SPATIO-TEMPORAL DISTRIBUTION OF POLLUTANT TRACE GASES DURING DIWALI OVER INDIA

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ABSTRACT:

People effected due to air pollution in India rose by almost 150% during 1990 to 2015. Diwali event is one of the major anthropogenic source contributing to the air pollution. The study focuses on spatial and temporal distribution of trace gases emitted during pre, on and post diwali days and identify areas with high concentration using station measured and satellite derived data during 2008-2017. The ground measured data shows that during diwali days, NO_2, SO_2, CO & O_3 concentration is almost 1.5 to 7 times the NAAQ safety limits over major cities particularly in northern, western and eastern India. Central and southern India experience low to moderate increase in pollution concentration. Spatial distribution over diwali days using satellite data reveal that NO_2 values over India are mostly below NAAQ standards, however high range are observed (27-48 μg/m^3) over Delhi, Punjab, Haryana region (Northern zones), Western, central and Eastern Indo-Gangetic plain and this concentration is seen denser on diwali days compared to pre and post diwali. The observation reveal that SO_2 concentration is below safety levels over almost entire country except few cities like Delhi region, part of Gujarat, Tamil Nadu and Kolkata region. CO concentration is at higher level than NAAQ standards over Western, central and Eastern Indo-gangetic plain. The regression shows that the satellite derived values are in close agreement with the ground measured over the diwali days. The analysis conclude that the peak of the pollutants during diwali may not be increasing quite drastically over many parts of the cities but the overall spatial distribution of the pollutants is increasing from 'moderate' to 'moderately high' range.

1. INTRODUCTION

1.1 Background

In recent years, there has been concern about the degradation of air quality and its subsequent effect on human health, and one of the reasons of its increase is due to the use of fireworks during festivals and celebrations. Fireworks during festival events or celebrations are closely linked to the increased levels of pollutants, including particulate matter, SO_2, NOx, CO and ozone, amongst others. In India, a number of festivals are celebrated throughout the year; Diwali, the festival of light, is one of the most important. Diwali is celebrated between the pre-winter season (October) and the post-monsoon season (November). As the festival of light, firecrackers are often used on the days before and during the festival, resulting in deteriorated air quality. WHO, 2014 reported that fireworks used during diwali create high mass concentrations of particulate matter (PM) with a chemical composition that varies from normal atmospheric conditions and can be harmful to human health (Gautam, *et al*. 2018). Diwali is celebrated for three consecutive days all over India. It includes lighting lamps and igniting fireworks. The fireworks contain 75% potassium nitrate, 15% carbon (C), and 10% sulphur (S). On igniting the firecrackers, the potassium nitrate present in these fireworks releases pollutant such as SO_2, NO_2, and PM_{10}, increasing their concentrations and massively degrading the air quality within a short time, which is associated with serious health impacts (Haque & Singh, 2017). The ignition of colour-emitting firecrackers generates a large amount of ozone, even in the absence of sunlight and nitrogen oxides, which can be harmful to children and elderly people particularly with heart and respiratory ailments (Attri, *et al*., 2001).

Worldwide ambient air pollution accounts for 25% of all deaths and disease from lung cancer, 17% of all deaths and disease from acute lower respiratory infection, 16% of all deaths from stroke, 15% of all deaths and disease from ischaemic heart disease, 8% of all deaths and disease from chronic obstructive pulmonary disease (WHO, 2017). India has the world's highest deaths of 1.81 million due to the air pollution followed by China 1.58 million (Lancet, 2015) estimating a GDP loss of 1.3% in developing countries compared to 0.5% in developed countries. Most of these deaths are caused by heat diseases, stroke, lung cancer, chronic obstructive pulmonary disease and upper respiratory tract infection.

From various studies and reports, the concern for air pollution throughout India is in a very critical position and addition to that Diwali celebration of firecrackers make nothing good for the government to control the various air pollutant level. The extensive use of fireworks was found to be related to short-term variation in air quality. During the festival, Total Suspended particulate (TSP) is almost of the same order as compared to the concentration at an industrial site in all the years. However, the concentrations of PM10, SO_2, and NO_2 increased 2 to 6 times during the Diwali period when compared to the data reported for an industrial site. Similar trend was observed when the concentrations of pollutants were compared with values obtained for a typical foggy day each year in December. The levels of these pollutants observed during diwali were found to be higher due to adverse meteorological conditions, *i.e.*,

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decrease in 24 hr average mixing height, temperature, and wind speed. The trend analysis shows that PM_{10}, NO_2, and SO_2 concentration increased just before diwali and reached to a maximum concentration on the day of the festival and the values gradually decreased after the festival. During diwali days, 24-hourly values of PM_{10} in 2002-2007 period were 3.6 times higher than prescribed limits of National Ambient Air Quality Standards as well as similarly for NO_2 values that was extremely higher in 2004 and 2007. These results indicate that fireworks during the diwali festival affected the ambient air quality adversely due to emission and accumulation of $PM_{2.5}$, PM_{10}, SO_2, and NO_2 (Singh *et al*., 2010). The present study tries to understand the spatio-temporal variability using satellite data and analyze the trend of concentration of air pollutants (NOx, CO, O_3 & SO_2), over various cities, divided into different zones across India, during pre, on and post diwali period for the 10 years (2008-2017).

2. STUDY AREA

In most of the mega cities around the world, the effects of air pollution on human health present a growing problem. The study focussed on India as there is reportedly urban air pollution related problems and are poorly reported and understood. Here area of interest is indirectly dependent on the availability of ground based records but more so over whole India is covered except Chattisgarh due to non-availability of ground data. The cities having the ground data are divided into six zone; these are - Northern Zone, consist of 29 cities from Punjab, UP, Haryana and New Delhi; Southern Zone, consist of 26 cities from Andhra Pradesh, Karnataka, Kerala, Telangana and Tamil Nadu; Eastern Zone, consist of 21 cities from Bihar, Jharkhand, West Bengal and Odisha; Western Zone, consist of 33 cities from Rajasthan, Maharashtra and Gujarat; Central Zone, consist of 8 cities from Madhya Pradesh and North-East Zone, consist of 11 cities from Assam, Nagaland and Mizoram. Figure 1 shows the distribution of 128 cities having ground data for trace gases SO_2 and NO_x.

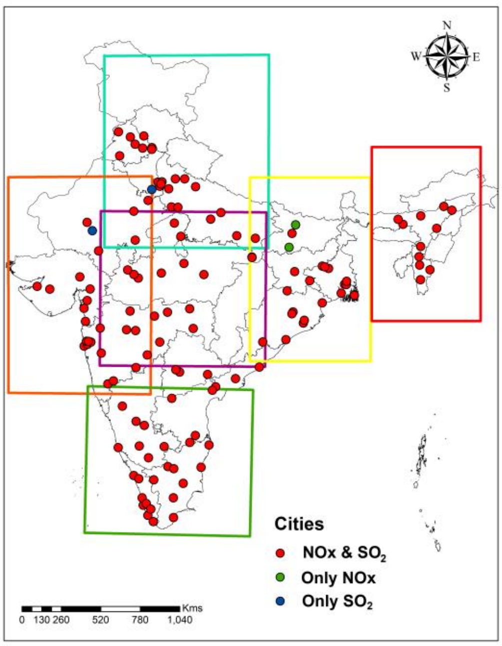


Figure 1. Distribution of SO_2 and NO_x across various cities in India.

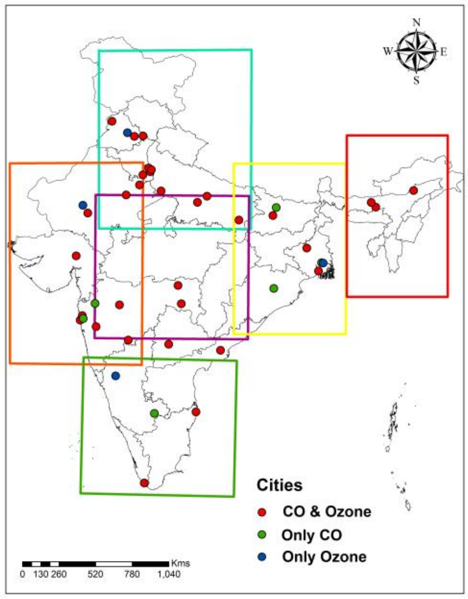


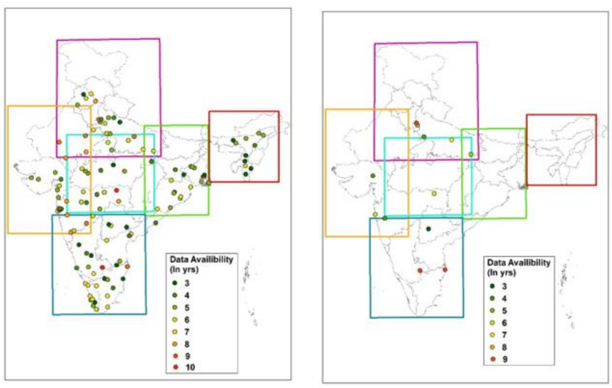
Figure 2. Distribution of CO and O_3 across 36 cities in India

3. MATERIAL AND METHODOLOGY

Ground based records have been collected from government sources i.e. Central Pollution Control Board (CPCB) and from other government data archive with reference to CPCB.

3.1 Ground Datasets for air pollutant gases

3.1.1 Data criteria and availability: Data for air quality records for SO_2, NO_x, CO and O_3 was collected from CPCB. Data criteria was defined for 13 days during diwali celebration for a 10-year duration i.e. 2008 to 2017. It was divided into three sessions 'pre-diwali' defined as 5 days prior from a day before diwali, 'on-diwali' defined for 3 days *i.e.* a day before, during and a day after diwali and 'post-diwali' defined as 5 days post day after diwali. As per the data criteria and duration for different air pollutant parameters, the data availability was the major problem arising during data assembling and processing. Figure 3 shows the spatial distribution of the cities with at least 3 years data available from CPCB.



(a) (b)

Figure 3. Cities having at least 3yrs data for (a) SO_2, NOx and (b) CO and Ozone

3.1.2 Ground data unit and conversion: CPCB provided standard unit in µg/m^3, mg/m^3 and ppb for SO_2, NO_x and O_3 respectively. All the units for various pollutants were standardized to µg/m^3.

3.2 Satellite datasets for air pollutant gases.

3.2.1 Dataset used: OMI –AURA (Ozone Monitoring Instrument) observed Level 3 daily data of 0.25 x 0.25-degree resolution is acquired for NO_2 and SO_2 concentration distribution while MEERA-2 (Modern-Era Retrospective analysis for Research and Applications version 2) derived level 4 hourly data of 0.625 x 0.5 degree resolution has been taken for surface concentration of CO (in ppbv). AIRS level 3 daily gridded product with 1 x 1 degree spatial resolution at 925 hPa was used for O_3. The details on OMI-AURA, MERRA-2 and AIRS can be found elsewhere (https://earthdata.nasa.gov/earth-observation-data).

3.2.2 Satellite data unit conversion: A conversion formula is applied to convert the satellite measurement unit (molecules/cm^2) to its equivalent in CPCB standard (µg/m^3) unit. The molar mass is used for converting microgram (µg) to number of molecules, [i.e. One molar mass of NO_2 (46.0055 g) contains Avogadro number (6.023×10^{23}) of molecules]. To find the number of molecules in unit volume (cm^2 to cm^3) a hypothetical condition is assumed in which each measurement corresponds to a height (100m) of the planetary boundary layer and within which NO_2 molecules are mixed homogeneously. The height of 100m is an estimated height from the comparison of surface measured values of NO_2 (mean) CPCB stations. Even though the data represents the total tropospheric column density (height~10–13km), most of the NO_2 molecules are occupied in the boundary layer (up to 1–2 km), with a rapid drop off at higher altitudes (Boersma *et al.*, 2011). Therefore, molecule/cm^2 is converted to Dobson Unit (DU) using the formula provided by Support to Aviation Control Service (SACS)-ESA. Following, DU has been converted to µg/m^3 using formula from Ramachandran *et al.*, 2013. The unit has been converted from ppb to µg/m^3 (Boguski, 2008).

3.3 Comparison of Ground and satellite data

The methodology followed up in this study is shown in following Figure 4. Trend analysis and investigation on spatial variation of air quality over six zones over India for last 10 year period is done using air pollutant parameter such as SO_2, NOx, CO and O_3. The trend has generated for both data and had been compared using time series data over India and correlation is obtained by regression analysis for pre, on and post-diwali event for last 10 years *i.e.* 2008 to 2017.

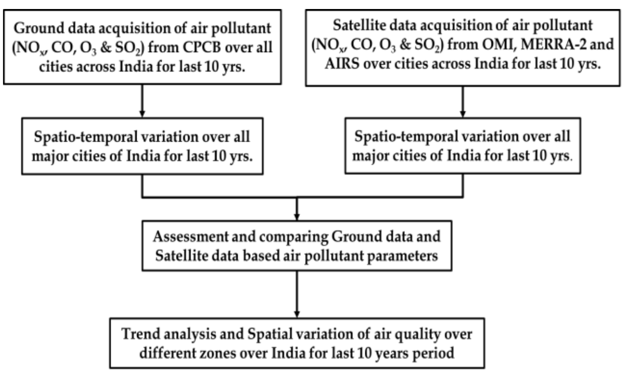
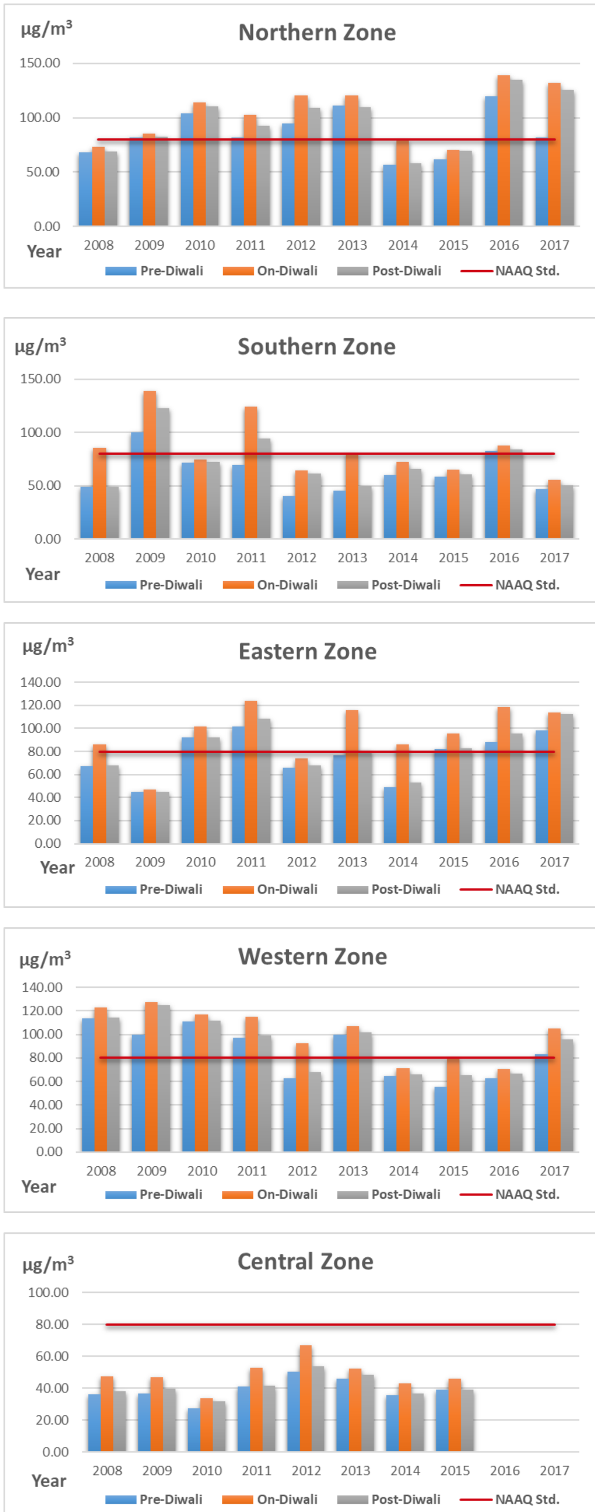


Figure 4. Flowchart of the Methodology

4. RESULTS AND DISCUSSION

4.1 Spatio-temporal variation of air pollutants across India during Diwali from ground based data

The spatio-temporal variation of SO_2, NO_2, CO and Ozone during 2008-17 was taken from government data sources. This spatial variation over India is distributed in six zone i.e. Northern, Southern, Eastern, Western, Central and North-Eastern Zone. Figure 5 shows the temporal distribution for annual NOx over different zones.



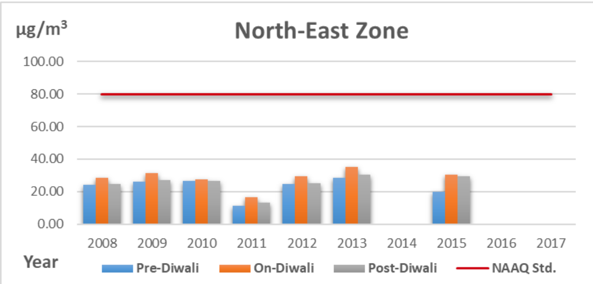
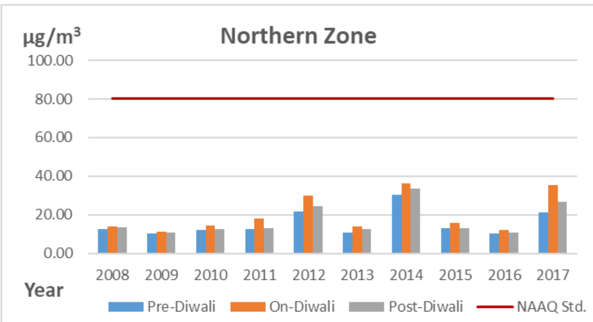
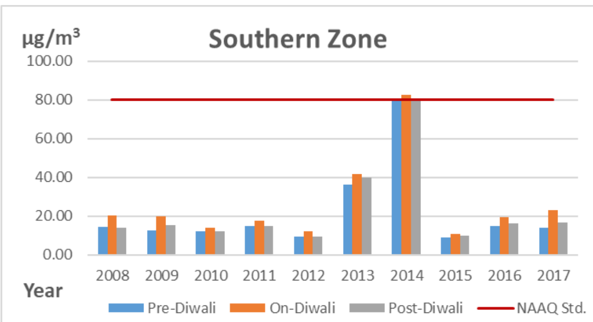
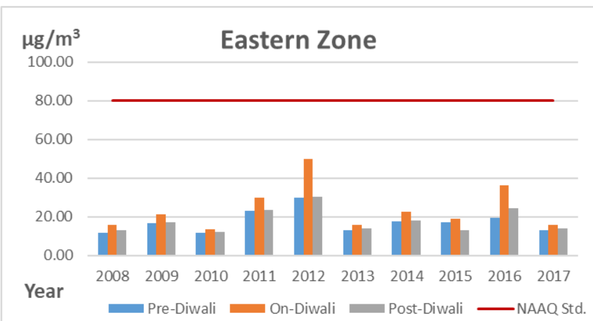


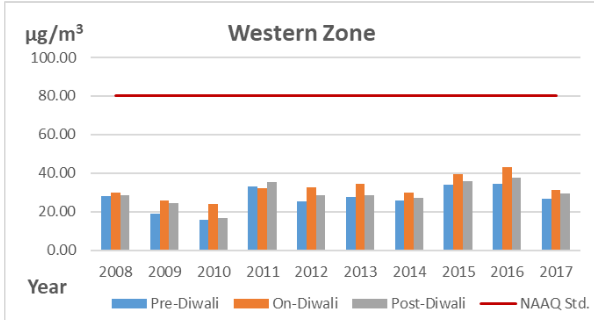
Figure 5. Spatio-temporal variation of annual NOx across different zones.

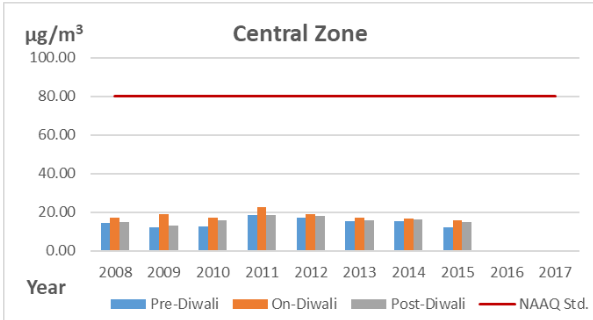
Results shows that NOx values in central and North East zones are within the range with respect to NAAQ safety standards (80 µg/m^3 for 24hrs average) (CPCB, 2015), however Northern, Western and Eastern zones have relatively higher values (range 100-150 µg/m^3) with respect to NAAQ safety standards over few cities. To be precise, NOx values are at highest level for pre, on and post diwali days over New Delhi (Northern zone), Ahmedabad, Mumbai and Bhiwadi (Western zone) and Kolkata (Eastern zone), which are major cities contributing the major NOx flux distribution. The temporal distribution for annual SO_2 across different zones is depicted in figure 6.











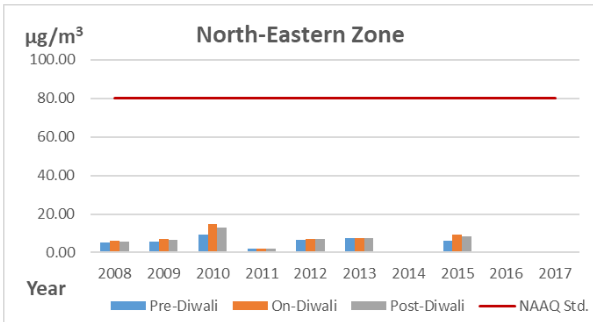


Figure 6. Spatio-temporal variation of annual SO_2 in different zones.

It is revealed that for almost all zones across India, SO_2 concentration is under NAAQ safety standards (80 µg/m^3 for 24hrs average), except in case of the Byrasandra, Tavarekere & Madiwala (BTM Layout) Bengaluru (Southern zone) during 2014. Over BTM layout there is a constant deterioration of air quality standard due to rapid increase in population and corresponding fuel combustion due to increase in transport, commercial vehicles, industries and domestic sectors. Particularly during diwali episodic event, the SO_2 level has increased by 1.23 times the NAAQ safety standards, while over Kolkata and Raniganj (Eastern zone) shows 2.13 times the NAAQ safety standard in 2014, 2013 and 2012 respectively. During year 2016 diwali episodic event, Thane (Western zone) shows 3.2 times the NAAQ safety standard level, while in 2010, Behmiyat, Meghalaya (North East zone) shows 10 times NAAQ level due to accidental fire broke out in factory on eve of diwali day. Figure 7 shows zone wise temporal distribution for annual CO concentration distribution across India.

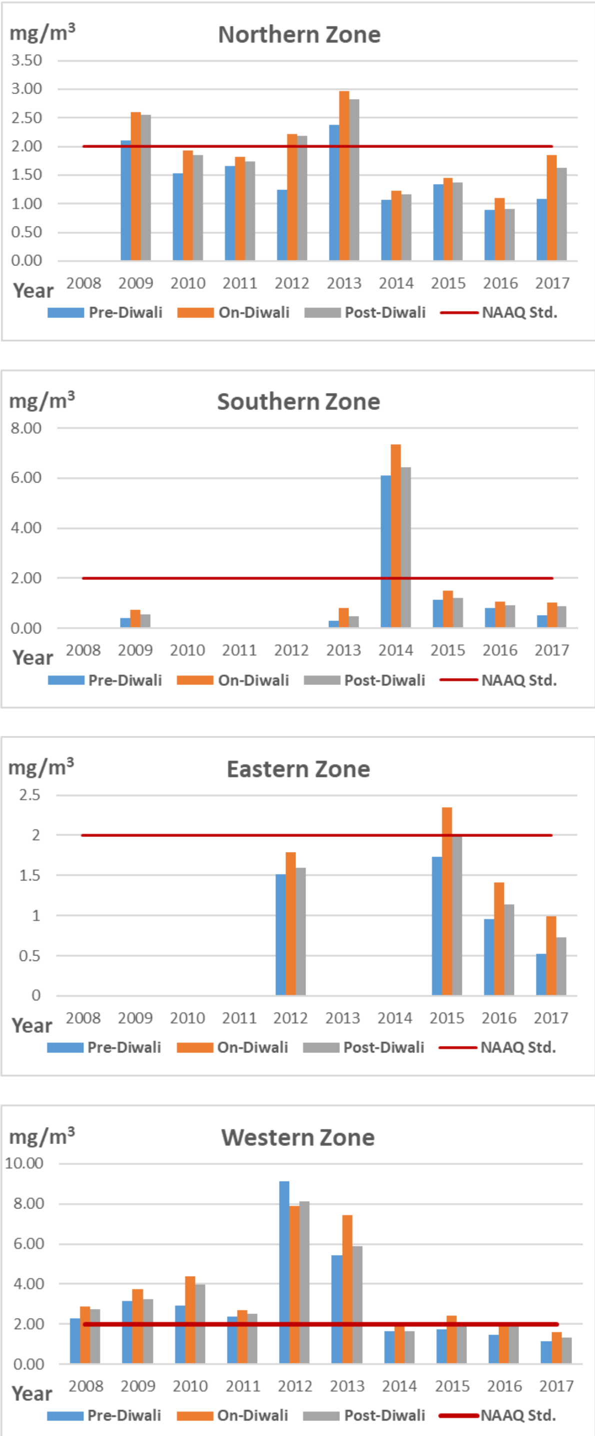


Figure 7. Spatio-temporal variation of annual CO in different zones.

Over Northern and Western zones the value of CO are higher than NAAQ safety standards i.e. 2 mg/m^3 for 24hrs average due to large number of combustive engines vehicles plying during pre, on and post diwali, whereas Southern zone shows relatively high value CO concentration, precisely in year 2014 where Bengaluru depict 1.5 time NAAQ safety standard and for same year Chennai shows 5 times NAAQ safety standards level. Similarly, Ahmedabad and Nagpur (Western zone) shows 7 times NAAQ level during 2012 and 2013 respectively and again Nagpur shows 3 times during 2010 and same year Mumbai (Western zone) shows 1.5 times NAAQ safety levels. There is no data availability for central and North-East zones during diwali. The zone wise temporal distribution for annual Ozone concentration in different zones across India is shown in figure 8.

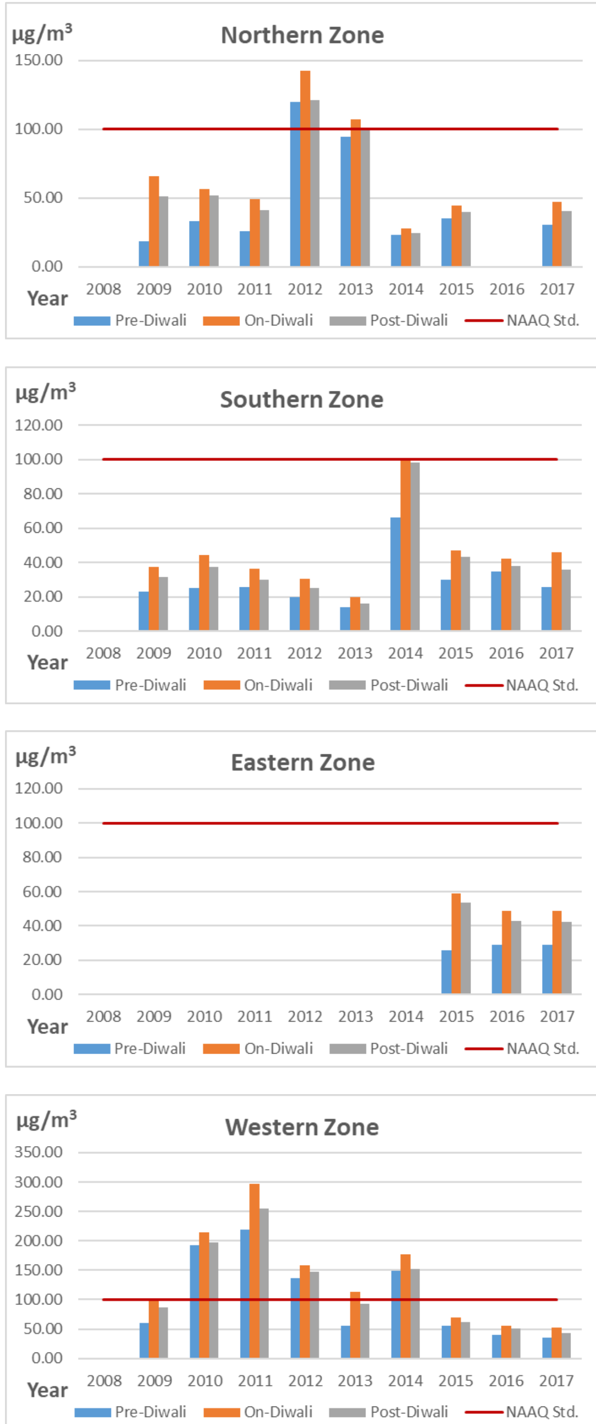


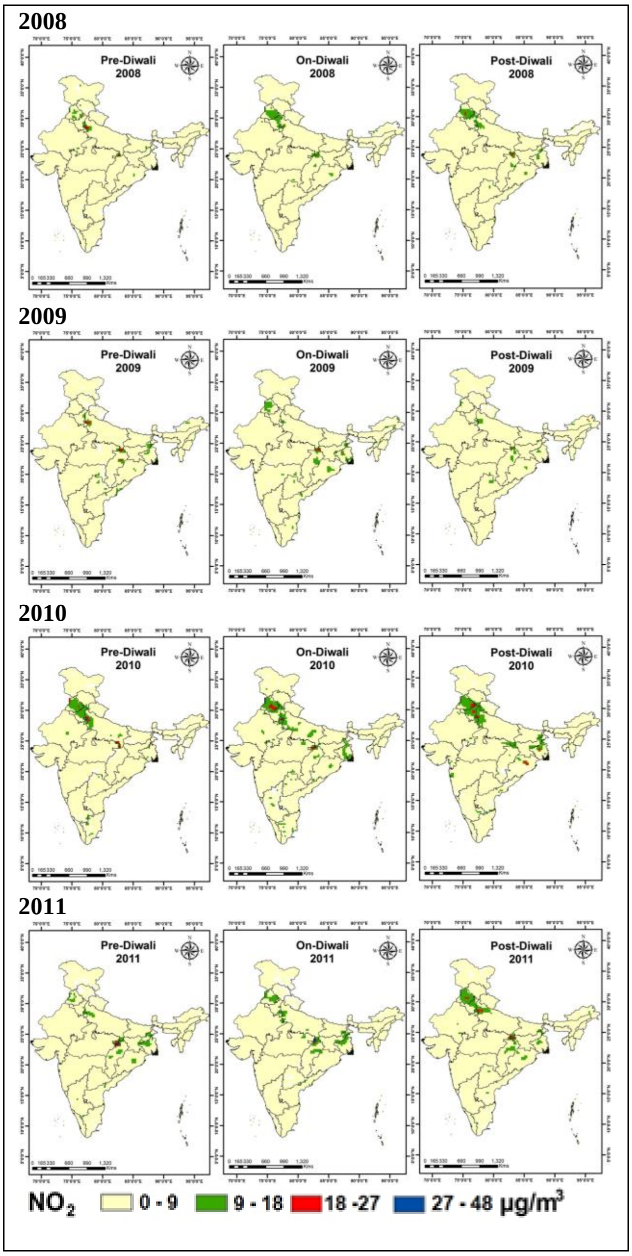
Figure 8. Spatio-temporal variation of annual Ozone in different zones.

It is observed that over western zone, the Ozone concentration is high with respect to the NAAQ safety standard (100 µg/m^3 for 24hrs average) during diwali, which is due to large number of combustive engines vehicles plying during pre, on and post diwali days. Particularly ozone values are substantive higher over western zone with cities like Mumbai (1.5 times NAAQ safety level), Ahmedabad (1.6 times NAAQ safety standard), Nagpur (7 times NAAQ safety standard); Northern zone with cities like Lucknow (1.6 times NAAQ safety level), Kanpur (3.7

times NAAQ safety standard); Southern zone with city like Bengaluru (1.5 times NAAQ safety standard) during 2012, 2013 and 2014. Data was not available for central and North East zones during the diwali days period.

4.2 Spatio-temporal variation of air pollutants across India during Diwali from satellite based data

Spatio-temporal variation of air pollutants SO_2, NO_2, CO and Ozone were generated for 10 years *i.e.* 2008 to 2017 using OMI-AURA (for SO_2 and NO_2), MERRA-2 (for CO) and AIRS (for Ozone). The spatial distribution of the air pollutants have been discussed over pre, on and post diwali days. Figure 9 shows the spatio-temporal annual distribution for NO_2 across India using OMI-AURA.



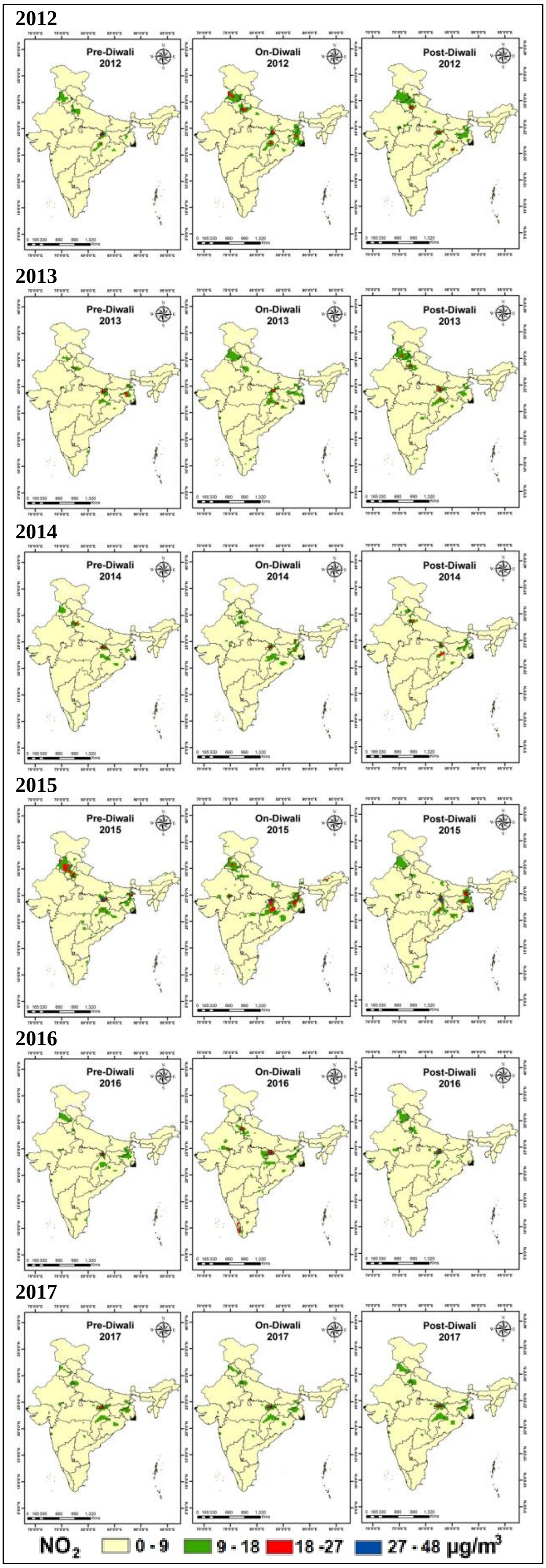
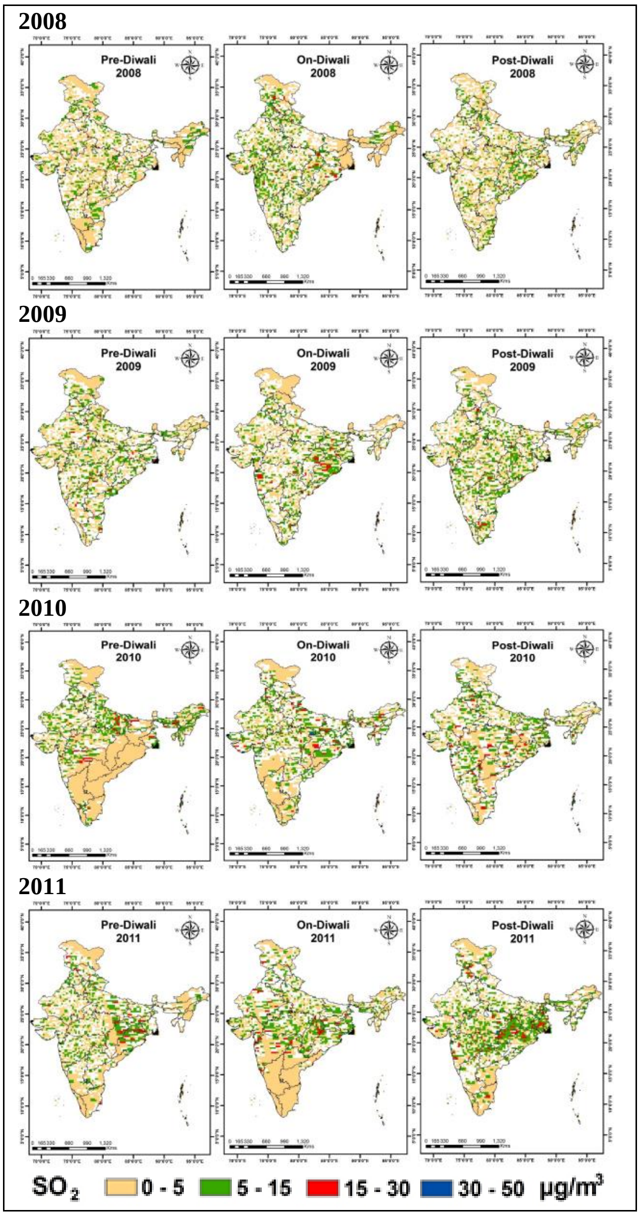


Figure 9. Spatio-temporal variation of NO_2 over India for pre, on and post diwali event during 2008 to 2017.

From the above figure it is observed that the NO_2 values over India are mostly below NAAQ safety standard (40 µg/m^3 for annual average), however high range of NOx values are observed (27-48 µg/m^3) over Delhi, Punjab, Haryana region in Northern zones, and Western, central and Eastern Indo-Gangetic plain and these high values are also observed to spread over the regions of Chattisgarh and Madhya Pradesh (central zone). This spread of concentration is seen denser on the diwali days as compared to pre and post diwali. The effect is also compounded with emissions from industrial, vehicular and thermal power plants in the regions.

The ground measured NO_2 concentration and satellite measured columnar NO_2 values differ in magnitudes but the trend over cities and different zones is observed to be similar. Ground observation also show low NO_2 values over entire India except high values over Northern and Eastern zones as compared with satellite measured values. Figure 10 shows the spatio-temporal distribution for SO_2 concentration across India using OMI-AURA.



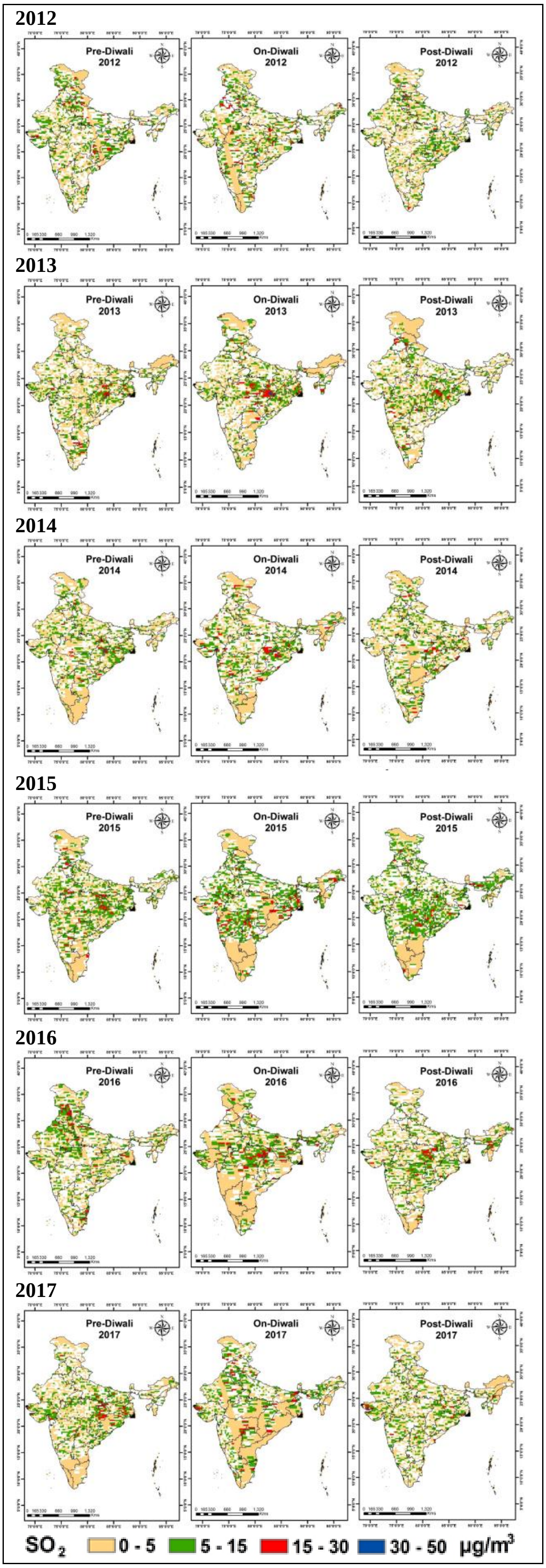
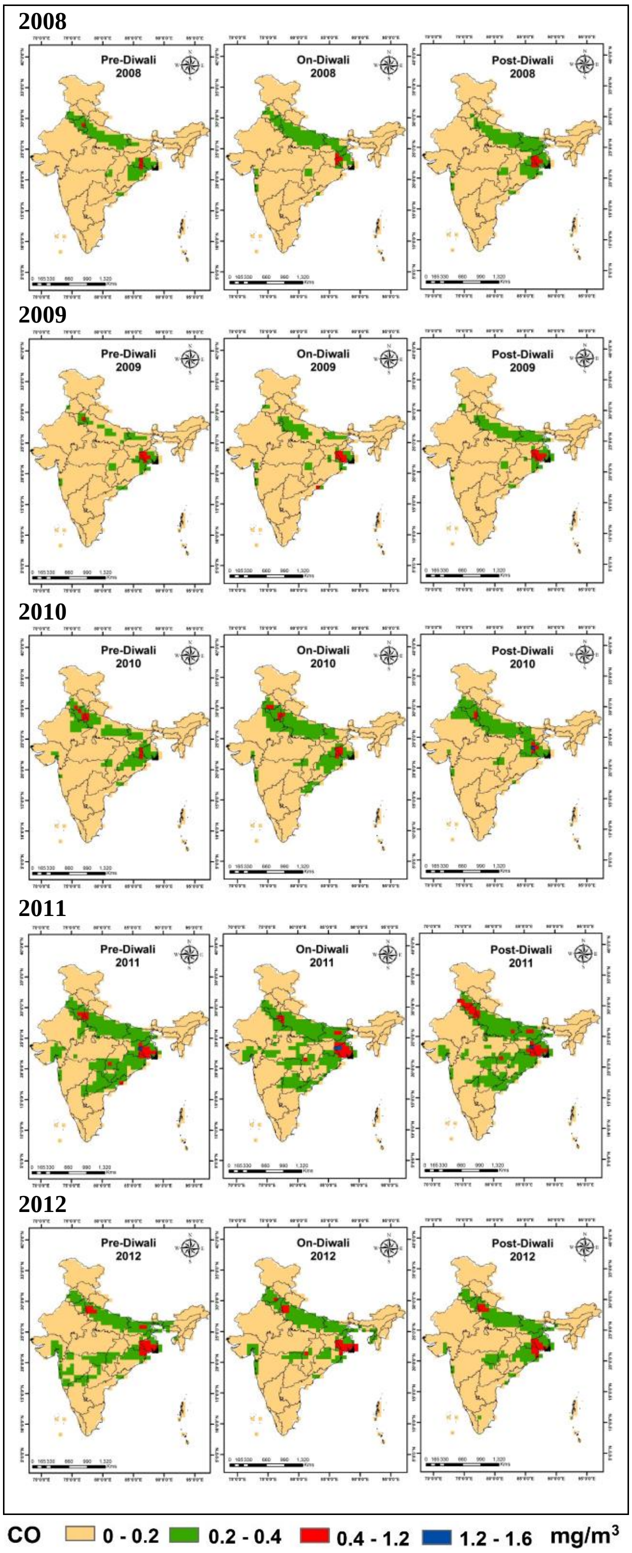


Figure 10. Spatio-temporal variation for SO_2 over India for pre, on and post diwali event during 2008 to 2017.

The observation reveal that SO_2 concentration is below safety levels at almost entire country except few cities like Delhi region, part of Gujarat, part of Tamil Nadu and Kolkata region. These satellite observation also equate well with the ground observations across different zones over India. The spatio-temporal distribution for CO across India using MERRA-2 is depicted in figure 11.



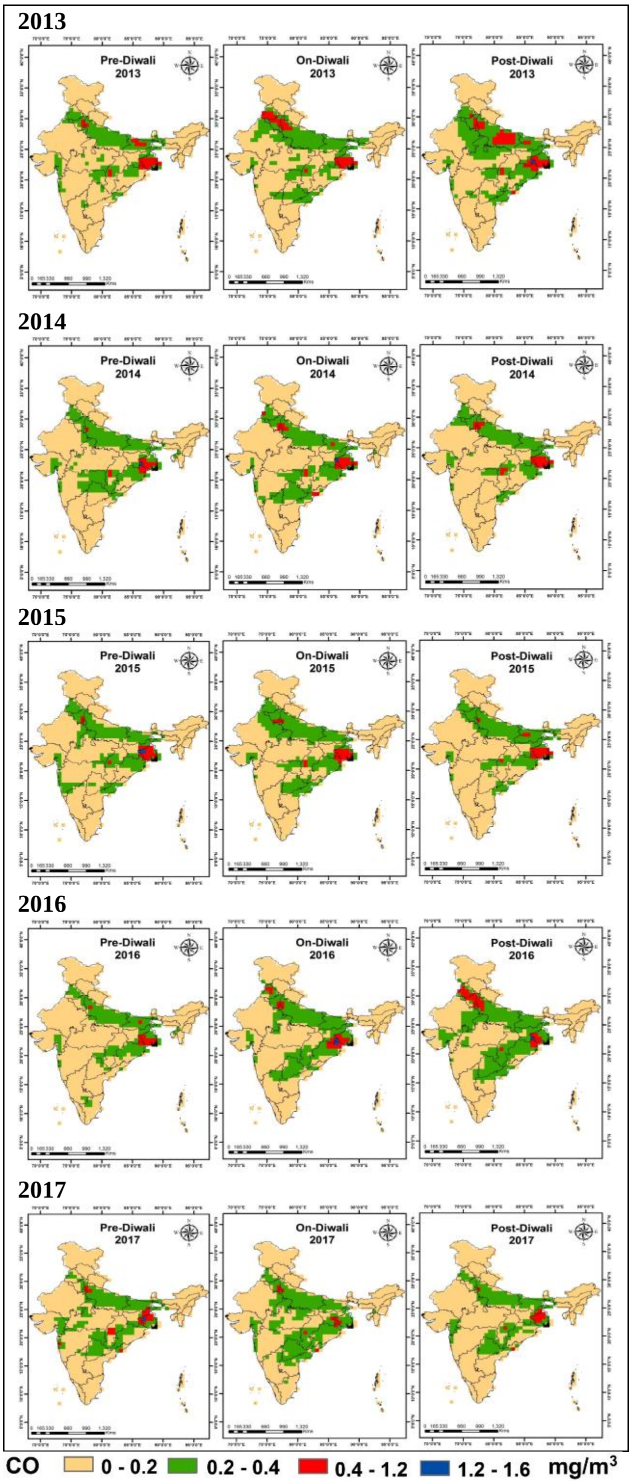


Figure 11. Spatio-temporal variation for CO over India for pre, on and post diwali event during 2008 to 2017.

The observation shows that CO concentration is at higher side of NAAQ safety standards over Western, central and Eastern indo-gangetic plain region. The same results were also observed from the ground data measurement discussed earlier. The higher value of NOx and CO are attributed majorly due to the combustion and burning of fire crackers and plying of large of number of combustive vehicles in major cities across India, especially Western and Northern India. Figure 12 describes the spatio-temporal distribution for Ozone across India using AIRS.

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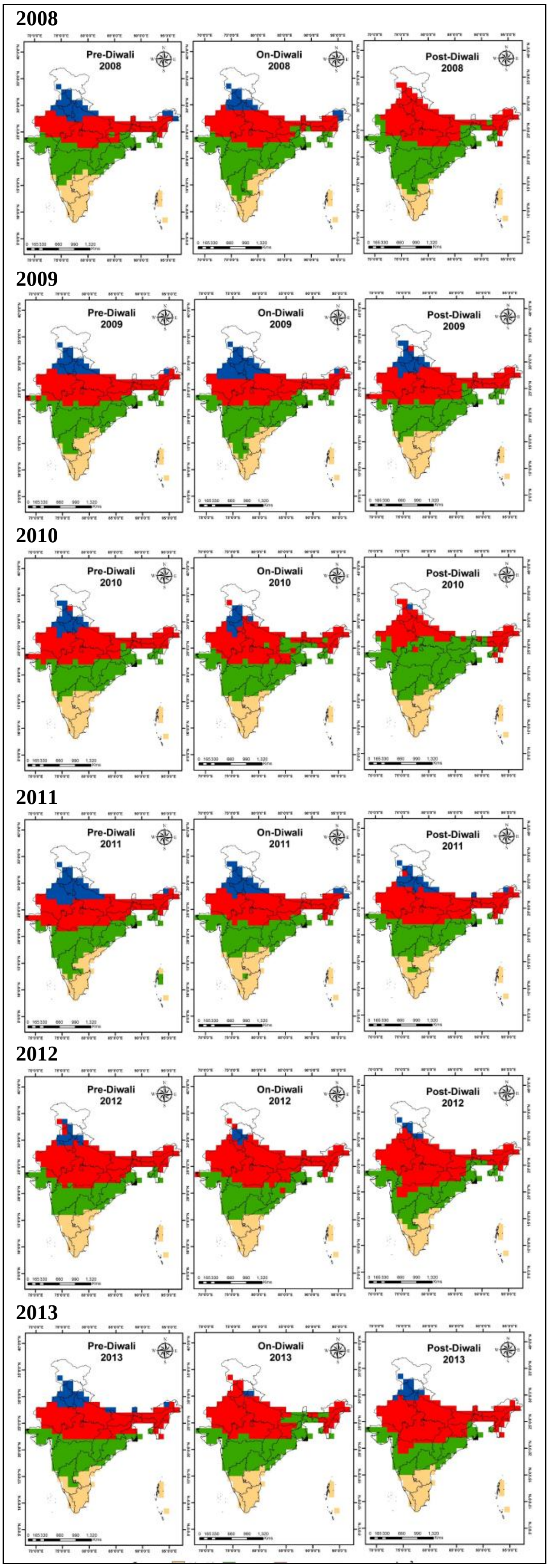


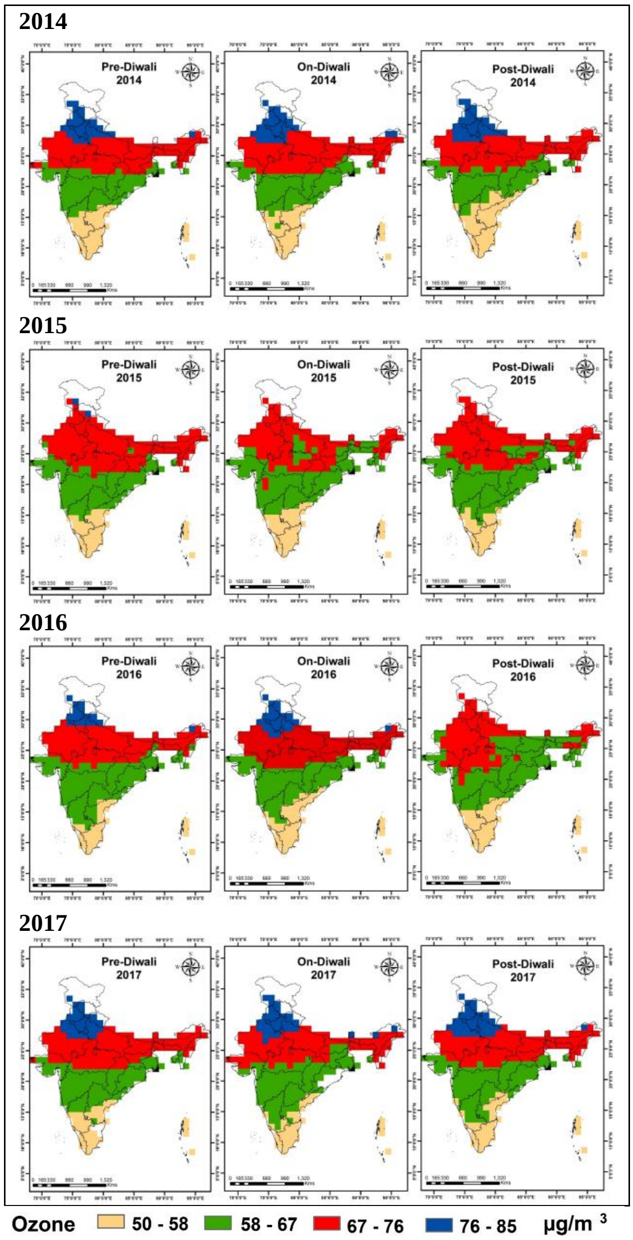


Figure 12. Spatio-temporal variation of Ozone over India for pre, on and post diwali event during 2008 to 2017.

The ozone values found to be under NAAQ safety standard across India and gradually decreases from North to South. It is also evident that the ozone values during the 10 years is relatively increasing over various cities in Northern region.

4.3 Comparison of Satellite Data from Ground based data

The satellite derived air pollutant parameters were compared with the ground measured values for almost 35-44 cities across India. For comparison purposes, similar dates of satellite and ground measurements were chosen. Due to lack of continues ground data from 2008 to 2018 during diwali days, most of the data that matches and taken were from 2017 year. Figure 13, 14, 15 & 16 shows the regression between ground and satellite data for year 2017 of NO_2 (spread over 35 cities across India) SO_2 (spread over 42 cities across India), CO (spread over 44 cities across India) & Ozone (spread over 39 cities across India) during pre, on and post diwali event here satellite and ground measurement respectively.

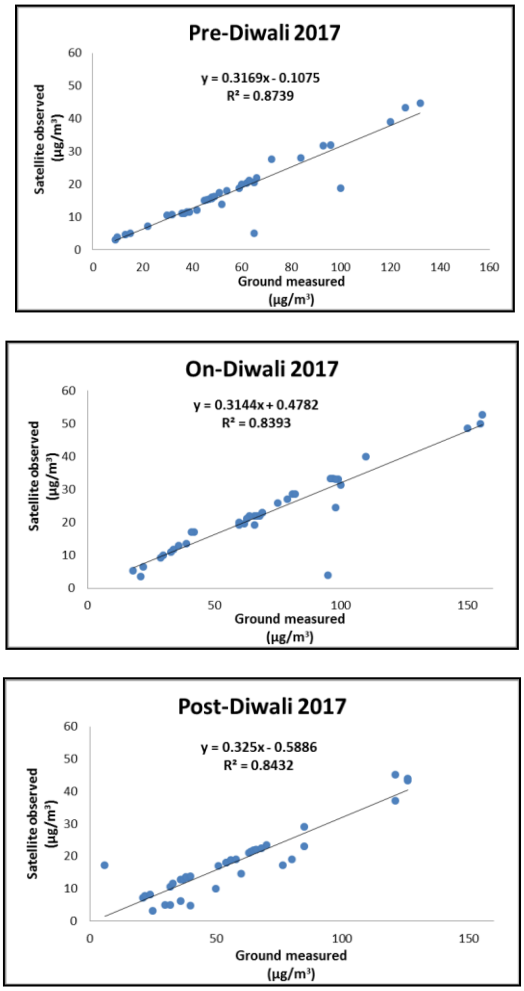
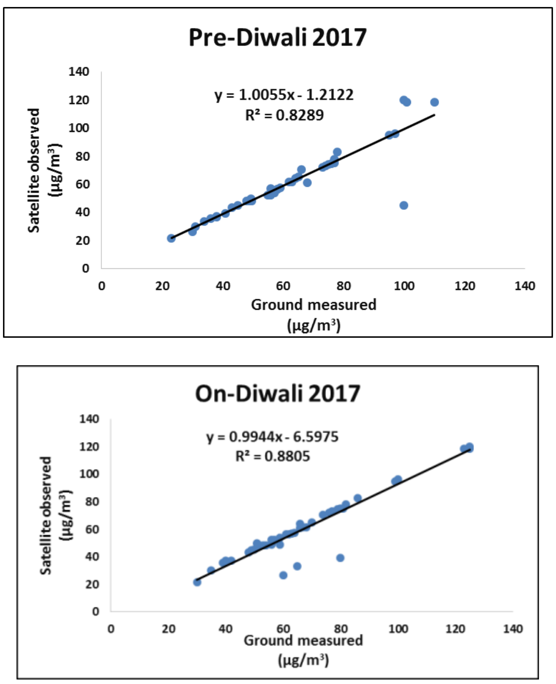


Figure 13. Validation of satellite derived NO_2 for Pre, On and Post Diwali 2017.



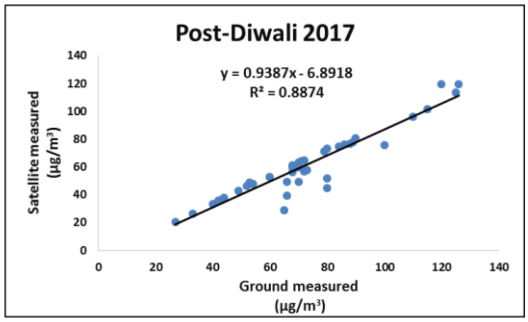


Figure 14. Validation of satellite derived SO_2 for Pre, On and Post Diwali 2017.

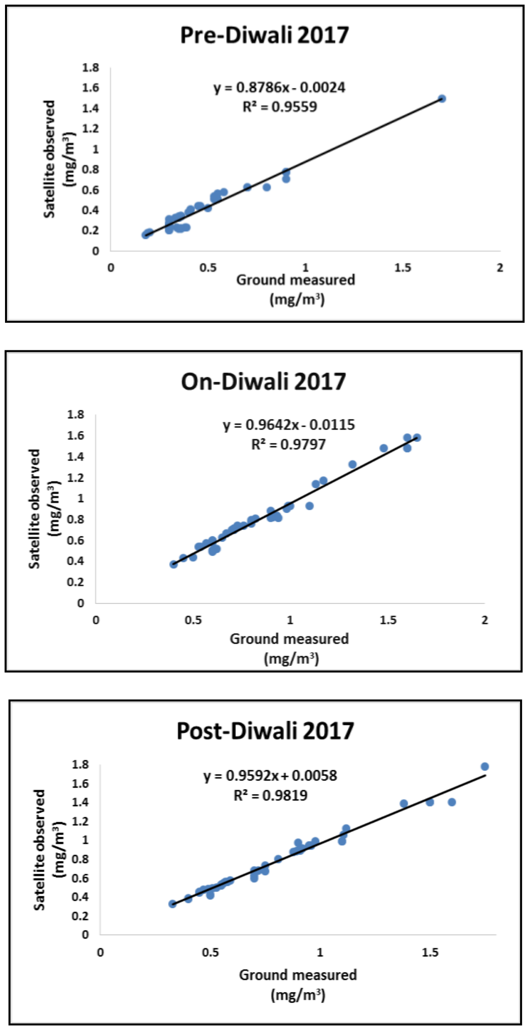
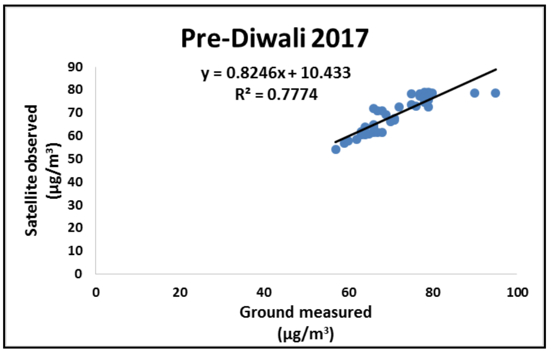
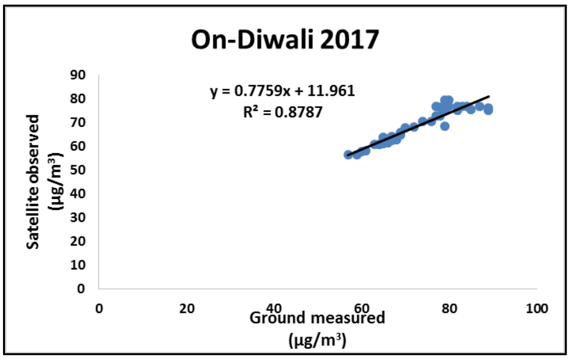


Figure 15. Validation of satellite derived CO for Pre, On and Post Diwali 2017.

The regression between ground measured and satellite estimated O_3 for 2017 during pre, on and post diwali is depicted in Figure 16. Here satellite and ground measurement are taken for 39 cities across India.





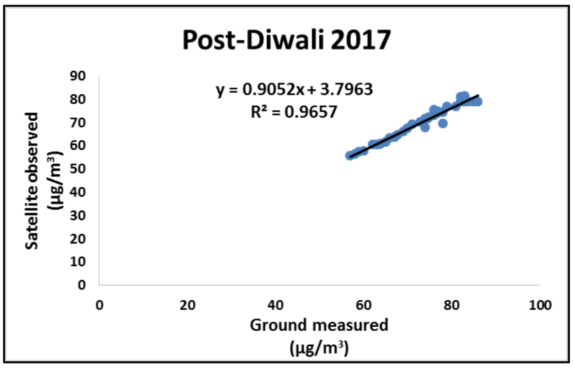


Figure 16. Validation of satellite derived Ozone for pre, on and post diwali 2017.

The regression shows that the satellite derived values are in close agreement with the ground measured over the diwali days. The slight offset in the agreement may be due to data difference in magnitude as for ground data is acquired at surface level while satellite data is as per tropospheric column. All parameters are showing good correlation between ground and satellite based data and the trend is more or less similar for satellite and ground based data indicating the variability and trends are similar in both cases during pre, on and post diwali days.

5. CONCLUSION

The analysis from satellite derived, ground values and the overall trend of pollutant trace gases over different cities suggests that the values are gradually high during diwali comparatively low in pre and post-diwali. The precise analysis of satellite derived CO reveals that the trend in peak values across the country has decreased after year 2012-13 during diwali event, although the spatial distribution of CO (in range of 0.2 – 0.6 mg/m^3). It is observed that over Northern India, spatial distribution & peak values in NO_2, has increased during diwali days followed by eastern and central region. Basically the distribution of NO_2 is noticed to be concentrated over few isolated areas in Punjab, Haryana, Delhi, northern Chhattisgarh, central West Bengal and central Odisha. The areas where seasonal crop residue burning occur during diwali time register quite high values of NO_2. One of the major sources from crackers is SO_2, and its distribution is observed in dispersed manner throughout the country however, yearly peaks are observed to be noticed mostly in northern and eastern zones. Regions of eastern Madhya Pradesh, Chhattisgarh, Odisha, and Jharkhand are found to be more susceptible for the pollution due to significant presence of SO_2. The northern Indian region i.e. Punjab, Haryana, Chandigarh, Delhi followed by the eastern and central Indian region are identified with significant higher concentration of O_3. Specifically the kharif crop residue burning combined with the diwali events make O_3 concentration level high enough cause the levels to rise and have adverse health impact. There have been few years when the post diwali period experienced more pollutant concentration than during on diwali period such as 2011 for SO_2; 2008, 2009, 2012, 2013 for CO; 2010, 2011 for NO_2; 2013 and 2017 for O_3. There were certain years where pre diwali period registered high pollution than post diwali period such as 2012 & 2015 for SO_2; 2017 for CO; 2016 for NO_2; 2010 for O_3. These anomalies are mainly due to certain local meteorological factors like precipitation, change in humidity or strong wind or else. The trend analysis of air pollutants over one decade conclude that the satellite based data depict better scenario about the distribution of pollutant gases across the country than the ground based information. The ground station data are quite irregular, provide only specific location information, and also the location of the stations are not evenly distributed across the cities. By studying the trend and comparing ground and satellite data we can conclude that the peak of the pollutants during diwali may not be increasing quite drastically over many parts of the cities but the overall spatial distribution of the pollutants is increasing from ‘moderate’ to ‘moderately high’ range. The NO_2 emitted distribution map indicates & focuses those targeted areas where the crop residue burning is practiced majorly, whereas SO_2 distribution map indicates the areas where the burning of crackers is high and O_3 distribution map shows the combined resultants of crackers and crop residue burning. The CO emitted distribution map shows those areas where the emissions due to fossils burning or due to the extensive use of oil for lighting pradeep, candles burning during diwali and also from the contribution of increasing vehicular transportation in those days. Hence, with these inferences of this study, the Indo-gangetic region is most likely to be sensitive for the abundance of these pollutant gases followed by the central and other parts of western India. The availability of moisture due to evaporation from the river and inland water bodies and low wind flow, helps in trapping and increasing the concentration of pollutant gases instead of settling down over the IGP.

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