A Comparative Study of Air Quality Index Based on Factor Analysis and US-EPA Methods for an Urban Environment

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Abstract

There are many different air quality indexes, which represent the global urban air pollution situation. Although the index proposed by USEPA gives an overall assessment of air quality, it does not include the combined effects (or synergistic effects) of the major air pollutants (Shenfeld, 1970; Ott and Thom, 1976; Thom and Ott, 1976; Murena, 2004). So an attempt is made to calculate the Air Quality Index based on Factor Analysis (NAQI) which incorporates the deficiencies of USEPA method. The daily, monthly and seasonal air quality indexes were calculated by using both these methods. It is observed that a significant difference exists between NAQI and EPAQI. However, NAQI followed the trends of EPAQI when plotted against time. Further, the indexes were used to rank various seasons in terms of air pollution. The higher index value indicates more pollution in relative terms. Moreover, the index may be used for comparing the daily and seasonal pollution levels in different sites.

Keywords: Eclipsing effect; Maximum operator concept (MOC); Principal component analysis (PCA); Variance, Ranking.

INTRODUCTION

Air pollution is a well-known environmental problem associated with urban areas around the world. Various monitoring programmes have been undertaken to know the quality of air by generating vast amount of

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data on concentration of each air pollutant (e.g., SPM, CO, NOx, SO_2, etc.) in different parts of the world. The large data often do not convey the air quality status to the scientific community, government officials, policy makers, and in particular to the general public in a simple and straightforward manner. This problem is addressed by determining the Air Quality Index (AQI) of a given area. AQI, which is also known as Air Pollution Index (API) (Shenfeld, 1970; Ott and Thom, 1976;

Thom and Ott, 1976; Murena, 2004) or Pollutant Standards Index (PSI) (Ott and Hunt, 1976; EPA, 1994), has been developed and disseminated by many agencies in U.S. Canada, Europe, Australia, China, Indonesia, Taiwan, etc (Cairncross *et al.*, 2007; Cheng *et al.*, 2007).

An "Air Quality Index" may be defined as a single number for reporting the air quality with respect to its effects on the human health (Thom and Ott, 1976; Bortnick *et al.*, 2002; Murena, 2004). In most elaborate form, it combines many pollutants concentrations in some mathematical expression to arrive at a single number for air quality.

AQI is an integral part of the Environmental Quality Index (EQI), which was developed and used by National Wildlife Federation of U.S. in late 1960s (Inhaber, 1976). In 1971 the EQI, with a numerical index scale from 0 to 100 (0 for complete environmental degradation and 100 for perfect environmental conditions), had seven components: soil, water, air, living space, minerals, timber and wildlife. Inhaber (1975) had suggested a set of air quality indexes for Canada. These indexes were Index of specific pollutants (e.g., SO_2, SPM, CO, total oxidants, NOx, and coefficient of haze); Index of Inter-Urban air quality (considering the visibility readings at airports) and index of industrial emissions (by taking the total emission and population of the area). In 1976 the USEPA established PSI which rated air quality from 0-500 with 100 equal to National Ambient Air Quality Standards (NAAQS). The daily PSI is determined by the highest value of one of the five main air

pollutants: PM_{10}, O_3, SO_2, CO and NO_2 (EPA, 1997; EPA, 1999). Lohani (1984) applied factor analysis approach to find environmental index for Taiwan. Here, he compared the air quality index based on factor analysis method and Pindex method. The ratings (or trends) obtained by both these methods are exactly same, but the AQI based on factor analysis shows a wider range which indicates that it is a better approach. Bezuglaya *et al.* (1993) developed an integral air pollution index (IAPI), which is the sum of individual air pollution indexes calculated by normalising the pollution concentrations to maximum permissible concentration (MPC). Since the main objective of AQI is to measure the air quality in relation to its impact on human health, the Environmental Protection Agency (EPA) of U.S. revised the previous method to calculate daily AQI in 1999. The EPA method is 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). The concentration values are converted into numerical indexes. The overall AQI is calculated by considering the maximum AQI among the monitored pollutants corresponding to a site or station. The scale of the index (0-500) is subdivided into six categories that are associated with various health messages.

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. Further the application of RAQI in Taiwan has

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 (Cheng *et al.*, 2007). Other prominent studies related to various aspects of air quality indexes are those of Kassomenos *et al.* (1999), Malakos and Wong (1999), Swamee and Tyagi (1999), Trozzi *et al.* (1999), Khanna (2000), Cogliani (2001), Bortnick *et al.* (2002), Murena (2004), Jiang *et al.* (2004), Longhurst (2005), Landulfo *et al.* (2007), Mayer and Kalberlah (2008), and Elshout *et al.* (2008).

In Indian context, the studies on AQIs have been carried out for the city of Mumbai (Sharma, 1999), Delhi (Sengupta *et al.*, 2000) and Kanpur (Sharma *et al.*, 2003). The mathematical functions for calculating these indexes are based on health criteria of the EPA and Indian air quality standards. In the same study, Sengupta *et al.* (2000) examined the Oak Ridge Air Quality Index (ORAQI) based on additive function of sub-indexes for Delhi. But it was found that this index suffered from eclipsing effect, i.e., when one pollutant exceeds its standard without the index exceeding its critical value (Thom and Ott, 1976). Further, it was observed that on 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 was violated. The maximum operator concept (MOC), which is generally used by EPA of U.S. to calculate EPAQI, is suggested to overcome this problem. The MOC only considers the maximum value of

any of the sub-indexes to define the overall AQI. This method has the following limitations. First, it discards the values of the other sub-indexes and the harmful levels associated with other pollutants (Radojevic and Hassan, 1999). Second, the index does not include the additive or synergistic effects of pollutants together on the human health. In addition to the above limitations, the other drawbacks pertaining to the EPA method are, first, the break points for calculating the index value for NO_2 concentrations less than 0.65 ppm is not defined. This deficiency is also associated with tropospheric ozone concentrations. Second, the sub-index describes the pollution level of the pollutant on an ordinal scale. This same scale is used for finding the aggregate index. So the severity of the pollution level described by the aggregate index is not linear. Third, a greater part of the world is not able to adopt AQI system mainly because the lack of $PM_{2.5}$ measurement capability (Cheng *et al.*, 2007). To address the above shortcomings, we propose an AQI based on simple statistical approach.

Therefore, an attempt has been made to calculate a New Air Quality Index (NAQI) which is based on the factor analysis technique assisted by principal component analysis (PCA). The details of materials and methods, results and discussion, and conclusions are given in the subsequent sections.

MATERIALS AND METHODS

Sampling of Air Pollutants

The sampling site in the present study was

at Jawaharlal Nehru University (JNU) Campus, an area situated in south of Delhi (Fig. 1). This site is sandwiched between the natural vegetation of JNU and a major road carrying vehicular traffic. The daily traffic density is moderate to high with peak periods found during morning and evening hours. Delhi, the capital city of India, with a population of 13.8 million in 2001 (Goyal and Sidhartha, 2003; India, 2006) and having approximately 3.5 million vehicles, is widely known to be one of the most polluted cities of the world. The climate of Delhi can be divided into four seasons as per the classification given by Indian Meteorological Department (NAAQMS, 2001). The four seasons are winter months (December- March), pre-monsoon or summer months (April-June),

Monsoon months (July-September) and Post-Monsoon months (October-November). The criteria pollutants namely NO_2, O_3, PM_{10}, CO and SO_2 have been considered for determining the two indexes for Delhi, namely, NAQI and the air quality index based on EPA method hereinafter called EPAQI.

The data of the above pollutants were recorded continuously at an interval of one-hour for a period of 24-hours on one random day in each month during the period September 2003 – June 2004 using electronic air pollution analysers fitted in the mobile air pollution laboratory. The analysers are NOx Analyser (ML 9841B, Monitor Labs, USA), Ozone Analyser (ML9810B, Monitor Labs, USA), Ambient particulate monitor for PM_{10} (TEOM series-1400a, Rupprecht and
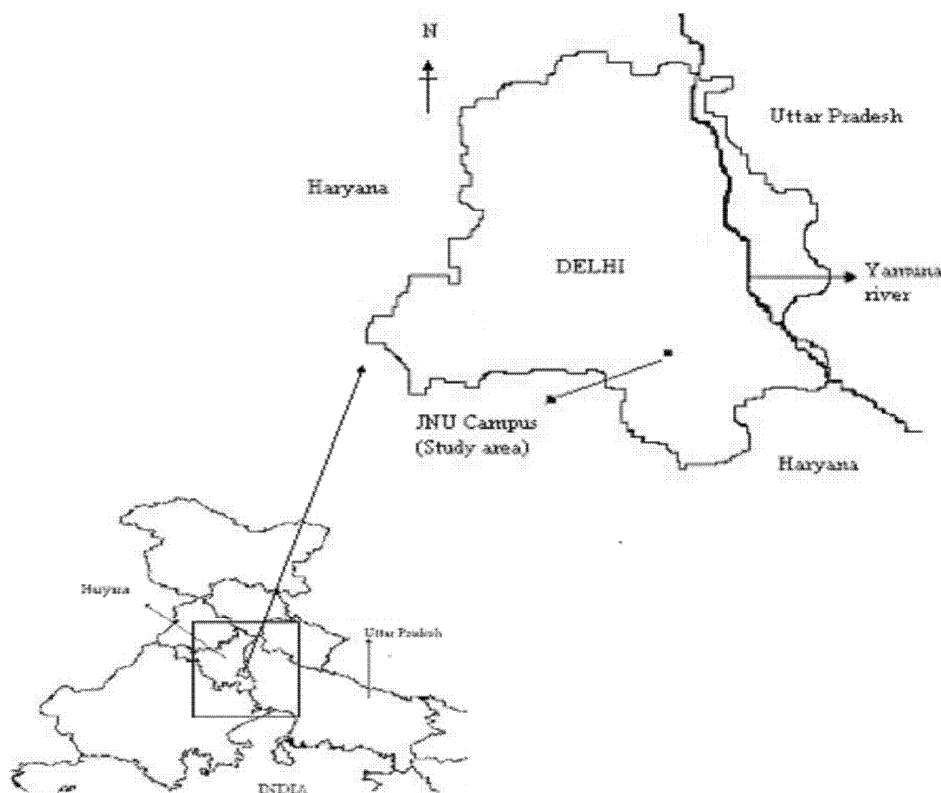
Fig. 1. Map of the study area.

Patashnick Co. Inc., USA), Carbon Monoxide-Analyser (ML-9830, Monitor Europe, Europe) and Sulphur Dioxide Analyser (ML-9850, Monitor Europe, Europe).

AQI by Using EPA Method (EPAQI)

The AQI measures daily pollution index of the pollutants for which EPA has established National Ambient Air Quality Standards (NAAQS). The index combines the NAAQS with an epidemiological function to determine a descriptor of human health effects due to short-term exposure (24 hour or less) to each pollutant (EPA, 1994, 1997). The index for a pollutant is calculated using the mathematical expression (EPA, 1999):

$$I_P = \frac{I_{Hi} - I_{LO}}{BP_{Hi} - BP_{LO}}(C_P - BP_{LO}) + I_{LO} \quad (1)$$

Where, I_P = the index value for pollutant, P; C_P = the truncated concentration of pollutant, P; BP_{Hi} = the breakpoint that is $\geq C_P$; BP_{LO} = the breakpoint that is $\leq C_P$; I_{Hi} = the AQI value corresponding to BP_{Hi}, I_{LO} = the AQI value corresponding to BP_{LO}.

The indexes for each of the pollutants NO_2, O_3, PM_{10}, CO and SO_2 were obtained from Eq. (1) using their respective break points and associated AQI values (EPA, 1999). Having calculated Ip of each pollutant, the EPAQI is evaluated by considering the maximum index value (Ip) of the single pollutant. Mathematically, it is expressed as EPAQI = Max (Ip).

An Improved New AQI by Factor Analysis (NAQI)

In Factor analysis, we have used the technique of Principal Component Analysis (PCA). The basic purpose of PCA is to account for the total variation among the 'n' number of subjects (variables) in p-dimensional space by forming a new set of orthogonal and uncorrelated composite variates. Each member of the new set of variates is a linear combination of the original set of measurements (Henry and Hidy, 1979; Lioy *et al.*, 1989). The linear combinations are generated in such a manner that each of the successive composite variates will account for a smaller portion of the total variation. The first composite (principal component) will have the largest variance, the second will have a variance smaller than the first but larger than the third, and so on. If first few principal components (or, eigenvector-eigenvalue pairs) account for more than 60% of the total variance, then there is hardly any requirement in taking more principal components (PCs) (Harman, 1968; Johnston, 1978; Dunteman, 1994) to compute the composite (overall) Air Quality Index. The higher order PCs explain only minimal amounts of total variance and are, therefore, treated as noise (Johnston, 1978; Dunteman, 1994; Kim and Mueller, 1994; Srivastava *et al.*, 2008).

The method of principal components (PCs) can be applied by using the original values of variables (X_j's) (where j = 1, 2, 3, ..., n) or their deviation from their means ($x_j = X_j - \bar{X}_j$), or the standardized variables; $Z_j = \frac{x_j}{S_j}$

where S_j is the standard deviation (Harman, 1968; Johnston, 1978; Kim and Mueller, 1994; Koutsoyiannis, 2001).

In our analysis, we have used raw data X_j's ($j = 1, 2, 3, …., n$). In the principal component model, X_j is expressed as a linear combination of the principal component as

$$X_j = \sum_{i=1}^{n} a_{ji} P_i \qquad (2)$$

Where, $j = 1, 2, …, n$; P_i is the ith principal component; a_{ji} is the factor loading of the jth variable on the ith principal component. Basically the factor loading is the jth component of the ith eigen-vector of the correlation matrix multiplied by the square root of the corresponding eigen-value. The principal components (Lohani, 1984) are given by,

$$P_i = \sum_{j=1}^{n} \frac{a_{ji} X_j}{\lambda_i} \qquad (3)$$

Where λ_i is the eigen-value associated with P_i. After obtaining the principal components (PCs), the New Air Quality Index (NAQI) is computed using the expression given below:

$$NAQI = \frac{\sum\limits_{i=1}^{n} (P_i E_i)}{\sum\limits_{i=1}^{n} E_i} \qquad (4)$$

Where, $n = 3$; P_is, i.e., P_1, P_2, P_3 are the three principal components for which the cumulative variance is more than 60%; E_is, i.e., $E1$, E_2, E_3 are the initial eigen-values (≥ 1) with respect to the 'percentage of variance'.

RESULTS AND DISCUSSION

Using the data of one-hour average concentration of each pollutant, NAQI and EPAQI have been determined. While computing the NAQI by PCA method, we have retained components with eigenvalue $\geq$ 1.0 and accounting for more than 60 % of variance. The components with eigenvalue < 1.0 explain less variance and hence discarded (Johnston, 1978; Kim and Mueller, 1994). The results of PCA were obtained by using SPSS 10.0 software and the NAQI was calculated by using Eq. (4).

Seasonal Variation of NAQI and EPAQI

The variations of NAQI and EPAQI with respect to (w.r.t.) time (hours of the day) are depicted in the Figs. 2-11. A perusal of these graphs reveals that NAQI follows almost a similar trend as EPAQI for all the months. For characterising the air quality based on EPAQI during the days of various seasons, frequency of its occurrence in a given index interval is determined. The percentage durations of different categories of air quality are presented in Table 1.

Seasonal Variation of EPAQI

It is clearly seen from Table 1 and Figs. 2-11 that for major part of the day, the air quality remains 'unhealthy' if not worse in all the seasons with the exception of monsoon
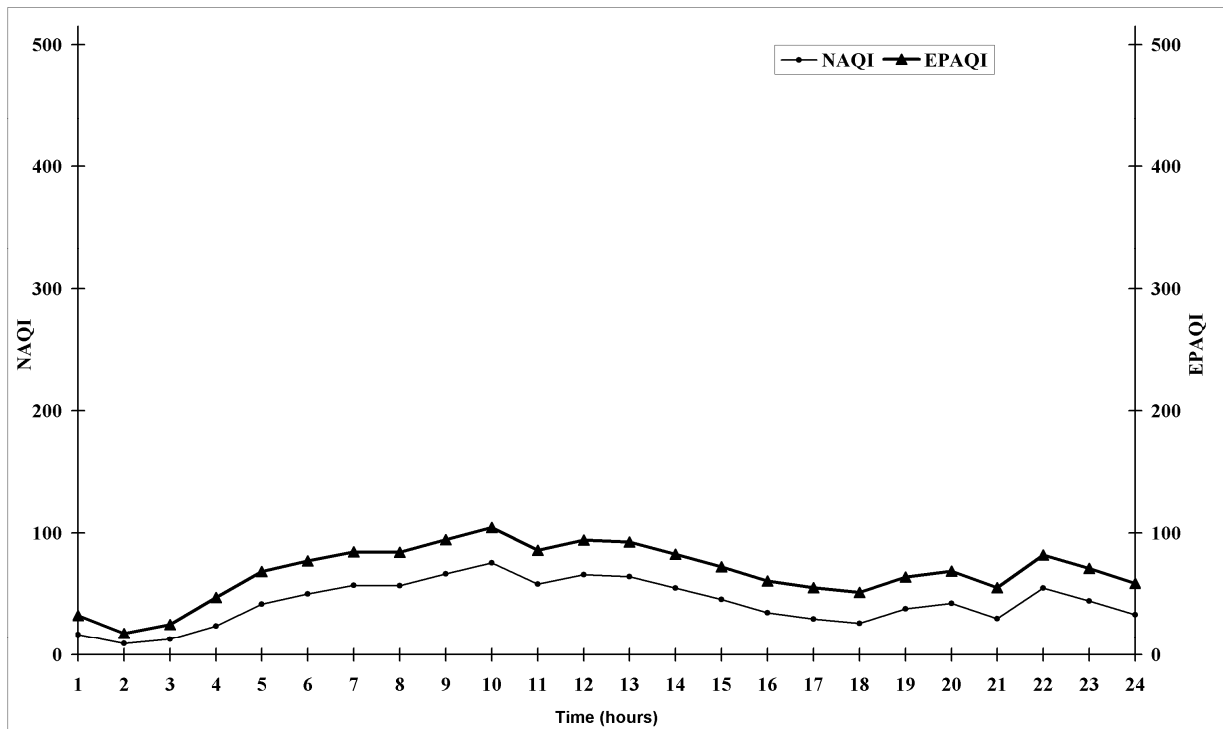
Fig. 2. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 24. 09. 03.
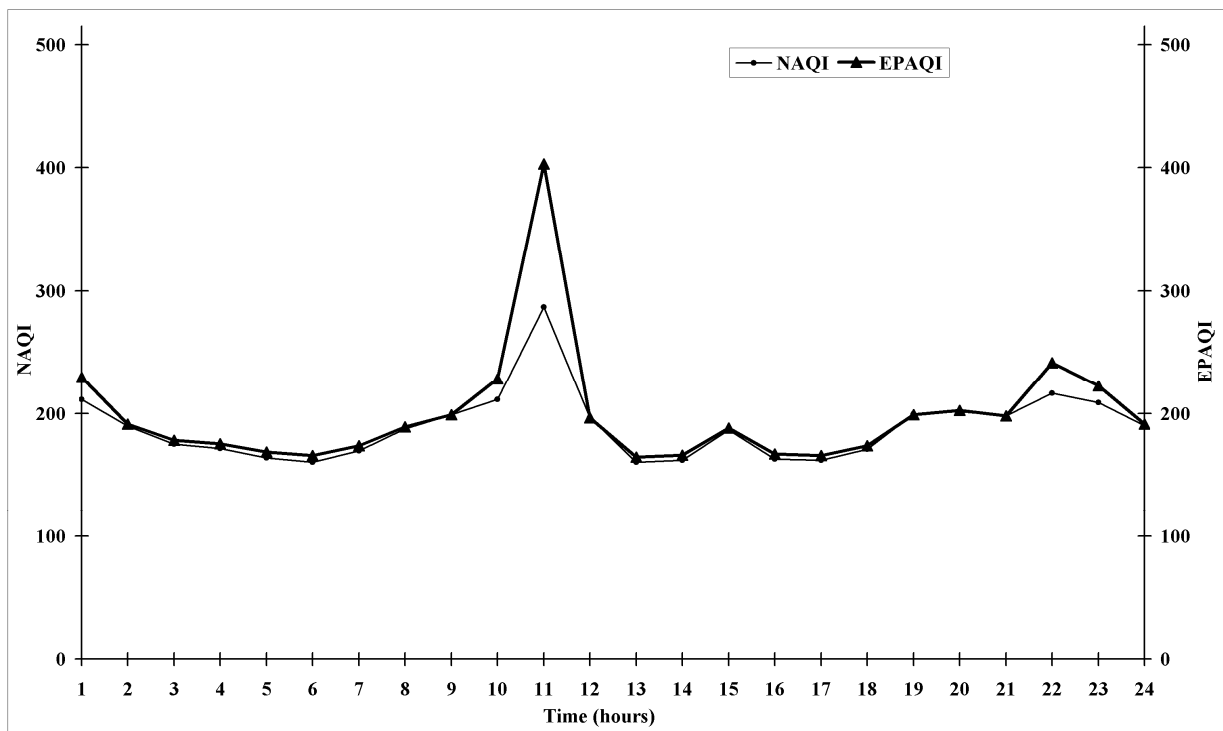

Fig. 3. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 21. 10. 03.
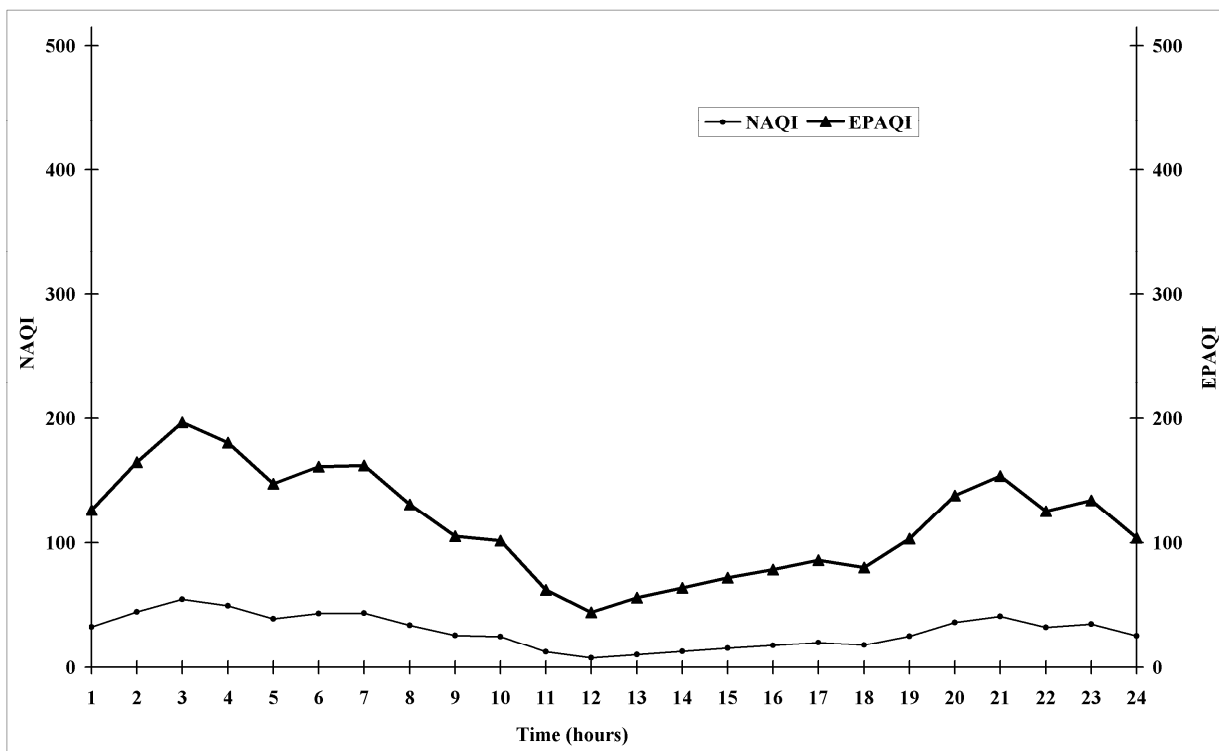
Fig. 4. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 24. 11. 03.
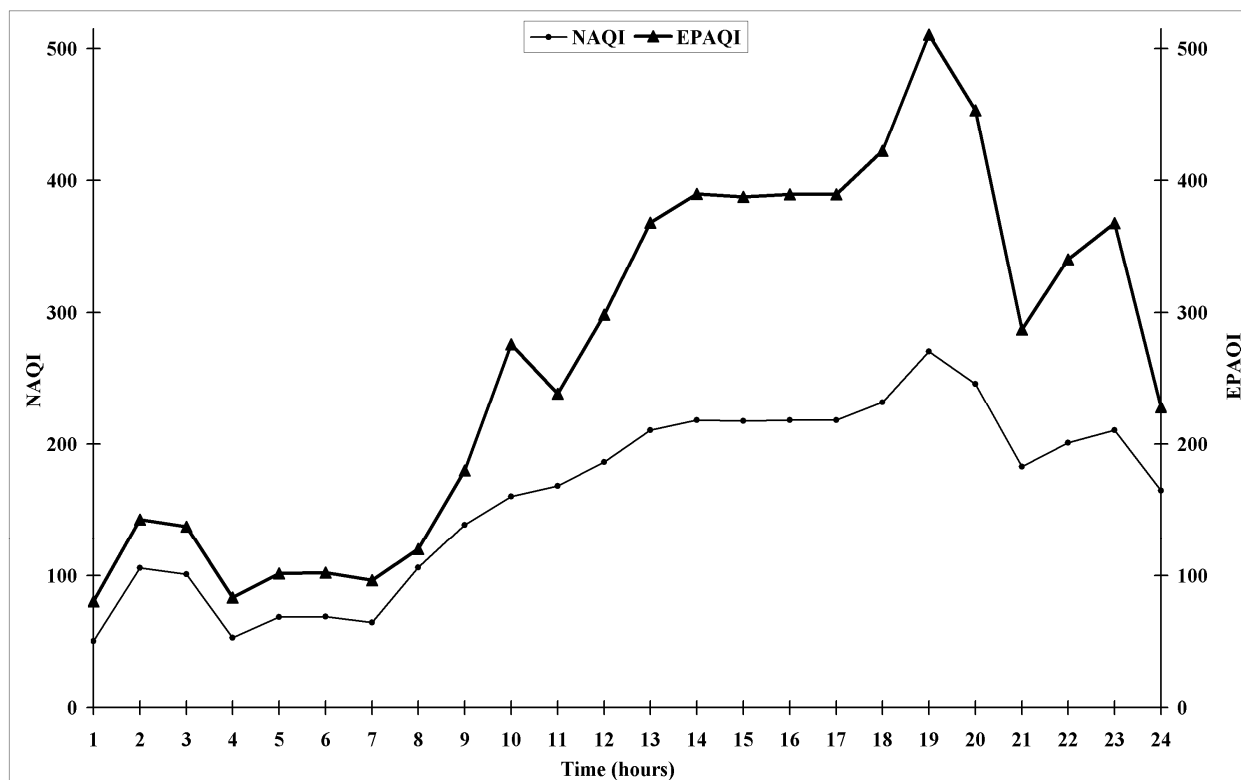

Fig. 5. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 28.12.03.
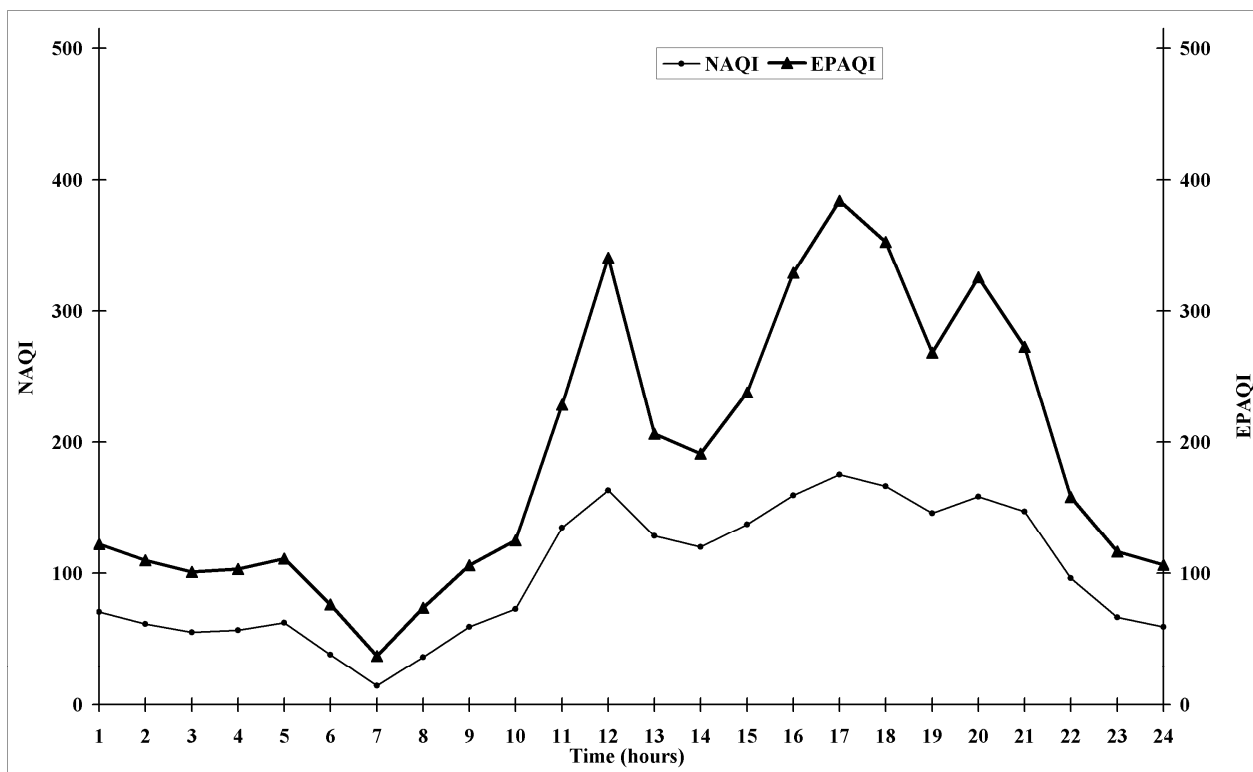
Fig. 6. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 12. 01. 04.
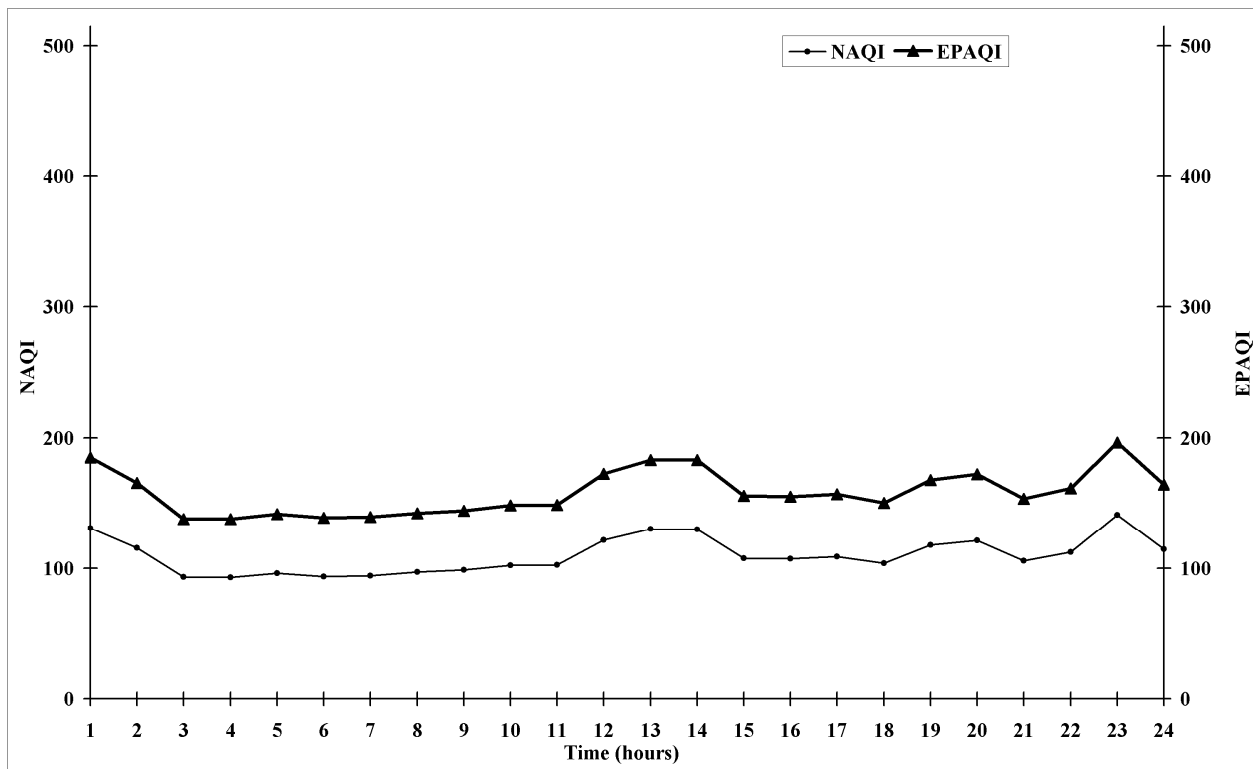

Fig. 7. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 20. 02. 04.

Fig. 8. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 03. 03. 04.

Fig. 9. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 22. 04. 04.
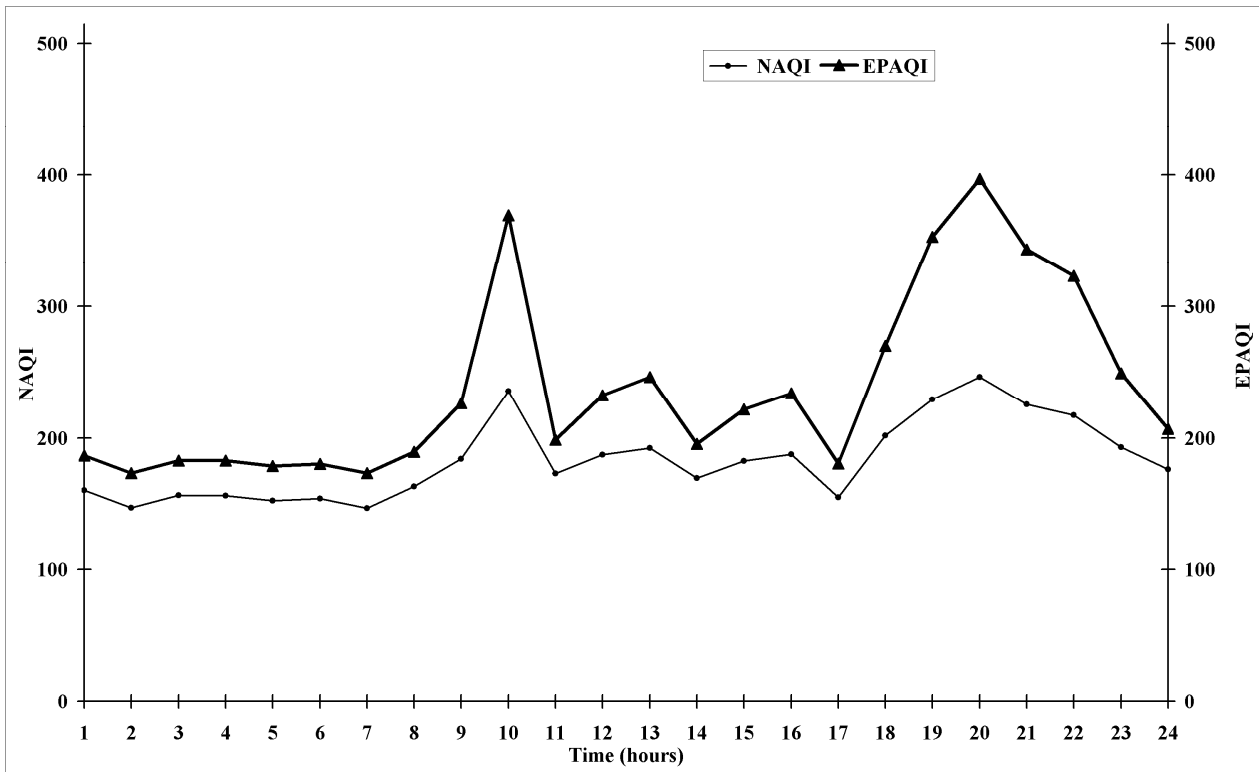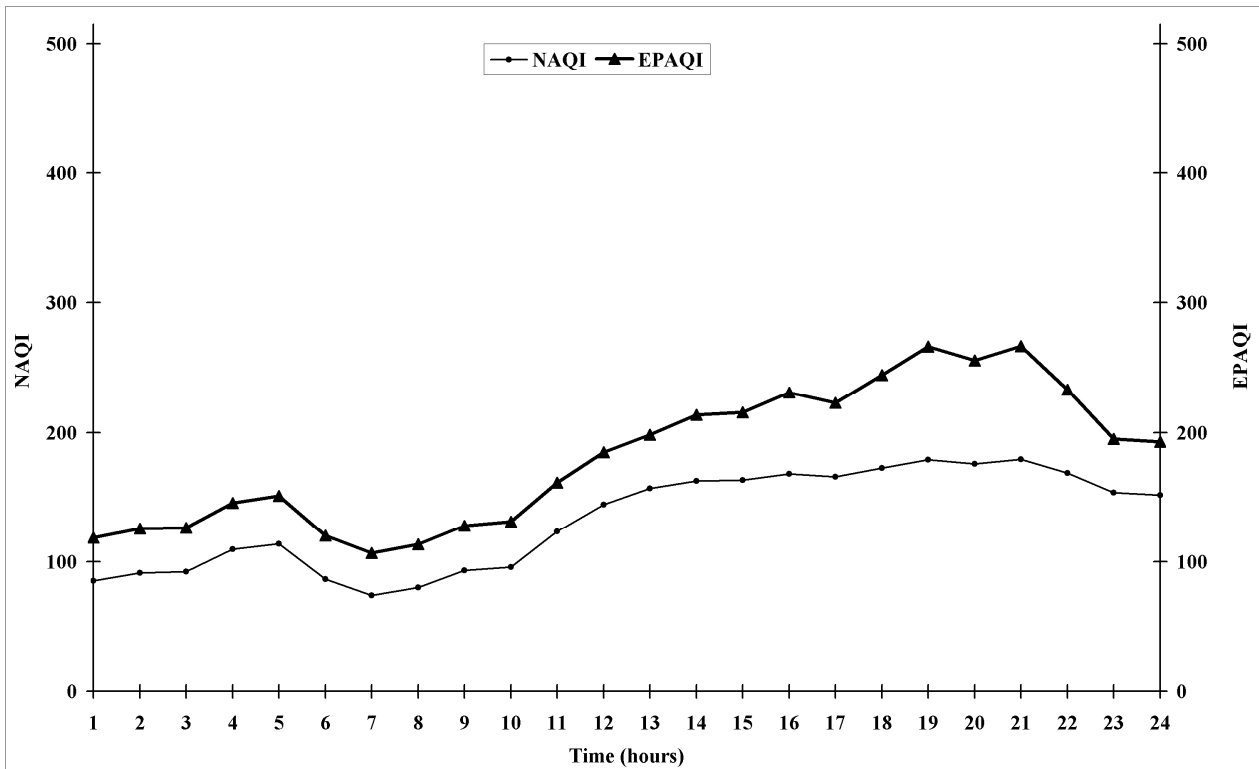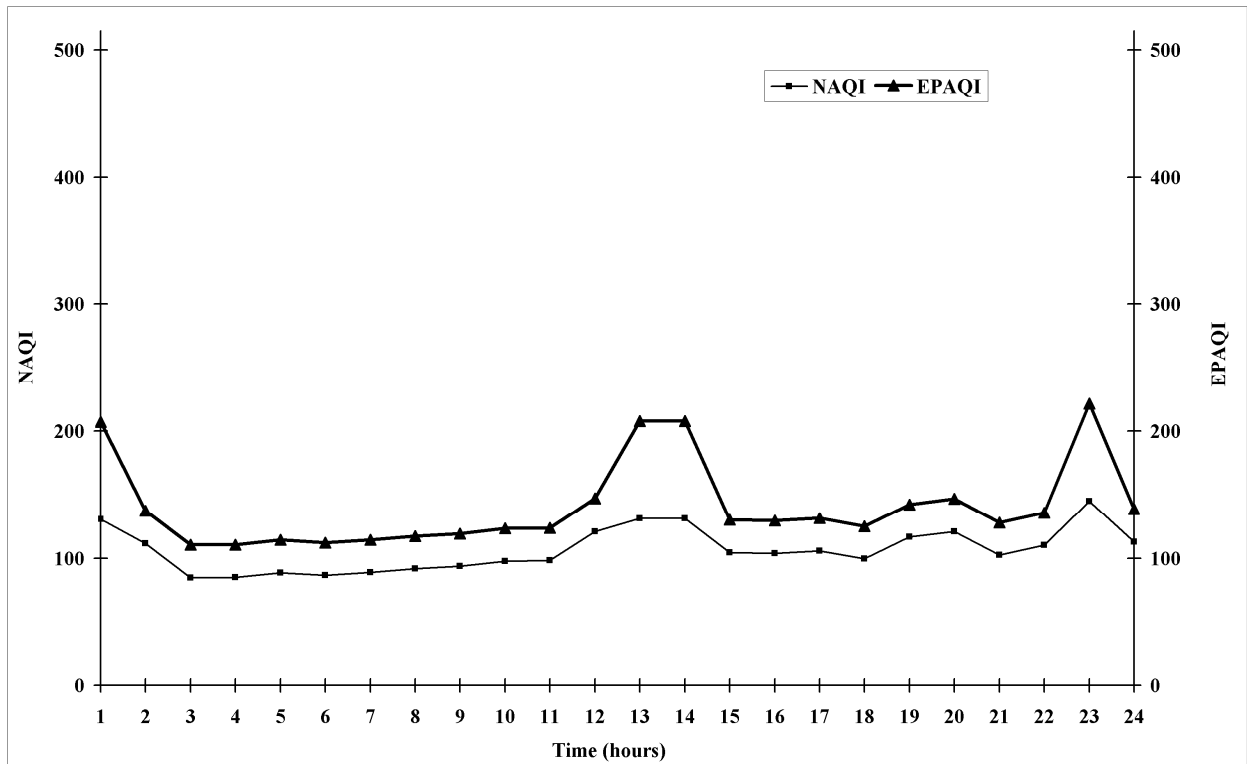
Fig. 10. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 12. 05. 04.
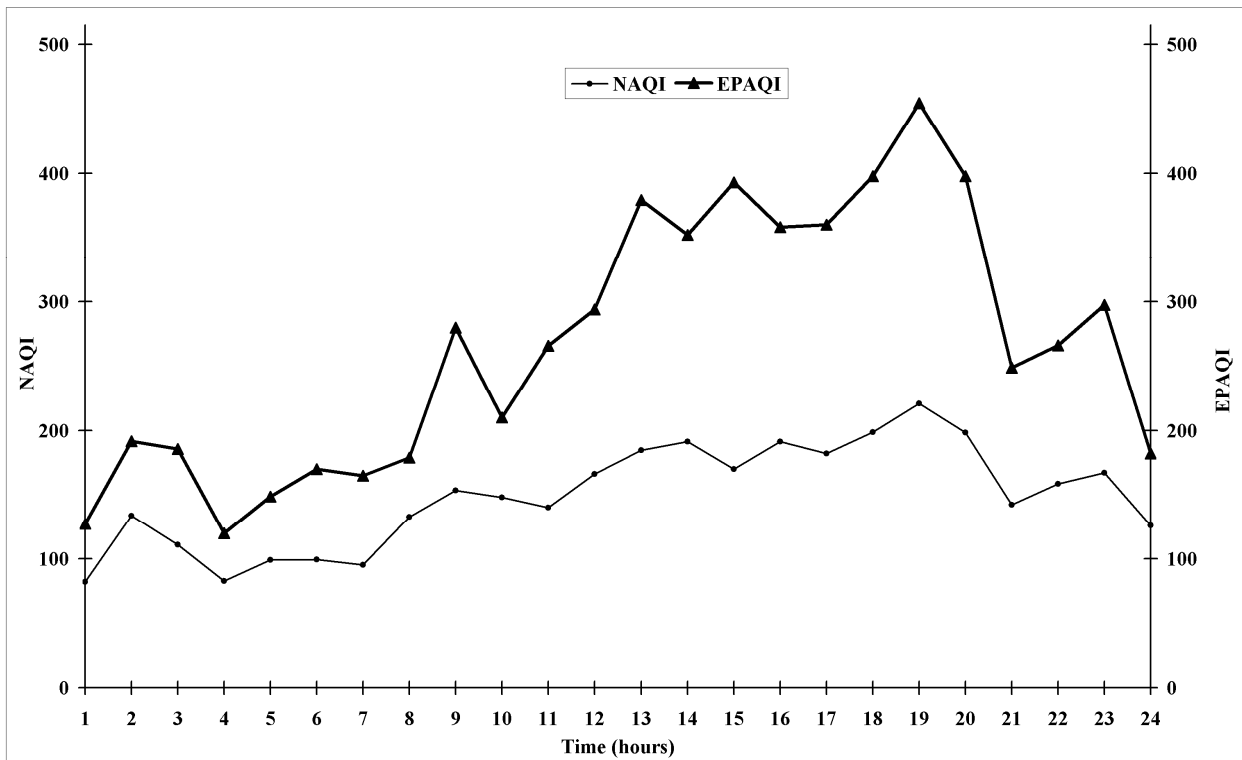

Fig. 11. Variation of NAQI and EPAQI w. r. t. Time (hours of the day) on 21. 06. 04.

Table 1. Frequency of occurrence of Air Quality categories during the day in different seasons

Air Quality Categories	EPAQI values	Frequency of occurrences during the day (in %)			
		Monsoon	Post monsoon	Winter	Summer
Good to moderate	0-100	68.75	17.62	9.8	2.08
Unhealthy	101-200	31.25	78.12	59.8	78.47
Very Unhealthy	201-400	00	5.20	27.0	18.75
Hazardous	> 400	00	1.04	3.1	0.69

season. The frequency of occurrence of the category 'very unhealthy' is also quite significant in the winter (27%) and summer (~19%) seasons. It is quite revealing that in summer season the air quality category 'good to moderate' does not exist for any significant length of time (~2%) during the day. Not too unexpectedly the monsoon season is associated with 'good to moderate' air quality for major part of the day (~69%).

Seasonal Variation of NAQI

Winter Season

The highest index values observed in winter season (Figs. 5-8) can be attributed first to the meteorological conditions prevailing in the north India and second to the low rate of removal of gaseous pollutants. This region is dominated by high pressure usually centred over western China causing increased atmospheric stability. This condition allows less general circulation and more stagnant air masses (Padmanabha Murthy, 1984; Aneja *et al.*, 2001). Further, the rate of chemical removal of gaseous pollutants (e.g. NO_2, CO, etc.) in the form of inorganic compounds such as HNO_3, H_2CO_3, etc is quite less due to the low concentration of OH-radicals as the formation of OH-radicals depends on intensity of light which is generally moderate to weak

in winter season (Varshney and Singh, 2002; Kumar *et al.*, 2008).

Summer Season and Monsoon Season

The high index values during the summer months (Figs. 9-11) can be attributed to the frequent severe dust storms covering the atmosphere of Delhi in spite the fact that during the summer season mixing height is at its maximum (PROBES, 2003). During monsoon month of September, the NAQI is comparatively very low (Fig. 2) due to precipitation, high wind velocities and changes in the general wind direction. The precipitation helps in wet deposition of pollutants. The changes in wind velocity and reversal of its direction carry the pollutants away from sources as well as increase the possibilities of dilution of concentration of pollutants also.

Post-monsoon season

In the post-monsoon months (Figs. 3-4) although the air quality is expressed to be relatively better compared to winter and summer months there is an exception in the month of October (Table 2) which has a rather high value of NAQI (= 29.72). This is mainly on account of lighting of massive fireworks during the two Hindu festivals namely

Table 2. Comparison of average index values of EPAQI and NAQI over a month in different seasons for Delhi

Index		Monsoon	Post-Monsoon		Winter				Summer			Standard (CPCB)
		Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
NAQI	Value	12.97	29.72	17.39	36.12	27.89	22.29	30.11	27.79	23.97	29.3	10.37
	Ranking	2	9	3	11	7	4	10	6	5	8	1
EPAQI	Value	88.0	173.0	112.0	216.0	165.32	136.0	176.0	165.3	144.0	171.0	73.0
	Ranking	2	9	3	11	7	4	10	6	5	8	1

Dussehara and Deepawali (Attri *et al.*,2001; Kulshrestha *et al.,* 2004) which happen to be in month of October.

Trends between NAQI and EPAQI

A careful examination of the trends of the EPAQI and NAQI reveals that the variation in NAQI closely follows that of EPAQI. Whereas, the magnitude of the values of the EPAQI is solely determined by the maximum value of a sub index of a given pollutant, the value of NAQI takes into account the variances of concentrations in different pollutants. In case, where a particular pollutant is dominant (i.e., the concentration of the pollutant far exceeds the permissible standards) and it also has large variances in its concentration values, both the indexes are expected to have higher magnitudes. Since in the present study the dominant pollutant is PM_{10}, which is associated with large variances in its concentration value, the trends of EPAQI and NAQI are not surprisingly similar.

Rankings of Various Months w.r.t. Standard NAQI

The average values of NAQI and EPAQI over a month have also been computed from

the hourly index values of these two indexes. These results (i.e. the average index values) for different seasons are summarised in Table 2. The values of two indexes for prescribed standards of pollutants as per Central Pollution Control Board (CPCB) norms are also mentioned in the last column of the Table 2. Now the various months have been ranked in terms of NAQI with respect to the rank of standard NAQI (taken as 1). An examination of NAQI values indicates that the air quality is worst in winter months of December (rank 11 and NAQI= 36.12) and March (rank 10 with NAQI = 30.11) followed by summer months (April, May, June) and Post-monsoon (October, November). Least value (= 12.97) of NAQI is observed for the monsoon month of September.

CONCLUSIONS

The proposed index (NAQI) is basically an air stress index with no established standards, i.e., the index would not show a pronounced relation to the health of the people. Therefore, it is not possible to characterise the air quality associated with the values of NAQI and also to draw any definitive inferences about the

category of air-quality as in the case of EPAQI. But it has the advantages of self-consistency as it combines the synergistic effects of all the five criteria pollutants. To evaluate its self-consistency w.r.t. health outcome matrix, we applied this index by using disability adjusted life years (DALYs) as the common metric of health effect which is widely used in burden of disease estimates (Cohen *et al.*, 2005). However this calculation requires considerable additional information on health status of exposed population. The NAQI is very much useful in defining the status of air in relative terms. Similarly by comparing NAQI values, one could evaluate the air quality status of different locations in relative terms. For instance if the value of NAQI has increased at a given location, it would mean worsening of the air quality and vice versa. NAQI can also be used to ascertain whether the air quality has worsened or improved over the months in different seasons as represented by their 'Ranking', i.e., higher ranking shows increased pollution levels and vice-versa.

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REFERENCES

Aneja, V.P., Agarwal, A., Roelle, P.A., Phillips, S.B., Tong, Q., Watkins, N. and Yablonsky, R. (2001). Measurements and Analysis of Criteria Pollutants in New Delhi, India. *Environ. Int.* 27: 35-42.

Attri, A. K., Kumar, U. and Jain, V.K. (2001). Formation of Ozone by Fireworks. *Nature.* 411: 1015.

Bezuglaya, E.Yu., Shchutskaya, A.B. and Smirnova, I.V. (1993). Air Pollution Index and Interpretation of Measurements of Toxic Pollutant Concentrations. *Atmos. Environ.* 27: 773-779.

Bortnick, S.M., Coutant, B.W. and Eberly. S.I. (2002). Using Continuous $PM_{2.5}$ Monitoring Data to Report an Air Quality Index. *J. Air Waste Manage. Assoc.* 52: 104-112.

Cairncross, E.K., John, J. and Zunckel, M. (2007). A Novel Air Pollution Index Based on the Relative Risk of Daily Mortality Associated with Short-term Exposure to Common Air Pollutants. *Atmos. Environ.* 41: 8442-8454.

Cheng, W., Kuo, Y., Lin, P., Chang, K., Chen, Y., Lin, T. and Huang, R. (2004). Revised Air Quality Index Derived from an Entropy Function. *Atmos. Environ.* 38: 383-391.

Cheng, W., Chen, Y., Zhang, J., Lyons, T.J., Pai, J. and Chang, S. (2007). Comparision of Revised Air Quality Index with the PSI and AQI indices. *Sci. Total Environ*. 382: 191-198.

Cogliani, E. (2001). Air Pollution Forecast in Cities by an Air Pollution Index Highly

Correlated with the Meteorological Variables. *Atmos. Environ.* 35: 2871-2877.

Cohen, A.J.H., Anderson, R., Ostra, B., Pandey, K.D., Krzyzanowski, M., Kunzli, N., Gutschmidt, K., Pope, A., Romieu, I. and Smith, K. (2005). The Global Burden of Disease Due to Outdoor Air Pollution. *J. Toxicol. Env. Health, part A.* 68: 1301-1307.

Dunteman, G.N. (1994). In *Factor Analysis and Related Techniques*, Vol. 5, Lewis-Beck, M.S. (Ed.), Sage Publications, London, p. 157.

Elshout, S. van den, Leger, K. and Nussio, F. (2008). Comparing Urban Air Quality in Europe in Real Time A Review of the Existing Air Quality Indices and the Proposal of a Common Alternative. *Environ. Int.* 34: 720-726.

EPA (Environmental Protection Agency) (1994). Measuring Air Quality: The Pollutant Standards Index. EPA 451/K-94-001.

EPA. (1997), National Air Quality and Emissions Trends Report 1997, EPA 454/R-98-016.

EPA. (1999), Air Quality Index Reporting; Final Rule. Federal Register, Part III, CFR Part 58.

Goyal, P. and Sidhartha (2003). Present Scenario of Air Quality in Delhi: a case study of CNG implementation. *Atmos. Environ.* 37: 5423-5431.

Harman, H.H. (1968). *Modern Factor Analysis*, 2nd Ed., Revised. University of Chicago Press, Chicago.

Henry, R.C. and Hidy, G.M. (1979). Multivariate Analysis of Particulate Sulfate and Other Air Quality Variables by Principal Components –Part I Annual Data From Los Angeles and New York. *Atmos. Environ.* 13: 158-196.

India (2006). *A reference Annual*. Publication Division, Ministry of Information and Broadcasting, Government of India, New Delhi.

Inhaber, H. (1975). A Set of Suggested Air Quality Indices for Canada. *Atmos. Environ.* 9: 353-364.

Inhaber, H. (1976). *Environmental Indices*. John Wiley & Sons Publication, New York.

Jiang, D., Zhang, Y., Hu, X., Zeng, Y., Tan, J. and Shao, D. (2004). Progress in Developing an ANN Model for Air Pollution Index Forecast. *Atmos. Environ.* 38: 7055-7064.

Johnston, R.J. (1978). *Multivariate Statistical Analysis in Geography*, Longman, New York.

Kassomenos, P., Skouloudis, A.N., Lykoudis, S. and Flocas, H.A. (1999). "Air-Quality Indicators" for Uniform Indexing of Atmospheric Pollution Over Large Metropolitan Areas. *Atmos. Environ.* 33: 1861-1879.

Khanna, N. (2000). Measuring Environmental Quality: an Index of Pollution. *Ecol. Econ.* 35: 191-202.

Kim, J-O. and Mueller, C.W. (1994). In *Factor Analysis and Related Techniques*, Vol. 5, Lewis-Beck, M.S. (Ed.), Sage Publications, London, p. 111.

Koutsoyiannis, A. (2001). *Theory of Econometrics*, 2nd Edition, Palgrave, New York.

Kulshrestha, U.C., Nageswara Rao, T., Azhaguvel, S. and Kulshrestha, M.J. (2004). Emissions and Accumulation of Metals in the Atmosphere Due to Crackers and Sparkles During Diwali Festival in India. *Atmos. Environ*. 38: 4421-4425.

Kumar, U., Prakash, A. and Jain, V.K. (2008). A Photochemical Modelling Approach to Investigate O_3 Sensitivity to NOx and VOCs in the Urban Atmosphere of Delhi. *Aerosol Air Qual. Res.* 8: 147-159.

Landulfo, E., Matos, C.A., Torres, A.S. Sawamura, P. and Uehara, S.T. (2007). Air Quality Assessment Using a Multi-Instrument Approach and Air Quality Indexing in an Urban Area. *Atmos. Res.* 85: 98-111.

Lioy, P.J., Zelenka, M.P., Cheng, M-D. and Reiss, N.M. (1989). The Effect of Sampling Duration on the Ability to Resolve Source Types Using Factor Analysis. *Atmos. Environ.* 23: 239-254.

Lohani, B.N. (1984). *Environmental Quality Management*, South Asian Publishers, New Delhi.

Longhurst, J. (2005). 1 to 100: Creating an Air Quality Index in Pittsburg. *Environ. Monit. Assess.* 106: 27-42.

Malakos, M. and Wong, K-F.V. (1999). Proposed Pollutant Index to Incorporate Synergistic Effects. *Int. J. Environ. Poll*. 12: 2-10.

Mayer, H. and Kalberlah, F. (2008). Two Impact Related Air Quality Indices as Tools to Assess the Daily and Long-Term Air Pollution. *Int. J. Environ. Poll.* 32: 232-243.

Murena, F. (2004). Measuring Air Quality over Large Urban Areas: Development and Application of an Air Pollution Index at the Urban Area of Naples. *Atmos. Environ.* 38: 6195-6202.

NAAQMS. (2001). Air Quality in Delhi (1989-2000), NAAQMS /17/ 2000-2001, Central Pollution Control Board, Parivesh Bhawan, Delhi, India.

Ott, W.R. and Hunt, W.F.Jr. (1976). A Quantitative Evaluation of the Pollutant Standards Index. *J. Air Poll. Control Assoc.* 26: 1050-1054.

Ott, W.R. and Thom, G.C. (1976). A Critical Review of Air Pollution Index Systems in the United States and Canada. *J. Air Poll. Control Assoc.* 26: 460-470.

Padmanabha Murty, B. (1984). Meteorological Potential for Urban Air Pollution in India. *Mausam.* 35:237-39.

PROBES (2003). Spatial Distribution of Hourly Mixing Depth Over Indian Region, PROBES/88/2002-03, Central Pollution Control Board, Parivesh Bhawan, Delhi, India.

Radojevic, M. and Hassan, H. (1999). Air quality in Brunei Darussalam During the 1998 Haze Episode. *Atmos. Environ.* 33: 3651-3658.

Sengupta, B., Sharma, M., Shukla, P., Maheshwari, M. (2000). Air Quality Index for Data Interpretation and Public Information. Proceedings of International Conference on Air Quality Index and Emission inventory for Delhi, Centre for Science and Environment, New Delhi, India.

Sharma, M., Pandey, R., Maheshwari, M., Sengupta, B., Shukla, B.P., Gupta, N.K. and

Johri, S. (2003). Interpretation of Air Quality Data Using an Air Quality Index for the City of Kanpur, India. *J. Environ. Eng. Sci*. 2: 453-462.

Sharma, V.K. (1999). Development of Air Quality Indices for Mumbai, India*. Int. J. Environ. Poll.* 11: 141-146.

Shenfeld, L. (1970). Note on Ontario's Air Pollution Index and Alert System. *J. Air Poll. Control Assoc*. 20: 612.

Srivastava, A., Gupta, S. and Jain, V.K. (2008). Source Apportionment of Total Suspended Particulate Matter in Coarse and Fine Size Ranges Over Delhi. *Aerosol and Air Qual. Res.* 8: 188-200.

Swamee, P.K. and Tyagi, A. (1999). Formation of an Air Pollution Index. *J. Air Waste Manage. Assoc.* 49: 88-91.

Thom, G.C. and Ott, W.R. (1976). A Proposed Uniform Air Pollution Index. *Atmos. Environ.* 10: 261-264.

Thom, G.C and Ott, W.R. (1976). *Air Pollution Indices: A Compendium and Assessment of Indices used in the United States and Canada*, Ann Arbor Science Publishers Inc., Michigan.

Trozzi, C., Vaccaro, R. and Crocetti, S. (1999). Air Quality Index and its Use in Italy's Management Plans. *Sci. Total Environ*. 235: 387-389.

Varshney, C.K. and Singh, A.P. (2002). Measurement of Ambient Concentration of NO_2 in Delhi using Passive Diffusion Tube sampler. *Current Science.* 83: 731-735.