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Assessment of the Ambient Air Quality at the Industrial Area using the Air Quality Index Method (AQI)

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ABSTRACT

Air quality Index (AQI) is a tool for identify the current status of air quality, as in the last few years, global issues have been brought up about the health impacts caused by deteriorating air quality mainly due to large-scale industrialization and urbanization. In order to estimate the AQI, five pollutants synergistic effect viz., PM_{10}, $PM_{2.5}$, NO_2, SO_2 and NH_3 were used to assess the prevailing ambient air quality in the industrial area, the ambient air quality was continuously monitored from Jan 2014 to Dec 2016, at five different locations with sampling time of 24 hrs and AQI was calculated using ORNAQI procedure. The results put forward suggests that pollutants were found beyond the permissible limit and the relative AQI was found in severe air pollution range, as the ORNAQI value observed during months of January and December for the investigative period of 2014, 2015 and 2016 respectively, were above 100 rating scale indicating dangerous/severe air pollution during that period in the area and ambient air quality standards were not attained.

Highlights

- Five pollutants synergistic effect were used to assess the prevailing ambient air quality in the industrial area.
- ORNAQI value observed for the investigative period of 2014, 2015 and 2016 (3 consecutive years).

Keywords: Air quality index, ORNAQI, fertilizers, IFFCO

Various monitoring programmes have been undertaken to know the quality of air by generating enormous amount of data on concentration of each air pollutant (e.g., SPM, CO, NOx, SO_2, etc.) in different parts of the world (Bishoi *et al.* 2009). Non-integrated baseline data predominantly proved to be inadequate to portray a clear picture of the adjacent environment (Banerjee and Srivastava 2009). The bulk of data often do not express the air quality status to the government officials, scientific society, policy makers and to the common public in a straightforward and uncomplicated manner; thus, inadequacy of the raw data to provide satisfactory information often results in lowering of public interests regarding environmental friendly practices. This problem is addressed by determining the Air Quality Index (AQI) of a given area, which were developed to calculate the fundamental ambient air pollution status (Mayer *et al*. 2008). AQI, also known as Air Pollution Index (API) (Murena 2004) or Pollutant Standards Index (PSI) (EPA 1994), has been developed by many agencies in U.S., Canada, Europe, Australia, China, etc (Cairncross *et al.* 2007). An Air Quality Index may be defined as a single numeral digit for reporting the air quality with respect to its effects on the human health (Murena 2004); or as a method that transform weighted values of individual air pollution related parameters into a single number (Cheng *et al.* 2007). In detailed form, it combines many pollutants concentrations in some mathematical expression to arrive at a single number for air quality or is a quantitative measure which collects and summarizes the accessible data on a particular problem to demonstrate the existence and trends of considerable conditions (Reddy *et al.*, 2004).

Since, the main purpose of AQI is to measure the air quality in relation to its impact on human health, the U.S. Environmental Protection Agency (EPA) revised the earlier method to calculate daily AQI in 1999, which was based on concentrations of five criteria pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM) and sulphur dioxide (SO_2) and these concentration values are converted into numerical indexes; the overall AQI is then calculated by taking into account the maximum AQI among the monitored pollutants corresponding to a site and the scale of the index (0-500) is subdivided into six categories that are related with a range of health messages (Bishoi *et al.* 2009). The criteria to formulate AQI should be universal and irrespective of the level of pollution where these indices are applied (Mayer *et al.* 2008) and should keep in mind some points before designing the AQI like pollutants type and number, method of calculation, categories in which index would be divided and criteria of health (Nagendra *et al.* 2007), also AQI should be adequately flexible to account different levels of inhabitants exposure, changeable meteorological and climatic conditions occurring in an area and the sensitivity of flora and fauna (Longurst 2005).

There are numerous researches related to applicability of AQI to stimulate ambient air quality. Cheng *et al.* (2004) proposed a revised EPA air quality index (RAQI) by introducing an entropy function to include effect of the concentrations of the rest of pollutants other than the pollutant with maximum AQI and in 2007, compared its applicability in Taiwan which showed that the suspended particulates have significantly greater impact on $PM_{2.5}/PM_{10}$ ratio in southern parts than central and northern area; and these ratios are higher as a whole compared to many other countries. Other important studies related to diverse aspects of air quality index were reported by Khanna (2000); Cogliani (2001); Bortnick *et al.* (2002); Jiang *et al.* (2004); Longhurst (2005); Landulfo *et al.* (2007); Mayer and Kalberlah (2008); Elshout *et al.* (2008); Lu *et al.* (2011); Kassomenos *et al.* (2012); Dimitriou *et al.* (2013) and Javed *et al.* (2014).

In Indian perspective, there have not been significant efforts to develop and use AQI, though few studies on AQIs have been carried out for Delhi (Sengupta *et al.*, 2000); Kanpur (Sharma *et al.* 2003); Lucknow (Shukla *et al.* 2010; Chaudhary *et al.* 2013); Jharkhand district (Dubey *et al.* 2014); Nagpur (Nigam *et al.* 2015). The mathematical approach for calculating these indices are based on health criteria of the EPA and Indian air quality standards.

In a study done by Sengupta *et al.* (2000) examined the Oak Ridge Air Quality Index (ORAQI) based on additive function of sub-indexes for Delhi and founded that this index suffered from eclipsing effect, i.e., when one pollutant exceeds its standard without the index exceeding its critical value and more than 90 percent of time the index estimated that the air quality falls under acceptable limits though the air quality standard for some pollutants were violated, though the maximum operator concept (MOC), generally used by U.S. EPA to calculate EPAQI, was recommended to overcome this problem. Hence, an effort should be made to calculate a New Air Quality Index (NAQI) which is based on the factor analysis technique assisted by principal component analysis (PCA) (Bishoi *et al.* 2009).

MATERIALS AND METHODS

Description of Study Area

The present research was conducted in Aonla based plant of Indian Farmers Fertiliser Cooperative Limited (IFFCO). The site is 28 km southwest of Bareilly on Bareilly Aonla Road in the state of Uttar Pradesh, India. Geographically Aonla fertilizer complex is located at in the northern region of India and at longitude 28° 13′ 34.87″ N and latitude 79° 14′ 50.63″ E at an elevation of 165 m above mean sea level.

Climatic Conditions

The climate of research area is warm, subtropical with dry hot summer and cold winter. When compared with winter, the summers have much more rainfall, starting in the third or fourth week of June and lasts up to September, in form of monsoon rains. The average annual temperature in the area is 25.1°C, with average annual rainfall is 1037 mm. The driest month is November, with 2 mm of rain. In July, the precipitation reaches its peak, with an average of 321 mm. June is the warmest month of the year with temperature averages of 33.3 °C.

At 15.0 °C average, January is the coldest month of the year. There is a difference of 319 mm of precipitation between the driest and wettest months. The variation in annual temperature is around 18.3 °C. The weather parameters for the study period (January 2014-december 2016) were persued from the regional meteorological station of IMD located at Lucknow in state of Uttar Pradesh, India.

Selection of Ambient Air Quality Monitoring (AAQM) Locations

In multi-objective air pollution monitoring programme, selection of monitoring locations can be made based on a range of principles. However, for this air pollution assessment and estimation study, importance were principally given to ensure suitable determination of the spatial and temporal variations of pollutants, coupled with probable evaluation of their overall mean pollutant concentrations surrounding IFFCO-Aonla. Based on the topography and meteorological conditions of the pre-defined study region, primarily a five AAQM location was selected in the IFFCO-Aonla industrial unit, out of these five location, four were located inside the industry area and the fifth one was located in the residential area.

Selection of AAQM location was significant in regard to assess the impacts of recent industrialization at surrounding residential and sensitive areas. Further, an fifth AAQM location was selected at the township area of IFFCO, considering its significance to assess emissions from both the vehicular pollution from adjacent State Highway-33 coupled with industrial sector. The site selection was based on importance of emission sources, sensitivity of receptors, predominant local activities and wind directions in the area. The stations were so chosen that there can be adequate safety measures as well as reduced interference of the local public with the devices used for the experiment.

Application of Air Quality Index (AQI) for Data Interpretation

Formulation of Air Quality Index

While designing an air quality index the following points were taken into consideration: (i) number of pollutants (ii) calculation mode (mathematical functional relationship between pollutant concentration and corresponding index) and (iii) description categories (clean air, light air pollution, severe air pollution, etc.)

To reflect the status of air quality and its effects on human health, ranges of the AQI values were categorized as clean air, light air pollution, moderate air pollution, heavy air pollution, severe air pollution. Although, the AQI was particularly developed for industrial area, the adaptation of a sound air pollution index has to be used for interpretation of air pollution quality of any city or area, so that the chances of uncertainty regarding air quality may be reduced. For this purpose the Oak Ridge National Air Quality Index (ORNAQI) which is a nonlinear index having exponential function with coefficient with other nonlinear relationship was selected for estimation of AQI. In this method, coefficient may be constant or may vary but the relationship contains at least one variable raised to a power and this index may be taken in several forms for assessment of air quality. The Oak Ridge National Air Quality Index also has advantage for the relative ranking of overall air quality status at different locations of the study area with different air pollutants parameter.

AQI for each year in the study area was estimated with the help of a mathematical equation developed by the Oak Ridge National Laboratory (ORNL), USA (Panwar, 2014) as given below:

$$AQI = [5.7 \sum C_i / C_s]^{1.37}$$

where,

C_i = value of air quality parameters PM_{10}, $PM_{2.5}$, NO_2, SO_2 and NH_3
C_s = standard or prescribed limit for air quality parameters
5.7 and 1.37 are constant

The rating scale is defined from 0 to 100 and it has further divided into 5 sub grades of air quality categories. This rating value is described in table 1.

Table 1: Oak Ridge National Air Quality Index (Ravikumar *et al.* 2014)

Index value	Descriptive category
(0 ≥ AQI ≤ 25)	clean air
(26 ≥ AQI ≤ 50)	light air pollution
(51 ≥ AQI ≤ 75)	moderate air pollution
(76 ≥ AQI≤ 100)	heavy air pollution
(AQI > 100).	severe air pollution

Table 2: Indian national ambient air quality standards (NAAQS) (CPCB, 2009)

Pollutants	Time weighted average	Concentration in ambient air	
		Industrial, residential, rural and other area	Ecologically sensitive area
Sulphur dioxide SO_2 (μg/m³)	Annual average*	50	20
	24 hours**	80	80
Nitrogen dioxide NO_2 (μg/m³)	Annual average*	40	30
	24 hours**	80	80
Particulate Matter PM_{10} (μg/m³)	Annual average*	60	60
	24 hours**	100	100
Particulate Matter $PM_{2.5}$ (μg/m³)	Annual average*	40	40
	24 hours**	60	60
AmmoniaNH₃ (μg/m³)	Annual average*	100	100
	24 hours**	400	400

*Note: * annual average values are the annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval and ** 24 hourly/ 8 hourly or 1 hourly monitored values should be met 98% of the time in a year. 2% of the time, it may exceed but not on two consecutive days.*

In the present study, an annual monitored air quality value was compared with recent Indian national ambient air quality standards (Table 2) for PM_{10}, $PM_{2.5}$, NO_2, SO_2 and NH_3.

RESULTS

The AQI is a referential parameter which describes air pollution levels and provides relevant information about real time ambient air quality. For the interpretation of air quality monitored in three different years in and around IFFCO fertilizer plant, Aonla was further evaluated by ORNAQI model, which is widely used all over the world to determine air quality status of an area. This ORNAQI model measures the level of pollution in the area mainly caused by industries and other sources, for parameter such as PM, NH_3, SO_2 and NO_2 and their calculated concentrations, which are subsequently converted into air quality index by using standard formulae and compared with the rating scale. The lower value of an index refer to the lower and safe concentration of air pollution level and higher value of the index gives an idea about higher air pollution status.

The calculated air quality index of present study vary from 63.877 to 106.379 for the monitoring year 2014 (Fig. 1), 79.549 to 108.109 for monitoring year 2015 (Fig. 2) and 82.089 to 109.054 for monitoring year 2016 (Fig. 3), on monthly basis respectively. The monitoring years represent the whole study period from January 2014 to December 2016 in and outside the industrial area which include the monitoring locations inside the fertilizer plant and its associated township.

The rating scale-wise air quality status on monthly basis is given in table 3. The moderate air quality index value has been calculated with rating scale between 51 ≥ AQI ≤ 75 in the months of July, August and September in the monitoring year 2014. The heavy air quality index value has been premeditated with evaluation scale between 76 ≥ AQI ≤ 100 in the months of February, March, April, May, June, October, November in the observing year 2014; February, March, April, May, June, July, August, September, October and November in the monitoring year 2015 and Febuary, March, April, May, June, July, August, September, October and November in the examining year 2016 respectively. The index value between AQI > 100 for severe air quality has been deliberated in the months of January and December for the exploratory period of 2014, 2015 and 2016 respectively.

The acquired results of monitoring period of three years thus reveals that ORNAQI value observed during months of January and December for the investigative period of 2014, 2015 and 2016 respectively, were above 100 rating scale indicating dangerous/severe air pollution during that period in the area and ambient air quality standards were not attained. Whereas, ORNAQI value observed during

Table 3: Month-wise ORNAQI rating for air quality status of study period (2014-2016)

Rating scale	Description	Air Quality Study Years		
		2014	2015	2016
(0 ≥ AQI ≤ 25)	clean air	—	—	—
(26 ≥ AQI ≤ 50)	light air pollution	—	—	—
(51 ≥ AQI ≤ 75)	moderate air pollution	July, 14; August, 14; Setember, 14	—	—
(76 ≥ AQI≤ 100)	heavy air pollution	February, 14; March,14; April, 14; May, 14; June, 14; October, 14; November, 14	February, 15; March, 15; April, 15; May, 15; June, 15; July, 15; August, 15; September, 15 October, 15; November, 15	February, 16; March, 16; April, 16; May, 16; June, 16; July, 16; August, 16; September, 16 October, 16; November, 16
(AQI > 100)	severe air pollution	January, 14; December, 14	January, 15; December, 15	January, 16; December, 16

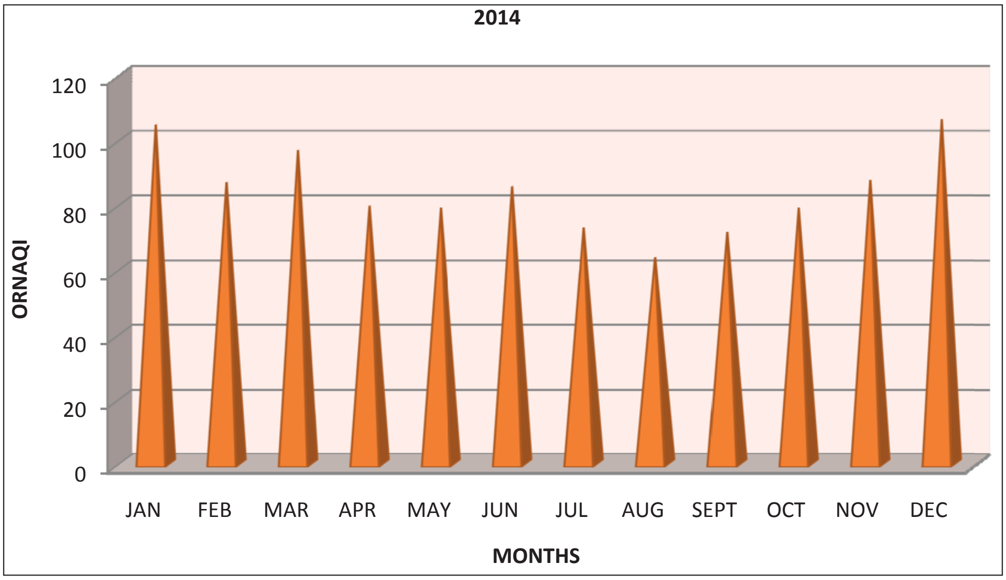

Fig. 1: Calculated Air Quality Index for the Monitoring Year 2014

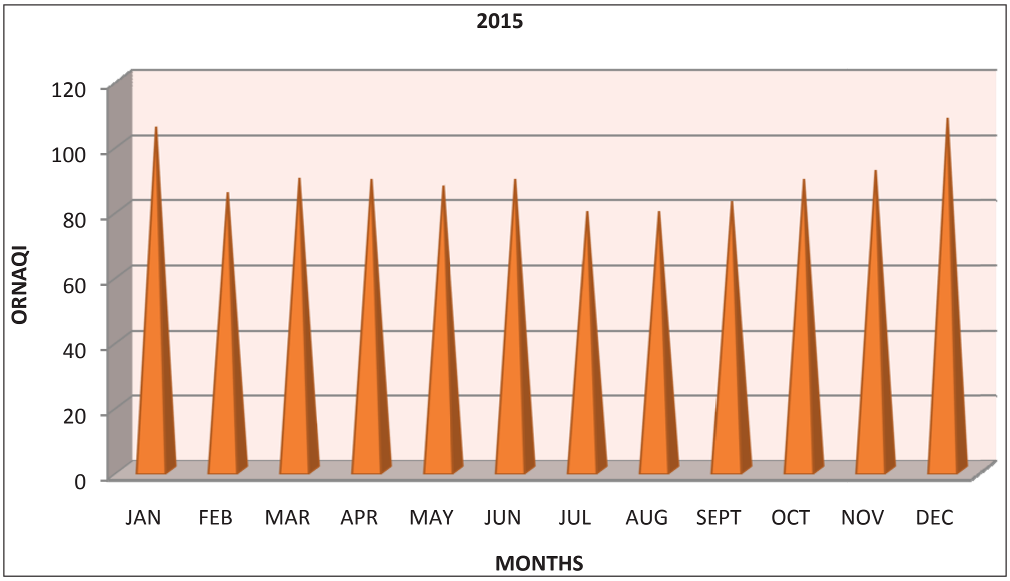

Fig. 2: Calculated Air Quality Index for the Monitoring Year 2015

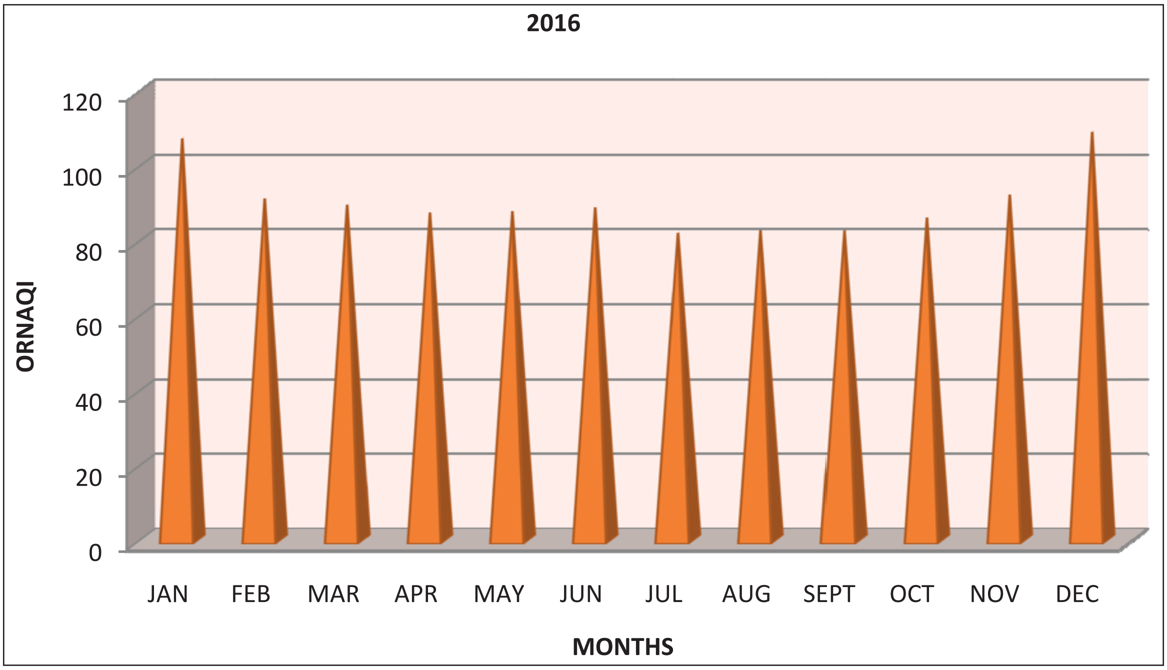

Fig. 3: Calculated Air Quality Index for the Monitoring Year 2016

months of Febuary, 14; March, 14; April, 14; May, 14; June, 14; October, 14; November, 14 and February to November of year 2015 and 2016, between the 76-100 rating scale also signify heavy air pollution in that locality which is also a matter of apprehension.

Moreover, maximum ORNAQI rating scale value has been observed highest in month of December for the monitoring year 2016 as compared to other monitoring years 2014 and 2015 (Fig. 4).

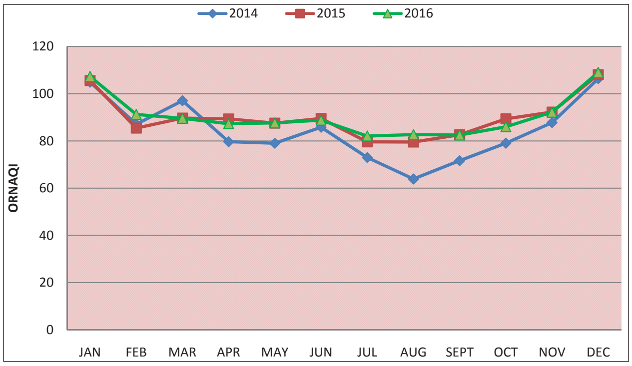

Fig. 4: Monthly variation of ORNAQI rating scale during the study period (2014-2016)

The significant higher values have also been obtained for the months of January and December in the monitoring year of 2014 and 2015. The elevated values may be due to more emissions from the fertilizer plant, more vehicular movement and/or changes in the meteorological conditions during the concerning months like prevalent calm conditions and low mixing heights (Panwar, 2014).

CONCLUSION

For the interpretation of ambient air quality monitored in three different years (2014-2016) in and around IFFCO fertilizer plant, Aonla was evaluated by ORNAQI model during the study period. The calculated air quality index reveals that ORNAQI values observed during months of January and December for the investigative period of 2014, 2015 and 2016 respectively, were above 100 rating scale indicating dangerous/severe air pollution during that period in the area and ambient air quality standards were not attained, whereas, ORNAQI value observed during months of February - June,14; October,14; November,14 and February to November of year 2015 and 2016, between the 76-100 rating scale also signify heavy air pollution in that locality which is also a matter of concern.

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