Fuzzy MCDM Approach for Air Quality Assessment

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Abstract

Due to industrialization and urbanization rate of air pollution is raising in developing countries which has given need to work out Air quality Indices which gives single value with respect to its effects on the human health due to air pollution. The vagueness related to classification of concentration of different pollutants for calculation of AQI depend on location is to be used leads to limitation of general AQI method. To deal with such limitation in this study Fuzzy MCDM approach has been used for AQI calculation using case study for vapi area (one location) for duration of March 2013- February 2014.It includes six pollutants(PM_{10}, $PM_{2.5}$, NOx, CO, SO_2, O_3) for AQI calculation. Depending on result Fuzzy MCDM approach for Air Quality assessment can be considered as effective tool.

Keywords: Air Pollution, Air Quality Index, Fuzzy logic, MCDM, Fuzzy set

I. INTRODUCTION

THE ever increasing rate of industrialization and urbanization, especially in developing countries, has led to increased levels of air pollution as well as increased concern about air pollution impact on human health. This has brought about a variety of strategies for air quality management and pollution control. Air quality indices are widely used in air quality management schemes [1]. Fuzzy set theory provides framework for urban planners to evaluate urban environmental quality more effectively than conventional method [3]. In the fuzzy sets and systems membership functions are used to handle uncertainty or express vague concepts. Membership function can be broadly classified in two different ways: direct and indirect approach. In Direct approach, expert's opinions are taken related to questions of various kinds that explicitly pertain to the constructed membership function. On For indirect approach, experts are required to answer simpler questions, which are only implicitly related to the constructed membership function and their answers are interpreted based on various assumptions. Fuzzy logic refers to all of the theories and technologies that employ fuzzy sets, which are classes with unsharp boundaries.

II. FUZZY MCDM APPROACH

A. Fuzzy Set Theory:

Zadeh (1965) first introduced the concept of fuzzy set theory. A fuzzy set can be defined mathematically by assigning to each possible individual in the universe of discourse a value representing its grade of membership in the fuzzy set. This grade represents the degree to which that individual is similar or compatible with the concept represented by the fuzzy set. Thus, an individual may belong in the fuzzy set to a greater or lesser degree as indicated by a larger or smaller membership grade. These membership grades are very often represented by real-number values ranging in the closed interval between 0 and 1. The fuzzy set, therefore, introduces vagueness (with the aim of reducing complexity) by eliminating sharp boundary dividing members of the class from non-members since the transition of member from non-member is gradual rather than abrupt (Klir and Folger 1988).[16]

B. Multi Criteria Decision Making:

A multi criteria decision-making problem can generally be represented in a matrix format as

$$D = \begin{array}{c} \\ A1 \\ A2 \\ \vdots \\ Am \end{array} \begin{array}{c} \begin{array}{cccc} c1 & c2 & \dots & cn \end{array} \\ \begin{bmatrix} x11 & x12 & \cdots & x1n \\ x21 & x22 & \cdots & x2n \\ \vdots & \vdots & \vdots & \vdots \\ xm1 & xm2 & \dots & xmn \end{bmatrix} \end{array}$$

W = [w1, w2, . . . wn]

Where A1, A2, . . . , Am = alternatives; c1 ,c2 , . . . ,cn = criteria with which performances of alternatives are measured; xij= rating or score of alternative Ai with respect to criterion cj, and wj =weight of criterion cj. The main purpose in the MCDM problem is to assess the overall importance values of the alternatives on some permissible scale. Alternatives are generally first evaluated explicitly with respect to each of the decision criteria to obtain some sort of criterion specific priority scores which are then aggregated into overall performance values.

III. METHODOLOGY

Figure 1 show flow sheet of the fuzzy decision framework for calculating Air quality index. For the proposed study for different pollutant significance four fuzzy numbers are predefined to describe the level of performance on decision criteria. Five linguistic variables are used. Table 1 shows the linguistics variables and fuzzy numbers used in this study

Table -1:
Linguistic Variables and Fuzzy Numbers

Linguistic variables	*Fuzzy numbers*
Vs(very significant)	*(0.7,0.8,0.9,1.0)*
S(significant)	*(0.5,0.6,0.7,0.8)*
As(average significant)	*(0.3,0.4,0.5,0.6)*
Ls(low significant	*(0.1,0.2,0.3,0.4)*
Ns(not significant)	*(0.0,0.0,0.1,0.2)*

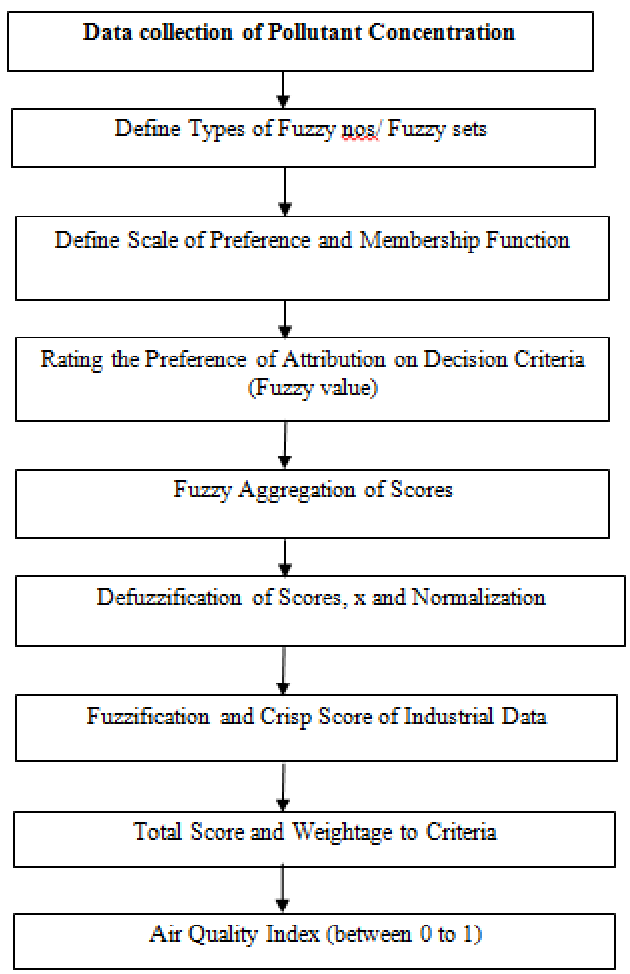

Fig. 1: Fuzzy Decision Framework for Air Quality Assessment

The Importance Weight Factors Are Computed For Pollutants Of Air Pollution (PM_{10}, $PM_{2.5}$, NOx, CO, SO_2, And O_3). For This Study Seven Expert's Opinion Has Been Considered For Calculation Of Air Quality Assessment.

Using The Equation (1) Given Below, Average Fuzzy Number For All Environmental Experts' Opinion Can Be Expressed As

$$A^k_{ij} = (1/P) \otimes (Aki1 \oplus Aki2 \oplus \ldots\ldots \oplus Akip) \text{ For } J = 1,2,\ldots..,P \tag{1}$$

Where P = Numbers Of Dms Involved In The Evaluation Process.

The Linguistic Variables As Assigned By The Experts Are Converted To Fuzzy Numbers Used In The Above Expressions Through Table 1. Now, The Defuzzified Values For The Pollutants Are Obtained By Using Equation (2).

$$e = (x_1 + x_2 + x_3 + x_4) / 4 \tag{2}$$

The Normalized Weight For Each Pollutant Of Air Pollution Is Obtained By Dividing The Scores Of Each Sub Criteria (Cij) By The Total Of All Sub-Criterion (Σ Cij). The Next Step Is To Convert The Concentration Of Pollutant To The Fuzzy Numbers (Membership Functions) Based On The Specified Statutory Norms (As Per GPCB Limits).

Similarly, Crisp Scores Can Be Computed For The Other Sub Criteria Of Air Pollution. Using Simple Additive Weighing Method (Hwang And Yoon 1981), The Total Scores (TS) For Each Pollutant Can Be Calculated As Follows.

$$TS = \sum(X_k * W(C_k)) \text{ For } K = 1,2,3.. \tag{3}$$

Where,

- $W(C_{ki})$ = Weight Or The Importance Value Of The Sub Criterion K And
- X_k = Crisp Score Of The Pollutant Data Against The Sub Criterion K.

Air Quality Index Can Be Obtained As,

$$AQI = \sum (TS(C_k)) \text{ For } K = 1, 2, 3... \tag{4}$$

Where,

$TS(C_k)$ = Total Score of the Sub Criterion K (Different Air Pollutants)

IV. CASE STUDY

The Case Study Represents The Calculation Of Air Quality Index For Data Of Vapi Municipality Office Location 20°22'23"N, 72°54'23"E For Duration Of March 2013- February 2014 Collected From Gujarat Pollution Control Board. Figure 2 Represents The Location Of Data Collected For Air Quality Index Calculation. Figure 3 Represents PM10, PM2.5, Nox Pollutant Concentration In Mg/M3 Of March 2013- February 2014 For Given Location. Figure 4 Represents CO, O3 Pollutant Concentration In Mg/M^3 Of March 2013- February 2014 For Given Location

Fig. 2: Location of Site For AQI Calculation

The Study Shows That the Average Concentration of PM_{10} Was 93 µg/M^3 and That of $PM_{2.5}$ Was 30.8 µg/M3 at Nagar Palika. The Average Concentration of SO_2 Was 13 µg/M^3 At Nagar Palika. The Average Concentration of NO_2 Was 17.4 µg/M3 At Nagar Palika.

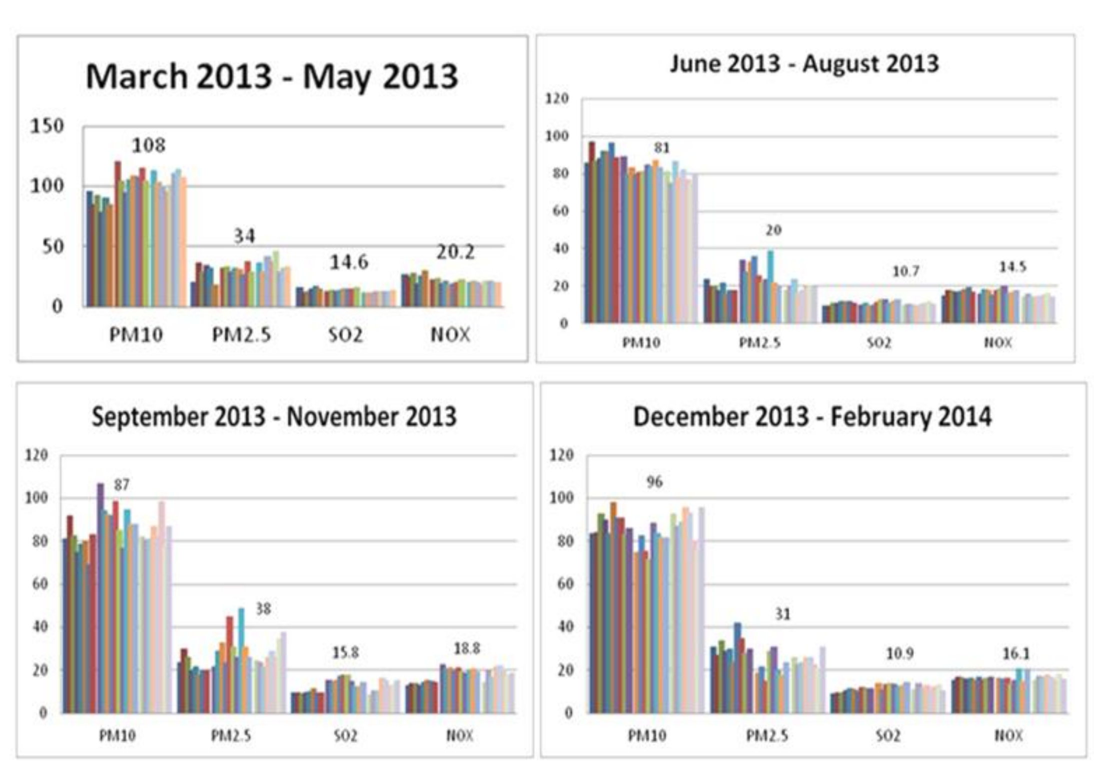

Figure 3: PM_{10}, $PM_{2.5}$, NOx, SO_2 Pollutant Concentration in Mg/M^3

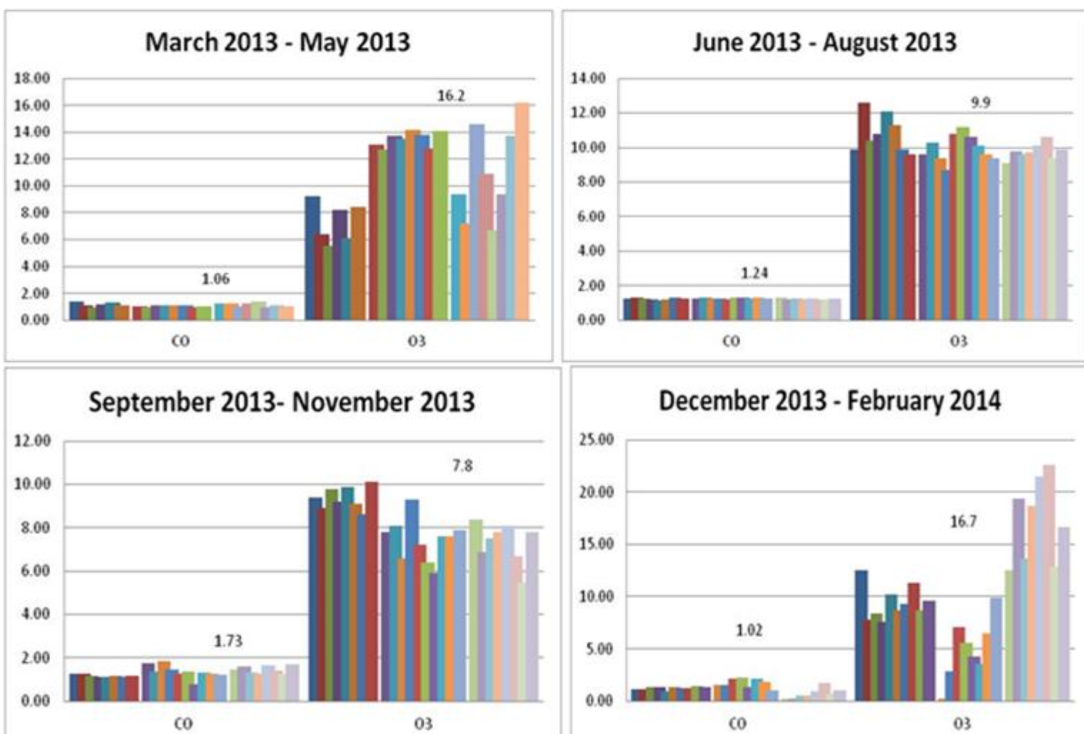

Figure 4: CO, O_3 Pollutant Concentration in Mg/M^3

First Of All Fuzzy Score Matrix Has Been Calculated For Each Pollutant Which Is Given In Table 2. For Final Total Score, A Unique Membership Value For Each Pollutant For Different Months Can Be Worked Out.

Table - 2
Fuzzy Score for Air Pollutant

Air Pollutant	*Fuzzy Score*			
PM_{10}	*0.6*	*0.7*	*0.8*	*0.9*
$PM_{2.5}$	*0.5*	*0.6*	*0.7*	*0.8*
SO_2	*0.7*	*0.8*	*0.9*	*1*
NO_X	*0.36*	*0.46*	*0.56*	*0.66*
CO	*0.5*	*0.6*	*0.7*	*0.8*
O3	*0.28*	*0.38*	*0.48*	*0.58*

Table 3 represents Normalized weight for different pollutant. This has been worked out by following method,
For PM10: Crisp Score = (0.6+0.7+0.8+0.9)/4 = 0.75

Normalized Weight = crisp score of PM10/ sum of total crisp values = 0.75/3.84 = 0.1953

Table - 3
Normalized Weight for Air Pollutant

Air Pollutant	*Crisp Score*	*Air Pollutant*	*Normalized Weight*
PM_{10}	*0.75*	*PM_{10}*	*0.1953*
$PM_{2.5}$	*0.65*	*$PM_{2.5}$*	*0.1693*
SO_2	*0.85*	*SO_2*	*0.2214*
NO_X	*0.51*	*NO_X*	*0.1328*
CO	*0.65*	*CO*	*0.1693*
O3	*0.43*	*O3*	*0.1120*
SUM =	*3.84*	*SUM =*	*1.0000*

Membership value for different parameters is as shown in figure 5, 6 for CO, O3 and PM10, PM2.5, NOx respectively. The membership value of different pollutant is in between of 0 to 1 as it is applicable for membership value in fuzzy logic.

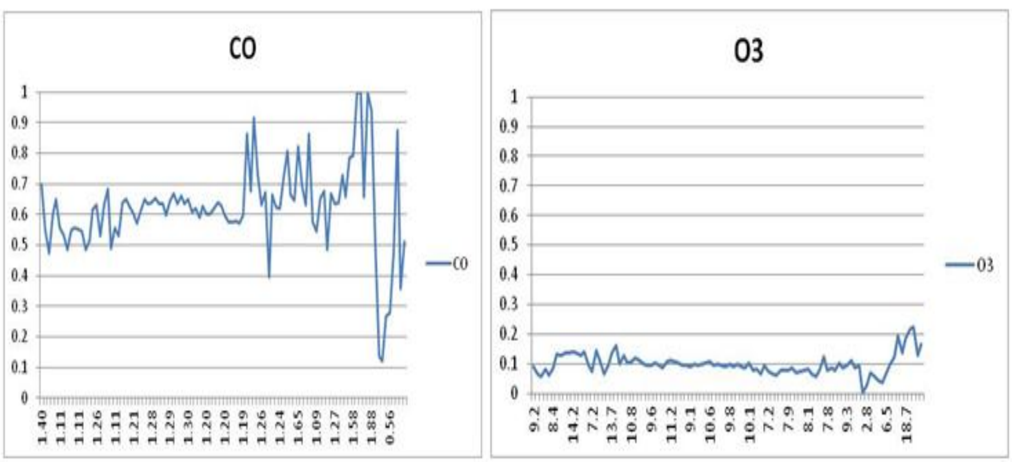

Fig. 5: CO, O3 pollutant Membership Value

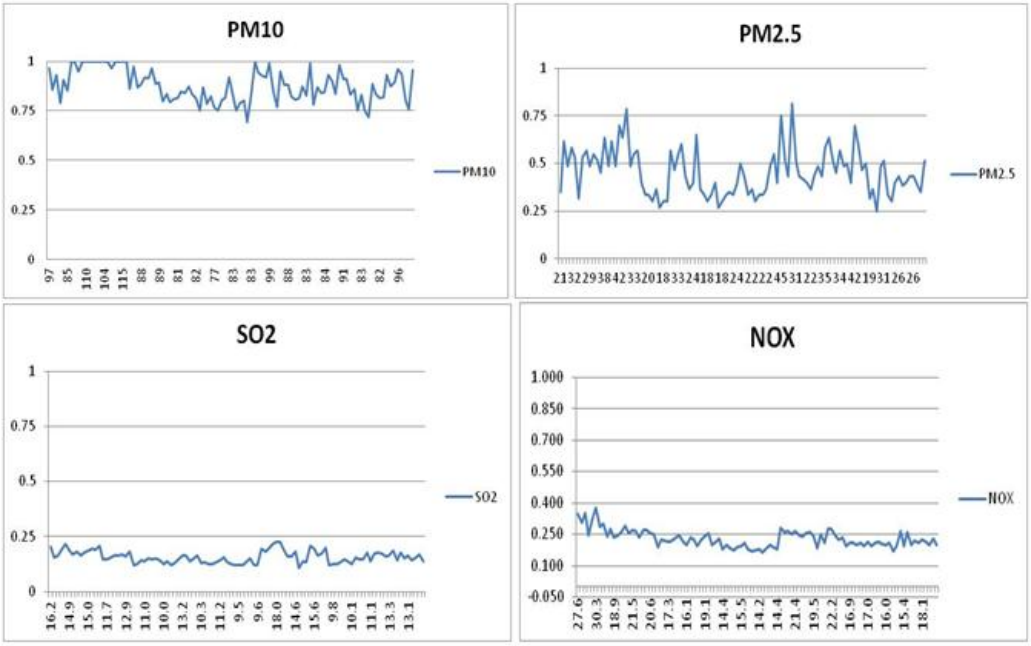

Fig. 6: PM_{10}, $PM_{2.5}$, NOx, SO_2 Pollutant Membership Value

Overall score for different pollutant can be calculated using equation (3) as follow.

For $PM_{2.5}$: $TS = \sum(X_k * W(C_k)) = 0.6167 * 0.1963 = 0.1211$

Total score for different pollutant is as shown in figure 7 for period of March 2013 to February 2014.

Air Quality Index can be calculated using equation (4) as follow.

$AQI_1 = TS_{PM10} + TS_{PM2.5} + TS_{SO2} + TS_{NOx} + TS_{CO} + TS_{O3}$

$= 0.1888 + 0.0687 + 0.0449 + 0.0458 + 0.093 + 0.0103 = 0.4514$

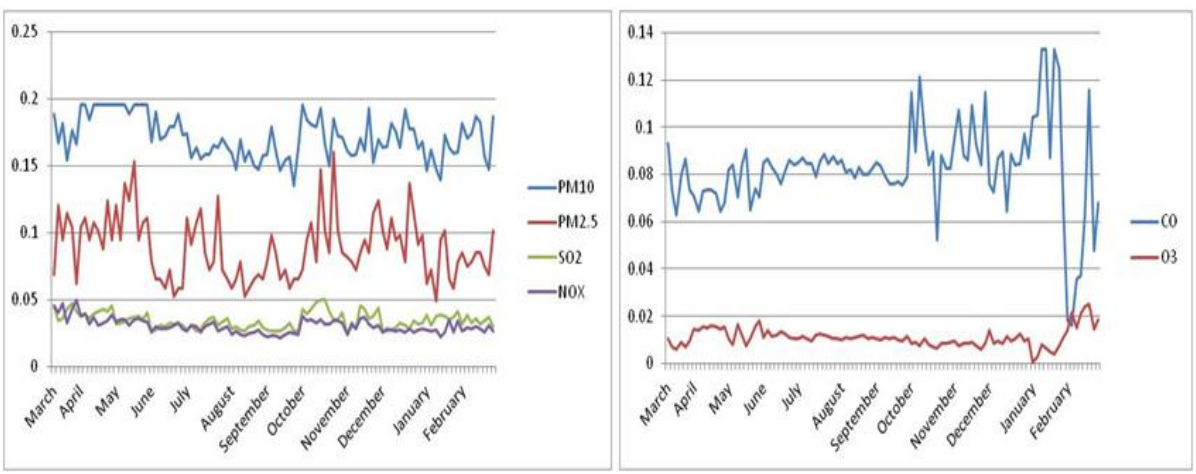

Fig. 7: PM10, PM2.5, NOx, SO2, CO, O3 Pollutant Total Score

V. RESULTS AND DISCUSSIONS

As discussed above, it can be interpreted that average Overall Score for PM10 was 0.1717; maximum Overall Score for PM10 was 0.1953 and minimum Overall Score for PM10 was 0.1354. For PM2.5 average Overall Score was 0.0890; maximum Overall Score was 0.1603 and minimum Overall Score was 0.0491. For NOx average Overall Score was 0.0305; maximum Overall Score was 0.0504 and minimum Overall Score was 0.0219. For SO2 average Overall Score was 0.0347; maximum Overall Score was 0.0501 and minimum Overall Score was 0.0240. For CO average Overall Score was 0.0825; maximum Overall Score was 0.1328 and minimum Overall Score was 0.0159. For O3 average Overall Score was 0.0110; maximum Overall Score 0.0253 and minimum Overall Score was 0.0003.

From the result shown in Figure 8, it can be inferred that, average AQI was 0.4195; Minimum AQI was 0.3380 and Maximum AQI was 0.5197. The value of AQI towards 0 refers as "Good" air quality and towards 1 refers as "Bad" air quality. Though air pollutant concentration is in limits, the value of AQI shows there is pollution which affects human health.

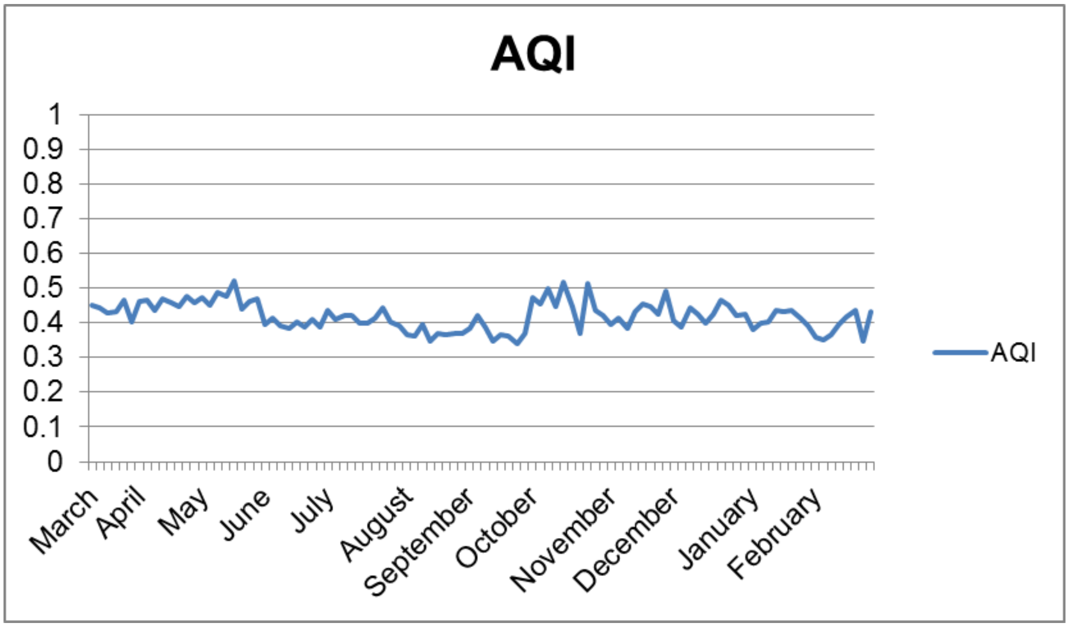

Fig. 8: Result and Discussion

In this present study an effort has been made to calculate Air Quality Index using Fuzzy MCDM approach. This can further be used for calculation of AQI for different location using same methodology.

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