International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 03 - Issue 02 || February 2018 || PP. 04-10

Time Series Analysis of Particulate Matter (PM_{10}) in Delhi

Abhinav Garg, Priyanka Sharma and Chirashree Ghosh*
Environmental Pollution Laboratory, Department of Environmental Studies
University of Delhi, Delhi, India

Abstract: Urban areas around the world and especially in developing countries are facing problem of deteriorating air quality attributing to growing population, vehicular density and unplanned land use makeup. The undertaken study analyses the spatio-temporal variation in PM_{10} at one of the most polluted city in the world, Delhi, India. The Decadal trend analysis from 2005 to 2014 was conducted at five zones (North, South, East, West and Central) in Delhi. The air quality analysis was also computed by calculating the Air Quality Index at all five sites from 2005 -2014. The result of the study depicted that out of all the five zones North Delhi is comparatively more polluted followed by East, West, South and Central Delhi. The air quality trend depicted the at all the sites and throughout the study period AQI ranged from Unhealthy to sensitive group (101 to 150) to Hazardous (301-500) category. However, the most inferior air quality was reported in year 2008-2011, where AQI ranged from Very Unhealthy (201-300) to Hazardous (301-500). The study shows that post 2011 there has been considerable decline in PM levels owing to vehicular and traffic regulations and implementation of norms by governmental agency. But despite all the efforts the pollution level of Delhi still crosses the safe permissible limit and is harmful for human health and wellbeing.

Introduction

Clean air is very important for human health and well-being of a society. Air pollution is not a recent issue but it continues to be a well-known environmental problem since the beginning of the industrial revolution in late 1700s and changed global atmosphere and its chemistry at an alarming rate. In developing countries, the ever increasing rate of industrialization and urbanization has led to severe problem of air pollution and its health impacts (Sowlat et. al., 2011). According to World Health Organization's (WHO) assessment of the burden of disease due to air pollution, 7 million people died - one in eight of total global deaths – as a result of air pollution exposure (WHO, 2014). For the purpose of protecting human health and environment, United States Environment Protection Agency (U.S. EPA), a government agency was formed for writing and enforcing various regulations based on laws. The Clean Air Act requires USEPA to set national ambient air quality standards (NAAQS) for pollutants with proven ill effects, also called as "Criteria Pollutants" (Table 1). Currently, five major pollutants are listed as criteria pollutants, Sulfur Dioxide (SO_2), Ozone (O_3), Carbon Monoxide (CO), Nitrogen Oxides (NO_2), and Particulate Matter (PM). Human exposure to various criteria air pollutants may lead to a variety of health problems ranging from cancer to death. All these pollutants (NO_2, CO, O_3, PM and SO_2) had significantly raised relative risks (for all age groups) of emergency hospital admissions for respiratory and cardiovascular diseases (Wong et al., 2013).

Present study focuses on the particulate pollution because of its acuteness i.e., ambient high concentration and associated increment in respiratory dysfunction. Particulate pollution is made up of a number of components, organic or inorganic chemicals and soil or dust particles. The size of particles is directly linked to their disease causing potential. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the upper respiratory system (throat and nose) and enter into the lower respiratory system (lungs). Once inhaled, these particles can affect the heart and lungs and cause serious health effects. National Morbidity Mortality Air Pollution Study (NMMAPS), reported a 10 $\mu g/m^3$ increase in PM_{10} caused an increase in cardiopulmonary mortality by 0.5% (Samet et al. 2000). Acute exposure is also related to cause coronary artery disease by changing the coagulation and platelet count (Anderson et al., 2012).

Year round seasonal variation of PM is another complex spatio-temporal issue; in general, PM needs to be viewed as a major reason for deteriorating air quality in India. Atmospheric lifetimes of PM seem to vary a few days in the boundary layer and a few weeks in the free troposphere (Jacob and Winner, 2009). The large sources of fine particles in India are coal fired power plant, fuel combustion in industries, and transportation corridors (Kumar and Joseph, 2006). Yadav et al. 2014, reported that in Delhi, the level of PM_{10} crosses the threshold level in all months of the year except for the monsoon season (July- October), with mass concentration maximum during the month of March and December.

In our study, we have carried out the time series analysis of PM_{10} for ten (10) years (2005-2014) in five location of Delhi viz., East, West, North, South and Central Delhi. Together with quantification, we have also indexed health impacts of PM_{10} using Air Quality Indexing (AQI) as a tool. The Air Quality Index (AQI) is a new public information tool that helps people to know the negative effects of air pollution. The Air Quality Index is a scale designed to aware public about their health by representing the quality of air around them in easy to understand color codes (Mintz (U.S. EPA) 2009).

Table 1: National Ambient Air Quality Standards for 24 Hours - Time Weighted Average

Pollutants	Industrial, Residential, Rural and Other areas	Ecologically Sensitive Area (Notified by Central Government)
Sulphur Dioxide, (SO_2), µg/m^3	80	80
Nitrogen Dioxide, NO_2), µg/m^3	80	80
Particulate Matter, PM_{10}, µg/m^3	100	100
Particulate Matter, PM2.5, µg/m^3	60	60
Ozone (O3), µg/m^3	180	180
Carbon Monoxide (CO), mg/m^3	04	04

(Source: www.cpcb.nic.in)

Methodology

Study Area: Delhi

Delhi is a city that bridges two different build up environment. Old Delhi, once the capital of Islamic India, is a labyrinth of narrow lanes lined with crumbling havelis and formidable mosques. In contrast, the imperial city of New Delhi created by the British Raj is composed of spacious, tree-lined avenues and imposing government buildings. Delhi also has third highest tree-cover among all cities of India. Delhi's urban population has grown from 1.4 million in 1951 to 16.3 million in 2011 (DSH, 2012).

Delhi, with 6 million registered vehicles, has repeatedly beaten the Chinese capital on particulate matter pollution (DSH, 2012). In the past five years, the city has enforced all the mitigation to reduce air pollution. It has advanced emission norms of vehicles; strengthened its 'pollution under control' system with new equipment; capped the number of three wheelers; converted buses to CNG; made it mandatory for new light commercial vehicles to run on CNG; and restricted commercial vehicles from entering the city during peak traffic hours. But in spite of all these actions, pollution levels are still on the rise. Currently, the city adds over 1,000 new personal vehicles each day on its roads.

According to a study by the Harvard International Review, every two in five persons in Delhi suffer from respiratory ailments (Jessica Sequeira, 2008). The Lancet's Global Health Burden, 2013 termed air pollution the sixth biggest human killer in India (Murray et al., 2015).

Data Collection and Analysis

To better understand the atrocity of PM_{10} in the city, spatial and time series data was critically analyzed for Ten years, 2005 – 2014. From the public data portal of the Central Pollution Control Board (CPCB), pollution data was collected for East, West, North, South and Central Delhi's representative monitoring station, viz. Shahdara, Janakpuri, Shahzada Bagh, Sirifort and Nizamuddin respectively. Pollutant data was recorded at 24 hourly averaged time interval for continuous ten years (2005-2014). Obtained data was computed and averaged monthly (Thirty (30) days), and yearly (Twelve (12) Months) for graphical representation and calculation of Air Quality Index (AQI).

Air Quality Index (AQI) Calculation:

AQI is a calculated numerical value used by government agencies to communicate to the public about the local air quality status (USEPA, 2011). It provides information on air quality in simple linguistic terms (color codes) that is easily understood by a common person (Figure 1). As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects.

Air quality index was calculated for 24 hourly data using the following formula; calculated AQI was then averaged monthly and yearly.

$$I_P = \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}}(C_P - BP_{LO}) + I_{LO}$$

Where,

$\mathbf{I_p}$ = the index for pollutant p

C_p = the rounded concentration of pollutant p
BP_{Hi} = the breakpoint that is greater than or equal to C_p
BP_{Lo} = the breakpoint that is less than or equal to C_p
BP_{Hi} = the breakpoint that is greater than or equal to C_p
I_{Hi} = the AQI value corresponding to BP_{Hi}
I_{Lo} = the AQI value corresponding to BP_{Lo}

Table 2: Color Coded Table of Air Quality Index

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*..air quality conditions are:*	*...as symbolized by this color:*
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Results and Discussion

Spatial – Temporal analysis of PM_{10} was carried out in Delhi for continuous ten (10) years, 2005 – 2014 at different locations, East, West, North, South and Central Delhi, represented by corresponding CPCB monitoring stations, viz. Shahdara, Janakpuri, Shahzada Bagh, Sirifort and Nizamuddin respectively. Through time series analysis, it was observed that in the whole decade (2005-2014), PM_{10} concentration was crossing the permissible limit (100 μgm^{-3}) at every selected location (Figure 1). Annual concentration was minimally 2.1 times higher than the permissible limit, recording least mass of PM_{10} in the year 2013 (211.8 μgm^{-3}). On upper side it is 4.8 times higher than the permissible limit in the year 2011 with an average PM_{10} concentration of 475.96μgm^{-3}.

Spatial variation depicted, North Delhi to be the most polluted location, followed by East, West, South and Central Delhi, with average concentration of 364.29, 356.944, 333.51, 329.07 and 307.42 μgm^{-3} respectively.On a time scale analysis, no particular trend was observed, but particulate pollution significantly reduced after 2011. Descending order of yearly concentration was like, 2011, 2009, 2008, 2010, 2006, 2007, 2005, 2012, 2014 and 2013, with concentration 475.96, 433.66, 418.29, 410.26, 374.18, 321.42, 276.1, 242.7, 218.1, 211.8 μgm^{-3}.

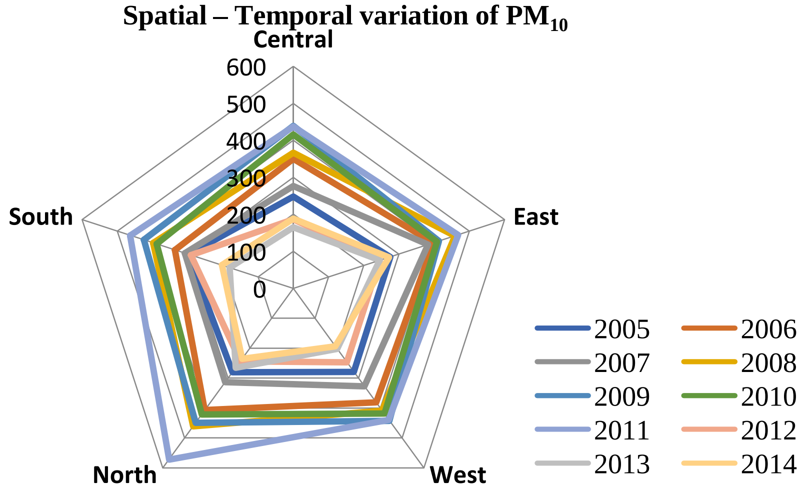

Figure 1: Spatial Temporal variation of PM_{10} (μgm^{-3}) in Delhi

The AQI was calculated using the methodology of US Environmental Protection Agency and trend of criteria pollutant, PM_{10} and its health concern was analyzed for selected locations, East, West, North, South and Central Delhi. Result showed that AQI values in all the locations ranged from sensitive group (101 to 150) to Hazardous (301-500) category, particularly the quality of air is worse in North and East Delhi as compared to other locations (Table 3). Particularly years 2008 to 2011 displayed the most inferior quality of air in the whole decade (2005 to 2014) where AQI ranged from Very Unhealthy (201-300) to Hazardous (301-500). Such inferior quality of air is extremely harmful for the inhabitants of Delhi and need serious consideration.

Table 3: The Spatial – Temporal Variation in Air Quality Index (AQI) for PM_{10}

Location	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Central	147	198	161	217	319	289	316	117	106	117
East	161	263	240	344	286	277	355	146	146	159
West	162	237	186	276	322	291	319	146	124	120
North	163	274	180	345	330	296	467	145	156	140
South	172	191	177	263	300	248	349	169	114	124

Legend:

0 to 50	51 to 100	101 to 150	151 to 200	201 to 300	301 to 500
Good	**Moderate**	**Unhealthy for Sensitive Groups**	**Unhealthy**	**Very Unhealthy**	**Hazardous**

In India there is widespread problem of particulate pollution especially in arid and semi-arid areas in north-western part of India, like Delhi, due to the synergistic effects of extensive urbanisation, industrialisation, construction activities, increased vehicular pollution and biomass burning (Khillare et al, 2004). As decadal temporal analysis depicted the highest concentration of PM_{10} was in year 2008 to 2010 which also reported the most inferior air quality as per the AQI study. The probable reason for this could be the construction work undertaken for the preparation of common wealth games. As per the report by Planning Department, 2009, government took up 59 projects/scheme for the Common Wealth Games, 2010 across Delhi. Metro construction activities too added huge amount of PM pollution in ambient air (Mishra et al., 2015). Beig et al., 2013, reported that control measures taken to curb pollution for the common wealth games by implementing vehicular and traffic regulation to relocation of industries and reduction in emission from power plant was not sufficient enough to control pollution of Delhi.

But after 2011 there was considerable decline in PM concentration and such decrease could be because of reduction in emission by implementing four sets of vehicular emission standards, mandatory retirement of older commercial vehicles and increase in the use of compressed natural gas (CNG) (Goel et al. 2015).

Spatial variation showed North Delhi to be most polluted area followed by East Delhi. This spatial trend could be because of high population density of these areas, congested built area and industrial (small scale) set up in these areas. Similar Spatial trend of emission was reported for PM_{10}, $PM_{2.5}$, CO and NOx in Delhi by Sharma and Dixit, 2016 with north Delhi showing higher emissions than other parts of Delhi.

Conclusion

Time series analysis of air pollution variation offers the approach to understand air pollution trend, problems, assessing and reviewing environmental measures. So that air pollution problems can be tackled in a systematic manner at local, national and global level. Time series analysis of air pollution (PM_{10}) in Delhi revealed North Delhi to be most polluted, in compare to other districts, East, West, South and Central Delhi. Knowing air pollution status helps air quality agencies like, Central Pollution Control Board, Delhi Pollution Control Board etc. to know when and how to take action to protect public health.

AQI is invaluable tool to make local people understand the status of air quality around them, which aid for taking precautionary measures to protect their health. Government agencies and policy makers also use AQI for decision making process aimed to curb air pollution.

Acknowledgment

Authors deeply acknowledge the Rajiv Gandhi National Fellowship for Disabled (RGNFD) for providing financial (scholarship) support and Central Pollution Control Board (CPCB), India for providing the pollution data of Delhi for the study.

References

[1]. Anderson JO, Thundiyil JG, Stolbach A., Clearing the air: a review of the effects of particulate matter air pollution on human health, J. Med. Toxicol., 8 (2012), pp. 166-175

[2]. Brunekreef B., G. Hoek, P.Fischer, F.T.H.M. Spieksma, Relation between airborne pollen concentrations and daily cardiovascular and respiratory-disease mortality 2000. The Lancet, Volume 355, Issue 9214, Pages 1517 - 1518

[3]. Christopher J L Murray, Ryan M Barber, Kyle J Foreman, Ayse Abbasoglu Ozgoren, Foad Abd-Allah, Semaw F Abera, Victor Aboyans, Jerry P Abraham, Ibrahim Abubakar, Laith J Abu-Raddad, Niveen M Abu-Rmeileh, Tom Achoki, Ilana N Ackerman, Zanfi na Ademi, Arsène K Adou, José C Adsuar, Ashkan Afshin, Emilie E Agardh, Sayed Saidul Alam, Deena Alasfoor, Mohammed I Albittar, Miguel A Alegretti, Zewdie A Alemu, Rafael Alfonso-Cristancho, Samia Alhabib, Raghib Ali, François Alla, Peter Allebeck, Mohammad A Almazroa, Ubai Alsharif, Elena Alvarez, Nelson Alvis-Guzman, Azmeraw T Amare, Emmanuel A Ameh, Heresh Amini, Walid Ammar, H Ross Anderson, Benjamin O Anderson, Carl Abelardo T Antonio, Palwasha Anwari, Johan Arnlöv, Valentina S Arsic Arsenijevic, Al Artaman, Rana J Asghar, Reza Assadi, Lydia S Atkins, Marco A Avila, Baff our Awuah, Victoria F Bachman, Alaa Badawi, Maria C Bahit, Kalpana Balakrishnan, Amitava Banerjee, Suzanne L Barker-Collo, Simon Barquera, Lars Barregard, Lope H Barrero, Arindam Basu, Sanjay Basu, Mohammed O Basulaiman, Justin Beardsley, Neeraj Bedi, Ettore Beghi, Tolesa Bekele, Michelle L Bell, Corina Benjet, Derrick A Bennett, Isabela M Bensenor, Habib Benzian, Eduardo Bernabé, Amelia Bertozzi-Villa, Tariku J Beyene, Neeraj Bhala, Ashish Bhalla, Zulfi qar A Bhutta, Kelly Bienhoff , Boris Bikbov, Stan Biryukov, Jed D Blore, Christopher D Blosser, Fiona M Blyth, Megan A Bohensky, Ian W Bolliger, Berrak Bora Başara, Natan M Bornstein, Dipan Bose, Soufi ane Boufous, Rupert R A Bourne, Lindsay N Boyers, Michael Brainin, Carol E Brayne, Alexandra Brazinova, Nicholas J K Breitborde, Hermann Brenner, Adam D Briggs, Peter M Brooks, Jonathan C Brown, Traolach S Brugha, Rachelle Buchbinder, Geoff rey C Buckle, Christine M Budke, Anne Bulchis, Andrew G Bulloch, Ismael R Campos-Nonato, Hélène Carabin, Jonathan R Carapetis, Rosario Cárdenas, David O Carpenter, Valeria Caso, Carlos A Castañeda-Orjuela, Ruben E Castro, Ferrán Catalá-López, Fiorella Cavalleri, Alanur Çavlin, Vineet K Chadha, Jung-Chen Chang, Fiona J Charlson, Honglei Chen, Wanqing Chen, Peggy P Chiang, Odgerel Chimed-Ochir, Rajiv Chowdhury, Hanne Christensen, Costas A Christophi, Massimo Cirillo, Matthew M Coates, Luc E Coff eng, Megan S Coggeshall, Valentina Colistro, Samantha M Colquhoun, Graham S Cooke, Cyrus Cooper, Leslie T Cooper, Luis M Coppola, Monica Cortinovis, Michael H Criqui, John A Crump, Lucia Cuevas-Nasu, Hadi Danawi, Lalit Dandona, Rakhi Dandona, Emily Dansereau, Paul I Dargan, Gail Davey, Adrian Davis, Dragos V Davitoiu, Anand Dayama, Diego De Leo, Louisa Degenhardt, Borja Del Pozo-Cruz, Robert P Dellavalle, Kebede Deribe, Sarah Derrett, Don C Des Jarlais, Muluken Dessalegn, Samath D Dharmaratne, Mukesh K Dherani, Cesar Diaz-Torné, Daniel Dicker, Eric L Ding, Klara Dokova, E Ray Dorsey, Tim R Driscoll, Leilei Duan, Herbert C Duber, Beth E Ebel, Karen M Edmond, Yousef M Elshrek, Matthias Endres, Sergey P Ermakov, Holly E Erskine, Babak Eshrati, Alireza Esteghamati, Kara Estep, Emerito Jose A Faraon, Farshad Farzadfar, Derek F Fay, Valery L Feigin, David T Felson, Seyed-Mohammad Fereshtehnejad, Jeff erson G Fernandes, Alize J Ferrari, Christina Fitzmaurice, Abraham D Flaxman, Thomas D Fleming, Nataliya Foigt, Mohammad H Forouzanfar, F Gerry R Fowkes, Urbano Fra.Paleo, Richard C Franklin, Thomas Fürst, Belinda Gabbe, Lynne Gaffi kin, Fortuné G Gankpé, Johanna M Geleijnse, Bradford D Gessner, Peter Gething, Katherine B Gibney, Maurice Giroud, Giorgia Giussani, Hector Gomez Dantes, Philimon Gona, Diego González-Medina, Richard A Gosselin, Carolyn C Gotay, Atsushi Goto, Hebe N Gouda, Nicholas Graetz, Harish C Gugnani, Rahul Gupta, Rajeev Gupta, Reyna A Gutiérrez, Juanita Haagsma, Nima Hafezi-Nejad, Holly Hagan, Yara A Halasa, Randah R Hamadeh, Hannah Hamavid, Mouhanad Hammami, Jamie Hancock, Graeme J Hankey, Gillian M Hansen, Yuantao Hao, Hilda L Harb, Josep Maria Haro, Rasmus Havmoeller, Simon I Hay, Roderick J Hay, Ileana B Heredia-Pi, Kyle R Heuton, Pouria Heydarpour, Hideki Higashi, Martha Hijar, Hans W Hoek, Howard J Hoff man, H Dean Hosgood, Mazeda Hossain, Peter J Hotez, Damian G Hoy, Mohamed Hsairi, Guoqing Hu, Cheng Huang, John J Huang, Abdullatif Husseini, Chantal Huynh, Marissa L Iannarone, Kim M Iburg, Kaire Innos, Manami Inoue, Farhad Islami, Kathryn H Jacobsen, Deborah L Jarvis, Simerjot K Jassal, Sun Ha Jee, Panniyammakal Jeemon, Paul N Jensen, Vivekanand Jha, Guohong Jiang, Ying Jiang, Jost B Jonas, Knud Juel, Haidong Kan, André Karch, Corine K Karema, Chante Karimkhani, Ganesan Karthikeyan, Nicholas J Kassebaum, Anil Kaul, Norito Kawakami, Konstantin Kazanjan, Andrew H Kemp, Andre P Kengne, Andre Keren,

Yousef S Khader, Shams Eldin A Khalifa, Ejaz A Khan, Gulfaraz Khan, Young-Ho Khang, Christian Kieling, Daniel Kim, Sungroul Kim, Yunjin Kim, Yohannes Kinfu, Jonas M Kinge, Miia Kivipelto, Luke D Knibbs, Ann Kristin Knudsen, Yoshihiro Kokubo, Soewarta Kosen, Sanjay Krishnaswami, Barthelemy Kuate Defo, Burcu Kucuk Bicer, Ernst J Kuipers, Chanda Kulkarni, Veena S Kulkarni, G Anil Kumar, Hmwe H Kyu, Taavi Lai, Ratilal Lalloo, Tea Lallukka, Hilton Lam, Qing Lan, Van C Lansingh, Anders Larsson, Alicia E B Lawrynowicz, Janet L Leasher, James Leigh, Ricky Leung, Carly E Levitz, Bin Li, Yichong Li, Yongmei Li, Stephen S Lim, Maggie Lind, Steven E Lipshultz, Shiwei Liu, Yang Liu, Belinda K Lloyd, Katherine T Lofgren, Giancarlo Logroscino, Katharine J Looker, Joannie Lortet-Tieulent, Paulo A Lotufo, Rafael Lozano, Robyn M Lucas, Raimundas Lunevicius, Ronan A Lyons, Stefan Ma, Michael F Macintyre, Mark T Mackay, Marek Majdan, Reza Malekzadeh, Wagner Marcenes, David J Margolis, Christopher Margono, Melvin B Marzan, Joseph R Masci, Mohammad T Mashal, Richard Matzopoulos, Bongani M Mayosi, Tasara T Mazorodze, Neil W Mcgill, John J Mcgrath, Martin Mckee, Abigail Mclain, Peter A Meaney, Catalina Medina, Man Mohan Mehndiratta, Wubegzier Mekonnen, Yohannes A Melaku, Michele Meltzer, Ziad A Memish, George A Mensah, Atte Meretoja, Francis A Mhimbira, Renata Micha, Ted R Miller, Edward J Mills, Philip B Mitchell, Charles N Mock, Norlinah Mohamed Ibrahim, Karzan A Mohammad, Ali H Mokdad, Glen L D Mola, Lorenzo Monasta, Julio C Montañez Hernandez, Marcella Montico, Thomas J Montine, Meghan D Mooney, Ami R Moore, Maziar Moradi-Lakeh, Andrew E Moran, Rintaro Mori, Joanna Moschandreas, Wilkister N Moturi, Madeline L Moyer, Dariush Mozaff arian, William T Msemburi, Ulrich O Mueller, Mitsuru Mukaigawara, Erin C Mullany, Michele E Murdoch, Joseph Murray, Kinnari S Murthy, Mohsen Naghavi, Aliya Naheed, Kovin S Naidoo, Luigi Naldi, Devina Nand, Vinay Nangia, K M Venkat Narayan, Chakib Nejjari, Sudan P Neupane, Charles R Newton, Marie Ng, Frida N Ngalesoni, Grant Nguyen, Muhammad I Nisar, Sandra Nolte, Ole F Norheim, Rosana E Norman, Bo Norrving, Luke Nyakarahuka, In-Hwan Oh, Takayoshi Ohkubo, Summer L Ohno, Bolajoko O Olusanya, John Nelson Opio, Katrina Ortblad, Alberto Ortiz, Amanda W Pain, Jeyaraj D Pandian, Carlo Irwin A Panelo, Christina Papachristou, Eun-Kee Park, Jae-Hyun Park, Scott B Patten, George C Patton, Vinod K Paul, Boris I Pavlin, Neil Pearce, David M Pereira, Rogelio Perez-Padilla, Fernando Perez-Ruiz, Norberto Perico, Aslam Pervaiz, Konrad Pesudovs, Carrie B Peterson, Max Petzold, Michael R Phillips, Bryan K Phillips, David E Phillips, Frédéric B Piel, Dietrich Plass, Dan Poenaru, Suzanne Polinder, Daniel Pope, Svetlana Popova, Richie G Poulton, Farshad Pourmalek, Dorairaj Prabhakaran, Noela M Prasad, Rachel L Pullan, Dima M Qato, D Alex Quistberg, Anwar Rafay, Kazem Rahimi, Sajjad U Rahman, Murugesan Raju, Saleem M Rana, Homie Razavi, K Srinath Reddy, Amany Refaat, Giuseppe Remuzzi, Serge Resnikoff , Antonio L Ribeiro, Lee Richardson, Jan Hendrik Richardus, D Allen Roberts, David Rojas-Rueda, Luca Ronfani, Gregory A Roth, Dietrich Rothenbacher, David H Rothstein, Jane T Rowley, Nobhojit Roy, George M Ruhago, Mohammad Y Saeedi, Sukanta Saha, Mohammad Ali Sahraian, Uchechukwu K A Sampson, Juan R Sanabria, Logan Sandar, Itamar S Santos, Maheswar Satpathy, Monika Sawhney, Peter Scarborough, Ione J Schneider, Ben Schöttker, Austin E Schumacher, David C Schwebel, James G Scott, Soraya Seedat, Sadaf G Sepanlou, Peter T Serina, Edson E Servan-Mori, Katya A Shackelford, Amira Shaheen, Saeid Shahraz, Teresa Shamah Levy, Siyi Shangguan, Jun She, Sara Sheikhbahaei, Peilin Shi, Kenji Shibuya, Yukito Shinohara, Rahman Shiri, Kawkab Shishani, Ivy Shiue, Mark G Shrime, Inga D Sigfusdottir, Donald H Silberberg, Edgar P Simard, Shireen Sindi, Abhishek Singh, Jasvinder A Singh, Lavanya Singh, Vegard Skirbekk, Erica Leigh Slepak, Karen Sliwa, Samir Soneji, Kjetil Søreide, Sergey Soshnikov, Luciano A Sposato, Chandrashekhar T Sreeramareddy, Jeff rey D Stanaway, Vasiliki Stathopoulou, Dan J Stein, Murray B Stein, Caitlyn Steiner, Timothy J Steiner, Antony Stevens, Andrea Stewart, Lars J Stovner, Konstantinos Stroumpoulis, Bruno F Sunguya, Soumya Swaminathan, Mamta Swaroop, Bryan L Sykes, Karen M Tabb, Ken Takahashi, Nikhil Tandon, David Tanne, Marcel Tanner, Mohammad Tavakkoli, Hugh R Taylor, Braden J Te Ao, Fabrizio Tediosi, Awoke M Temesgen, Tara Templin, Margreet Ten Have, Eric Y Tenkorang, Abdullah S Terkawi, Blake Thomson, Andrew L Thorne-Lyman, Amanda G Thrift, George D Thurston, Taavi Tillmann, Marcello Tonelli, Fotis Topouzis, Hideaki Toyoshima, Jeff erson Traebert, Bach X Tran, Matias Trillini, Thomas Truelsen, Miltiadis Tsilimbaris, Emin M Tuzcu, Uche S Uchendu, Kingsley N Ukwaja, Eduardo A Undurraga, Selen B Uzun, Wim H Van Brakel, Steven Van De Vijver, Coen H van Gool, Jim Van Os, Tommi J Vasankari, N Venketasubramanian, Francesco S Violante, Vasiliy V Vlassov, Stein Emil Vollset, Gregory R Wagner, Joseph Wagner, Stephen G Waller, Xia Wan, Haidong Wang, Jianli Wang, Linhong Wang, Tati S Warouw, Scott Weichenthal, Elisabete Weiderpass, Robert G Weintraub, Wang Wenzhi, Andrea Werdecker, Ronny Westerman, Harvey A Whiteford, James D Wilkinson, Thomas N Williams, Charles D Wolfe, Timothy M Wolock, Anthony D Woolf, Sarah Wulf, Brittany Wurtz, Gelin Xu, Lijing L Yan, Yuichiro Yano, Pengpeng Ye, Gökalp K Yentür, Paul Yip, Naohiro Yonemoto, Seok-Jun Yoon, Mustafa Z Younis, Chuanhua Yu, Maysaa E Zaki, Yong Zhao, Yingfeng Zheng, David Zonies, Xiaonong Zou, Joshua A Salomon, Alan D Lopez, Theo Vos, "Global, regional, and national disability-adjusted life years (DALYs) for 306 diseases and injuries and healthy life expectancy (HALE) for 188 countries, 1990–2013: quantifying the epidemiological transition", The Lancet 2015; 386: 2145–91

[4]. GufranBeig, Dilip M.Chate, Sachin. D.Ghude, A.S.Mahajan, R.Srinivas, K.Ali, S.K.Sahu, N.Parkhi, D.Surendran, H.R.Trimbake. Quantifying the effect of air quality control measures during the 2010 Commonwealth Games at Delhi, India. Atmospheric Environment, Volume 80, December 2013, Pages 455-463.

[5]. Jacob D.J., D.A. Winner, Effect of climate change on air quality 2009, Atmospheric Environment Vol. 43(1), Pages 52-63.

[6]. Kumar R., E.A. Joseph, Air pollution concentrations of $PM_{2.5}$, PM_{10} and NO_2 at ambient and kerbsite and their correlation in metro city-Mumbai 2006. Environmental Monitoring Assessment Vol. 119, Pages 191-199.

[7]. Mintz, D. 2009. Technical assistance document for the reporting of daily air quality –the Air Quality Index (AQI). USEPA Office of Air Quality Planning and Standards Report, EPA-454/B09-001

[8]. Mukesh Sharma and Onkar Dikshit, Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi, submitted to Department of Environment Government of National Capital Territory of Delhi and Delhi Pollution Control Committee, Delhi, January 2016

[9]. P. S. Khillare S. Balachandran, Bharat Raj Meena, Spatial and Temporal Variation of Heavy Metals in Atmospheric Aerosol of Delhi, Environmental Monitoring and Assessment, January 2004, Volume 90, Issue 1–3, pp 1–21

[10]. P. S. Khillare, S. Balachandran, Bharat Raj Meena, Spatial and Temporal Variation of Heavy Metals in Atmospheric Aerosol of Delhi, Environmental Monitoring and Assessment, January 2004, Volume 90, Issue 1–3, pp 1–21

[11]. Rahul Goel and Sarath K. Guttikunda, Evolution of on-road vehicle exhaust emissions in Delhi, Atmospheric Environment, 105 (2015) 78 – 90

[12]. Rajeev Kumar Mishra, Tarun Joshi, Nikhil, Himanshu, Amrit Kumar Monitoring and analysis of PM_{10} concentration at Delhi Metro construction sites. International Journal of Environment and Pollution 57(1):27-37 · January 2015

[13]. Samet J.M., Dominici F., Curriero F.C., Coursac I., Zeger S.L. Fine particulate air pollution and mortality in 20 U.S. cities, 1987-1994. *N. Engl. J. Med.* (2000);343:1742–1749.

[14]. Sohail Ahmad, Mack Joong Choic, Jinsoo Koc, 2013, Quantitative and qualitative demand for slum and non-slum housing in Delhi: Empirical evidences from household data , Habitat International, Volume 38, Pages 90-99

[15]. Sowlat M.H., H. Gharibi, M. Yunesian, M.T. Mahmoudi, S. Lotfi, A novel, fuzzy-based air quality index (FAQI) for air quality assessment 2011, Atmospheric Environment Vol. 45, Issue 12, Pages 2050-2059.

[16]. Wong T.W., W.W.S. Tam, I.T.S. Yu, A. Kai Hon Lau, S. Wing Pang, Andromeda H.S. Wong, Developing a risk-based air quality health index 2013, Atmospheric Environment Vol. 76, Pages 52-58.

[17]. Yadav R, G. Beig , S.N.A. Jaaffrey , The linkages of anthropogenic emissions and meteorology in the rapid increase of particulate matter at a foothill city in the Arawali range of India 2014. Atmospheric Environment Vol. 85, Pages 147-151.

Reports:

[1]. DSH (Delhi Statistical Handbook), Government of National Capital Territory of Delhi, Directorate of Economics & Statistics, New Delhi (2012), p. 369

[2]. Jessica Sequeira, A toxic Issue, Harward International Review, December 19, 2008

[3]. Planning Department, 2009. Economic survey of Delhi 2008–2009. Government of NCT of Delhi.

[4]. WHO (2005) Air quality guidelines for particulate matter, ozone, nitrogen, dioxide and sulfur dioxide.

[5]. World Health Organisation (WHO), 2014, Geneva, News release, 7 million premature deaths annually linked to air pollution

[6]. World health report 2002. Reducing risks, promoting healthy life. Geneva, World Health Organization, 2002.