Major source of NO_2 in rural India is road transport, which was considered to be an urban-based emission source. The importance of this study is that rural sources account for a significant portion of NO_2, around 41% of the overall NO_2 pollution in India, whereas solely urban sources with 59% were the focus of earlier studies. Using the population weighted NO_2 we find that areas with higher population are often associated with higher NO_2 values. Therefore, the population-weighted average would be a better indicator of the NO_2 pollution exposure to the public. This assessment has far-reaching implications for how India and other emerging countries view atmospheric pollution. It is also pertinent, considering that these nations are focusing on tackling air pollution in rural areas, and they need to be informed of magnitude of the problem. Sources of rural NO_2 identified here are different from the past studies, as those analyses had the limitation and difficulties in delineation urban and rural regions. This study is giving a clear indication for the need of attention towards rural air quality due to the increasing NO_2 pollution in rural India, which can be tackled at this stage to regulate the air pollution within WHO standards. We have investigated the amount of dispersion outside the city or industrial centre, and in rural areas, which were previously unknown to be at risk. With this contrast in pollution, attention should be driven towards the rural air quality. Government policies and norms similar to **Bharat Stage (BS)** for restricting vehicular emissions need to be implemented for the thermal power plants and other fossil fuel based industries in order to reduce the NO_2 pollution in rural regions. Introducing new natural gas-fed power plants or using **selective catalytic reduction (SCR)** in older power plants may be considered as an effective method for eliminating NO_2 from various non-transportation sources. The findings of this study can be used as reference for implementing and planning actions for protecting health and saving lives of a significant portion of population living in rural regions, together with improving the surface observations in rural regions for monitoring of air quality in India. Similar policy interventions at global scale might help improving rural air quality in other developing nations as well.

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