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Short term change in relative humidity during the festival of Diwali in India

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Abstract

The changes in humidity levels during the Diwali festivities have been examined over a period of 13 years at three Indian metro cities: Ahmedabad, New Delhi and Kolkata. A small short term increase in relative humidity even in the absence of transport of humid air from Arabian Sea and Bay of Bengal has been observed. The relative humidity levels were found to be exceeding the ambient levels during night and lying below the ambient levels during morning hours, indicating an increase in the survival rates of viruses responsible for the transmission of viral infections, as well as triggering immune-mediated illnesses such as asthma during Diwali.

1. Introduction

Pollution from ozone, carbon monoxide, carbon dioxide, nitrogen dioxide, sulphate and suspended particulate matter (K, Mg, Sr, Ba and Pb) due to ignition of fireworks during the festival of Diwali (Attri et al., 2001; Khaiwal et al., 2003; Kulshrestha et al., 2004; Ganguly, 2009; Barman et al. 2008 and 2009; Nishanth et al., 2012; Jing et al., 2014; Deka and Hoque., 2014) and its harmful effects on children and elderly people (Becker et al., 2000; Hirai et al., 2000) is well established. Also, the influence of meteorological parameters such as air temperature, relative humidity (RH) and mixing height on the distribution, dispersion and overall lifetime of atmospheric pollutants emitted during Diwali has been widely studied. However, except for Saha et al., 2014, very little study has been reported on the possible causes for the observed changes in meteorological parameters during Diwali.

RH is the ratio of the actual amount of water vapour present in the air at a specific temperature at any time, to the maximum amount of water vapour that air at that temperature could possibly hold. At higher temperatures, air expands and can therefore hold more water vapour, resulting in a decrease in RH (Shaman and Kohn, 2009). Although RH exhibits high natural variability throughout the year, any short term enhancement in humidity levels coupled with high level of pollutants during Diwali might prove to be fatal for a large number of elderly people and children with respiratory ailments. Therefore the influence of pollutants emitted during Diwali on meteorological parameters such as air temperature and relative humidity (RH) and in turn the effect of short term change in environmental parameters on the survival of viruses responsible for the transmission of viral infections such as common cold, as well as triggering immune-mediated illnesses such as asthma has been examined in this paper over a period of 13 years at three cities in India namely; Ahmedabad, New Delhi and Kolkata.

Petrol and diesel (average chemical formula is C_{12}H_{22}, ranging approximately from C_{10}H_{20} to C_{15}H_{28}) used in vehicles are a complex mixture of many individual hydrocarbon components (75% saturated hydrocarbons such as paraffin including n, iso and cycloparaffins and 25% aromatic hydrocarbons such as naphthalene and alkyl benzenes), which on ignition produce carbon dioxide and water vapour. Sarkar et al. (2010) reported that the high levels of atmospheric polycyclic aromatic hydrocarbons observed during Diwali festivities at New Delhi were not sourced from fireworks; instead, they correlated well with changes in traffic patterns indicating vehicular pollution as their primary source.

Fireworks contain harmful chemicals such as potassium perchlorate, sulphur, strontium nitrate, barium nitrate, sodium oxalate, calomel, aluminium and manganese to create the colourful effects (Holmes, 1983). The ignition of fireworks can be explained by the reaction

\[ 6\text{KNO}_3 + C_2\text{H}_4\text{O}_2 + 2\text{S} \rightarrow K_2\text{CO}_3 + K_2\text{SO}_4 + K_2\text{S} + 4\text{CO}_2 + 2\text{CO} + 2\text{H}_2 \]
O+3N_2 in which CO_2 and H_2O are produced as end products.

The heat emitted by the ignition of fireworks excites the electrons in the metal atom to higher energy levels. These excited states are unstable, so the electron quickly returns to its ground state, emitting excess energy as light (Khaiwal et al., 2003). A significant proportion of this emitted light has a wavelength below 240 nm (Attri et al., 2001; Reader and Corliss; 1982–83). The radiative energy of these emissions is sufficient to dissociate organic molecules (molecules containing C, H and O) present in the air, enabling the reaction

\[(0.8CH_4+0.2CH_3O) + Y(0.79N_2 + 0.21O_2) \rightarrow 1.2CO_2 + 2.2H_2O + (0.21Y-2.3)O_2 + (0.79)N_2, \text{ (where Y is the number of kmol of air)}\]
to take place.

The effect of environmental parameters such as temperature, humidity, sunlight and pollution on the survival of airborne infectious organisms such as viruses is well established. Airborne infection involves the production of an infectious organism in one host to its transmission to a secondary host. Tang (2009) has observed that environmental exposure is a common hazard for these infectious organisms during their journey between hosts as temperature, humidity and sunlight (ultraviolet light) can act to inactivate these free-floating organisms. As temperature affects the state of viral proteins (including enzymes) and the virus genome (RNA or DNA), virus survival decreases with increase in temperature.

The survival of viruses responsible for the transmission of viral infections such as common cold, as well as triggering immunemediated illnesses such as asthma (Arundel et al., 1986; Hersoug, 2005) depends partially on levels of RH. Generally, viruses with lipid envelopes (respiratory viruses such as influenza, coronaviruses, respiratory syncytial virus and parainfluenza viruses) tend to survive longer at 20–30% RH (Harper, 1961; Schaffer et al., 1976; Ijaz et al., 1985). Conversely, non-lipid enveloped viruses (such as respiratory adenoviruses and rhinoviruses) tend to survive longer at 70–90% RH (Karim et al., 1985; Arundel et al., 1986; Cox, 1988, 1998). Although the findings from all studies are not consistent, there seems to be some general indication that minimal survival for both lipid enveloped and non-lipid-enveloped viruses occurs at an intermediate RH of 40–70% (Arundel et al., 1986; Tang, 2009). Outside this range, viruses thrive and multiply.

Ahmedabad (23.03°N; 72.58°E) is located in western India on the banks of river Sabarmati in north-central Gujarat. It covers an area of 464 km². With a population of around 6.3 million, it is the seventh most populous metropolitan city of India. Kolkata (22.65°N; 88.44°E), the capital of West Bengal is located on the eastern bank of river Hooghly and is the principal commercial, cultural, and educational centre of East India. It covers an area of 1027 km². With a population of around 14.1 million, it is the third most populous metropolitan city of India. New Delhi (28.57°N; 77.12°E), the capital of India, lies on the flood plains of the river Yamuna on the Indo-Gangetic Plain. It covers an area of 1484 km² and has a population of around 27 million residents. It is a densely populated, cosmopolitan city and has one of the highest living standards in India. Diwali or Deepawali, also known as the “Festival of Lights” is one of the oldest, and most popular cultural and religious festival, which is celebrated throughout India every year during October/November with fervour and gaiety. In north India (New Delhi), Diwali signifies Lord Ram’s return to Ayodhya after defeating Ravana and his coronation as king; in Gujarat (Ahmedabad), Diwali signifies worship of goddess Lakshmi and marks the beginning of New Year, while in West Bengal (Kolkata), it is associated with the worship of goddess Kali. The celebrations include lighting of lamps, candles and bursting of fireworks. The festive fever starts a few days prior to Diwali with people igniting fireworks, shopping for the celebrations and visiting each other and reaches a crescendo on the day of Diwali.

2. Data and techniques

The surface air temperature and relative humidity levels have been obtained from the website http://www.wunderground.com. Concentration of SO_2, PM_{10}, O_3, CO, C_6H_6 and NH_3 at New Delhi has been obtained from the website of ENVIS Central Pollution Control Board. Local noon time surface UV Irradiance at 305 nm, 310 nm, 324 nm and 380 nm from Aura OMI used in this paper were obtained from Giovanni online data system, developed and maintained by the NASA GES DISC. The five day 3D back trajectories at different altitudes have been obtained from the European Centre for Medium-Range Weather Forecasts. The details of cases involving respiratory disorders at Ahmedabad have been obtained from Government Civil Hospital, Sola in Ahmedabad.

To delineate the effects of festivities on the humidity levels, the daily maximum RH level before and after Diwali (+2 days to +7 days) were averaged and used as background (normal), while the daily maximum RH level a day prior to, on the Diwali day and a day after Diwali were averaged and plotted to represent the effect of Diwali. Similarly, the daily maximum temperature (°C) was averaged over the entire month to represent the background (normal) temperature, while the maximum temperature (°C) on the Diwali day was used to represent the effect of Diwali. Further, the diurnal variation of RH before and after Diwali (+2 days to +7 days) were averaged and compared with the averaged diurnal variation of RH a day prior to, on the Diwali day and a day after Diwali for any abnormal variations in RH levels at these three cities.

3. Results and discussions

The changes in RH (%) and surface air temperature (°C) at New Delhi, Ahmedabad and Kolkata on the day of Diwali, compared to the background value are shown in Fig. 1. It was observed that the RH during Diwali was higher compared to the background levels for the years 2000, 2002–2008, 2010–2012 at Ahmedabad, for the years 2002, 2006, 2007, 2010–2012 at New Delhi and for the years

![Fig. 1. Changes in relative humidity (%) and surface air temperature (°C) at New Delhi, Ahmedabad and Kolkata during Diwali compared to the background value. Source: www.wunderground.com.](image-url)
2000, 2003, 2004, 2007–2011 at Kolkata. The surface air temperature (°C) on the day of Diwali was observed to be lower compared to the background temperature at all the three cities over the entire period of study. The observed decrease in temperature and increase in RH on the Diwali day compared to the normally observed background value at these cities varied significantly from 5 °C to 8 °C and from 6% to 16%, respectively.

The five day back trajectories at 1000 hPa, 900 hPa, 800 hPa, 700 hPa and 500 hPa pressure levels (surface, 1 km, 2 km, 3 km and 5.5 km altitude, respectively) were studied at Ahmedabad, New Delhi and Kolkata during all these years. The years during which the back trajectories indicated transport of humid air from Arabian Sea and Bay of Bengal (such as the years 2000, 2004, 2006, 2008 and 2010 at Ahmedabad; the years 2006 and 2011 at New Delhi and the years 2003, 2004 and 2009 at Kolkata) have been omitted from this study as these humid air parcels might be responsible for the observed high RH levels. During the remaining years (such as 2002, 2003, 2005, 2007, 2011 and 2012 at Ahmedabad; 2002, 2007, 2010 and 2012 at New Delhi; and 2000, 2007, 2008, 2010 and 2011 at Kolkata), the back trajectories indicated transport of air from dry north and north west land regions. One such back trajectory at each of these three cities is presented as an example in Fig. 2. This rules out the possibility of increase in humidity levels due to advection of humid air from sea and indicates that some other factor might be contributing to the short term increase in RH during these years.

The background and Diwali levels of SO2 and PM10 (μg/m³), and the time series of SO2 and PM10 levels on the day of Diwali observed at Janakpuri, a residential area of New Delhi are plotted in Figs. 3 and 4, respectively. The sulphate and suspended particulate matter released into the atmosphere during the ignition of fireworks contribute to the high levels of SO2 and PM10 (μg/m³) observed during Diwali compared to the background levels (Fig. 3). It is further observed from Fig. 4, that the SO2 and PM10 levels are high during the years 2007, 2010 and 2012 under study at New Delhi. The observed short term increase in RH may be because, these sulphate and suspended particulate matter reduce solar irradiation from reaching the earth’s surface thereby reducing the earth’s surface temperature and increasing relative humidity.

The profiles of air pollutants such as ozone (O3), carbon monoxide (CO), Benzene (C6H6) and ammonia (NH3) measured at Dilshad Garden and NSIT Dwarka, New Delhi during Diwali 2014 (Fig. 5) suggests that the second possibility for the observed high RH levels at night might be due to significant amount of combustion of petrol and diesel fuels from enhanced traffic during Diwali festivities resulting in the production of carbon dioxide and water vapour.

\[
(0.8\text{CH}_4+0.2\text{C}_2\text{H}_6)+\gamma(0.79\text{N}_2+0.21\text{O}_2) \rightarrow 1.2\text{CO}_2+2.2\text{H}_2\text{O}+(0.21\gamma-2.3)\text{O}_2+(0.79\gamma)\text{N}_2, \text{ (where } \gamma \text{ is the number of kmol of air).}
\]

It is further observed that the years during which the relative humidity was higher during Diwali compared to the background values are not identical at all these three cities. Therefore one arbitrary case study involving diurnal variation of RH is presented as an example at each of these cities to determine the difference in magnitude and pattern of variation between background and Diwali RH.

The diurnal variation of RH at Ahmedabad in the year 2005 (Fig. 6) indicates that the background RH was maximum (80%) at sunrise (08:00 h IST); decreased gradually to a minimum (30%) around 13:00 h IST, remained low up to around 18:00 h IST and thereafter increased to reach a maximum (75%) at night. However the RH levels during Diwali was 90% (higher than the background level by around 30%) at midnight (00:00 h IST), continued to increase thereafter, reaching a maximum of 94% around 02:00–03:00 h IST, remained high till 09:00 h IST in the morning, decreased sharply thereafter to 24% around 16:00 in the evening and increased thereafter to 82% at night. Similar diurnal pattern was observed during Diwali for the years 2000, 2002–2008, 2010–2012, although the magnitude of difference between background and Diwali RH levels varied from one year to another.

The background RH at New Delhi in the year 2007 was observed to be maximum (60%) around 6:00 h IST at sunrise;
decrease gradually to a minimum (18%) around 15:00–16:00 h IST and thereafter increase to reach a maximum (60%) around 3:00 h IST at night. However it was observed that the RH levels during Diwali was 88% (higher than the background level by around 39%) at midnight (00:00 h IST), continued to increase thereafter, reaching a maximum of 94% around 02:00–06:00 h IST decreased sharply thereafter to 51% around 17:00 in the evening and increased thereafter to 94% at night. Similar diurnal pattern of RH was observed during Diwali for the years 2000, 2003, 2004, 2007–2011, although the magnitude of difference between background and Diwali RH levels varied from one year to another. The RH levels continued to remain high till morning hours at all stations for all years because the hydrocarbons released into the air by enhanced traffic continued to react with molecular oxygen in presence of the UV radiations emitted from the firecrackers and weak sunlight to produce water vapour to its maximum potential. The local noontime surface UV Irradiance at 305 nm, 310 nm, 324 nm and 380 nm averaged over these three cities (Fig. 7) indicates that although the surface UV Irradiance during Diwali (8 Nov., 9 Nov., and 10 Nov., 2007) is low (by 13.04%, 9.09%, 3.83% and 3.25% less respectively compared to the background levels), it does not differ significantly from the background levels. This indicates that the chemistry of NOx–VOC is active during Diwali noon time. Therefore, as the day progressed, photo-chemical production of ozone through the standard OH–CO–NO and NOx–CO–HC reactions (Crutzen, 1974), resulted in a decrease in RH levels. This is validated by the observations of Atri et al. (2001) that during the festival period the ozone concentration peaked at around noon.

The background RH at Kolkata in the year 2011 was observed to be maximum (83%) at sunrise (06:00 h IST); decrease gradually to a minimum (35%) around 14:00–15:00 h IST in the afternoon and thereafter increase to reach a maximum (83%) at night. However it was observed that the RH levels during Diwali was 89% (higher than the background level by around 15%) at midnight (00:00 h IST), continued to increase thereafter, reaching a maximum of 94% around 02:00–06:00 h IST decreased sharply thereafter to 51% around 17:00 in the evening and increased thereafter to 94% at night. Similar diurnal pattern of RH was observed during Diwali for the years 2000, 2003, 2004, 2007–2011, although the magnitude of difference between background and Diwali RH levels varied from one year to another. The RH levels continued to remain high till morning hours at all stations for all years because the hydrocarbons released into the air by enhanced traffic continued to react with molecular oxygen in presence of the UV radiations emitted from the firecrackers and weak sunlight to produce water vapour to its maximum potential. The local noontime surface UV Irradiance at 305 nm, 310 nm, 324 nm and 380 nm averaged over these three cities (Fig. 7) indicates that although the surface UV Irradiance during Diwali (8 Nov., 9 Nov., and 10 Nov., 2007) is low (by 13.04%, 9.09%, 3.83% and 3.25% less respectively compared to the background levels), it does not differ significantly from the background levels. This indicates that the chemistry of NOx–VOC is active during Diwali noon time. Therefore, as the day progressed, photo-chemical production of ozone through the standard OH–CO–NO and NOx–CO–HC reactions (Crutzen, 1974), resulted in a decrease in RH levels. This is validated by the observations of Atri et al. (2001) that during the festival period the ozone concentration peaked at around noon.
and fell to negligible levels after sunset and Ali et al. (2012) that surface ozone concentration and relative humidity are inversely correlated.

The RH levels at Ahmedabad, New Delhi and Kolkata were found to be exceeding the ambient RH levels (40–70%) during night, while the RH level at Ahmedabad was found to be lower than the ambient RH level during morning hours (Fig. 6), indicating an increase in the survival rates of viruses responsible for the transmission of viral infections, as well as triggering immune-mediated illnesses such as asthma during Diwali. The percentage of cases involving respiratory disorders reported during Diwali out of total number of cases reported during the entire year at Government Civil Hospital, Sola in Ahmedabad is shown in Fig. 8. The sudden spurt in respiratory infection cases reported during Diwali may be a possible consequence of an increase in the survival rates of viruses responsible for the transmission of viral infections due to change in temperature and RH levels.

4. Conclusions

The changes in humidity levels during the Diwali festivities have been examined over a period of 13 years at three Indian metro cities: Ahmedabad, New Delhi and Kolkata. It is concluded
that the toxic pollutants emitted due to the ignition of fire works during Diwali are not only fatal for a large number of elderly people and children with respiratory ailments who inhale the polluted air directly, but they also influence the meteorological parameters such as temperature and relative humidity, which in turn control the survival rate of viruses responsible for the transmission of viral infections resulting in a sudden spike in respiratory infection cases reported during Diwali. However, as the causes of outbreaks of viral infections are quite complex and do not have a simple relationship with change in temperature or RH; it is difficult to differentiate the magnitude of respiratory ailments caused directly by inhaling the pollutants from that caused indirectly by increase in survival rate of viruses due to change in temperature and RH.

Acknowledgments

The author acknowledges her gratitude to the anonymous reviewers for their valuable suggestions and Dr. P.K. Solanki and Dr. Komal Patel for providing the details of respiratory disorder cases reported at Government Civil Hospital, Sola in Ahmedabad for this study. The relative humidity levels and surface air temperature data has been obtained from the website http://www.wunderground.com. Analyses for local noontime surface UV irradiance at 305 nm, 310 nm, 324 nm and 380 nm obtained from Aura OMI used in this paper were obtained from Giovanni online data system, developed and maintained by the NASA GES DISC. Concentration of SO2, PM10, O3, CO, C6H6 and NH3 at New Delhi has been obtained from the website of ENVIS Central Pollution Control Board. Five day back trajectories at different altitudes have been obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF: http://badc.nerc.ac.uk).

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