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# An innovative approach for determination of air quality health index

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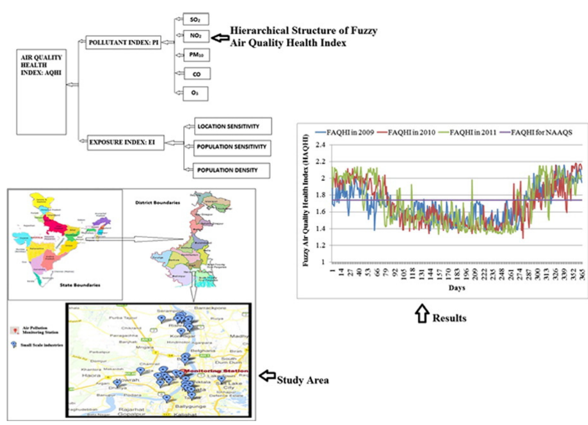
## HIGHLIGHTS

- Designed a fuzzy-AHP model for determination of fuzzy air quality health index
- Demonstrated the application of the model for air quality health impact assessment
- Examined the diurnal variations of FAQHI for health impact assessment.
- Compared the observed FAQHI with the permissible level of FAQHI.
- Demonstrated the calculation of permissible FAQHI on the basis of NAAQS

## GRAPHICAL ABSTRACT

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## ABSTRACT

Fuzzy-analytical hierarchical process (F-AHP) can be extended to determine fuzzy air quality health index (FAQHI) for deducing health risk associated with local air pollution levels, and subjective parameters. The present work aims at determining FAQHI by considering five air pollutant parameters ($SO_2$, $NO_2$, $O_3$, CO, and $PM_{10}$) and three subjective parameters (population sensitivity, population density and location sensitivity). Each of the individual pollutants has varying impacts. Hence the combined health effects associated with the pollutants were estimated by aggregating the pollutants with different weights. Global weights for each evaluation alternatives were determined using fuzzy-AHP method. The developed model was applied to determine FAQHI in Howrah City, India from daily-observed concentrations of air pollutants over the three-year period between 2009 and 2011. The FAQHI values obtained through this method in Howrah City range from 1 to 3. Since the permissible value of FAQHI (as calculated for NAAQS) for residential areas is 1.78, higher index values are of public health concern to the exposed individuals. During the period of study, the observed FAQHI values were found to be higher than 1.78 in most of the day in the months of January to March, and October to December. However, the index values were below the recommended limit during rest of the months. In conclusion, FAQHI in Howrah city was above permissible limit in winter months and within acceptable values in summer and rainy months. Diurnal variations of FAQHI showed a similar trend during the three-year period of assessment.


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## 1. Introduction

Air pollution is global environmental problem that influences mostly health of urban population. Over the past few decades, epidemiological studies have demonstrated adverse health effects due to higher ambient levels of air pollution. Studies have indicated that repeated exposures to ambient air pollutants over a prolonged period of time increases the risk of air-borne diseases like cardiovascular disease, respiratory disease, and lung cancer (WHO, 2009). Air pollution has been consistently linked to substantial burdens of ill-health in developed and developing countries (Schwartz, 1994; WHO, 1999; Bruce et al., 2000; Smith et al., 2000; Gorai et al., 2014).

Globally, many cities continuously assess air quality using monitoring networks designed to measure and record air pollutant concentrations at several points deemed to represent exposure of the population to these pollutants. Current research indicates that guidelines of recommended pollution values cannot be regarded as threshold values below which a zero adverse response may be expected (WHO, 2000; Koenig and Mar, 2000; Gent et al., 2003). Therefore, the simplistic comparison of observed values against guidelines may mislead unless suitably quantified. Again, each of the individual pollutants may have varying impacts and thus the combined health effects associated with various pollutants should be determined by aggregating the pollutants with different weights. Thus, a more sophisticated tool has been developed to communicate the health risk of ambient concentrations using air pollution index (API) or air quality index (AQI). Various air quality indices have been developed to integrate air quality variables worldwide (U.S. EPA, 1976, 1998; Malaysia, 1997; Ontario, 1991; ORAQI, 1971) but most of the methods have different characteristics not only with type of aggregation but also with number and type of pollutants.

The present research attempts to demonstrate the development of a fuzzy-analytical hierarchical process (FAHP) model for determination of fuzzy air quality health index (FAQHI). FAQHI will help to link the health risk associated with local air pollution levels, location sensitivity, population sensitivity, and population density. Since the impact of air pollution on human health involves uncertainty, the present study also considers the uncertainty factors involved in air quality assessment.

## 2. Fuzzy-analytical hierarchical process (F-AHP)

Fuzzy analytical hierarchy process (F-AHP) is the extension of analytical hierarchy process (Saaty, 1980) used for structuring the problem. AHP is particularly useful for evaluating complex multi-attribute alternatives involving subjective criteria. There are few essential steps in the application of AHP viz. decomposing a general decision problem in a hierarchical fashion into sub-problems that can be easily comprehended and evaluated; determining the priorities of the elements at each level of the decision hierarchy, and synthesizing the priorities to determine the overall priorities of the decision alternatives. However, the subjective pair-wise comparison is prone to vagueness type uncertainty and hence there is a need for exploring fuzzy-based techniques. The first attempt in the integration of fuzzy-based technique with AHP is done by van Laarhoven and Pedrycz (1983) for comparison of fuzzy ratios described by triangular fuzzy numbers (TFNs) and weight computation using logarithmic least squares method. Subsequently the method has been modified by many researchers (Buckley, 1985; Boender et al., 1989; Cheng, 1999; Chang, 1996; Zhu et al., 1999; Lee et al., 1999; Deng, 1999; Leung and Cao, 2000) to improve the applicability in various fields.

The present work demonstrates the application of fuzzy-AHP approach for determining the weights for air quality health index attributes, which subsequently used in determination of fuzzy air quality health index (FAQHI). Most of the existing air quality index system (AQI or PSI system of U.S. EPA, ORAQI system of Oak Ridge National Laboratory, Ontario AQI system etc.) either based on the single parameter index or do not consider the subjective parameters and thus does not reflect the combined effects due to existence of multi-pollutant and subjective parameters. The present work attempts to develop an air quality health index model by considering the multi-pollutant parameters ($SO_2$, $NO_2$, $O_3$, CO, and $PM_{10}$) along with subjective parameters (population sensitivity, population density and location sensitivity). The study also considers the different weights for different attributes in determining the FAQHI. The process of the weight determination problem primarily depends upon the health impacts of the people. In case of simple AHP, it is difficult to incorporate preference scales (such as “less likely”, “more likely” etc.) in the analytical models. In fact, the scale of preference is fuzziness in nature. Therefore, using a crisp value for pair-wise comparison is not suitable because it does not accurately represents the individual semantic cognition state of the decision makers. Fuzzy logic (Zadeh, 1965) is a proven scientific technique that allows us to convert linguistic measures into crisp measure using membership functions. Membership functions define the fuzzy boundary between two measurements scales such as ‘less likely’ and ‘likely’.

## 3. Materials and methods

The present work builds on the application of F-AHP by incorporating the decision maker's attitude in determination of air quality health index. The flowchart of the working methodology is shown in Fig. 1. A step-by-step description of the methodology for fuzzy air quality health index (FAQHI) model development is presented as follows:

### *3.1. Development of hierarchical structures*

The basic risk attributes are grouped into higher-level risk factors that form a multi-stage hierarchical model of aggregative risk for air quality health index. The usage of fuzzy set techniques for air quality indexing enables the incorporation of field data (e.g. observed air quality) and soft qualitative data (e.g. expert opinion).

To develop the hierarchical model for air quality health index, all the attributes or influencing factors have to be structured into different hierarchical levels. A three level hierarchical tree is illustrated in Fig. 2. The first layer of the hierarchy corresponds to objective or goal (air quality health index), and the last layer corresponds to the evaluation alternatives (options), whereas the intermediate levels correspond to different criteria. Each criterion in the intermediate levels is influenced by the corresponding evaluation option respectively.

### *3.2. Weighting scheme*

The proposed methodology requires information for relative importance of attributes or criteria of various parameters considered in the model. The relative importance was established using fuzzy-AHP method. The methodology is explained below in detail.

#### *3.2.1. Pair-wise comparisons*

Fuzzy pair wise comparison matrices are developed for each of the group of variables as shown in Fig. 2. The detailed method is explained in Appendix A. Matrices PI, EI, FAQHI are representing pair-wise comparison matrices for pollutant variables, exposure variables, and air quality health index variables respectively.

$$\mathrm{PI} = \begin{array}{c} \\ \boldsymbol{SO_2} \\ \boldsymbol{CO} \\ \boldsymbol{PM_{10}} \\ \boldsymbol{NO_2} \\ \boldsymbol{O_3} \end{array} \begin{bmatrix} \boldsymbol{SO_2} & \boldsymbol{CO} & \boldsymbol{PM_{10}} & \boldsymbol{NO_2} & \boldsymbol{O_3} \\ \tilde{1} & 1/\tilde{1.5} & 1/\tilde{2} & 1/\tilde{2.5} & 1/\tilde{3} \\ \tilde{1.5} & \tilde{1} & 1/\tilde{1.5} & 1/\tilde{2} & 1/\tilde{2.5} \\ \tilde{2} & \tilde{1.5} & \tilde{1} & 1/\tilde{1.5} & 1/\tilde{2} \\ \tilde{2.5} & \tilde{2} & \tilde{1.5} & \tilde{1} & 1/\tilde{1.5} \\ \tilde{3} & \tilde{2.5} & \tilde{2} & \tilde{2.5} & \tilde{1} \end{bmatrix};$$

$$EI = \begin{array}{c} \\ \boldsymbol{LS} \\ \boldsymbol{PD} \\ \boldsymbol{PS} \end{array} \begin{bmatrix} \boldsymbol{LS} & \boldsymbol{PD} & \boldsymbol{PS} \\ \tilde{1} & 1/\tilde{3} & 1/\tilde{5} \\ \tilde{3} & \tilde{1} & 1/\tilde{3} \\ \tilde{5} & \tilde{3} & \tilde{1} \end{bmatrix}; \qquad \mathrm{FAQHI} = \begin{array}{c} \\ \boldsymbol{EI} \\ \mathrm{PI} \end{array} \begin{bmatrix} \boldsymbol{EI} & \mathrm{PI} \\ \tilde{1} & 1/\tilde{3} \\ \tilde{3} & \tilde{1} \end{bmatrix}$$