Adaptive noise risk modelling: fuzzy logic approach

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\textbf{ABSTRACT}

Recently, noise pollution has taken place as one of the most human health disorders. The main sources of noise are coming from human malpractices on reckless car driving and the use of loud speakers in different festivals at different places. Behavioural study explores that in many places the local usual road traffic noise level exceeds the normal standards. However, few people have adaptive capacity to ignore the effect of ambient noise pollution within considerable limits. Thus, in this article, we have developed an adaptive traffic noise model over the vulnerable society of a specific noise-prone zone. We develop a fuzzy logic to analyse the noise risk, and then it has been compared by the odds ratio of the experimental data. Moreover, we have considered the normality and non-normality in participation for various noise parameters, namely noise level, exposure time and affected age group of the people of a particular place as well. Finally, graphical illustrations are made for global justification of the model.

1. Introduction

The modern technology has given us a comfortable life and it becomes increasing with the urge of human beings. Automation is one of the most essential parts of technological as well as machinery development for uplifting the human civilization. Again, the sounds obtained from several vehicles keep the major role to create health hazards especially over cardiovascular problems among the people of different countries. Thus, noise pollution has become a major concern of communities living in the vicinity of highways/road corridors, and intersections (Goswami, 2009, 2011; Goswami & Swain, 2012a, 2012b; Goswami, Swain, Mohapatra, & Bal, 2013; Swain & Goswami, 2012, 2013a, 2013b, 2014; Swain, Goswami, & Das, 2013; Swain, Goswami, & Panda, 2012; Swain, Goswami, & Tripathy, 2012; Swain, Panda, & Goswami, 2012). Sleep disturbance is a major component of the health issue of transportation noise (Annon, 1952; Berglund, Lindvall, & Schwela, 1999; Burgess, 1977; Fritschi, Brown, Kim, Schwela, & Kephalopoulos, 2011). The physiological effect of transporting noise on human sleep may depend more on the level and number of noise events in traffic streams than on energy equivalent measures (Griehahn, Marks, & Robens, 2006; Griffiths & Langdon, 1968; Pirrera, De Valck, & Cluydt, 2010). The emergence of noise annoyance may also be determined, at least in part, by noise events, which distract attention and interfere with activities (Björkman, 1991; De Coensel et al., 2009; Sato, Yano, Björkman, & Rylander, 1999). Basically, people from different countries of the world are suffering mainly from cardiovascular problems. Babisch, Beule, Schust, Kersten, and Ising (2005) developed a road traffic noise risk model using $L_{den}$ values and computed odds ratios (ORs) of various noise levels to measure the health hazards due to noise pollution. Blaikie, Wise, Cannon, and Davis (1994) analysed the pressure and release model by considering the risk $R = H \times V \times E$ ($H =$ hazard, $V =$ vulnerability, $E =$ exposure) on vulnerable society in the account of natural disaster management problems. Sekhavati, Mohammadizadeh, Mohammadfam, and Zarandi (2015) developed a noise pollution risk ($R$) assessment model considering possibility ($P$) of occurring the noise, encounter rate ($E$) and consequence of severity ($C$) as a whole using the formula $R = C \times E \times P$ and finally they have used William Fine method to make a wise decision. Besides this, legal control on noise pollution was studied by Singh (2016).

However, the concept of fuzzy logic is quite new in the application of noise modelling. Zadeh (1973, 1975, 1996) gave the first concept to deal with more complex problems and decision-making under fuzzy environment. Recently, Gulliver et al. (2015) developed a noise exposure...
model to identify the best possible level of human health. Prakash and Veerappa (2015) were able to interpret the effects of noise pollution on human being, using fuzzy logic techniques. On the other hand, with the help of precautionary principle, the problem of risk management was studied by Cameron and Peloso (2005). The authors such as Haimes (2009) and Takas (2010) have developed several models over multilevel fuzzy approach to risk and disaster management for studying the noise annoyance. Shivdev, Nagarajappa, Lokeshappa, and Kusagur (2015) discussed empirically a noise pollution model considering noise level \( N \), affected people of different age \( A \) groups and exposure time duration \( T \) by the formula \( R = N \times A \times T \). Utilizing this formula via fuzzy logic control, they were able to find the resultant pollution level and total risk also.

In adaptive network, several attempts have been made with the help of fuzzy logic by the authors such as Jang (1993), Kukolj (2002), etc. Mamdani and Assilian (1975) studied with the linguistic synthesis with a fuzzy logic control. Mishra, Rathore, Ahmad, and Mallick (2012) were able to develop a traffic constable’s comfort modelling under noise pollution using noise level, exposure time and traffic density as decision parameters by IF–THEN rules in fuzzy expert system. Nouri, Zare, and Alavi (2012) discussed over fuzzy modelling for noise annoyance in urban environment. The complex noise control system was studied by Takagi and Sugeno (1985). Zaheeruddin, Shing, and Jain (2003) studied a fuzzy modelling of human work efficiency in noisy environment; Zaheeruddin and Jain (2004) discusses the effects of noise pollution on human performance under fuzzy modelling. Using fuzzy expert system, the health disorder due to sleep disturbance was analysed by Zaheeruddin and Jain (2006), Prakash and Veerappa (2015), which has kept a remarkable destination over the subject. In addition, at least 37% death (30–44 years of age group) of the total death for environmental pollution occurs due to road traffic incidence as per report made by Mohan (2004) in Indian scenario. On medical aspects, several attempts over ischaemic heart disease, sleep disturbance and cardiovascular failure have been analysed by Marathe (2012), Saseedharan, Pathrose, Chaddha, and Dahale (2015), Miao et al. (2016) in recent times.

From the above study we notice that none of the researchers has considered the process of adaptation in the three valued risk models. In this article we consider a case study first, and then we have discussed all possible cases of age groups (Gaussian normality and non-normality) who are actually dominating the society. To qualify the model, we classify each of the noise parameter into three different intervals. Then we develop appropriate triangular fuzzy sets. Thereafter, centre of gravity method has been utilized upon net membership function and score functions (to the cases of adaptations) for defuzzifications. Finally, various expected noise parameters along with risk measures are computed and the results are being compared by the ORs explicitly. Graphical illustrations are made for its global justification also.

### 1.1. Case study

The present study was conducted along NH-316 near Puri City [19°48′ North latitude and 85°52′ East longitude (Figure 1)] during May 2015. The basic data were gathered using digital maps and field observations. The noise levels were measured following standard procedure using calibrated sound level (dB(A)) meter (Model LUTREN, SL-4010). The experimental data are recorded by means of average value during day, evening and night time and these are put in Tables 1–3.

![Figure 1. Study area in India.](image)

| Parameters     | Group/class | Linguistic fuzzy value | Observed data |
|----------------|-------------|------------------------|---------------|
| Noise level    | Normal      | (night, evening, day)  | (79, 83, 93)  |
|                | High        | (night, evening, day)  | (88, 99, 110) |
|                | Very high   | (night, evening, day)  | (103, 116, 121)|
| Exposure time  | Short       | (night, evening, day)  | (30, 60, 90)  |
|                | Medium      | (night, evening, day)  | (85, 120, 200)|
|                | Long        | (night, evening, day)  | (180, 200, 240)|

Note: Day time – 7 am to 7 pm (12 h); evening time – 7 pm to 11 pm (4 h); night time – 11 pm to 7 am (8 h); areas up to 100 m around certain premises such as hospitals, educational institutes and courts may be declared as silence zone.
Table 2. Observed noise fuzzy inputs.

| Parameters   | Group/class | Fuzzy intervals | Observed data |
|--------------|-------------|-----------------|---------------|
| Noise level  | Normal      | \((L_1, L_2, L_3)\) | \((79, 83, 93)\) |
|              | High        | \((L_4, L_5, L_6)\) | \((88, 99, 110)\) |
|              | Very high   | \((L_7, L_8, L_9)\) | \((103, 116, 121)\) |
| Age          | Young age   | \((A_1, A_2, A_3)\) | \((20, 30, 38)\) |
|              | Middle age  | \((A_4, A_5, A_6)\) | \((35, 42, 58)\) |
|              | Old age     | \((A_7, A_8, A_9)\) | \((55, 62, 80)\) |
| Exposure time| Short       | \((T_1, T_2, T_3)\) | \((30, 60, 90)\) |
|              | Medium      | \((T_4, T_5, T_6)\) | \((85, 120, 200)\) |
|              | Long        | \((T_7, T_8, T_9)\) | \((180, 200, 240)\) |

Table 3. Recognized adaptive noise inputs.

| Parameters | Group/class | Fuzzy intervals | Observed data |
|------------|-------------|-----------------|---------------|
| Noise level| Medium      | \((L_{10}, L_{11}, L_{12})\) | \((85, 110, 118)\) |
| Age group  | Young age   | \((A_{10}, A_{11}, A_{12})\) | \((25, 32, 42)\) |
| Exposure time| Medium  | \((T_{10}, T_{11}, T_{12})\) | \((100, 180, 240)\) |

Note: Noise level standards according to Central Pollution Control Board (CPCB, 2000), India.

2. Model assumptions

2.1. The following assumptions are made to develop the fuzzy noise model

(i) The area under study is a popular commercial and residential tourist spot.

(ii) The data are real-time data and the source distances and speed of noise have been ignored.

(iii) The affected people under study are of middle and old age. Young-aged people usually ignore whatever the pollution of noise is.

(iv) The adaptation reported on the basis of hearing problems, sleep disturbances, cardiac problems, work inefficiencies, attention loss, etc.

2.2. Concept of normality (Karmakar, De, & Goswami, 2015)

Here we analyse the different noise parameters such as noise levels, age groups of the people and the exposure time under Gaussian normality and non-normality curve. The graphical representation of the proposed noise levels is given by Figures 2–4 and likewise we use this for the other cases also.

2.3. The problem under study is stated as follows

(i) Does the observed data really responsible for affecting the public health in the city?

(ii) What is the expected reduced adaptive noise level, exposure time duration and affected age group of that city?

(iii) What is the observed expected noise level, exposure time duration and affected age group of that city?

2.4. Babisch (2000): The ODDS ratio (OR) for assessing noise risk

The expected noise level \(L_{\text{den}}\) for 24 h in a day is given by the following formula:

\[
L_{\text{den}} = 10 \log \left[ \frac{1}{24} \left(12.10^{\text{day} / 10} + 4.10^{\text{evening} + 5 / 10} + 8.10^{\text{night} - 15 / 10}\right) \right].
\]
Here we assume: day time – 7 am to 7 pm (12 h); evening time – 7 pm to 11 pm (4 h); night time – 11 pm to 7 am (8 h) as per local time table. The corresponding exposure-response (relative risk) equation is obtained as follows:

\[
OR = 1.629657 - 0.000613 (L_{\text{den}} - 2)^2 + 0.000007357 (L_{\text{den}} - 2)^3.
\]  

(2)

3. Fuzzy noise modelling (NAT model, noise–age–time model)

Here, first of all we shall classify the most common standards (Shivdev et al., 2015) of the parameters regarding noise pollution and it is stated in Table 4. We also assume that the pollution level is the function of three independent variables, namely noise level \(N\), age level \(A\) and exposure time \(T\). Thus the pollution function becomes \(P = f(N, A, T)\).

Now, we use the triangular fuzzy variables to quantify the linguistic fuzzy variables and it is defined in Table 5.

The graphical representations of the fuzzy membership functions for the several fuzzy noise inputs are stated in Figures 5–7.

Table 4. Classification of standard noise inputs/outputs.

| Parameters      | Group/class | Fuzzy intervals   |
|-----------------|-------------|-------------------|
| Noise level     | Normal      | 0–75 dB(A)        |
|                 | High        | 72–110 dB(A)      |
|                 | Very high   | 105–130 dB(A)     |
| Age             | Young age   | 20–40 years       |
|                 | Middle age  | 35–60 years       |
|                 | Old age     | 55–80 years       |
| Exposure time   | Short       | 0–90 s            |
|                 | Medium      | 85–180 s          |
|                 | Long        | > 170 s           |
| Health effects  | Low risk    | 0–30%             |
|                 | Medium risk | 28–60%            |
|                 | High risk   | > 57%             |

Note: Noise level standards according to CPCB (2000), India.

Table 5. Noise inputs in terms of compromise fuzzy interval (as per Table 4).

| Parameters      | Group/class | Fuzzy variables | Fuzzy intervals   |
|-----------------|-------------|-----------------|-------------------|
| Noise level     | Normal      | \((L_1, L_2, L_3)\) | (10, 50, 75)      |
|                 | High        | \((L_4, L_5, L_6)\) | (72, 85, 110)     |
|                 | Very high   | \((L_7, L_8, L_9)\) | (105, 120, 130)   |
| Age             | Young age   | \((A_1, A_2, A_3)\) | (20, 25, 35)      |
|                 | Middle age  | \((A_4, A_5, A_6)\) | (38, 50, 60)      |
|                 | Old age     | \((A_7, A_8, A_9)\) | (57, 65, 80)      |
| Exposure time   | Short       | \((T_1, T_2, T_3)\) | (10, 50, 90)      |
|                 | Medium      | \((T_4, T_5, T_6)\) | (85, 120, 180)    |
|                 | Long        | \((T_7, T_8, T_9)\) | (170, 200, 250)   |

Note: IS 4954 (1968) and Noise level standards according to CPCB (2000), India.

3.1. Membership considerations

We consider the degrees of membership functions of the various types of noise level, different age groups of the people and the exposure time of the noisy zone, respectively, as follows:

3.1.1. Noise level

(i) For normal noise level

\[
\mu_{1N}(x) = \begin{cases} 
  x - L_1 & \text{for } L_1 < x < L_2, \\
  \frac{L_2 - L_1}{L_3 - L_2} (x - L_1) & \text{for } L_2 < x < L_3, \\
  0 & \text{elsewhere.}
\end{cases}
\]  

(3)
(ii) For high noise level

\[ \mu_{2N}(x) = \begin{cases} \frac{x - L_4}{L_5 - L_4} & \text{for } L_4 < x < L_5, \\ \frac{L_6 - x}{L_6 - L_5} & \text{for } L_5 < x < L_6, \\ 0 & \text{elsewhere.} \end{cases} \] (4)

(iii) For very high noise level

\[ \mu_{3N}(x) = \begin{cases} \frac{x - L_7}{L_8 - L_7} & \text{for } L_7 < x < L_8, \\ \frac{L_9 - x}{L_9 - L_8} & \text{for } L_8 < x < L_9, \\ 0 & \text{elsewhere.} \end{cases} \] (5)

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

\[ \mu_N(x) = \frac{1}{n} [w_1 \mu_{1N}(x) + w_2 \mu_{2N}(x) + w_3 \mu_{3N}(x)], \] (6)

subject to \( w_1 + w_2 + w_3 = 1, \)

\[ n = \text{total number of levels, here } n = 6. \] (7)

3.1.2. Age level of human population

(iv) For young age group

\[ \mu_{1P}(y) = \begin{cases} \frac{y - A_1}{A_2 - A_1} & \text{for } A_1 < y < A_2, \\ \frac{A_3 - y}{A_3 - A_2} & \text{for } A_2 < y < A_3, \\ 0 & \text{elsewhere.} \end{cases} \] (8)

(v) For middle-age group

\[ \mu_{2P}(y) = \begin{cases} \frac{y - A_4}{A_5 - A_4} & \text{for } A_4 < y < A_5, \\ \frac{A_6 - y}{A_6 - A_5} & \text{for } A_5 < y < A_6, \\ 0 & \text{elsewhere.} \end{cases} \] (9)

(vi) For old age group

\[ \mu_{3P}(y) = \begin{cases} \frac{y - A_7}{A_8 - A_7} & \text{for } A_7 < y < A_8, \\ \frac{A_9 - y}{A_9 - A_8} & \text{for } A_8 < y < A_9, \\ 0 & \text{elsewhere.} \end{cases} \] (10)

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

\[ \mu_P(y) = \frac{1}{6} [w_1 \mu_{1P}(y) + w_2 \mu_{2P}(y) + w_3 \mu_{3P}(y)]. \] (11)

3.1.3. Exposure time of noise

(vii) For short exposure time

\[ \mu_{1T}(t) = \begin{cases} \frac{t - T_1}{T_2 - T_1} & \text{for } T_1 < t < T_2, \\ \frac{T_3 - t}{T_3 - T_2} & \text{for } T_2 < t < T_3, \\ 0 & \text{elsewhere.} \end{cases} \] (12)

(viii) For medium exposure time

\[ \mu_{2T}(t) = \begin{cases} \frac{t - T_4}{T_5 - T_4} & \text{for } T_4 < t < T_5, \\ \frac{T_6 - t}{T_6 - T_5} & \text{for } T_5 < t < T_6, \\ 0 & \text{elsewhere.} \end{cases} \] (13)

(ix) For long exposure time

\[ \mu_{3T}(t) = \begin{cases} \frac{t - T_7}{T_8 - T_7} & \text{for } T_7 < t < T_8, \\ \frac{T_9 - t}{T_9 - T_8} & \text{for } T_8 < t < T_9, \\ 0 & \text{elsewhere.} \end{cases} \] (14)

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

\[ \mu_T(t) = \frac{1}{6} [w_1 \mu_{1T}(t) + w_2 \mu_{2T}(t) + w_3 \mu_{3T}(t)]. \] (15)

Now defuzzifying Equations (6), (11) and (15), we can easily get the expected noise level.

3.2. Normal adaptive level consideration

Here we assume the adaptive level of noise parameters recognized by the authority of the particular society and it can be put in Table 6.

The corresponding membership function of the adaptive noise parameters are given by

(x) For noise level

\[ \delta_N(x) = \begin{cases} \frac{x - L_{10}}{L_{11} - L_{10}} & \text{for } L_{10} < x < L_{11}, \\ \frac{L_{12} - x}{L_{12} - L_{11}} & \text{for } L_{11} < x < L_{12}, \\ 0 & \text{elsewhere.} \end{cases} \] (16)

Table 6. Classification of normal adaptive noise inputs.

| Parameters | Group/class | Fuzzy intervals |
|------------|-------------|-----------------|
| Noise level | Medium | \([L_{10}, L_{11}, L_{12}]\) |
| Age        | Young age  | \([A_{10}, A_{11}, A_{12}]\) |
| Exposure time | Medium | \([T_{50}, T_{51}, T_{52}]\) |
(xi) For age group

\[
\delta_p(y) = \begin{cases} 
\frac{y - A_{10}}{A_{11} - A_{10}} & \text{for } A_{10} < y < A_{11}, \\
\frac{A_{12} - y}{A_{12} - A_{11}} & \text{for } A_{11} < y < A_{12}, \\
0 & \text{elsewhere.}
\end{cases}
\]

(xii) For exposure time

\[
\delta_T(t) = \begin{cases} 
\frac{t - T_{10}}{T_{11} - T_{10}} & \text{for } T_{10} < t < T_{11}, \\
\frac{T_{12} - t}{T_{12} - T_{11}} & \text{for } T_{11} < t < T_{12}, \\
0 & \text{elsewhere.}
\end{cases}
\]

Therefore, the total expected membership functions for the affective groups of the noise parameters are obtained by using Equations (6), (11); (15), (16); and (17), (18), respectively, and they can be defined as follows:

\[
\mu_{EN}(x) = \mu_N(x) - w \delta_N(x), \tag{19}
\]

\[
\mu_{EP}(x) = \mu_P(x) - w \delta_P(x), \tag{20}
\]

\[
\mu_{EN}(x) = \mu_T(x) - w \delta_T(x). \tag{21}
\]

Here, \(w\) is their corresponding participation in the normal standard.

Now, defuzzifying Equations (19)–(21), we can easily get the expected affective noise parameter’s levels. Here we have seen that, the levels can be evaluated independently by the following way:

\[
\int x \mu_{\mu N}(x) \, dx
\]

\[
= \frac{1}{6} \left[ w_1 \int_{L_1}^{L_2} x \mu_{1N}(x) \, dx + w_2 \int_{L_1}^{L_4} x \mu_{2N}(x) \, dx + w_3 \int_{L_1}^{L_8} x \mu_{3N}(x) \, dx \right]
\]

\[
= \frac{1}{36} \left[ w_1 (L_3 - L_1) (L_1 + L_2 + L_3) + w_2 (L_2 - L_1) (L_3 - L_2) + w_3 (L_2 - L_1) (L_3 - L_2) \right]
\]

\[
= \left[ \int \mu_N(x) \, dx \right]
\]

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

\[
= \frac{1}{12} [w_1 (L_3 - L_1) + w_2 (L_2 - L_1) + w_3 (L_2 - L_1)]
\]

Thus, using Equations (22) and (23), the expected noise level for a specific group of people with specific time exposure at a particular place is given by

\[
N_{noise} = \frac{\int x \mu_{\mu N}(x) \, dx}{\int \mu_N(x) \, dx}
\]

\[
= \frac{1}{36} \left[ w_1 (L_3 - L_1) (L_1 + L_2 + L_3) + w_2 (L_2 - L_1) (L_3 - L_2) + w_3 (L_2 - L_1) (L_3 - L_2) \right]
\]

\[
= \frac{1}{12} [w_1 (L_3 - L_1) + w_2 (L_2 - L_1) + w_3 (L_2 - L_1)]
\]

Similarly, the affected age group of that particular place with specific time exposure is given by

\[
\int y \mu_{\mu P}(y) \, dy
\]

\[
= \frac{1}{36} \left[ w_1 (A_3 - A_1) (A_1 + A_2 + A_3) + w_2 (A_2 - A_1) (A_2 + A_3) + w_3 (A_2 - A_1) (A_2 + A_3) \right]
\]

\[
= \frac{1}{3} \left[ w_1 (A_3 - A_1) + w_2 (A_2 - A_1) + w_3 (A_2 - A_1) \right]
\]

\[
= \frac{1}{3} \left[ w_1 (A_3 - A_1) + w_2 (A_2 - A_1) + w_3 (A_2 - A_1) \right]
\]

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

\[
T_{\text{expo}} = \frac{\int t \mu_T(t) \, dt}{\int \mu_T(t) \, dt}
\]

\[
= \frac{1}{36} \left[ w_1 (T_3 - T_1) (T_1 + T_2 + T_3) + w_2 (T_2 - T_1) (T_2 + T_3) + w_3 (T_2 - T_1) (T_2 + T_3) \right]
\]

\[
= \frac{1}{3} \left[ w_1 (T_3 - T_1) + w_2 (T_2 - T_1) + w_3 (T_2 - T_1) \right]
\]

However, the affected expected adaptive noise parameters’ levels are given by
\[ N_{\text{affect}}^{\text{noise}} = N_{\text{noise}} - \frac{1}{3} w(L_{10} + L_{11} + L_{12}), \quad (27) \]
\[ p_{\text{affect}}^{\text{age}} = p_{\text{age}} - \frac{1}{3} w(A_{10} + A_{11} + A_{12}) \quad (28) \]

and
\[ T_{\text{affect}}^{\text{expo}} = T_{\text{expo}} - \frac{1}{3} w(T_{10} + T_{11} + T_{12}), \quad (29) \]

where \( w \) is the corresponding weight for those particular parameters.

Moreover, to assess the various risk indexes of the noise parameters, we use the formula developed by Omidvar, Ghaebar, and Imani (2006) and they can be defined as follows:

(a) If observed value > expected standard value, then risk index for noise level is
\[ I_{nr} = \frac{N_{\text{obs}} - N_{\text{exp}}}{N_{\text{obs}}} \quad \text{(crude risk mode).} \quad (30) \]

(b) If observed value \( \leq \) expected value, then
\[ I_{ns} = \frac{N_{\text{exp}} - N_{\text{obs}}}{N_{\text{exp}}} \quad \text{(fair risk mode).} \quad (31) \]

(c) If observed value > expected standard value, then risk index for specific age group is
\[ I_{pr} = \frac{p_{\text{obs}} - p_{\text{exp}}}{p_{\text{obs}}} \quad \text{(crude risk mode).} \quad (32) \]

(d) If observed value \( \leq \) expected value, then
\[ I_{ps} = \frac{p_{\text{exp}} - p_{\text{obs}}}{p_{\text{exp}}} \quad \text{(fair risk mode).} \quad (33) \]

(e) If observed value > expected value, then risk index for time exposure is
\[ I_{tr} = \frac{T_{\text{obs}} - T_{\text{exp}}}{T_{\text{obs}}} \quad \text{(crude risk mode).} \quad (34) \]

(f) If observed value \( \leq \) expected value, then
\[ I_{ts} = \frac{T_{\text{exp}} - T_{\text{obs}}}{T_{\text{exp}}} \quad \text{(fair risk mode).} \quad (35) \]
Now, in Venn diagram, the total risk index can be shown in Figure 8 and it can be evaluated by applying the probability rule (Omidvar et al. 2006).

\[
P(N + A + T) = P(N) + P(A) + P(T) - P(N)P(A) - P(A)P(T) - P(N)P(T) + P(N)P(A)P(T),
\]

(36)

and get the formulae for total risk index as

\[
l_r = l_{nr} + l_{pr} + l_T - l_{nr}l_{pr} - l_{pr}l_T - l_{nr}l_T + l_{nr}l_{pr}l_T. \tag{37}
\]

The complete scheme of noise modelling is given by Figure 9.

### 4. Numerical illustrations

Here we use the data set obtained from the case study (defined in Tables 1–3).

Now, utilizing the formulas (1) and (2), we get the following results stated in Tables 7 and 8.

#### 4.1. Fuzzy outputs

Here we shall compute numerically for the different input variables by applying above formulas (22), (23) and (24) for non-adaptive and Equations (25), (26) and (26) for adaptive and that for risk (crude and fair) indexes Equations (28)–(35), respectively; these can be put in Tables 9–15.

#### 4.2. Discussion on Tables 9–15

From Table 9, we have, when all the noise parameters are assumed to be normal standard, then the expected observed noise level becomes 99.49 dB(A) with 134.67 s exposure time for the affected age group around 46.67 years having low risk index 17.4%. But whenever we apply adaption of middle-age group, then the rest of the society gets 19.3% risk from that noise pollution. From Table 10 we can see that, for the cases of normal age group of the place and for the higher values of the noise level...
Table 12. Fuzzy outputs and risk measures (young age group, N, T<sup>a</sup>).

| Parameters                  | Compromise level of standard based on local authority | Adaptive level reduction based on recognition | Expected level based on observed data | Component wise risk index | Adaptive risk reduction | Total risk index (100%) | Total risk reduction index (100%) |
|-----------------------------|------------------------------------------------------|---------------------------------------------|--------------------------------------|---------------------------|------------------------|-------------------------|---------------------------------|
| Noise level                 | 80.54                                                | 90.31                                       | 107.00                               | 0.247                     | 0.108                  | 30.14                   | 17.25                           |
| Age group                   | 49.90                                                | 39.52                                       | 39.52                                | −0.208                    | −0.208                 |                         |                                 |
| Exposure time               | 128.33                                               | 167.03                                      | 167.03                               | 0.232                     | 0.232                  |                         |                                 |

<sup>a</sup>Stands for very high.

Table 13. Fuzzy outputs and risk measures (normal N and T but old age).

| Parameters                  | Compromise level of standard based on local authority | Adaptive level reduction based on recognition | Expected level based on observed data | Component wise risk index | Adaptive risk reduction | Total risk index (100%) | Total risk reduction index (100%) |
|-----------------------------|------------------------------------------------------|---------------------------------------------|--------------------------------------|---------------------------|------------------------|-------------------------|---------------------------------|
| Noise level                 | 80.54                                                | 28.547                                      | 99.49                                | 0.188                     | −0.646                 | 33.45                   | −34.91                          |
| Age group                   | 49.90                                                | 57.99                                       | 57.99                                | 0.140                     | 0.140                  |                         |                                 |
| Exposure time               | 128.33                                               | 134.67                                      | 134.67                               | 0.047                     | 0.047                  |                         |                                 |

Table 14. Fuzzy risk indexes under different noise levels (L<sub>den</sub>).

| Methodology                | People exposed | Low   | High  | Very high |
|----------------------------|----------------|-------|-------|-----------|
| OR Normal standard         | 1.15           | 3.39  | 6.52  |           |
| Observed OR                | 1.98           | 3.45  | 5.11  |           |
| Fuzzy outputs              |                |       |       |           |
| City for normal age group  | 1.74           | 2.94  | 3.85  |           |
| City of young-age-dominated group | 1.78     | 2.58  | 3.75  |           |
| City of old-age-dominated group | 2.96     | 4.56  | 5.35  |           |
| City of middle-age-dominated group | 1.61    | 3.75  | 4.86  |           |
| City of adaptive middle-age group | 1.72 | 2.71  | 6.51  |           |

and exposure time, there is a chance of getting medium risk (38.5%) with 107 dB(A) noise level and 167 s exposure time duration approximately. Also for the reduced adaptive group, there is a chance of getting low risk (27.1%) with 90.3 dB(A) noise level for 167 s exposure time duration in that particular place. Table 11 shows that, for normal age group, when noise level assumes low amount but exposure time becomes high, then there is a chance of getting low risk (29.4%) with maximum noise level 93.22 dB(A) and maximum exposure time 167 s. For the reduced adaptive group, the risk impact of noise is 11.9% only. From Table 12 we get, for the place dominated by young-aged people, when the noise level and exposure time assume high, the chance of noise impact becomes medium (30.14%) and that for reduced adaptive group gets low risk 17.25% only. In Table 13, we can see that, when the noise level and exposure time are assumed to be normal and the place dominated by older people, then the chance of getting noise risk impact becomes medium (33.45%) and subsequently the risk of the reduced adaptive group reduces to 34.91% in fair risk mode. Table 14 reveals the comparative study between the existing method and the fuzzy outputs. Here we see the observed low OR is 1.98, which is 72% higher than the normal standard. The maximum risk intervals for the young group is (17.8–37.5%), for old age group is (29.6–53.5%), for middle-age group is (16.1–48.6%) and that for adaptive middle-age group is (17.2–65.1%). In the whole table, we see adaptive age group has the maximum risk limit than the older ones. Table 15 gives the total exposed people of different age group under several noise level (L<sub>den</sub>). Here we see that, for ideal society, in adaptive system the expose of older people becomes high with respect to the other age groups. The young people have 5.7% less expose and the middle-aged people have 11.1% expose reduction, but the older people getting 16.8% more expose with respect to non-adaptive system.

Table 15. People exposed (%) due to road traffic noise pollution.

| Noise level L<sub>den</sub> | % of people exposed (non-adaptive) | % of people exposed (adaptive) | Existing normal<sup>a</sup> (%) | Simulated normal<sup>b</sup> (%) |
|-----------------------------|----------------------------------|--------------------------------|-------------------------------|-------------------------------|
| < 60                        | 19.5                             | 13.1                           | 65.4                          | 18.1                          |
| 61–70                       | 46.6                             | 5.8                            | 16.2                          | 4.4                           |
| 71–80                       | 1.9                              | 1.9                            | 10.5                          | 1.6                           |
| 81–100                      | 1.2                              | 1.0                            | 3.5                           | 0.7                           |
| 101–121                     | 0.4                              | 0.1                            | 2.4                           | 0.8                           |
| Total                       | 27.6                             | 21.9                           | 100                           | 31.9                          |

<sup>a</sup>Census of India 2011: Odisha, Part-XII-B, Series-22, District Census Handbook, Puri. Total populations of Puri city: 1,697,983 (year-2016), affected people – 3.7%.

<sup>b</sup>Results obtained from fuzzy simulation.
5. Graphical interpretations of the model

Here we shall draw graphs to show the global justification of the model. Figure 10 shows a comparative risk study over different noise levels. At low-level noise, the risk is near 2.0, which was supposed to be near 1 in normal standard. The adaptive group has the high risk but it is less with respect to the reported normal standard.

Figure 11 shows, within a specific range of noise level, the observed expected risk index varies from 17.4% to 38.5%. Among them, for the risk spans 17.4–29.4%, the reduced adaptive index shifted from fair risk mode (19.3%) to the low crude risk mode (11.9%) positively. The reduced risk index has a sudden fall towards fair risk mode in between the observed expected risk index range 30.1–33.5% and after that it began to increase towards medium risk mode.

Figure 12 reveals that the risk curve under existing method (OR) dominates the risk curve that obtained from fuzzy outputs for the average and on above noise levels explicitly. Also, for lower noise levels, risk curves attain minimum and observed risk by OR keeps maximum (very high) but that from fuzzy outputs likely to get value within. All the three curves cut each other whenever the noise levels assume medium (high) values. So it is expected that the people are really exposed with severity in health damage of the study place.

Figure 13 shows that the range of risk under normal standard are basically high (10–65%) in Indian scenario. The Puri society having population with normal age size is getting maximum risk (30–40%) against the very high noise level. If we think of young-age-dominated study site, then the trend of risk is something getting high (40–50%) towards high noise thrust. However, if we consider the case of elderly (old)-dominated city then we see that for many of the cases the risk lies within (40–50%), but in rare cases it would reach near 55% implicitly. Wonderfully, we notice that, the adaptive age group of the study site is getting risk within (15–45%) for most of the cases. Furthermore, our study site has rare incidences to occur death due to noise annoyance. But we may suggest to the common people that they should keep themselves beyond affected zone during peak time otherwise to make a policy from the concerned government such that sound pressure can be minimized to sustain the human health for a longer time.

Figure 14 shows the critical region (the zone in between observed and reduced noise levels) of noise level [90.3–93.2 dB(A)] for the exposure time duration 163–167 s. Beyond that, the reduced noise level vary from 28.6 dB(A) to 90.3 dB(A) for exposure time duration 107–167 s. But for normal expected noise levels [93.2–107 dB(A)], the exposure time duration starts from 135 s onwards. In the case of standardized level of noise parameters, the noise levels getting bound at 80.54 dB(A) and the exposure time duration assumes values within 128.3 s alone.

Figure 15 shows the severity triangle based on data survey on road traffic noise pollution. Here we see that people exposed under fair risk constitute 85.1% and those under crude risk make up 14.9%. This study also reveals that the ratio of deaths, hospital treatment and average health disorder is 1:15:70 approximately (data in agreement with Mohan, 2004).
6. Conclusion

In this article we have studied over the noise pollution level and its associated risk upon human health of the Puri City. OR is the existing most popular method to explain the noise risk. Since this formula has some limitations, so we have used fuzzy logic to compute any kind of risk assessment. The focus of attention is health hazards, people exposed due to traffic noise especially. However this study includes the problem such as sleep disturbances and cardiovascular diseases. To tackle the problem, we have computed the ORs of the experimental data obtained from the study area first. Then using triangular fuzzy membership of the several noise parameters (noise levels, age group of the exposed people, exposure time), we get the expected and adaptive noise levels via centre of gravity method of defuzzifications. The crude risks and fair risks are calculated to justify the actual noise thrust that usually hit the people of different age groups in the study area. The novelty of this study lies in the process of computation of various risk measures. Moreover, ORs did not cover the individual risk, but this gap has been removed through the extensive use of strong methodological robustness drives by fuzzy logic itself. In addition, the graphical illustrations explore to what extent the people of the study place are going to be exposed of and what precautionary measures are to be taken care of accordingly on urgent basis.

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References

Anon. (1952). Handbook of acoustic noise control WADC technical report 52–204. Wright Air Development Center.

Babisch, W. (2000). Traffic noise and cardiovascular disease: Epidemiological review and synthesis. Noise & Health, 2(8), 9–32.
Babisch, W., Beule, B., Schust, M., Kersten, N., & Ising, H. (2005). Traffic noise and risk of myocardial infarction. *Epidemiology*, 16, 33–40.

Berglund, B., Lindvall, T., & Schwela, D. H. (1999). *Guidelines for community noise*. Geneva: World Health Organization.

Björkman, M. (1991). Community noise annoyance: Importance of noise levels and the number of noise events. *Journal of Sound and Vibration*, 151(3), 497–503.

Blaikie, P., Wise, B., Cannon, T., & Davis, D. (1994). *Precautionary principle: A fuzzy logic model*. Operations & Logistics, 1, 1–7.

Cameron, E., & Peloso, G. F. (2005). Risk management and the precautionary principle: A fuzzy logic model. *Risk Analysis*, 25(4), 901–911.

Central Pollution Control Board. (2000). *Ambient air quality in respect of noise*. New Delhi: Central Pollution Control Board (Schedule-Part II, Sec. 3).

De Coensel, B., Botteldooren, D., De Mue, T., Berglund, B., Nilsson, M. E., & Lercher, P. (2009). A model for the perception of environmental sound based on notice-events. *The Journal of the Acoustical Society of America*, 126(2), 656–665.

Fritschi, L., Brown, A. L., Kim, R., Schwela, D., & Kephalopoulos, S. (2011). Burden of disease from environmental noise: Quantification of healthy life years lost in Europe. Copenhagen: World Health Organization Regional Office for Europe.

Goswami, S. (2009). Road traffic noise: A case study of Balasore town, Odisha, India. *International Journal of Environmental Research*, 3(2), 309–316.

Goswami, S. (2011). Soundscape of Bhadrak town, India: An analysis from road traffic noise perspective. *Asian Journal of Water, Environment and Pollution*, 8(4), 85–91.

Goswami, S., & Swain, B. K. (2012a). Occupational exposure in stone crusher industry with special reference to noise: A pragmatic appraisal. *Journal of Acoustical Society of India*, 39(2), 70–81.

Goswami, S., & Swain, B. K. (2012b). Preliminary information on noise pollution in commercial banks of Balasore, India. *Journal of Environmental Biology*, 33(6), 999–1002.

Goswami, S., Swain, B. K., Mohapatra, H., & Bal, K. (2013). A preliminary assessment of noise level during deepawali festival in Balasore, India. *Journal of Environmental Biology*, 34(6), 981–984.

Grieffahn, B., Marks, A., & Robens, S. (2006). Noise emitted from road, rail and air traffic and their effects on sleep. *Journal of Sound Vibration*, 295(1–2), 129–140.

Griffiths, I. D., & Langdon, F. J. (1968). Subjective response to road traffic noise. *Journal of Sound and Vibration*, 8, 16–32.

Gulliver, J., Moreley, D., Vienneau, D., Fabbri, F., Bell, M., Goodman, P., . . . Fecht, D. (2015). Development of an open source road traffic noise model for exposure assessment. *Environmental Modelling & Software*, doi:10.1016/j.envsoft.2014.12.022

Haines, Y. Y. (2009). *Risk modeling, assessment and management* (3rd ed.). Hoboken, New Jersey: John Wiley & Sons.

IS 4954. (1968). *Indian Standard. Recommendations for noise abatement in town planning*.

Jang, J. S. R. (1993). ANFIS: Adaptive network based fuzzy inference system. *IEEE Transactions Systems, Man and Cybernetics*, 23, 665–685.

Karmakar, S., De, S. K., & Goswami, A. (2015). A deteriorating EQQ model for natural idle time and imprecise demand: Hesitant fuzzy approach. *International Journal of System Science: Operations & Logistics*, doi:10.1080/23302674.2015.1087070

Kukolj, D. (2002). Design of adaptive Takagi-Sugeno-Kang fuzzy models. *Applied Soft Computing*, 2, 89–103.

Mamdani, E. H., & Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man Machine Studies*, 7, 1–13.

Marathe, P. D. (2012). Traffic noise pollution. *IJED*, 9(1), 63–68.

Miao, W., Wang, L., Cui, Y., Zhang, F., Wang, S., Liu, N., . . . Cai, X. (2016). Noise exposure could increase the mortality of coronary heart disease: Evidence from a meta-analysis. *International Journal of Clinical and Experimental Medicine*, 9(6), 11030–11036.

Mishra, R. V., Rathore, S., Ahmad, S., & Mallick, Z. N. (2012). Modelling of traffic constant comfort level variation in NCR region by fuzzy expert system. *International Journal of Engineering Science and Technology*, 4(5), 2072–2082.

Mohan, D. (2004). *The road ahead: Traffic injuries and fatalities in India*. Delhi: IIT.

Nouri, J., Zare, R., & Alavi, M. (2012). A fuzzy approach for modeling noise annoyance in urban environment. *Archives Des Sciences*, 65(6), 294–305.

Omidvar, B., Ghazban, F., & Imani, S. (2006). Improving existing relations for calculation of natural disaster risk and fair risk management (pp. 1–11). Tehran: Natural Disaster Management Group, University of Tehran.

Pirrera, S., De Valck, E., & Cluydts, R. (2010). Nocturnal road traffic noise: A review on its assessment and consequences on sleep and health. *Environment International*, 36(5), 492–498.

Prakash, T. N., & Veerappa, B. N. (2015). Interpretation of noise pollution effects on human being using fuzzy logic techniques. *International Journal of Computer Science and Mobile Computing*, 4(4), 670–683.

Saseedharan, S., Pathrose, E., Chaddha, R., & Dahale, D. (2015). Statistical study of noise levels in an adult ICU-A case from India. *International Journal of Biomedical Research*, 6(11), 880–886.

Sato, T., Yano, T., Björkman, M., & Rylander, R. (1999). Road traffic noise annoyance in relation to average noise level, number of events and maximum noise level. *Journal of Sound and Vibration*, 223(5), 775–784.

Sekhavati, E., Mohammadizadeh, M., Mohammadfam, I., & Zarandi, A. F. (2015). Noise pollution risk assessment in cement factory of Larestan using William fine method. *Journal of Applied Environmental and Biological Sciences*, 5(8S), 208–213.

Shivdev, P. P., Nagarajappa, D. P., Lokeshappa, B., & Kusagur, A. (2015). Fuzzy logic technique for noise induced health effects in mine site. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(7), 5096–5103.

Singh, R. (2016). Legal control of noise pollution in India: A critical evaluation. *International Journal of Research in Humanities and Social Studies*, 3(4), 34–45.

Swain, B. K., & Goswami, S. (2012). Road traffic noise assessment and modeling in Bhubaneswar, capital of Odisha State, India: A comparative and comprehensive monitoring study. *International Journal of Earth Science and Engineering*, 5(5), 1358–1370.

Swain, B. K., & Goswami, S. (2013a). Integration and comparison of assessment and modeling of road traffic noise in Baripada.
Swain, B. K., Goswami, S. (2013b). Data of monitored highway noise and predictive models: A relative and inclusive case study. *International Journal of Earth Sciences and Engineering, 6*(5), 1079–1085.

Swain, B. K., & Goswami, S. (2014). Analysis and appraisal of urban road traffic noise of the city of Cuttack, India. *Pakistan Journal of Scientific and Industrial Research, 57*(1), 10–19.

Swain, B. K., Goswami, S., & Das, M. (2013). A preliminary assessment of noise level during the Dussehra festival: A case study of Balasore, India. *International Journal of Earth Sciences and Engineering, 6*(2), 375–380.

Swain, B. K., Goswami, S., & Panda, S. K. (2012). Road traffic noise assessment and modeling in Bhubaneswar, India: A comparative and comprehensive monitoring study. *International Journal of Earth Sciences and Engineering, 5*(5), 1358–1370.

Swain, B. K., Goswami, S., & Tripathy, J. K. (2012). Stone crushers induced noise at and around Mitrapur, Balasore, India. *Anwesa, 6*, 12–16.

Swain, B. K., Panda, S., & Goswami, S. (2012). Dynamics of road traffic noise in Bhadrak city, India. *Journal of Environmental Biology, 33*(6), 1087–1092.

Takagi, T., & Sugeno, M. (1985). Fuzzy identification of systems and its application to modeling and control. *IEEE Transactions on Systems, Man and Cybernetics, SMC-15*, 116–132.

Takas, M. (2010). Multilevel fuzzy approach to the risk and disaster management. *Acta Polytechnica Hungarica, 7*(4), 91–102.

Zadeh, L. A. (1973). Outline of a new approach to the analysis of complex systems and decision process. *IEEE Transactions on Systems, Man and Cybernetics, SMC-3*, 28–44.

Zadeh, L. A. (1975). The concept of linguistic variable and its application to approximate reasoning. *Information Sciences, 8*, 199–249.

Zadeh, L. A. (1996). Fuzzy logic = computing with words. *IEEE Transactions on Fuzzy Systems, 4*, 103–111.

Zaheeruddin, & Jain, V. K. (2004). A fuzzy approach for modeling the effects of noise pollution on human performance. *Journal of Advanced Computational Intelligence and Intelligent Informatics, 8*, 332–340.

Zaheeruddin, & Jain, V. K. (2006). A fuzzy expert system for noise induced sleep disturbance. *Expert Systems with Application, 30*(4), 761–771.

Zaheeruddin, Shing, G. V., & Jain, V. K. (2003). Fuzzy modeling of human work efficiency in noisy environment. *Proceedings of the IEEE International Conference on Fuzzy Systems, 1*, 120–124.