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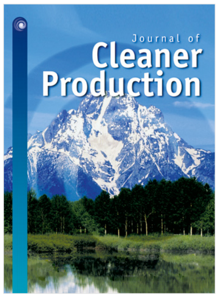


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PII: S0959-6526(21)02466-5
DOI: https://doi.org/10.1016/j.jclepro.2021.128250
Reference: JCLP 128250

To appear in: *Journal of Cleaner Production*

Received date : 17 February 2021
Revised date : 20 June 2021
Accepted date : 6 July 2021

Please cite this article as: T. Bera and N.K. Mahapatra, Ranking of thermal power plants focusing on air pollution: A Neutrosophic assessment. *Journal of Cleaner Production* (2021), doi: https://doi.org/10.1016/j.jclepro.2021.128250.

# Ranking of thermal power plants focusing on air pollution : a Neutrosophic assessment

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**Abstract** This study aims to rank a number of thermal power plants (TPP) based on the emission rate of different air pollutants. It will encourage the managing director of the respective plant to make more attention to lower down the emission rate of pollutants. Since it is almost impossible to assess the emission of pollutants from a TPP on daily basis and as the rate of pollutant discharge from a particular TPP may vary under several grounds, so the emission rates of pollutants are characterized here as uncertain parameter. The discharge rate of air pollutant is assessed in three divided periods instead of taking a unique rate throughout the year to have a fair justification and is expressed by single valued triangular neutrosophic number (*svtrn*-number) to emphasize the hesitancy of experts independently in experimental data. The huge number of data of an *svtrn*-number is manipulated using graded mean integration concept. A methodology is developed to find the rank of plant by making a co-relation between its emission rate of air pollutants and the permissible norm specified by Pollution Control Board of the respective country. A TPP may have several number of power generation units with different capacity. So an importance is also given to each unit of a TPP in measurement of its overall emission rate. A user friendly algorithm is furnished to sketch the methodology and it is illustrated to find the rank of four coal fired power plants at different locations in India. The potentiality of the proposed methodology is claimed after comparing it with some of the existing literatures.

**Keywords** Impact of air pollution on environment; emission in thermal power plants and its standard; neutrosophic set; single valued triangular neutrosophic number; graded mean integration; ranking methodology.

## 1 Introduction

Electricity power plays a key role in industrial and agricultural growth of any country. It enhances the economic development and improves the quality of life. Coal is commonly used as power generation fuel in terms of both cost and energy security over the world, especially in Asian countries. But its combustion releases severe air pollutants like Sulphur dioxide ($SO_2$), Nitrogen oxide ($NO_X$), Carbon monoxide ($CO$), Particulate matters ($PM$), Carbon dioxide ($CO_2$), Ozone ($O_3$), Mercury ($Hg$), Lead ($Pb$) etc which call an adverse impact to environment and human health. These are acidic in nature and so the ecosystem is being gradually destroyed due to increase of such substances. The gaseous emissions like $NO_X$, $SO_2$ etc are converted into particles in presence of air moisture. These particles are the key source of air pollution.

The Ministry of Power in India has expressed that about 80 percent of electricity requirements in the country is met from coal based power plants. Centre for Science and Environment, India shows in a study [29] that coal fired thermal power plants (TPP) are responsible for 60 percent of $PM$ emission, 50 percent of $SO_2$, $NO_X$ emission and more than 80 percent of mercury emissions among all industries. Government of India states by the Economic Survey (Vol. 2) in the year 2016-2017 that the number of deaths linked to coal based power plants pollution is around 115000 annually by negative impact on the respiratory system, cardiovascular diseases, neurological effects, etc. Hence it is urgent to minimize and control the emission of pollutants from coal-fired TPPs through some proper environmental managements. Central Pollution Control Board (CPCB) in India suggests to reduce $PM$ emissions by 40 percent, $SO_2$ and $NO_X$ emissions by 48 percent each, $Hg$ emissions by 60 percent and water consumption by 40 percent [30]. Ministry of Environment, Forest and Climate Change, India brought the new emission standard [31] for TPPs acted on 07.12.2015.

Everyday assessment of the pollutant discharge from a plant is a very tough job. Generally, a single assessment is done monthly basis or in a certain period. Also the daily demand of power generation as well as the fuel consumption in a plant is not unique but its capacity is fixed. Hence, there is a much possibility to have a fluctuation on the rate of pollutant discharge, and thus the emission rate of a TPP is completely uncertain by nature throughout a period. The notion of Zadeh's fuzzy set [28] and Attanasov's intuitionistic fuzzy set [2] were generalised by Smarandache [21] in the field of uncertainty measure. Fuzzy set [28] defines an object by membership value while Intuitionistic fuzzy set [2] addresses it by membership and non-membership value simultaneously. Between acceptance and rejection, there may be a neutral stage as seen in the result of sports event, decision making etc. Neutrosophic set ($NtS$-set) theory [21,22] describes an object in light of three independent views namely acceptance, hesitation and rejection. Thus measurement of uncertainty will be realistic and in a more precise way using $NtS$-set theory than the others.

Air pollution was assessed under fuzzy environment from coal-fired power plants by Li et al. [17]. Rumenjak and Stambuk [20] developed a fuzzy modelling in air protection using linguistic variables. The sources and control of air pollution was described by Heinsohn and Kabel [13]. Two fuzzy modelings for environmental pollution potential ranking of industries were innovated by Lad et al. [15,16] based on air pollution. Upadhyaya and Dashore [26] designed a fuzzy model for monitoring air quality index. Using fuzzy multi-criteria decision making approach, assessments of air quality were made by Chitnis et al [4], Sowlat et al. [24]. Kahyaoglu-Koracin et al. [14] applied a scenario-based modeling to evaluate the air quality impacts of future growth. Soni and Shukla [23] predicted the air pollution in urban areas using neuro-fuzzy concept.

Fisher [11] brought a fuzzy based decision making on application to air pollution. Decision making for personal selection under fuzzy environment was approached by Dursun and Karsak [10], Mammadova and Jabrayilova [18]. Deli and Subas [5,6] developed solution approaches of multi-criteria decision making problems using single valued neutrosophic numbers. Further, two group decision making models were designed by Deli [7,8] under neutrosophic atmosphere. Deli and Ozturk [9] proposed a new single-valued neutrosophic multiple-attribute decision-making method based on fuzzy graph theory and was illustrated in practical field. Angelevska et al. [1] designed a guiding frame for urban air quality to support and assist the local authorities in management of road transport pollution and also to evaluate their effects estimating the changes in air pollution levels. Air quality indices are generally defined depending on the main pollutants and ignore the compositional nature of the concentrations of air pollutants. To improve this understanding, Gibergans-Baguena et al. [12] brought some steps based on compositional data analysis. Qerimi et al. [19] directed a model to use solar thermal energy in urban areas by giving a proposal on replacement of the conventional water heaters with the domestic solar water heaters. The emissions related to food transportation were studied by Striebig et al. [25] to determine what impact getting local food instead of non-local food could make on the overall emissions of the food system.

This work develops a methodology to find the rank of a number of coal fired TPPs with respect to the the emission of air pollutants. The motivation is to make a healthy competition among these TPPs to lower down the emission rate which is too much necessary for the benefit of human society and for our natural environment. A TPP don't emit the pollutants at a constant rate throughout a period due to climate change, fluctuation of power generation, use of upgraded technology, the quality and quantity of fuel used, etc. Also, it is almost impossible to measure the discharge rate of pollutants everyday for a TPP. In that perspective, it is intelligent to assess the emission rate of pollutants as uncertain parameter. Here, it is expressed by single valued triangular neutrosophic number (*svtrn*-number) to cultivate the hesitancy of experts independently in experimental data, and this matter is realistic and acceptable in uncertain scenario. The huge number of data of an *svtrn*-number is manipulated by use of Graded mean integration concept. A TPP may have multi power generation units with distinct capacity, and the emission rate of pollutants for all units may not be same. To put an importance to each unit of a TPP, this study considers a mean discharge rate of pollutants on behalf of all units. The assessment is done in three divided periods instead of taking a unique rate throughout the year to justify it fairly, and then their average value is considered. This value acts as the daily mean emission rate of a pollutant for a TPP throughout the year. Finally, the rank of a TPP is determined by making a co-relation between this daily mean emission rate of pollutants and its norm specified by Pollution Control Board (PCB) of respective country. The methodology is illustrated to find the rank of four coal fired TPPs at different locations in India.

The study is organised in the following way. Some useful definitions and information are placed in Section 2. The feature of *svtrn*-number and its score are presented in Section 3. A methodology of ranking TPPs and a suitable algorithm are developed in Section 4. Section 5 illustrates the proposed methodology on behalf of four TPPs in different parts of India. The superiority of the proposed methodology is claimed after comparing it with some of the existing literatures. In Section 6, the study is summarised along with its limitation and future aspect.

## 2 Preliminary result

Let us recall some useful definitions and result to build this study.

### 2.1 Definition [21,22,27]

An object $x$ in the universe $U$ is characterised by an $NtS$-set $\widetilde{Q}$ in light of three functions namely acceptance ($\delta_{\widetilde{Q}}$), hesitation ($\zeta_{\widetilde{Q}}$) and rejection ($\lambda_{\widetilde{Q}}$). Thus $\widetilde{Q}$ is presented as : $\widetilde{Q} = \{< x, (\delta_{\widetilde{Q}}(x), \zeta_{\widetilde{Q}}(x), \lambda_{\widetilde{Q}}(x)) >: x \in U\}$ for $\delta_{\widetilde{Q}}, \zeta_{\widetilde{Q}}, \lambda_{\widetilde{Q}} : U \to ]^{-}0, 1^{+}[$ and $^{-}0 \leq \delta_{\widetilde{Q}}(x) + \zeta_{\widetilde{Q}}(x) + \lambda_{\widetilde{Q}}(x) \leq 3^{+}$.

When $\delta_{\widetilde{Q}}, \zeta_{\widetilde{Q}}, \lambda_{\widetilde{Q}} : U \to [0, 1]$, then $\widetilde{Q}$ is called single valued neutrosophic set ($SVNtS$-set). Thus an $SVNtS$-set $\widetilde{Q}$ is put as :
$\widetilde{Q} = \{< x, (\delta_{\widetilde{Q}}(x), \zeta_{\widetilde{Q}}(x), \lambda_{\widetilde{Q}}(x)) >: x \in U\}$ with $0 \leq \delta_{\widetilde{Q}}(x) + \zeta_{\widetilde{Q}}(x) + \lambda_{\widetilde{Q}}(x) \leq 3$.

### 2.2 Definition [5]

An $SVNtS$-set $\tilde{p}$ is called a single valued neutrosophic number ($svn$-number) if it is defined on the set of all real numbers $\mathbf{R}$ and takes the form $\tilde{p} = \langle([p_1, q_1, s_1, t_1]; u_{\tilde{p}}), ([p_2, q_2, s_2, t_2]; v_{\tilde{p}}), ([p_3, q_3, s_3, t_3]; w_{\tilde{p}})\rangle$ where $p_i \leq q_i \leq s_i \leq t_i\,(i = 1, 2, 3)$ and $u_{\tilde{p}}, v_{\tilde{p}}, w_{\tilde{p}} \in (0, 1]$. Thus an $svn$-number consists of three components and these corresponds to the acceptance, hesitation and rejection respectively. Here $[q_i, s_i], p_i, t_i$ are respectively called the mean interval, the lower and upper limits of three components in the $svn$-number $\tilde{p}$ for $i = 1, 2, 3$. The function of acceptance ($\delta_{\tilde{p}}$), hesitation ($\zeta_{\tilde{p}}$) and rejection ($\lambda_{\tilde{p}}$) are respectively designed as follows :

$$\delta_{\tilde{p}} : \mathbf{R} \to [0, u_{\tilde{p}}], \qquad \delta_{\tilde{p}}(x) = \begin{cases} g^l_\delta(x), & p_1 \leq x \leq q_1, \\ u_{\tilde{p}}, & q_1 \leq x \leq s_1, \\ g^r_\delta(x), & s_1 \leq x \leq t_1, \\ 0, & \text{otherwise.} \end{cases}$$

$$\zeta_{\tilde{p}} : \mathbf{R} \to [v_{\tilde{p}}, 1], \qquad \zeta_{\tilde{p}}(x) = \begin{cases} g^l_\zeta(x), & p_2 \leq x \leq q_2, \\ v_{\tilde{p}}, & q_2 \leq x \leq s_2, \\ g^r_\zeta(x), & s_2 \leq x \leq t_2, \\ 1, & \text{otherwise.} \end{cases}$$

$$\lambda_{\tilde{p}} : \mathbf{R} \to [w_{\tilde{p}}, 1], \qquad \lambda_{\tilde{p}}(x) = \begin{cases} g^l_\lambda(x), & p_3 \leq x \leq q_3, \\ w_{\tilde{p}}, & q_3 \leq x \leq s_3, \\ g^r_\lambda(x), & s_3 \leq x \leq t_3, \\ 1, & \text{otherwise.} \end{cases}$$

The functions $g^l_\delta : [p_1, q_1] \to [0, u_{\tilde{p}}], g^r_\zeta : [s_2, t_2] \to [v_{\tilde{p}}, 1], g^r_\lambda : [s_3, t_3] \to [w_{\tilde{p}}, 1]$ are continuous and non-decreasing functions satisfying : $g^l_\delta(p_1) = 0, g^l_\delta(q_1) = u_{\tilde{p}}, g^r_\zeta(s_2) =$

$v_{\tilde{p}}, g^r_\zeta(t_2) = 1, g^r_\lambda(s_3) = w_{\tilde{p}}, g^r_\lambda(t_3) = 1$. The functions $g^r_\delta : [s_1, t_1] \to [0, u_{\tilde{p}}], g^l_\zeta : [p_2, q_2] \to [v_{\tilde{p}}, 1], g^l_\lambda : [p_3, q_3] \to [w_{\tilde{p}}, 1]$ are continuous and non-increasing functions satisfying : $g^r_\delta(s_1) = u_{\tilde{p}}, g^r_\delta(t_1) = 0, g^l_\zeta(p_2) = 1, g^l_\zeta(q_2) = v_{\tilde{p}}, g^l_\lambda(p_3) = 1, g^l_\lambda(q_3) = w_{\tilde{p}}$.

## 2.3 Definition [3]

Two continuous mappings $\triangle, \triangledown$ from $[0,1] \times [0,1]$ to $[0,1]$ are respectively called $t$-norm and $s$-norm under the following disciplines.
(i) $\triangle, \triangledown$ are associative and commutative.
(ii) $m \triangle 1 = 1 \triangle m = m, \quad m \triangledown 0 = 0 \triangledown m = m, \quad \forall m \in [0,1]$.
(iii) $m \triangle q \leq n \triangle s, \quad m \triangledown q \leq n \triangledown s$ for $m \leq n, q \leq s$ with $m, q, n, s \in [0,1]$.
$m \triangle q = mq$, $m \triangle q = \min\{m, q\}$, $m \triangle q = \max\{m + q - 1, 0\}$ are commonly used $t$-norms and
$m \triangledown q = m + q - mq$, $m \triangledown q = \max\{m, q\}$, $m \triangledown q = \min\{m + q, 1\}$ are commonly used $s$-norms.

## 2.4 Emission standard in India [31]

Following table (Table 1) is the new emission standard for TPPs acted on 07.12.2015 by the Ministry of environment, forest and climate change, New Delhi, India.

Table 1 : Emission standard of TPPs by Ministry of environment, India.

| Parameter ↓ | Standard | Power generation | Category |
|---|---|---|---|
| $SO_2$ | 600 mg/Nm$^3$ | less than 500 MW | installed before 31st Dec, 2003* |
| | 200 mg/Nm$^3$ | 500 MW or above | |
| $NO_X$ | 600 mg/Nm$^3$ | no limit | |
| $PM$ | 100 mg/Nm$^3$ | no limit | |
| $Hg$ | 0.03 mg/Nm$^3$ | 500 MW or above | |
| $SO_2$ | 600 mg/Nm$^3$ | less than 500 MW | installed after 1st Jan, 2003 upto 31st Dec, 2016* |
| | 200 mg/Nm$^3$ | 500 MW or above | |
| $NO_X$ | 300 mg/Nm$^3$ | no limit | |
| $PM$ | 50 mg/Nm$^3$ | no limit | |
| $Hg$ | 0.03 mg/Nm$^3$ | no limit | |
| $SO_2$ | 100 mg/Nm$^3$ | no limit | installed from 1st Jan, 2017** |
| $NO_X$ | 100 mg/Nm$^3$ | no limit | |
| $PM$ | 30 mg/Nm$^3$ | no limit | |
| $Hg$ | 0.03 mg/Nm$^3$ | no limit | |

$*$ TPPs (units) shall meet the limits within two years from date of publication of this notification.
$**$ Includes all the TPPs (units) which have been accorded environmental clearance and are under construction.

# 3 Single valued triangular neutrosophic number

The feature of *svtrn*-number, its geometrical interpretation are provided here. Then using Graded mean integration concept, the crisp score of *svtrn*-number is evaluated.

## 3.1 Definition

An *svn*-number $\tilde{p} = \langle([p_1, q_1, s_1, t_1]; u_{\tilde{p}}),\ ([p_2, q_2, s_2, t_2]; v_{\tilde{p}}),\ ([p_3, q_3, s_3, t_3]; w_{\tilde{p}})\rangle$ becomes a single valued trapezoidal neutrosophic number (*svtn*-number) when the three mean intervals are equal i.e., when $[q_1, s_1] = [q_2, s_2] = [q_3, s_3]$ holds. Thus $\tilde{s} = \langle([p_1, q, s, t_1]; u_{\tilde{s}}), ([p_2, q, s, t_2]; v_{\tilde{s}}), ([p_3, q, s, t_3]; w_{\tilde{s}})\rangle$ is an *svtn*-number. Its function of acceptance ($\delta_{\tilde{s}}$), hesitation ($\zeta_{\tilde{s}}$) and rejection ($\lambda_{\tilde{s}}$) are drawn as follows :

$$\delta_{\tilde{s}} : \mathbf{R} \to [0, u_{\tilde{s}}], \qquad \delta_{\tilde{s}}(x) = \begin{cases} \frac{(x-p_1)u_{\tilde{s}}}{q-p_1}, & x \in [p_1, q), \\ u_{\tilde{s}}, & x \in [q, s], \\ \frac{(t_1-x)u_{\tilde{s}}}{t_1-s}, & x \in (s, t_1], \\ 0, & \text{elsewhere.} \end{cases}$$

$$\zeta_{\tilde{s}} : \mathbf{R} \to [v_{\tilde{s}}, 1], \qquad \zeta_{\tilde{s}}(x) = \begin{cases} \frac{(q-x)+v_{\tilde{s}}(x-p_2)}{q-p_2}, & x \in [p_2, q), \\ v_{\tilde{s}}, & x \in [q, s], \\ \frac{(x-s)+v_{\tilde{s}}(t_2-x)}{t_2-s}, & x \in (s, t_2], \\ 1, & \text{elsewhere.} \end{cases}$$

$$\lambda_{\tilde{s}} : \mathbf{R} \to [w_{\tilde{s}}, 1], \qquad \lambda_{\tilde{s}}(x) = \begin{cases} \frac{(q-x)+w_{\tilde{s}}(x-p_3)}{q-p_3}, & x \in [p_3, q), \\ w_{\tilde{s}}, & x \in [q, s], \\ \frac{(x-s)+w_{\tilde{s}}(t_3-x)}{t_3-s}, & x \in (s, t_3], \\ 1, & \text{elsewhere.} \end{cases}$$

## 3.2 Definition

An *svtn*-number $\tilde{s} = \langle([p_1, q, s, t_1]; u_{\tilde{s}}),\ ([p_2, q, s, t_2]; v_{\tilde{s}}),\ ([p_3, q, s, t_3]; w_{\tilde{s}})\rangle$ is turned into an *svtrn*-number when the mean interval $[q, s]$ of its three components are reduced to a point. Thus $\tilde{q} = \langle([p_1, q, t_1]; u_{\tilde{q}}), ([p_2, q, t_2]; v_{\tilde{q}}), ([p_3, q, t_3]; w_{\tilde{q}})\rangle$ is an *svtrn*-number whose function of acceptance ($\delta_{\tilde{q}}$), hesitation ($\zeta_{\tilde{q}}$) and rejection ($\lambda_{\tilde{q}}$) are put as follows :

$$\delta_{\tilde{q}} : \mathbf{R} \to [0, u_{\tilde{q}}], \qquad \delta_{\tilde{q}}(x) = \begin{cases} \frac{(x-p_1)u_{\tilde{q}}}{q-p_1}, & x \in [p_1, q), \\ \frac{(t_1-x)u_{\tilde{q}}}{t_1-q}, & x \in [q, t_1], \\ 0, & \text{elsewhere.} \end{cases}$$

$$\zeta_{\tilde{q}} : \mathbf{R} \to [v_{\tilde{q}}, 1], \qquad \zeta_{\tilde{q}}(x) = \begin{cases} \frac{(q-x)+v_{\tilde{q}}(x-p_2)}{q-p_2}, & x \in [p_2, q), \\ \frac{(x-q)+v_{\tilde{q}}(t_2-x)}{t_2-q}, & x \in [q, t_2], \\ 1, & \text{elsewhere.} \end{cases}$$

$$\lambda_{\tilde{q}} : \mathbf{R} \to [w_{\tilde{q}}, 1], \qquad \lambda_{\tilde{q}}(x) = \begin{cases} \frac{(q-x)+w_{\tilde{q}}(x-p_3)}{q-p_3}, & x \in [p_3, q), \\ \frac{(x-q)+w_{\tilde{q}}(t_3-x)}{t_3-q}, & x \in [q, t_3], \\ 1, & \text{elsewhere.} \end{cases}$$

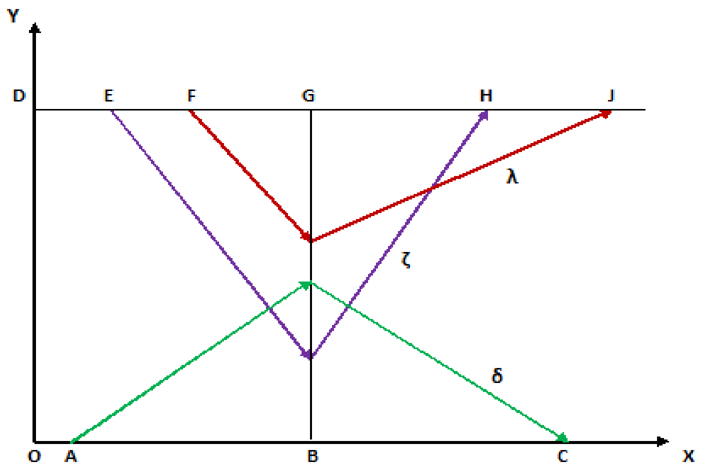


FIGURE 1 : An example of svtrn-number

Each of three components $\delta_{\tilde{q}}, \zeta_{\tilde{q}}, \lambda_{\tilde{q}}$ is a fuzzy number having two parts : left part $(L)$ and right part $(R)$. We write $\delta_{\tilde{q}} \Leftrightarrow [L_{\delta_{\tilde{q}}}, R_{\delta_{\tilde{q}}}] = [\frac{(x-p_1)u_{\tilde{q}}}{q-p_1}, \frac{(t_1-x)u_{\tilde{q}}}{t_1-q}]$ and so on. Here $L_{\delta_{\tilde{q}}}, R_{\zeta_{\tilde{q}}}, R_{\lambda_{\tilde{q}}}$ are continuous and non-decreasing functions whereas $R_{\delta_{\tilde{q}}}, L_{\zeta_{\tilde{q}}}, L_{\lambda_{\tilde{q}}}$ are continuous and non-increasing functions in the respective interval.

## 3.3 Geometrical interpretation

An *svtrn*-number geometrically consists of three triangles. Here different supports (bases of triangles) and heights are considered for each function of *svtrn*-number so that decision makers can easily chose and compare different numbers in their study. FIGURE 1 executes the geometrical structure of a particular *svtrn*-number.

## 3.4 Definition

Consider two *svtrn*-numbers $\tilde{a} = \langle([a_1, a, b_1]; \rho_1), ([a_2, a, b_2]; \rho_2), ([a_3, a, b_3]; \rho_3)\rangle$ and $\tilde{c} = \langle([c_1, c, d_1]; \tau_1), ([c_2, c, d_2]; \tau_2), ([c_3, c, d_3]; \tau_3)\rangle$ and $\beta$ being any real number. Then its addition and scalar multiplication are defined as :

$$\begin{aligned}
\tilde{a} \oplus \tilde{c} &= \langle([a_1 + c_1, a + c, b_1 + d_1]; \rho_1 \bigtriangleup \tau_1), ([a_2 + c_2, a + c, b_2 + d_2]; \rho_2 \bigtriangledown \tau_2), \\
&\quad ([a_3 + c_3, a + c, b_3 + d_3]; \rho_3 \bigtriangledown \tau_3)\rangle \\
\beta\tilde{a} &= \langle([\beta a_1, \beta a, \beta b_1]; \rho_1), ([\beta a_2, \beta a, \beta b_2]; \rho_2), ([\beta a_3, \beta a, \beta b_3]; \rho_3)\rangle, \;\; \beta \geq 0 \\
&= \langle([\beta b_1, \beta a, \beta a_1]; \rho_1), ([\beta b_2, \beta a, \beta a_2]; \rho_2), ([\beta b_3, \beta a, \beta a_3]; \rho_3)\rangle, \;\; \beta < 0
\end{aligned}$$

## 3.5 Score of *svtrn*-number

Let us consider the *svtrn*-number $\tilde{q}$ presented in Definition 3.2; For $a \in [0, 1]$ and $x \in [0, u_{\tilde{q}}]$, the Graded mean integration of $\delta_{\tilde{q}}$ is defined as :

$$\begin{aligned} G_m(\delta_{\tilde{q}}) &= \int_0^{u_{\tilde{q}}} x[a\,L^{-1}_{\delta_{\tilde{q}}}(x) + (1-a)R^{-1}_{\delta_{\tilde{q}}}(x)]dx \Big/ \int_0^{u_{\tilde{q}}} x dx \quad (1) \\ &= \frac{ap_1 + 2q + (1-a)t_1}{3} \end{aligned}$$

where $L^{-1}_{\delta_{\tilde{q}}}(x) = p_1 + \frac{x}{u_{\tilde{q}}}(q - p_1)$, $R^{-1}_{\delta_{\tilde{q}}}(x) = t_1 - \frac{x}{u_{\tilde{q}}}(t_1 - q)$.

For $b \in [0,1]$ and $y \in [v_{\tilde{q}}, 1]$, the Graded mean integration of $\zeta_{\tilde{q}}$ is expressed as :

$$\begin{aligned} G_m(\zeta_{\tilde{q}}) &= \int_{v_{\tilde{q}}}^1 (1-y)[(1-b)\,L^{-1}_{\zeta_{\tilde{q}}}(y) + bR^{-1}_{\zeta_{\tilde{q}}}(y)]dy \Big/ \int_{v_{\tilde{q}}}^1 (1-y)dy \quad (2) \\ &= \frac{(1-b)p_2 + 2q + bt_2}{3} \end{aligned}$$

where $L^{-1}_{\zeta_{\tilde{q}}}(y) = \frac{(1-y)q + (y - v_{\tilde{q}})p_2}{1 - v_{\tilde{q}}}$, $R^{-1}_{\zeta_{\tilde{q}}}(y) = \frac{(1-y)q + (y - v_{\tilde{q}})t_2}{1 - v_{\tilde{q}}}$.

For $c \in [0,1]$ and $z \in [w_{\tilde{q}}, 1]$, the Graded mean integration of $\lambda_{\tilde{q}}$ is drawn as :

$$\begin{aligned} G_m(\lambda_{\tilde{q}}) &= \int_{w_{\tilde{q}}}^1 (1-z)[(1-c)\,L^{-1}_{\lambda_{\tilde{q}}}(z) + cR^{-1}_{\lambda_{\tilde{q}}}(z)]dz \Big/ \int_{w_{\tilde{q}}}^1 (1-z)dz \quad (3) \\ &= \frac{(1-c)p_3 + 2q + ct_3}{3} \end{aligned}$$

where $L^{-1}_{\lambda_{\tilde{q}}}(z) = \frac{(1-z)q + (z - w_{\tilde{q}})p_3}{1 - w_{\tilde{q}}}$, $R^{-1}_{\lambda_{\tilde{q}}}(z) = \frac{(1-z)q + (z - w_{\tilde{q}})t_3}{1 - w_{\tilde{q}}}$.

Now finally the Graded mean integration of *svtrn*-number $\tilde{q}$ is defined as :

$$\begin{aligned} G_m(\tilde{q}) &= \frac{1}{3}\{G_m(\delta_{\tilde{q}}) + G_m(\zeta_{\tilde{q}}) + G_m(\lambda_{\tilde{q}})\} \\ &= \frac{1}{9}\{kp_1 + 2q + (1-k)t_1 + (1-k)p_2 + 2q + kt_2 + (1-k)p_3 + 2q + kt_3\} \\ &\quad \text{(taking } a = b = c = k \text{ say)} \\ &= \frac{1}{9}\{k(p_1 + t_2 + t_3) + 6q + (1-k)(t_1 + p_2 + p_3)\} \quad (4) \end{aligned}$$

Expression (4) provides the score of $\tilde{q}$ for a pre-assigned $k$. This score will not be biased from left or right if $k = \frac{1}{2}$ is chosen. Expression (4) then takes the form as :

$$G_m(\tilde{q}) = \frac{1}{18}\{(p_1 + p_2 + p_3) + 12q + (t_1 + t_2 + t_3)\} \quad (5)$$

# 4 Ranking of thermal power stations

It describes the methodology for ranking of a number of TPPs of a country in virtue of air pollutants discharge. A suitable algorithm is also drawn to sketch that description.

## 4.1 Description of methodology

Environmental experts think that coal fired TPPs play a great role to pollute the air, water, soil by emitting many harmful gases, fly ash, waste water etc. Ranking of a number of coal based TPPs in a country are generally established under the amount of release of these pollutants. Suppose in a country $X$ there are $m$ coal fired TPPs $T_1, T_2, \cdots, T_m$ to be ranked with respect to the emission of air pollutants. The domestic and industrial power consumption in a country may be based on the diversity of climate and consequently the discharge rate of pollutants are not unique through out the year due to the fluctuation of energy production, variation of the quantity and quality of fuel to be used, etc. The assessment year $Y$ (say) of discharge is here divided into three periods $P_1, P_2, P_3$, each of which consists of four months. Such division is taken as three major seasons (i.e., Summer, Rainy, Winter) are generally seen in a country. Further the periodical assessment of pollutant discharge from a TPP may not be at a constant rate, it may oscillate in a range usually and this range is not presupposed, it again may have a slight variation. It is almost impossible for the experts to assess the emission quantity everyday for a period. So, experts compel to use an average rate of emission of pollutants for individual period. Thus, as a whole, there is a vagueness and uncertainty in the emission quantity of pollutants. Based on the observed data, the rate of pollutant discharge is here expressed by *svtrn*-number so that experts can get an opportunity to include their hesitancy independently in setting of experimental data. But this assessment should obey the standard permitted by PCB of the respective country. Moreover this specification will be modified (here it is reduced) from time to time because of the gradual degradation of natural environment and have a scope of reducing emission by using new technology.

A TPP has more than one unit, all of which may have not equal power generation capacity and may not be installed from a same date. When a new unit runs, it should obey the revised emission standard acted on or before its journey. Clearly, all units of a TPP in such case may not follow the same emission standard. Treating all units of that TPP as the single, a mean standard is here set following the generation capacity and commencement date of plant. For instance, we consider a TPP **Z** in India described in Table 2. Now from Table 1, it is seen that the standard of $SO_2$ emission for Unit 1, Unit 2 and Unit 3 in the TPP **Z** are respectively 600 mg/Nm$^3$, 200 mg/Nm$^3$ and 100 mg/Nm$^3$. Thus the mean standard of $SO_2$ emission for the TPP **Z** (assuming to have a single unit) is 300 mg/Nm$^3$.

Table 2 : Description of TPS **Z**

| Unit → | Unit 1 | Unit 2 | Unit 3 |
|---|---|---|---|
| Commencement date | 20th April, 1998 | 10th September, 2011 | 4th January, 2018 |
| Generation capacity | 400MW | 600MW | 250MW |

Similarly, instead of taking different emission rates of a pollutant for all units in a period, an average emission rate is considered on behalf of a TPP. Suppose, there be $k$ number of units in the TPP $T_m$ and they emit a particular pollutant in a period at the rates $\tilde{m}_1, \tilde{m}_2, \cdots, \tilde{m}_k$ (presented by *svtrn*-numbers). Then the average emission

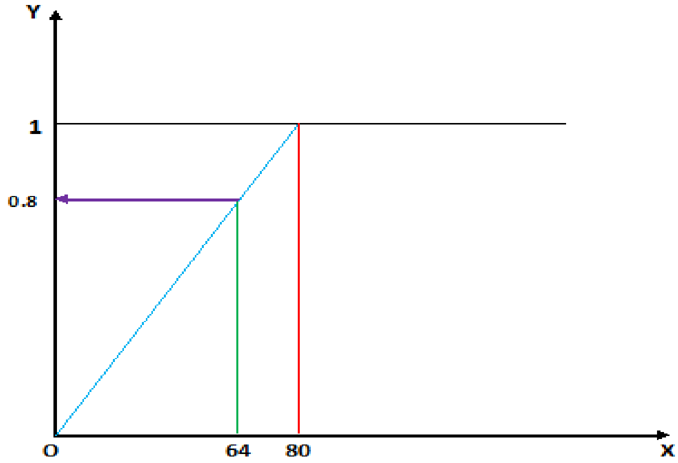


FIGURE 2 : Fuzzy number for non-acceptability of PM discharge

rate of this pollutant on behalf of $k$ number of units in the TPP $T_m$ for that period is designed by an *svtrn*-numbers $\widetilde{m}$ as :

$$\widetilde{m} \;=\; \frac{1}{k}\{\tilde{m}_1 \oplus \tilde{m}_2 \oplus \cdots \oplus \tilde{m}_k\} \tag{6}$$

To manipulate the huge number of data of an *svtrn*-number, its score is evaluated by the expression (5) of Graded mean integration. Then daily discharge rate of each pollutant throughout the year $Y$ is calculated by the mean score of three periods for each TPP. Now, as directed in FIGURE 2, these mean values are converted to the fuzzy numbers for non-acceptability (with membership functions $\mu_{ij}$, $i$ indicates the number pollutants to be considered and $j$ refers the number of TPPs to be ranked) depending on the norm specified by PCB of the country in order to put the emission in a common standard scale. For instance, if the norm of $PM$ emission be 80 $mg/Nm^3$ for a TPP and its daily mean discharge be 64 $mg/Nm^3$, then the respective membership function of fuzzy number for non-acceptability is 0.8. For each TPP, the sum $S_j$ of the membership functions for non-acceptability (i.e., $\sum_i \mu_{ij}$) over the pollutants is worked out. The normalized weight $NW_{ij}$ of each pollutant is now derived to divide $\mu_{ij}$ by $S_j$. Finally the full score $FS_j$ of $j^{th}$ TPP based on the emission rates of pollutants is evaluated by the expression $\sum_i(\mu_{ij} \times NW_{ij})$. The rank of TPPs are hence arranged with the descending order of all $FS_j$.

## 4.2 Algorithm for ranking of TPSs

The methodology of ranking TPPs is based on the following steps.

Step 1 : Find the latest emission standard specified by PCB.
Step 2 : Sketch the generation capacity and installation date of all units in each TPP to be ranked as shown in Table 2.
Step 3 : Set the mean standard of emission rate for all units in a TPP following the information gathered in Step 1 and Step 2.
Step 4 : For every unit of a TPP, express the discharge rate of a pollutant in a period

by *svtrn*-numbers and take their average as described in (6). This refers the average discharge rate of the pollutant on behalf of all units of this TPP in that particular period. Perform the same for each pollutant to be considered and also for each of three periods in the year.
Step 5 : Repeat the Step 4 for all TPPs to be ranked.
Step 6 : Find the score of all *svtrn*-numbers using the expression (5) of Graded mean integration to manipulate its several data.
Step 7 : For a TPP, calculate the mean values of all three periodical scores of each emission. This is the daily mean rate of emission of a pollutant for a power plant throughout the year.
Step 8 : Evaluate the membership function of fuzzy number for non-acceptability of each mean value calculated in Step 7 upon the respective mean standard of emission rate drawn in Step 3.
Step 9 : Find the normalised weight of all pollutants for individual TPP using the data obtained in Step 8.
Step 10 : Multiply the membership function for non-acceptability of each pollutant with its respective normalised weight and then taking the sum over all pollutants to determine the full score of each individual TPP.
Step 11 : List the rank of TPPs using the full score obtained in Step 10. The maximum full score indicates the worst TPP and the least score indicates the best TPP based on the emission rate of pollutants.

### 4.3 Graphical overview of methodology

| |
|---|
| Sketch the power generation capacity and installation date of all units in each TPP. |
| ⇓ |
| Set the mean standard of emission on behalf of all units of each TPP following its generation capacity, installation date and the latest emission norm specified by PCB. |
| ⇓ |
| Set the average discharge rate (by means of *svtrn*-number) for each of pollutants to be considered on behalf of all units for a TPP in a period. Repeat the same for three periods in the year and for all TPPs to be ranked. |
| ⇓ |
| Find the score of all *svtrn*-numbers and calculate the mean value (daily mean rate of emission throughout the year) of three periodical scores of each pollutant for a TPP. |
| ⇓ |
| Evaluate the membership function of fuzzy number for non-acceptability of daily mean emission rate upon the respective mean standard assigned for a TPP and then calculate the normalized weight of each membership function. |
| ⇓ |
| Multiply the membership function for non-acceptability of a pollutant with its respective normalised weight and then take the sum over all pollutants for each TPP. Thus the full score of TPP and its rank is established. |

## 5 Application of methodology

Let us consider four coal fired TPPs (TPP1, TPP2, TPP3, TPP4) situated at different locations in India. This study only considers the scope of air pollution with respect to the major emission of five acidic pollutants $SO_2, NO_X, CO, PM, Hg$ only. The different steps of methodology are illustrated as follows.

**Step 1 :** As the experiment is here driven on four TPPs in India, the data regarding the emission standard will be followed by Table 1.

**Step 2 :** Table 3 describes the four TPPs along with the generation capacity of power and the commencement date of all its units.

Table 3 : Description of four coal fired thermal power plants

| TPP1 | | | TPP2 | | |
|---|---|---|---|---|---|
| Unit | Capacity | Commencement | Unit | Capacity | Commencement |
| U 1 | 210 MW | Sep, 1990 | U 1 | 300 MW | Sep, 2008 |
| U 2 | 210 MW | Mar, 1986 | U 2 | 300 MW | Nov, 2009 |
| U 3 | 210 MW | Oct, 1985 | U 3 | 500 MW | Dec, 2015 |
| U 4 | 210 MW | Apr, 1996 | U 4 | 500 MW | Jan, 2017 |
| U 5 | 210 MW | May, 1991 | | | |
| U 6 | 210 MW | Jan, 1994 | | | |
| **TPP3** | | | **TPP4** | | |
| Unit | Capacity | Commencement | Unit | Capacity | Commencement |
| U 1 | 210 MW | Nov, 2000 | U 1 | 225 MW | Jan, 1986 |
| U 2 | 210 MW | Apr, 2001 | U 2 | 225 MW | Dec, 1987 |
| U 3 | 210 MW | Oct, 2004 | U 3 | 225 MW | Aug, 1988 |
| U 4 | 210 MW | Mar, 2009 | U 4 | 500 MW | Sep, 1992 |
| U 5 | 210 MW | Jun, 2010 | U 5 | 550 MW | Feb, 1994 |
| | | | U 6 | 500 MW | Apr, 2012 |

**Step 3 :** Each power plant has several units to generate power. On behalf of all units of a TPP, a mean standard rate of pollutant emission is calculated in Table 4 following the information of Table 1 and Table 3.

Table 4 : Mean standard for the emission rate of pollutants from TPPs.

| Pollutant → | $SO_2$ (mg/Nm$^3$) | $NO_X$ (mg/Nm$^3$) | •$CO$ (mg/Nm$^3$) | $PM$ (mg/Nm$^3$) | $Hg$ (mg/Nm$^3$) |
|---|---|---|---|---|---|
| TPP1 | 600 | 600 | 200 | 100 | 0.03 |
| TPP2 | 375 | 250 | 200 | 45 | 0.03 |
| TPP3 | 600 | 480 | 200 | 80 | 0.03 |
| TPP4 | 400 | 550 | 200 | 92 | 0.03 |

• Source (standard for the pollutant $CO$) : Authors

**Step 4 and Step 5 :** The rate of emission is assessed in three periods *viz.* $P_1$ (March, April, May, June), $P_2$ (July, August, September, October), $P_3$ (November, December, January, February) for the year. Table 5 provides the average discharge rate of pollutant periodically for four TPPs assuming each to have a single unit.

Table 5 : Average discharge rate of pollutant periodically for four TPPs.

| Criteria ↓ | TPP1 | | | TPP2 | | | TPP3 | | | TPP4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P1 | P2 | P3 | P1 | P2 | P3 | P1 | P2 | P3 |
| $SO_2$ (mg/Nm$^3$) | $\tilde{a}_{11}$ | $\tilde{a}_{12}$ | $\tilde{a}_{13}$ | $\tilde{b}_{11}$ | $\tilde{b}_{12}$ | $\tilde{b}_{13}$ | $\tilde{c}_{11}$ | $\tilde{c}_{12}$ | $\tilde{c}_{13}$ | $\tilde{d}_{11}$ | $\tilde{d}_{12}$ | $\tilde{d}_{13}$ |
| $NO_X$ (mg/Nm$^3$) | $\tilde{a}_{21}$ | $\tilde{a}_{22}$ | $\tilde{a}_{23}$ | $\tilde{b}_{21}$ | $\tilde{b}_{22}$ | $\tilde{b}_{23}$ | $\tilde{c}_{21}$ | $\tilde{c}_{22}$ | $\tilde{c}_{23}$ | $\tilde{d}_{21}$ | $\tilde{d}_{22}$ | $\tilde{d}_{23}$ |
| $CO$ (mg/Nm$^3$) | $\tilde{a}_{31}$ | $\tilde{a}_{32}$ | $\tilde{a}_{33}$ | $\tilde{b}_{31}$ | $\tilde{b}_{32}$ | $\tilde{b}_{33}$ | $\tilde{c}_{31}$ | $\tilde{c}_{32}$ | $\tilde{c}_{33}$ | $\tilde{d}_{31}$ | $\tilde{d}_{32}$ | $\tilde{d}_{33}$ |
| $PM$ (mg/Nm$^3$) | $\tilde{a}_{41}$ | $\tilde{a}_{42}$ | $\tilde{a}_{43}$ | $\tilde{b}_{41}$ | $\tilde{b}_{42}$ | $\tilde{b}_{43}$ | $\tilde{c}_{41}$ | $\tilde{c}_{42}$ | $\tilde{c}_{43}$ | $\tilde{d}_{41}$ | $\tilde{d}_{42}$ | $\tilde{d}_{43}$ |
| $Hg$ (mg/Nm$^3$) | $\tilde{a}_{51}$ | $\tilde{a}_{52}$ | $\tilde{a}_{53}$ | $\tilde{b}_{51}$ | $\tilde{b}_{52}$ | $\tilde{b}_{53}$ | $\tilde{c}_{51}$ | $\tilde{c}_{52}$ | $\tilde{c}_{53}$ | $\tilde{d}_{51}$ | $\tilde{d}_{52}$ | $\tilde{d}_{53}$ |

The different *svtrn*-numbers of emission quantity in Table 5 are described below.

$$\begin{aligned}
\tilde{a}_{11} &= <([470, 500, 515]; 0.6), ([490, 500, 530]; 0.4), ([480, 500, 550]; 0.3)> \\
\tilde{a}_{12} &= <([375, 420, 450]; 0.5), ([365, 420, 460]; 0.5), ([355, 420, 440]; 0.7)> \\
\tilde{a}_{13} &= <([500, 540, 570]; 0.8), ([510, 540, 555]; 0.6), ([525, 540, 565]; 0.4)>
\end{aligned}$$

$$\begin{aligned}
\tilde{a}_{21} &= <([520, 555, 570]; 0.7), ([530, 555, 560]; 0.2), ([525, 555, 575]; 0.4)> \\
\tilde{a}_{22} &= <([455, 480, 500]; 0.4), ([465, 480, 495]; 0.6), ([470, 480, 510]; 0.3)> \\
\tilde{a}_{23} &= <([450, 535, 500]; 0.3), ([440, 535, 510]; 0.5), ([460, 535, 515]; 0.2)>
\end{aligned}$$

$$\begin{aligned}
\tilde{a}_{31} &= <([150, 170, 175]; 0.6), ([160, 170, 180]; 0.4), ([140, 170, 185]; 0.2)> \\
\tilde{a}_{32} &= <([130, 150, 170]; 0.4), ([135, 150, 160]; 0.5), ([125, 150, 175]; 0.6)> \\
\tilde{a}_{33} &= <([140, 160, 180]; 0.2), ([150, 160, 175]; 0.7), ([145, 160, 170]; 0.5)>
\end{aligned}$$

$$\begin{aligned}
\tilde{a}_{41} &= <([60, 75, 83]; 0.2), ([65, 75, 85]; 0.7), ([55, 75, 80]; 0.4)> \\
\tilde{a}_{42} &= <([55, 60, 75]; 0.7), ([50, 60, 70]; 0.2), ([52, 60, 65]; 0.5)> \\
\tilde{a}_{43} &= <([75, 80, 90]; 0.6), ([70, 80, 85]; 0.3), ([65, 80, 95]; 0.6)>
\end{aligned}$$

$$\begin{aligned}
\tilde{a}_{51} &= <([.012, .02, .025]; 0.7), ([.01, .02, .022]; 0.4), ([.015, .02, .026]; 0.3)> \\
\tilde{a}_{52} &= <([.01, .015, .02]; 0.7), ([.012, .015, .022]; 0.5), ([.00, .015, .017]; 0.3)> \\
\tilde{a}_{53} &= <([.021, .025, .028]; 0.3), ([.022, .025, .027]; 0.5), ([.02, .025, .026]; 0.8)>
\end{aligned}$$

$$\begin{aligned}
\tilde{b}_{11} &= <([330, 350, 360]; 0.6), ([340, 350, 365]; 0.4), ([335, 350, 355]; 0.5)> \\
\tilde{b}_{12} &= <([325, 340, 355]; 0.4), ([335, 340, 345]; 0.7), ([330, 340, 350]; 0.2)> \\
\tilde{b}_{13} &= <([350, 360, 370]; 0.8), ([355, 360, 365]; 0.3), ([345, 360, 367]; 0.4)>
\end{aligned}$$

$$\begin{aligned}
\tilde{b}_{21} &= <([220, 235, 240]; 0.7), ([225, 235, 245]; 0.2), ([230, 235, 250]; 0.4)> \\
\tilde{b}_{22} &= <([200, 210, 225]; 0.2), ([205, 210, 220]; 0.6), ([200, 210, 215]; 0.4)> \\
\tilde{b}_{23} &= <([225, 230, 245]; 0.5), ([215, 230, 235]; 0.3), ([220, 230, 240]; 0.6)>
\end{aligned}$$

$$\begin{aligned}
\tilde{b}_{31} &= <([150, 175, 178]; 0.2), ([160, 175, 180]; 0.6), ([140, 175, 175]; 0.3)> \\
\tilde{b}_{32} &= <([130, 145, 170]; 0.5), ([135, 145, 160]; 0.3), ([125, 145, 175]; 0.4)> \\
\tilde{b}_{33} &= <([170, 180, 185]; 0.7), ([165, 180, 187]; 0.5), ([175, 180, 190]; 0.6)>
\end{aligned}$$

$$\begin{aligned}
\tilde{b}_{41} &= <([30, 35, 45]; 0.4), ([33, 35, 40]; 0.7), ([35, 35, 38]; 0.2)> \\
\tilde{b}_{42} &= <([25, 30, 35]; 0.3), ([28, 30, 40]; 0.6), ([20, 30, 45]; 0.5)> \\
\tilde{b}_{43} &= <([32, 40, 45]; 0.9), ([35, 40, 42]; 0.2), ([38, 40, 43]; 0.3)>
\end{aligned}$$

$$\tilde{b}_{51} = <([.02, .026, .026]; 0.8), ([.022, .026, .028]; 0.3), ([.024, .026, .03]; 0.6)>$$
$$\tilde{b}_{52} = <([.00, .01, .015]; 0.5), ([.00, .01, .02]; 0.3), ([.00, .01, .018]; 0.6)>$$
$$\tilde{b}_{53} = <([.021, .022, .028]; 0.4), ([.022, .022, .027]; 0.4), ([.02, .022, .026]; 0.2)>$$
$$\tilde{c}_{11} = <([500, 530, 555]; 0.4), ([490, 530, 540]; 0.5), ([515, 530, 550]; 0.4)>$$
$$\tilde{c}_{12} = <([465, 485, 510]; 0.5), ([475, 485, 500]; 0.6), ([470, 485, 490]; 0.2)>$$
$$\tilde{c}_{13} = <([535, 550, 560]; 0.6), ([530, 550, 565]; 0.7), ([520, 550, 555]; 0.3)>$$
$$\tilde{c}_{21} = <([435, 445, 455]; 0.3), ([440, 445, 460]; 0.7), ([430, 445, 450]; 0.5)>$$
$$\tilde{c}_{22} = <([420, 430, 440]; 0.9), ([435, 430, 445]; 0.3), ([425, 430, 435]; 0.1)>$$
$$\tilde{c}_{23} = <([450, 460, 470]; 0.4), ([445, 460, 465]; 0.5), ([440, 460, 475]; 0.8)>$$
$$\tilde{c}_{31} = <([160, 185, 190]; 0.2), ([180, 185, 195]; 0.6), ([170, 185, 200]; 0.3)>$$
$$\tilde{c}_{32} = <([140, 150, 160]; 0.5), ([145, 150, 165]; 0.3), ([135, 150, 155]; 0.4)>$$
$$\tilde{c}_{33} = <([180, 190, 195]; 0.7), ([185, 190, 200]; 0.5), ([175, 190, 193]; 0.6)>$$
$$\tilde{c}_{41} = <([65, 70, 75]; 0.4), ([60, 70, 80]; 0.3), ([55, 70, 76]; 0.4)>$$
$$\tilde{c}_{42} = <([52, 60, 65]; 0.3), ([50, 60, 70]; 0.4), ([55, 60, 75]; 0.6)>$$
$$\tilde{c}_{43} = <([70, 75, 80]; 0.8), ([68, 75, 78]; 0.5), ([65, 75, 77]; 0.5)>$$
$$\tilde{c}_{51} = <([.019, .023, .025]; 0.4), ([.016, .023, .026]; 0.7), ([.018, .023, .028]; 0.2)>$$
$$\tilde{c}_{52} = <([.013, .018, .022]; 0.7), ([.015, .018, .021]; 0.6), ([.017, .018, .024]; 0.3)>$$
$$\tilde{c}_{53} = <([.017, .024, .029]; 0.5), ([.020, .024, .025]; 0.4), ([.023, .024, .026]; 0.1)>$$
$$\tilde{d}_{11} = <([345, 360, 375]; 0.3), ([350, 360, 380]; 0.7), ([340, 360, 370]; 0.4)>$$
$$\tilde{d}_{12} = <([300, 320, 335]; 0.5), ([310, 320, 325]; 0.3), ([315, 320, 330]; 0.6)>$$
$$\tilde{d}_{13} = <([365, 380, 395]; 0.1), ([370, 380, 385]; 0.9), ([375, 380, 390]; 0.4)>$$
$$\tilde{d}_{21} = <([480, 500, 520]; 0.4), ([485, 500, 515]; 0.5), ([490, 500, 525]; 0.6)>$$
$$\tilde{d}_{22} = <([460, 470, 485]; 0.6), ([455, 470, 475]; 0.4), ([465, 470, 480]; 0.5)>$$
$$\tilde{d}_{23} = <([490, 520, 535]; 0.5), ([500, 520, 530]; 0.6), ([510, 520, 533]; 0.4)>$$
$$\tilde{d}_{31} = <([145, 160, 170]; 0.6), ([150, 160, 175]; 0.3), ([140, 160, 180]; 0.5)>$$
$$\tilde{d}_{32} = <([110, 130, 150]; 0.5), ([120, 130, 145]; 0.6), ([125, 130, 140]; 0.3)>$$
$$\tilde{d}_{33} = <([150, 170, 180]; 0.3), ([160, 170, 175]; 0.5), ([175, 170, 185]; 0.6)>$$
$$\tilde{d}_{41} = <([65, 80, 88]; 0.2), ([70, 80, 90]; 0.4), ([60, 80, 92]; 0.7)>$$
$$\tilde{d}_{42} = <([60, 70, 80]; 0.4), ([55, 70, 75]; 0.7), ([58, 70, 85]; 0.2)>$$
$$\tilde{d}_{43} = <([70, 85, 95]; 0.7), ([80, 85, 92]; 0.2), ([75, 85, 90]; 0.4)>$$
$$\tilde{d}_{51} = <([.011, .019, .02]; 0.8), ([.015, .019, .021]; 0.4), ([.013, .019, .025]; 0.3)>$$
$$\tilde{d}_{52} = <([.010, .013, .017]; 0.3), ([.011, .013, .015]; 0.8), ([.012, .013, .019]; 0.4)>$$
$$\tilde{d}_{53} = <([.019, .023, .027]; 0.4), ([.020, .023, .025]; 0.3), ([.015, .023, .029]; 0.8)>$$

**Step 6 :** The Graded mean values (taking two decimal places) for the rate of emissions in different periods are evaluated from the expression (5) and are arranged in Table 6.

Table 6 : Graded mean value of *svtrn*-numbers in different periods.

| Criteria ↓ | TPP1 | | | TPP2 | | |
|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P1 | P2 | P3 |
| $SO_2$ (mg/Nm$^3$) | 501.94 | 415.83 | 539.17 | 349.17 | 340.00 | 359.56 |
| $NO_X$ (mg/Nm$^3$) | 552.22 | 480.83 | 516.39 | 235.00 | 210.28 | 230.00 |
| $CO$ (mg/Nm$^3$) | 168.33 | 149.72 | 160.00 | 171.28 | 146.38 | 179.56 |
| $PM$ (mg/Nm$^3$) | 073.78 | 060.39 | 080.00 | 035.61 | 030.72 | 039.72 |
| $Hg$ (mg/Nm$^3$) | 0.0194 | 0.0145 | 0.0247 | 0.0257 | 0.0100 | 0.0227 |
| Criteria ↓ | TPP3 | | | TPP4 | | |
| | P1 | P2 | P3 | P1 | P2 | P3 |
| $SO_2$ (mg/Nm$^3$) | 528.33 | 485.00 | 548.06 | 360.00 | 319.72 | 380.00 |
| $NO_X$ (mg/Nm$^3$) | 445.00 | 431.11 | 459.17 | 500.83 | 470.00 | 496.39 |
| $CO$ (mg/Nm$^3$) | 184.17 | 150.00 | 189.33 | 160.00 | 130.56 | 170.28 |
| $PM$ (mg/Nm$^3$) | 069.50 | 060.39 | 074.33 | 079.17 | 069.61 | 084.56 |
| $Hg$ (mg/Nm$^3$) | 0.0227 | 0.0182 | 0.0238 | 0.0185 | 0.0133 | 0.0228 |

**Step 7 :** The average emission rate of each pollutant is now calculated over the three periods and is executed in Table 7. Clearly this quantity refers the daily mean emission rate of pollutant for a power plant throughout the year. For convenience of the entries in Table 7, the daily mean emission rate of $SO_2$ throughout the year for TPP1 is $(501.94 + 415.83 + 539.17) \div 3 = 485.65$.

Table 7 : Daily average emission rate and mean standard of TPPs.

| Criteria ↓ | TPP1 | Standard | TPP2 | Standard |
|---|---|---|---|---|
| $SO_2$ (mg/Nm$^3$) | 485.65 | 600 | 349.58 | 375 |
| $NO_X$ (mg/Nm$^3$) | 516.48 | 600 | 225.09 | 250 |
| $CO$ (mg/Nm$^3$) | 159.35 | 200 | 165.74 | 200 |
| $PM$ (mg/Nm$^3$) | 71.39 | 100 | 35.35 | 45 |
| $Hg$ (mg/Nm$^3$) | 0.01953 | 0.03 | 0.01947 | 0.03 |
| Criteria ↓ | TPP3 | Standard | TPP4 | Standard |
| $SO_2$ (mg/Nm$^3$) | 520.46 | 600 | 353.24 | 400 |
| $NO_X$ (mg/Nm$^3$) | 445.09 | 480 | 489.07 | 550 |
| $CO$ (mg/Nm$^3$) | 174.5 | 200 | 153.61 | 200 |
| $PM$ (mg/Nm$^3$) | 68.07 | 80 | 77.78 | 92 |
| $Hg$ (mg/Nm$^3$) | 0.02157 | 0.03 | 0.01820 | 0.03 |

**Step 8 :** The membership function of fuzzy number for non-acceptability of daily average emission rate is derived upon the mean standard and is displayed in Table 8. One calculation is drawn to make out the entries of Table 8. The membership function for non-acceptability of $SO_2$ for the TPP2 is $(349.58 \div 375) = 0.932$.

Table 8 : Membership function for non-acceptability of emission rate

| Criteria ↓ | TPP1 | TPP2 | TPP3 | TPP4 |
|---|---|---|---|---|
| $SO_2$ | 0.809 | 0.932 | 0.867 | 0.883 |
| $NO_X$ | 0.861 | 0.900 | 0.927 | 0.889 |
| $CO$ | 0.797 | 0.829 | 0.873 | 0.768 |
| $PM$ | 0.714 | 0.786 | 0.851 | 0.845 |
| $Hg$ | 0.651 | 0.649 | 0.719 | 0.607 |
| $\sum$ | 3.832 | 4.096 | 4.237 | 3.992 |

**Step 9 :** The normalised weight of pollutants for each TPP is now calculated and is arranged in Table 9. For instance, the normalised weight of $NO_X$ for the TPP3 is $(0.927 \div 4.237) = 0.219$.

Table 9 : Normalised weight of pollutants for four TPPs

| Criteria ↓ | TPP1 | TPP2 | TPP3 | TPP4 |
|---|---|---|---|---|
| $SO_2$ | 0.211 | 0.228 | 0.205 | 0.221 |
| $NO_X$ | 0.225 | 0.220 | 0.219 | 0.223 |
| $CO$ | 0.208 | 0.202 | 0.206 | 0.192 |
| $PM$ | 0.186 | 0.192 | 0.201 | 0.212 |
| $Hg$ | 0.170 | 0.158 | 0.170 | 0.152 |

**Step 10 :** The full scores of TPPs are now calculated from the two arrays as shown below. The 1st array represents the data of Table 8 and 2nd array tells about the normalised weight ($NW_j$) for the emissions from $j^{th}$ TPP, $j = 1, 2, 3, 4$.

$$\downarrow \begin{pmatrix} TPP1 & TPP2 & TPP3 & TPP4 \\ 0.809 & 0.932 & 0.867 & 0.883 \\ 0.861 & 0.900 & 0.927 & 0.889 \\ 0.797 & 0.829 & 0.873 & 0.768 \\ 0.714 & 0.786 & 0.851 & 0.845 \\ 0.651 & 0.649 & 0.719 & 0.607 \end{pmatrix} \times \begin{pmatrix} NW_1 & NW_2 & NW_3 & NW_4 \\ 0.211 & 0.228 & 0.205 & 0.221 \\ 0.225 & 0.220 & 0.219 & 0.223 \\ 0.208 & 0.202 & 0.206 & 0.192 \\ 0.186 & 0.192 & 0.201 & 0.212 \\ 0.170 & 0.158 & 0.170 & 0.152 \end{pmatrix} \downarrow$$

**Step 11 :** The rank of power plants with the full score is now drawn in Table 10. The score of TPP4 is calculated in detail as : $(0.883 \times 0.221 + 0.889 \times 0.223 + 0.768 \times 0.192 + 0.845 \times 0.212 + 0.607 \times 0.152) = 0.8123$.

Table 10 : Full score and rank of TPPs in neutrosophic ground

| Criteria ↓ | TPP1 | TPP2 | TPP3 | TPP4 |
|---|---|---|---|---|
| Score | 0.7737 | 0.8314 | 0.8539 | 0.8123 |
| Rank | 4 | 2 | 1 | 3 |

Hence, the attention should be paid on TPPs to lower down the emission rate in descending order as : TPP3 > TPP2 > TPP4 > TPP1.

## 5.1 Potentiality of proposed method

Let us find the rank of four TPPs in intuitionistic fuzzy atmosphere. Then hesitation part of all *svtrn*-numbers projected in Table 5 are discarded. Then Table 6 is now implemented as in Table 11. Corresponding Graded mean value is evaluated by the following expression :

$$G_m(\widetilde{Q}) = \frac{1}{12}\{(p_1 + p_3) + 8q + (r_1 + r_3)\} \quad (7)$$

Table 11 : Graded mean value of emission rate in different periods

| Criteria ↓ | TPP1 | | | TPP2 | | |
|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P1 | P2 | P3 |
| $SO_2$ (mg/Nm$^3$) | 501.25 | 415.00 | 540.00 | 346.67 | 340.00 | 359.33 |
| $NO_X$ (mg/Nm$^3$) | 552.50 | 481.25 | 517.08 | 235.00 | 210.00 | 230.83 |
| $CO$ (mg/Nm$^3$) | 167.50 | ,150.00 | 159.58 | 170.25 | 146.67 | 180.00 |
| $PM$ (mg/Nm$^3$) | 073.16 | 060.58 | 080.00 | 035.67 | 030.42 | 039.83 |
| $Hg$ (mg/Nm$^3$) | 0.0198 | 0.0139 | 0.0246 | 0.0257 | 0.0094 | 0.0226 |
| **Criteria ↓** | **TPP3** | | | **TPP4** | | |
| | P1 | P2 | P3 | P1 | P2 | P3 |
| $SO_2$ (mg/Nm$^3$) | 530.00 | 484.58 | 547.50 | 359.17 | 320.00 | 380.42 |
| $NO_X$ (mg/Nm$^3$) | 444.17 | 430.00 | 459.58 | 501.25 | 470.83 | 519.00 |
| $CO$ (mg/Nm$^3$) | 183.33 | 149.17 | 188.58 | 159.58 | 130.42 | 170.83 |
| $PM$ (mg/Nm$^3$) | 069.25 | 060.58 | 074.33 | 078.75 | 070.25 | 084.17 |
| $Hg$ (mg/Nm$^3$) | 0.0228 | 0.0183 | 0.0239 | 0.0184 | 0.0135 | 0.0228 |

The rank of power plants with its full score is now available in Table 12 under intuitionistic fuzzy environment following the algorithm in [4.2].

Table 12 : Full score and rank of TPPs in intuitionistic fuzzy ground

| Criteria ↓ | TPP1 | TPP2 | TPP3 | TPP4 |
|---|---|---|---|---|
| Score | 0.77287 | 0.82932 | 0.88495 | 0.81597 |
| Rank | 4 | 2 | 1 | 3 |

Hence, the attention should be paid on TPPs to lower down the emission rate in descending order as : TPP3 > TPP2 > TPP4 > TPP1. The order is identical as seen in neutrosophic environment for this particular example but in general it may not be occurred. As intuitionistic fuzzy climate does not provide the scope to cultivate the hesitancy of experts independently in setting of experimental data of decision making, so the emission rates are not precisely measured here. Experts compel to undergo to a limitation in fuzzy and intuitionistic fuzzy climate. In neutrosophic ground, experts have a scope to measure the emission in a more flexible way. As $NtS$-set is the generalised form of fuzzy and intuitionistic fuzzy set, so the algorithm proposed here may be practiced also in fuzzy and intuitionistic fuzzy climate.

In the work [4] and [16] under fuzzy environment, some linguistic variables are considered to arrange the data in a small scale. But it may mislead the evaluation because the fuzzy number representing a particular linguistic variable may not be fit suitably everywhere, it may be somewhere narrow or may be broad. So it is better to make focus on the individual practical emission to measure it more precisely. Another fact is that an industry or power plant may have several number of production or power generation units. They may have different capacities of production and are adapted by different technology. Naturally, all units don't emit at a unique rate. In the present work, special attention is paid on this corner. Moreover, the permissible norm by PCB in a country is critically practiced to rank the TPPs. From all these angles, the study has a superiority than existing one and it is more realistic.

## 6 Conclusion

This work develops a methodology to establish the rank of a number of coal fired TPPs with respect to its pollutant discharge rate. The motivation is to make a healthy competition among these TPPs to lower down the emission rate which is too much necessary for the save of our natural environment. A TPP don't emit the pollutants at a uniform rate throughout the year under several circumstances. Moreover, it is almost impossible to measure the emission rate everyday. Taking into account all these, the emission rate of pollutants are assessed as uncertain parameter and it is here expressed by *svtrn*-number to include the hesitancy of experts independently in experimental data. The proposed methodology of finding the rank of TPPs reflects on the five major real issues : (1) a TPP may have more than one power generation unit whose capacity and the date of installation may not be same, (2) the rate of emission of pollutants may not be same for all units of a TPP, (3) every TPP must obey the norm of emission rate specified by PCB of respective country but it is not unique for all units in a TPP, (4) throughout the year, any power generation unit don't emit the pollutants at a constant rate, (5) to fix the discharge rate of pollutants, experts suffer from a lot of hesitation. An attempt is taken here to overcome all these real facts. The proposed methodology is demonstrated on the four TPPs in different parts of India to test its efficiency.

This is a proposed model and so the data here adopted are not collected from true sources, these are guessed values. Also the study is driven over only the five pollutants, it needs to incorporate more. For some pollutants like $CO_2$, the quantity of coal used in a TPP makes a factor. So further study is welcome in those angles. However, the paper will bring a ray of advancement to the future research, we believe. Inspiring from this study and getting the rank of a TPP, Managing director can take following actions to reduce the emission rate.

- New technology and latest device for emission control system should be installed and be operated satisfactorily at the station.
- The quality of pollutants released from the power station is within the norms stipulated by PCB, it should be ensured.
- Any significant deterioration in environmental quality should be identified as early as possible and be mitigated by advance planning.
- Based on a time frame, regular monitoring of emission level of power plant should be done to assess the effectiveness of pollution controlling measures.
- There should be an well planning to recycle / utilise of emission like $CO_2$, fly ash etc as much as possible. For instance, $CO_2$ may be used for farming of algal, spirulina or to produce dry ice. Fly ash may be utilised in cement factory, bricks industry etc.
- The power plant authority should install adequate number of air quality monitoring stations in and around the power stations.
- Routine medical checkup of the workers of a TPP and the local resident surrounding

it should be done.

# 7 Declaration

There is no any funding source behind the construction of manuscript. Authors have made the work in their own interest.
The manuscript has no any conflict of interest or any competing interest.
This work has been done in collaboration between both authors. Author Bera has written the first draft of the manuscript and managed the literature searches in consultation with the author Mahapatra. Author Mahapatra has brought the protocol and literature searches. Both authors have read and approved the final manuscript.

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# Credit Author Statement

We have revised our manuscript thoroughly following the direction of respected reviewers. As per their opinions, we have changed the title of our manuscript as **“Ranking of thermal power plants focusing on air pollution : a Neutrosophic assessment”**. A detailed response is now provided to the respected reviewers’ queries. We hope that the revised version of the manuscript will be appropriate and suitable to mitigate the questions raised by respected reviewers.

# Declaration of Interest Statement

1. There is no any funding source behind the construction of manuscript. Authors have made the work in their own interest.

2. The manuscript has no any conflict of interest or any competing interest.

3. This work has been done in collaboration with both authors. Author Bera has written the first draft of the manuscript and managed the literature searches in consultation with the author Mahapatra. Author Mahapatra has brought the protocol and literature searches. Both authors have read and approved the final manuscript.