Noise Risk Assessment: Fuzzy Logic Approach

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ABSTRACT

Noise pollution is one of the most harmful pollution relating to health hazards like other pollutions in the present world scenario. The main sources of noise have been generating from human malpractices to use of loud speakers in different festivals and several occasions and reckless horn pressing during car driving. Behavioral study explores that in many places, a large part of peoples are adopting with this environment years after year without taking care of health consciousness over different age groups. In our study we have shown how the noise pollution affects the peoples' health of a specific region. Also we have developed a most reliable model for risk analysis using fuzzy inference logic. We have also assumed the normality in contributions for various noise parameters namely, noise level, exposure time and affected age group of the people of a particular place as well. However, we have developed the key indexes of normal expected level of noise parameters extensively. Finally, graphical illustrations are made for global justification of the model itself keeping some scope of future research.

1. Introduction

Behind any kind of technological innovations there corresponds some pollution. The pollution can be measured in several dimensions; it may be in the form of soil pollution, water pollution, air pollution especially on noise pollution.It has some adverse and instant effect on human health which cannot be ignored. So to deal with healthy environment it is very much important to know and assess the actual noise levels which are continuously happening around us. By this assessment we may feel ourselves the environment under study whether adoptable and favorable to our health or not.In the literature, study on major concern over transportations, vehicle passing on roads, sound disturbances from stone crusher machine near community have been viewed(Swain *et al*.[17,18,19,20,21,22,23,24]). Sleep disturbances are the major problems on health hazards (Annon[1],Burgess [4], Berglund et al.[2]). The psycho-physiological effect of noise on human sleep may depend more on the level and number of noise events in traffic streams than on energy equivalent measures (Griefahn*et al*.[6]; Griffiths and Langdon [7],Pirrera*et al*.[14]).

Though, numerous research articles have been published covering the mean, median, mode etc. of popular statisticsdiscipline. But, the concept of fuzzy logic is quite new in the application of noise modeling.

Zadeh ([27], [28], [29])gave the first concept to deal with more complex problems and decision making under fuzzy environment. Recently,Gulliver*et al.*[8]developed a noise exposure model to identify the best possible level of human health. Prakash and Veerappa[15]were able to interpret the effects of noise pollution on human being using fuzzy logic techniques;Shivdev*et al.*[16]discussed noise induced health effects in mine site using fuzzy logic technique.On the other side, the problem of risk managementwas developed byCameron and Peloso[5]with the help of precautionary principle.

Multilevel fuzzy approach to risk and disaster management for studying the noise annoyance has been discussed by Haimes[9] and Takacs[26]. Mamdani and Assilian[12]studied with the linguistic synthesis with a fuzzy logic control. In adaptive network, several attempts have been made with the help of fuzzy logic by the authors likeJang [10], Kukolj[11],Nouri*et al.*[13]discussed over fuzzy modeling for noise annoyance in urban environment. Takagi and Sugeno[25]pointed the complexities in identifying the noisy system and modeling with control.Zaheeruddinet *al.*[31]studied a fuzzy modelling of human work efficiency in noisy environment,and Jain[32]discusses the effects of noise pollution on human performance under fuzzy modelling.Using fuzzy expert system, the health disorder due to sleep disturbance was analyzed byZaheeruddin and Jain[30]which has kept a remarkable destination over the subject.

However it is quite natural that people of different age groups usually follow the Gaussian normality curve. Also the noise level and exposure time duration are not usually high or low throughout the day and hence they can follow the same normality principle. Thus we are intending to develop a normalized noise model. Moreover, the impact of noise pollution, we have determined by means of risk indexes. It is a common phenomenon that the middle age group can adapt easily with any adverse threat of noise than the other age groups of a specific society. But, in our model we have assumed the most common medium groups for all the cases recognized by the authority of the noise prone zone. To tackle the problem we fuzzify the noise parameters first, and then applying normalization and centre of gravity method to get the defuzzified value. Finally, we have analyzed the fuzzy inputs under standard outputs of the model itself.

2. Model assumptions

2.1. The followingassumptions are made to develop the noise model

i) The area under study is completely residential and tourist spot.

ii) The population of the area assumes the normal distribution with respect to different age group.

iii) The exposure time of noise assumes the normal distribution.

iv) The data are real time data and the source distances and speed of noise have been ignored. Noises are generated on spot and assume Gaussian normality in intensity throughout the place.

v) The affected people under study are of young, middle and old aged.

vi) Adaptive capacity is negnigible.

vii) The health hazards reported on the basis of hearing problems, sleep disturbances, cardiac problems, work inefficiencies and attention loss etc..

2.2. Concept of normality

Studying from the basic statistics discipline, we can categories {low, medium and high} to the different noise levels, age groups of the people and the exposure time under Gaussian normality curve. The possible cases are shown in the following figures Fig-(1.1, 1.2 and 1.3).

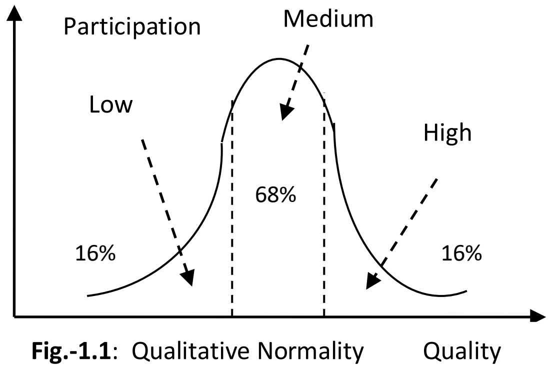


Fig.-1.1: Qualitative Normality

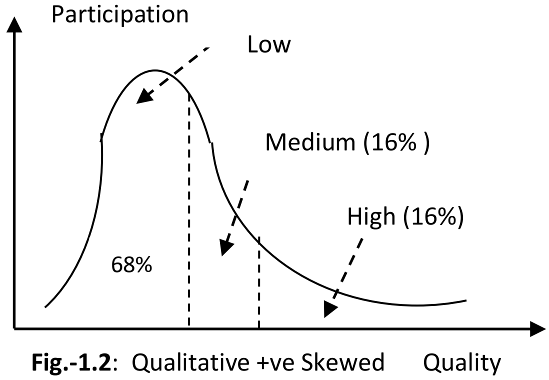


Fig.-1.2: Qualitative +ve Skewed

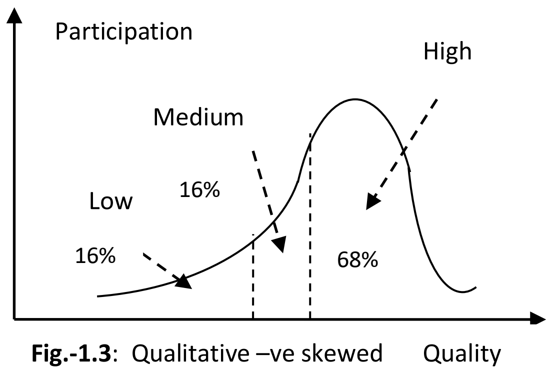


Fig.-1.3: Qualitative –ve skewed

2.3. The problem under study is stated as follows

i) Does the observed datareally responsible for affecting the public health in the city?

ii) What is the observed expectednoise level, exposure time duration and affected age group of that city?

iii) What is the expected observed exposure time duration of that city?

3. Noise inputs and equivalent fuzzy intervals

3.1. Standard noise levels

As perShivdev et *al*.[16]the basic parameters associated tonoise pollution are given in Table-1. We also assume that, the pollution level is the function three independent variables namely, Noise level (*N*), Age level (*A*) and Exposure time (T) and the pollution level $P = f(N, A, T)$.

Table-1: Classification of standard noise inputs/outputs

Parameters	**Group/ Class**	**Fuzzy intervals**
Noise level	Normal	0-75dB(A)
	High	72-110dB(A)
	Very high	105-140dB(A)
Age	Young age	20-40 years
	Middle age	35-60 years
	Old age	55-80 years
Exposure time	Short	0-90 sec.
	Medium	85-180 sec.
	Long	>170 sec.
Health effects	Low risk	0-30%
	Medium risk	28-60%
	High risk	>57%

Now, we use the triangular fuzzy variables to quantify the linguistic fuzzy variables and it is defined on Table-2.

Table-2: Compromise fuzzy noise inputs (as per Table-1)

Parameters	Group/ Class	Fuzzy variables	Fuzzy intervals
Noise level	Normal	$< L_1 , L_2 , L_3 >$	< 20,50,75 >
	High	$< L_4 , L_5 , L_6 >$	< 75, 95 110 >
	Very high	$< L_7 , L_8 , L_9 >$	< 105, 125, 140 >
Age	Young age	$< A_1 , A_2 , A_3 >$	< 18, 25, 40 >
	Middle age	$< A_4 , A_5 , A_6 >$	< 35, 45, 60 >
	Old age	$< A_7 , A_8 , A_9 >$	< 55, 65, 80 >
Exposure time	Short	$< T_1 , T_2 , T_3 >$	< 15, 60, 90 >
	Medium	$< T_4 , T_5 , T_6 >$	< 85, 140, 180 >
	Long	$< T_7 , T_8 , T_9 >$	< 172, 195, 240 >

The graphical representations of the fuzzy membership functions for the several fuzzy noise inputs are stated in Figs.(2-4)

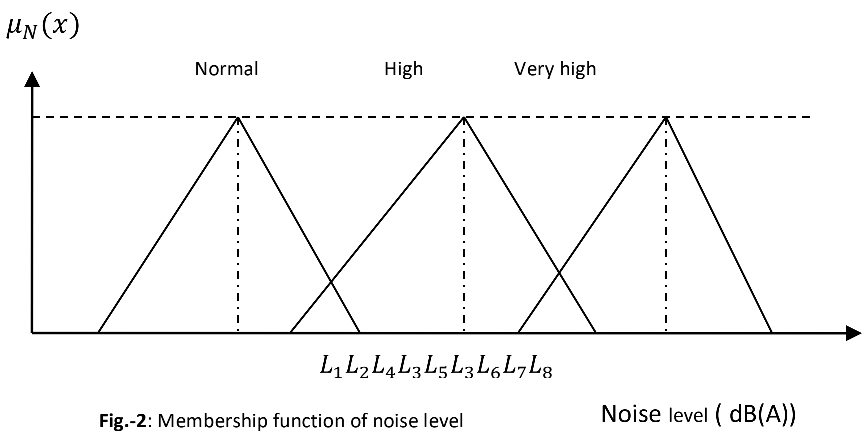


Fig.-2: Membership function of noise level

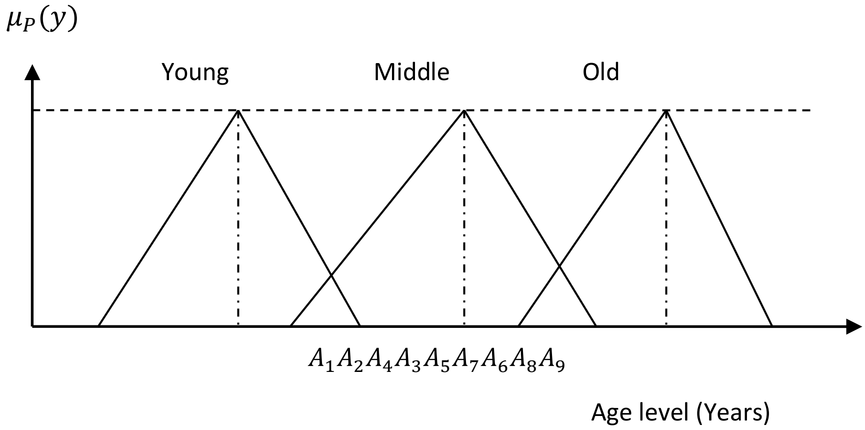


Fig.-3: Membership function of age groups

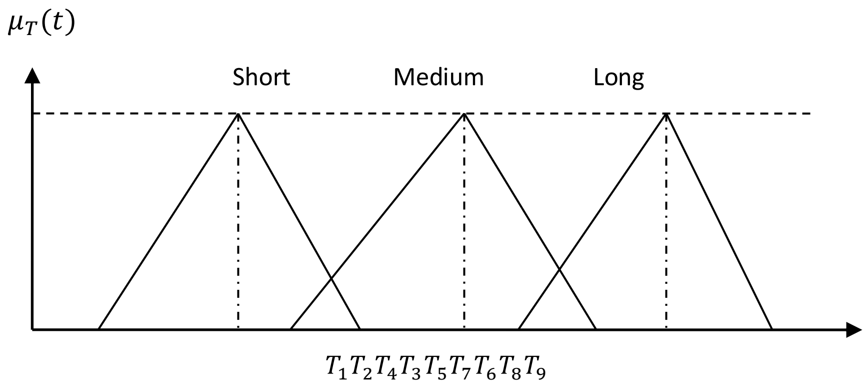


Fig.-4: Membership function of exposure time Time duration (Sec.)

3.2. Membership considerations

We consider the triangular membership functions for each of the noise levels, age groups of the affected people and the exposure time and they are stated respectively as follows:

3.2.1Noise level

i) For normal noise level $$\mu_{1N}(x) = \begin{cases} \frac{x-L_1}{L_2-L_1} for L_1 < x < L_2 \\ \frac{L_3-x}{L_3-L_2} for L_2 < x < L_3 \\ 0 \quad elsewhere \end{cases} \quad (1)$$

ii) For high noise level $\mu_{2N}(x) = \begin{cases} \frac{x-L_4}{L_5-L_4} for L_4 < x < L_5 \\ \frac{L_6-x}{L_6-L_5} for L_5 < x < L_6 \\ 0 \quad elsewhere \end{cases}$ (2)

iii) For very high noise level $\mu_{3N}(x) = \begin{cases} \frac{x-L_7}{L_8-L_7} for L_7 < x < L_8 \\ \frac{L_9-x}{L_9-L_8} for L_8 < x < L_9 \\ 0 \quad elsewhere \end{cases}$ (3)

Using the normality, the total expected membership function for the various noise level is given by

$\mu_N(x) = \frac{1}{n}[w_1\mu_{1N}(x) + w_2\mu_{2N}(x) + w_3\mu_{3N}(x)]$ (4)

Subjectto $w_1 + w_2 + w_3 = 1, n = \text{total number of levels, here} n = 6$(5)

3.2.2 Age level of human population

iv) For young age group $\mu_{1P}(y) = \begin{cases} \frac{y-A_1}{A_2-A_1} for A_1 < y < A_2 \\ \frac{A_3-y}{A_3-A_2} for A_2 < y < A_3 \\ 0 \quad elsewhere \end{cases}$ (6)

v) For middle age group $\mu_{2P}(y) = \begin{cases} \frac{y-A_4}{A_5-A_4} for A_4 < y < A_5 \\ \frac{A_6-y}{A_6-A_5} for A_5 < y < A_6 \\ 0 \quad elsewhere \end{cases}$ (7)

vi)For old age group $\mu_{3P}(y) = \begin{cases} \frac{y-A_7}{A_8-A_7} for A_7 < y < A_8 \\ \frac{A_9-y}{A_9-A_8} for A_8 < y < A_9 \\ 0 \quad elsewhere \end{cases}$ (8)

Therefore, the total expected membership function for peoples' participation in that area is given by

$\mu_P(y) = \frac{1}{6}[w_1\mu_{1P}(y) + w_2\mu_{2P}(y) + w_3\mu_{3P}(y)]$ (9)

3.2.3 Exposure time of noise

vii) For short exposure time $\mu_{1T}(t) = \begin{cases} \frac{t-T_1}{T_2-T_1} for T_1 < t < T_2 \\ \frac{T_3-t}{T_3-T_2} for T_2 < t < T_3 \\ 0 \quad elsewhere \end{cases}$ (10)

viii) For medium exposure time $\mu_{2T}(t) = \begin{cases} \frac{t-T_4}{T_5-T_4} for T_4 < t < T_5 \\ \frac{T_6-t}{T_6-T_5} for T_5 < t < T_6 \\ 0 \quad elsewhere \end{cases}$ (11)

ix) For long exposure time $\mu_{3T}(t) = \begin{cases} \frac{t-T_7}{T_8-T_7} for T_7 < t < T_8 \\ \frac{T_9-t}{T_9-T_8} for T_8 < t < T_9 \\ 0 \quad elsewhere \end{cases}$ (12)

3.3. Defuzzification and expected noise parameters

Therefore, the total expected membership function for the exposure time duration is given by

$$\mu_T(x) = \frac{1}{6}[w_1\mu_{1T}(t) + w_2\mu_{2T}(t) + w_3\mu_{3T}(t)] \quad (13)$$

Now defuzzifying (4), (9), (13) we can easily get the expected noise parametric level.

Here we have seen that, the levels can be evaluated independently by the following way:

$$\int x\,\mu_N(x)dx = \frac{1}{6}\left[w_1 \int x\,\mu_{1N}(x)dx + w_2 \int x\,\mu_{2N}(x)dx + w_3 \int x\,\mu_{3N}(x)dx\right]$$

$$= \frac{1}{6}\left[w_1\left[\int_{L_1}^{L_2} \frac{x(x-L_1)}{L_2-L_1}dx + \int_{L_2}^{L_3} \frac{x(L_3-x)}{L_3-L_2}dx\right] + w_2\left[\int_{L_4}^{L_5} \frac{x(x-L_4)}{L_5-L_4}dx + \int_{L_5}^{L_6} \frac{x(L_6-x)}{L_6-L_5}dx\right] + w_3\left[\int_{L_7}^{L_8} \frac{x(x-L_7)}{L_8-L_7}dx + \int_{L_8}^{L_9} \frac{x(L_9-x)}{L_9-L_8}dx\right]\right]$$

$$= \frac{1}{36}[w_1(L_3-L_1)(L_1+L_2+L_3) + w_2(L_6-L_4)(L_4+L_5+L_6) + w_3(L_9-L_7)(L_7+L_8+L_9)] \quad (14)$$

And $\int \mu_N(x)dx = \frac{1}{6}[w_1 \int \mu_{1N}(x)dx + w_2 \int \mu_{2N}(x)dx + w_3 \int \mu_{3N}(x)dx]$

$$= \frac{1}{12}[w_1(L_3 - L_1) + w_2(L_6 - L_4) + w_3(L_9 - L_7)] \qquad (15)$$

Thus, using (14) and (15) the expected noise level for a specific group of people with specific time exposure at a particular place is given by

$$N_{noise} = \frac{\int x\, \mu_N(x) dx}{\int \mu_N(x)\, dx}$$

$$= \frac{\frac{1}{36}[w_1(L_3 - L_1)(L_1 + L_2 + L_3) + w_2(L_6 - L_4)(L_4 + L_5 + L_6) + w_3(L_9 - L_7)(L_7 + L_8 + L_9)]}{\frac{1}{12}[w_1(L_3 - L_1) + w_2(L_6 - L_4) + w_3(L_9 - L_7)]}$$

$$= \frac{1}{3}\frac{[w_1(L_3-L_1)(L_1+L_2+L_3)+w_2(L_6-L_4)(L_4+L_5+L_6)+w_3(L_9-L_7)(L_7+L_8+L_9)]}{[w_1(L_3-L_1)+w_2(L_6-L_4)+w_3(L_9-L_7)]} \qquad (16)$$

Similarly, the affected age group of that particular place with specific time exposure is given by $P_{age} = \frac{\int y \mu_P(y) dy}{\int \mu_P(y) dy} =$

$$\frac{1}{3}\frac{[w_1(A_3-A_1)(A_1+A_2+A_3)+w_2(A_6-A_4)(A_4+A_5+A_6)+w_3(A_9-A_7)(A_7+A_8+A_9)]}{[w_1(A_3-A_1)+w_2(A_6-A_4)+w_3(A_9-A_7)]} \qquad (17)$$

And the expected exposure time duration of noise for a particular place is given by

$$T_{expo} = \frac{\int t\, \mu_T(t) dt}{\int \mu_T(t)\, dt}$$

$$= \frac{1}{3}\frac{[w_1(T_3-T_1)(T_1+T_2+T_3)+w_2(T_6-T_4)(T_4+T_5+T_6)+w_3(T_9-T_7)(T_7+T_8+T_9)]}{[w_1(T_3-T_1)+w_2(T_6-T_4)+w_3(T_9-T_7)]} \qquad (18)$$

where *w's* are the corresponding weights for those particular parameters.

However, to assess the various risk indexes of the noise parameters we consider the following:

a) If observed value > expected standard value then risk index for noise level is

$$I_{nr} = \frac{N_{noise}^{obs} - N_{noise}^{exp}}{N_{noise}^{obs}} \quad \text{(Risk mode)} \qquad (19)$$

b) If observed value ≤ expected value then

$$I_{ns} = \frac{N_{noise}^{exp} - N_{noise}^{obs}}{N_{noise}^{exp}} \quad \text{(Safety mode)} \quad (20)$$

c) If observed value > expected standard value then risk index for specific age group is

$$I_{pr} = \frac{P_{age}^{obs} - P_{age}^{exp}}{P_{age}^{obs}} \quad \text{(Risk mode)} \quad (21)$$

d) If observed value ≤ expected value then

$$I_{ps} = \frac{P_{age}^{exp} - P_{age}^{obs}}{P_{age}^{exp}} \quad \text{(Safety mode)} \quad (22)$$

e) If observed value > expected value then risk index for time exposure is

$$I_{tr} = \frac{T_{expo}^{obs} - T_{expo}^{exp}}{T_{expo}^{obs}} \quad \text{(Risk mode)} \quad (23)$$

f) If observed value ≤ expected value then

$$I_{ts} = \frac{T_{expo}^{exp} - T_{expo}^{obs}}{T_{expo}^{exp}} \quad \text{(Safety mode)} \quad (24)$$

Now , in Venn diagram, the total risk index can be shown in Fig.-5 and it can be evaluated by applying the probability rule Blaikieet *al.*[3]

$$P(N + A + T) = P(N) + P(A) + P(T) - P(N)P(A) - P(A)P(T) - P(N)P(T) + P(N)P(A)P(T) \quad (25)$$

And get the formulae for total risk index as ,

$$I_r = I_{nr} + I_{pr} + I_{tr} - I_{nr}I_{pr} - I_{pr}I_{tr} - I_{tr}I_{nr} + I_{nr}I_{pr}I_{tr} \quad (26)$$

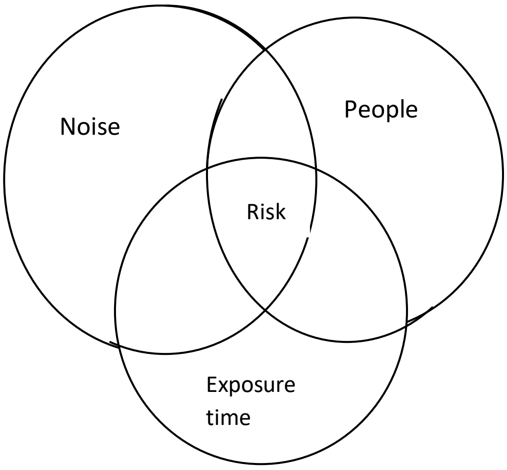


Fig.-5: Venn diagram of noise risk index

The complete scheme of noise modeling is given by **Fig.-6.**

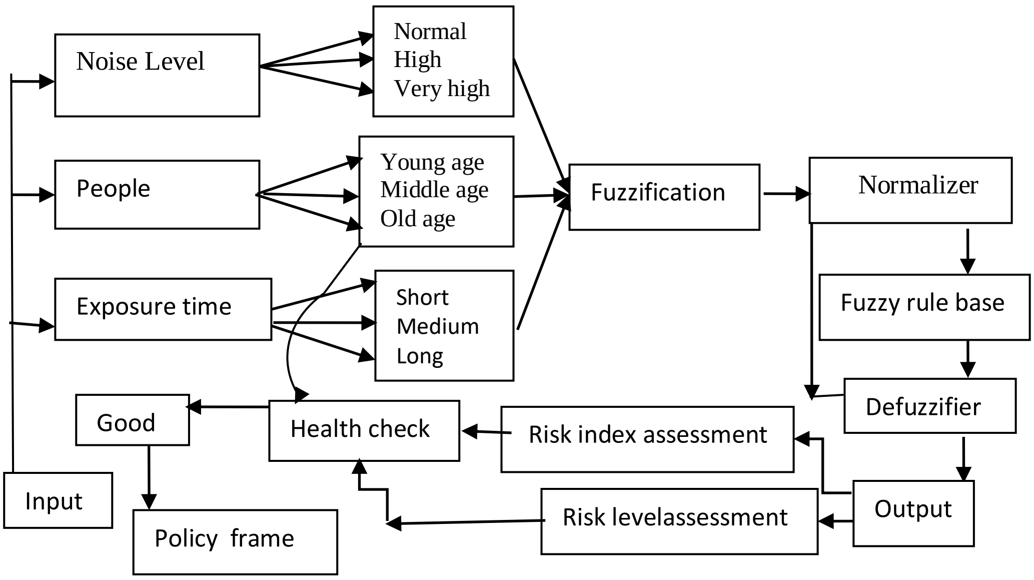


Fig.6: A complete overview of fuzzy noise risk Assessment

4. Numerical Illustrations

Suppose, in Baranasi city (State of Uttar Pradesh, India), the following observations are found (shown in **Table-3).**

Table-3: Observed noise inputs at Baranasi city (India)

Parameters	**Group/Class**	**Fuzzy intervals**	**Observed data**
Noise level	Normal	$< L_1 , L_2 , L_3 >$	< 80,95,100 >
	High	$< L_4 , L_5 , L_6 >$	< 95, 100, 115 >
	Very high	$< L_7 , L_8 , L_9 >$	<108, 120, 128 >
Age	Young age	$< A_1 , A_2 , A_3 >$	< 18, 25, 38 >
	Middle age	$< A_4 , A_5 , A_6 >$	< 35, 42, 58 >
	Old age	$< A_7 , A_8 , A_9 >$	< 55, 65, 82 >
Exposure time	Short	$< T_1 , T_2 , T_3 >$	< 30, 60, 90 >
	Medium	$< T_4 , T_5 , T_6 >$	< 85, 125, 180 >
	Long	$< T_7 , T_8 , T_9 >$	< 180, 210, 250>

Now, we shall applying risk analysis formulas from (9), (13), (15) and (16-26) to get the results obtained in Tables-(4,5).

Table-4: Fuzzy out puts and risk measures **(** *N*, *A*, *T* are normal standard**)**

Parameters	Compromise level of standard based on local authority	Expected level based on observed data	Component wise expected risk index (%)	Total expected risk index (%)
Noise level dB(A)	87.03	103.92	19.41	19.98
Age group (Years)	47.20	46.68	0(-1.10)	(20.86)
Exposure time (Seconds)	132.13	133.06	0.71	< 30

Table-5: Fuzzy out puts and risk measures

Parameters	Risk measures (%)		
	NS	S	PS
Noise level (dB)	12.43	19.41	28.56
Age group (Years)	0/(-19.22)	0/(-1.1)	24.92
Exposure time (Seconds)	0/(-23.26)	0.71	32.83

NS=Negative Standard (Low) ; S= Normal Standard(Medium);
PS= Positive Standard (High)

The fuzzy outputs of Table-4 shows, compromise noise level along with time exposure of standard based on affective age group recognized by local municipal authority. However, the expected noise level with exposure time based on observed data put in column 3. Column 4 and 5 shows component wise risk measure and total risk measure respectively. The value under parentheses shows the risk level under non adaptive groups of study. Table-5 shows a simulated data for various noise levels and exposure time duration in the particular place having affected age groups namely young, medium and old aged groups dominated society.

Table-6 gives the all possible simulated dataset for various noise risk measures, component wise of the people of various affected age groups.

Table-6: Risk index for different age groups

No.	Noise level (dB)	Age group (Years)	Exposure time (Seconds)	Total risk index (%)	Remarks (Risk)
1	S	S	S	19.98/20.86	Low
2	S	S	NS	19.41/20.29	Low
3	S	S	PS	45.87/46.46	Medium
4	S	NS	NS	19.41/34.90	Low/Medium
5	S	NS	S	19.98/35.36	Low/ Medium
6	S	NS	PS	45.86/56.27	Medium

7	S	PS	S	39.92	Medium
8	S	PS	NS	39.49/53.57	Medium
9	S	PS	PS	59.36	High
10	NS	S	S	13.05/14.01	Low
11	NS	S	NS	12.43	Low
12	NS	S	PS	41.18/41.83	Medium
13	NS	NS	S	13.05/29.76	Low
14	NS	NS	NS	12.43/29.26	Low
15	NS	NS	PS	41.17/52.48	Medium
16	NS	PS	S	34.72	Medium
17	NS	PS	NS	34.25/49.54	Medium
18	NS	PS	PS	55.84	Medium
19	PS	S	S	29.07/29.85	Low
20	PS	S	NS	28.56/29.35	Low
21	PS	S	PS	52.01/52.54	Medium
22	PS	NS	S	29.07/42.70	Low/Medium
23	PS	NS	NS	28.56/42.29	Low/Medium
24	PS	NS	PS	51.01/61.23	Medium/High
25	PS	PS	S	46.74	Medium
26	PS	PS	NS	46.36/58.84	Medium/High
27	PS	PS	PS	63.97	High

NS=Negative Standard (Low) ; S= Normal Standard(Medium);
PS= Positive Standard (High)

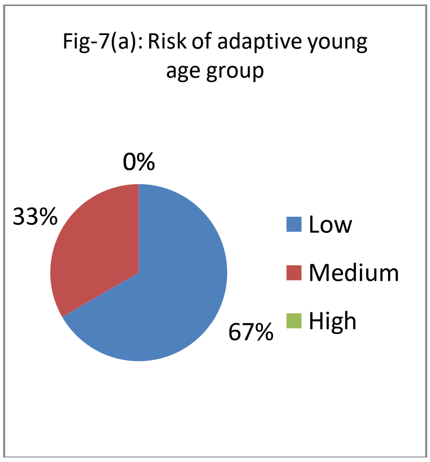
Now we shall make a summary on the output of Table-6 in Table-7. The data of the second row of each component except for middle aged group shows the non adaptive fuzzy outputs.

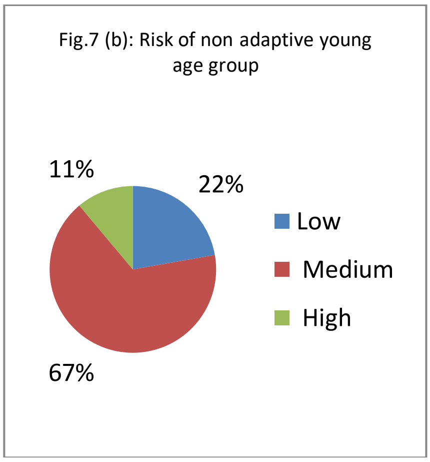
Table-7: Frequency count of different risk measures

Age group	Low	Medium	High
Young	6	3	0
	2	6	1
Middle	6	3	0
Old	0	7	2
	0	6	3

5. Graphical illustrations of different risk measures

We take the data set of Table-7 to draw the age group wise risk analysis and it can be stated in Figures-7(a), 7(b), 8(a), 8(b), 9 and 10 respectively.





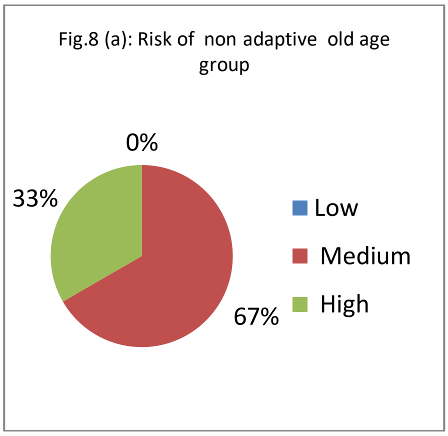


Fig.8 (a): Risk of non adaptive old age group
0%
33%
67%
Low
Medium
High

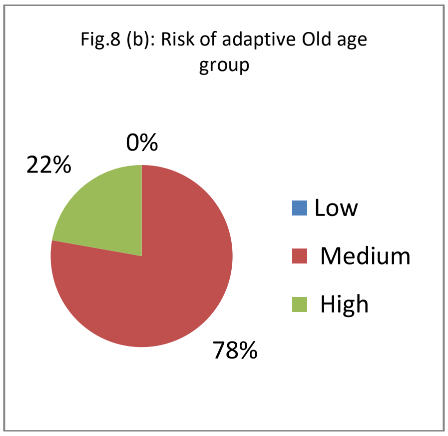


Fig.8 (b): Risk of adaptive Old age group
0%
22%
78%
Low
Medium
High

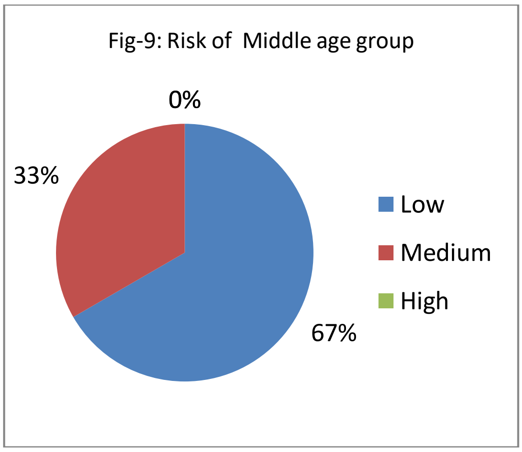


Fig-9: Risk of Middle age group
0%
33%
67%
Low
Medium
High

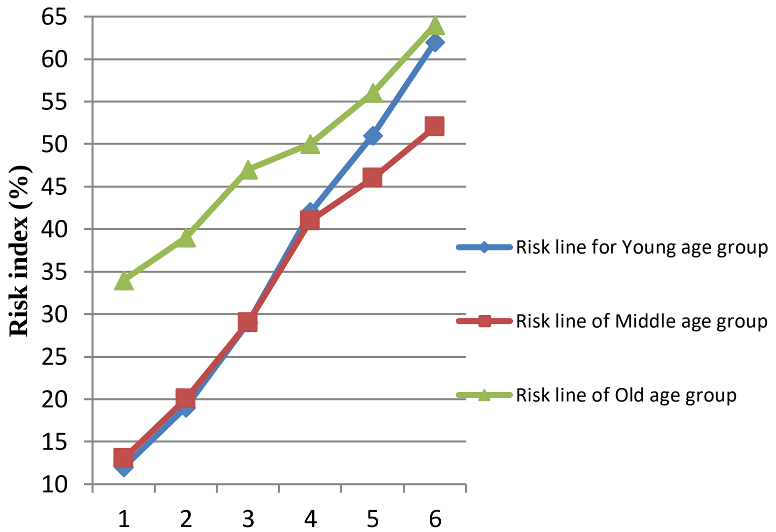


Fig.-10: Risk curves for different Age groups under several observations

5.1 Discussion on figures -7(a), 7(b), 8(a), 8(b), 9 and 10

Figure 7(a) shows, the thrust of noise pollution may affect on adaptive younger generation by 67% low and 33% medium, no high risk has been found in this study. Figure 7(b) explores, the noise pollution may harm highly by 11% on non adaptive younger group, medium by 67% low by 22% alone.

Figure 8(a) shows, the noise pollution may affect on non adaptive old age group by 67% medium, 33% high and no low risk has been found yet. Figure 8(b) explores, the noise pollution might harm highly by 22% on adaptive old age people, medium by 78% and no low risk has been observed yet.

Figure 9 shows tremendously, for the case of middle age group, the thrust of noise pollution may affect 67% low and 33% medium, no high risk is seen. Figure 10 reveals, a comparative study on risk factors among Young, Middle aged and Old aged people due to noise pollution of a particular area. The graph shows, up to near 40 % risk , the medium risk, whether the young or the middle aged people would follow the same risk curve. But after that, the curve for middle aged group began to get bend downwards and that for younger group began to increase and finally meet the old aged group curve instead. This graph also explained that the old aged group are more endanger condition , the risk curve having being increasing to 65% risk for which immediate measures have to take care of.

6.Conclusion

Compromisationof noise pollution is quite non tolerable to every citizen because of health disorders. So any body will search their won comfort level of noise pollution to maximum extent in their day to day livelihood. But question arise: what way they should measure the same and how much authentic it is? We know, the sleep disturbances, anxiety, hearing problems, cardiac problems etc. are one of the negative externalities of the noise pollution. However, some people are affecting with such types of syndrome every time and years after year, meansthe sever genetic change of human body takes place so that the total population slowly getting deafness. By this study we have measured the risk of noise level for each of the age groups separately. Employing fuzzy logic, we can able to capture the pollution process of a noise prone zone. Again the data for normal standard may be harmful to any age groups, thus we have incorporated the reverse logic of risk by assessing the safety mode as well as risk measures of noise pollutions. The clinical study reveals the old aged group people are affecting more by this pollution.

By this study we have developed the following:

i) The measures of noise level can be found from a single formula
ii) The affected age group can be evaluated directly from simple formula
iii) The feedback mechanism and overall assessment of noise pollution can be found in more simplified form
iv) The fuzzy outputs may be changed with the change of standard recognized noise data.

Acknowledgements

I am very much thankful to Editor-in chief, Associate Editors of this esteemed journal to improve the presentation of this article.

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