ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Optimal ranking of nanotoxicity assesement methods using interval-valued neutrosophic multicriteria decision making

Xavier Adaikalaraj [a], Nivetha Martin [a], P. Pandiammal [b], N. Ramila Gandhi [c]

[a] Department of Mathematics, Arul Anandar College (Autonomous), Karumathur, India
[b] Department of Mathematics, GTN Arts College (Autonomous), Dindigul, India
[c] Department of Mathematics, PSNA College of Engineering and Technology, Dindigul, India

ARTICLE INFO

Article history:
Received 7 September 2020
Accepted 8 October 2020
Available online xxxx

Keywords:
Nano toxicology
Nano toxicity
Assessment methods
Interval – valued neutrosophic fuzzy values
Decision making

ABSTRACT

The technological progression has presently landed in the exploration of nanotechnology, a segment of science dealing with the applications of nano particles. The extensive pros of the objects scaled to 10^{-9} nm finds prime position in industrial and medical applications. The robust attributes of nano particles have also attracted the production sectors to integrate in their product production and this has further accelerated the growth of nanotechnology, but at the same time, the harmful impacts of these nano particles on the biological and environmental systems have paved way for the emerge of Nanotoxicology, a study of nano toxins. Lack of wide-ranging regulations of the utility of nano materials is one of the contributing factors for gloomy assessment of nanotoxicity. Researches over many decades have devised many *in vitro* methods of nanotoxicity assessment which differs from one another in their efficacy. This paper is intended to rank these *in vitro* methods using a multicriteria decision making model with interval – valued neutrosophic values representing the weights of criteria and expert's opinion. The optimal ranking of the *in vitro* methods such as Proliferative assay, Apoptosis assay, Necrosis assay, Oxidative Stress assay and Inflammatory assay is based on the feedback of three experts and five criteria namely Cost Effective, Efficiency in mitigating the generation of toxic wastes, Accuracy in quantitative indices, Robust Nature and Consistency in results. This research work will certainly assist the decision makers on the assessment of nano risks in its exposure to the external environment.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Nanoelectronics, Nanophotonics, Nanomaterials, Nanobioscience & Nanotechnology.

1. Introduction

Nano materials which are naturally present have wide ranging applications in the field of medicine, industries, transportation, pharmaceutical sciences and other related domains.

The consumable products are the composition of nano particles which are mostly non–biodegradable and when exposed to the environment, the sustainability of the ecosystem and the health of the human get affected. The exposure of these nano particles has adverse effects on human health and the vulnerable organs of the body are skin, gastrointestinal tract, lungs and eyes. The ingress of the nano particles into human system affects the functioning and the intensity of the impacts depends on the nano toxicity of the nano particles [8]. The toxicity of the nano materials are categorized as metallic and non-metallic and the disclosure causes serious health disorders such as cancer, cardiovascular and respiratory diseases.

The manufacturing sectors and expel of products made of nano particles into environment are the points of entrance of nano toxins into human. The rate of exposure of mankind to such dreadful materials increases as rigid regulations on the employability of nano materials in production are quite deficit and the determination of the presence of nano materials in the products are difficult. It has become inevitable to cease the usage of nano materials but testing and checking the nano toxicity of the nano materials is very essential for treatment before exposure. The degree of nano toxicity of the nano materials should be assessed based on consistent methods. Literature [1] suggests *in vitro* methods are most compatible for assessing nano toxicity.

https://doi.org/10.1016/j.matpr.2020.10.994
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Nanoelectronics, Nanophotonics, Nanomaterials, Nanobioscience & Nanotechnology.

Please cite this article as: X. Adaikalaraj, N. Martin, P. Pandiammal et al., Optimal ranking of nanotoxicity assesement methods using interval-valued neutrosophic multicriteria decision making, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.10.994

As nano materials finds prime place in the industrial sectors, it is highly essential to assess the nano toxicity of the materials by using methods fulfilling the criteria of Cost Effective, Efficiency in mitigating the generation of toxic wastes, Accuracy in quantitative indices, Robust Nature and Consistency in results. There are many *in vitro* methods and each has its own merits and limitations [7]. Generally *in vitro* methods are quite feasible, but the optimal *in vitro* method is to be uncovered by the method of ranked. Ranking is the method of arranging the entities based on certain criteria using scientific and systematic methods. It is also a decision making process comprising of many alternatives, criteria and expert's opinion on the significance of the criteria and the degree of satisfaction of the criteria by the alternatives. The process of ranking the alternatives with the consideration of criteria involves the influence of uncertainty and ambiguity. To resolve such instances fuzzy decision making tools are employed.

The pioneer of fuzzy set theory is Lofti. A. Zadeh [9] and its extension to interval valued fuzzy sets by Turksen, intuitionistic fuzzy sets by Atanssov [2], hesistant sets by Tora [8] and Neutrosophic fuzzy sets by Florentin Smarandache [3] find bounteous applications in almost all domains of decision making. Researchers have devised many methods of decision making and it ranges from group decision making to multi criteria decision making. The predominant decision making methods such as Simple Additive Weighting (SAW), Analytic Hierarchy Process (AHP), The technique for order preference by similarity to ideal solution (TOPSIS), Elimination and Choice expressing reality (ELECTRE) and Vlse kriterijumska optimisacija kompromisno resenje (VIKOR in Serbian) are applied to formulate optimal solutions to the decision making problems. These methods are modified based on the requirements of the decision makers and the nature of the problem. One such notable work is accomplished by Foroozesh [4] who proposed interval-valued hesitant fuzzy modified VIKOR decision making method with the introduction of new operators of addition and multiplication of hesitant fuzzy sets and interval valued hesitant fuzzy sets for determining the expert's significance and new index for ranking the possible alternatives in interval valued hesitant fuzzy environment. The proposed method is highly efficient but the computation not time effective. To overcome this, VIKOR method with score function using weighted average operator in Interval – valued Neutrosophic fuzzy environment is proposed. Neutrosophic fuzzy sets represent the degree of truth, false and indeterminacy which reflects the real opinion of the experts. Neutrosophic set is more realistic and pragmatic in nature than hesitant fuzzy set as it comprises of values of membership, non–membership and indeterminacy. Huang et al [5] has proposed VIKOR method with interval neutrosophic fuzzy sets with the integration of interval Neutrosophic representation of the expert's opinion and conventional procedure of VIKOR method. But in this research work the expert's opinion on the significance of criteria, criterial satisfaction and criterion weight are represented in interval neutrosophic fuzzy sets. The optimal ranking is determined using score functions rather than the usual trend of finding the positive and negative ideal solutions.

The paper is structured as follows: section 2 comprises of the proposed methodology; section 3 consists of the optimal ranking of the *in vitro* methods of nano toxicity assessment; section 4 comprises of the results and inferences and the final section concludes the research work.

2. Methodology

This section comprises of the following steps of the proposed VIKOR method with score function using weighted average operator in Interval – valued Neutrosophic fuzzy environment [5,6].

Step 1. The alternatives and criteria of the decision making problem are initially determined and the degree of satisfaction of the criteria by the alternatives are expressed in terms of Neutrosophic fuzzy sets. A Neutrosophic fuzzy set N is of the form (x,μ(x),$\vartheta(x)$, ω(x)), where μ(x),$\vartheta(x)$, ω(x) are the degrees of truth membership, indeterminacy and falsity membership and each is a function defined from X to [0,1], X is the universal set. The relative importance weight $\rho_k^F$of each expert is determined by

$$\rho_k^F = \left(\frac{\sum_i^m \sum_j^n \left(\mu_{ij}^{kU} + \mu_{ij}^{kL}\right)}{\sum_k^K \sum_i^m \sum_j^n \delta_{ij}^k}, \frac{\sum_i^m \sum_j^n \left(\vartheta_{ij}^{kU} + \vartheta_{ij}^{kL}\right)}{\sum_k^K \sum_i^m \sum_j^n \delta_{ij}^k}, \frac{\sum_i^m \sum_j^n \left(\omega_{ij}^{kU} + \omega_{ij}^{kL}\right)}{\sum_k^K \sum_i^m \sum_j^n \delta_{ij}^k} \right)$$

Step 2. Interval – valued neutrosophic decision matrix N is constructed with ρ_k^F

Step 3. The aggregated Interval – valued Neutrosophic weights of criteria are calculated:

$$w_j = \left(\frac{\mu_{w_j}^L + \mu_{w_j}^U}{\sum_{j=1}^n \delta_{wj}}, \frac{\vartheta_{w_j}^L + \vartheta_{w_j}^U}{\sum_{j=1}^n \delta_{wj}}, \frac{\omega_{w_j}^L + \omega_{w_j}^U}{\sum_{j=1}^n \delta_{wj}} \right)$$

Step 4. Interval valued neutrosophic aggregation for the alternatives with the respective criteria is determined.

$$\left(\left[\prod_{k=1}^K \mu_k^{L^{w_j}}, \prod_{k=1}^K \mu_k^{U^{w_j}} \right], \left[\prod_{k=1}^K \vartheta_k^{L^{w_j}}, \prod_{k=1}^K \vartheta_k^{U^{w_j}} \right], \left[\prod_{k=1}^K \omega_k^{L^{w_j}}, \prod_{k=1}^K \omega_k^{U^{w_j}} \right] \right)$$

Step5. The interval Neutrosophic weighted average operator is used to determine the expert's opinion of the alternatives Ai $\left(\left[1 - \prod_{k=1}^K 1 - \mu_k^{L^{w_j}}, 1 - \prod_{k=1}^K 1 - \mu_k^{U^{w_j}} \right], \left[\prod_{k=1}^K \vartheta_k^{L^{w_j}}, \prod_{k=1}^K \vartheta_k^{U^{w_j}} \right], \left[\prod_{k=1}^K \omega_k^{L^{w_j}}, \prod_{k=1}^K \omega_k^{U^{w_j}} \right] \right)$

Table 3.2
Relative importance of the Experts.

Relative importance of the Experts Interval valued Neutrosophic fuzzy values
E1 (0.195808,0.03695,0.09762)
E2 (0.18036,0.04247,0.111969)
E3 (0.193602,0.038058,0.103144)

Table 3.1

Assessment Techniques [8]	Criteria
*Apoptosis assay (A1)*This assay is a form of programmed cell death used to inspect the morphological changes. It comprises of DNA laddering, Caspase assay, Comet assay, TUNEL assay and Annexin V	Cost Effective (C1)
*Proliferative assay (A2)*This assay comprises of Tetrazolium salts assay, Alamar Blue, Incorporation of 3H thymidine into DNA, Cologenic assays and it is used to find the nature of cells after the impact of stimulus exposure.	Efficiency in mitigating the generation of toxic wastes (C2)
*Necrosis assays (A3)*These assays are based on the examination of changes in the cells and it consists of neural red intake, trypan blue assay, LDH,	Accuracy in quantitative indices (C3)
*Oxidative Stress Assay (A4)*This assay determines the changes in the oxidative balance and it encompasses 2,7 dichlorofluorescin assai, electroparamagnetic resonance, lipid peroxidation, plasmid assay	Robust Nature (C4)
*Inflammatory Assay (A5)*This assay is biochemical and Enzyme – linked immunosorbent assay is one of its kind.	Consistency in results (C5)

Table 3.3
Expert's opinion on the significance of the criteria.

	C1	C2	C3	C4	C5
E 1	([0.9,1], [0.0,0.1],[0.1,0.2])	([0.9,1], [0.0,0.1],[0.1,0.2])	([0.5,0.8],[0.1,0.2],[0.3,0.4])	([0.5,0.8],[0.1,0.2],[0.3,0.4])	([0.5,0.8],[0.1,0.2],[0.3,0.4])
E 2	([0.9,1], [0.0,0.1],[0.1,0.2])	([0.5,0.8],[0.1,0.2],[0.3,0.4])	([0.9,1], [0.0,0.1],[0.1,0.2])	([0.1,0.2),[0.2,0.3],[0.9,0.1])	([0.9,1], [0.0,0.1],[0.1,0.2])
E 3	([0.4,0.5),[0.2,0.3],[0.8,0.9])	([0.5,0.8],[0.1,0.2],[0.3,0.4])	([0.5,0.8],[0.1,0.2],[0.3,0.4])	([0.9,1], [0.0,0.1],[0.1,0.2])	([0.5,0.8],[0.1,0.2],[0.3,0.4])

Table 3.4
Aggregated Interval – valued Neutrosophic weights of criteria.

Criteria	Aggregation of weights
C1	(0.134286,0.02,0.065714)
C2	(0.128571,0.02,0.048571)
C3	(0.128571,0.02,0.048571)
C4	(0.1,0.028571,0.057143)
C5	(0.128571,0.022857, 0.048571)

Table 3.7
Ranking of the Alternatives.

Alternatives	Score values	Rank
A1	0.476809	3
A2	0.499956	1
A3	0.481731	2
A4	0.451315	4
A5	0.298036	5

Step 6. The alternatives Ai are ranked by using the score function L (δ).

$$L(\delta) = \frac{2+\mu^L+\mu^U-2\vartheta^L-2\vartheta^U-\omega^L-\omega^U}{4}$$

3. Optimal ranking of the *in vitro* methods of nano toxicity assessment

The decision making problem of ranking the *in vitro* methods of nano toxicity assessment comprises of the following alternatives and criteria presented in Table 3.1.

The expert's opinion representing the degree of satisfaction of the criteria by the alternatives is represented in terms of interval valued Neutrosophic fuzzy sets.

The relative importance of the experts is presented in Table 3.2.

The expert's opinion on the significance of the criteria is presented in Table 3.3.

The aggregated Interval – valued Neutrosophic weights of criteria are presented in Table 3.4 as follows:

The Interval valued neutrosophic aggregation for the alternatives with the respective criteria is presented in Table 3.5.

The expert's opinion of the alternatives Ai is presented in Table 3.6 using interval Neutrosophic weighted average operator.

The ranking of the alternatives is presented in Table 3.7.

4. Results and discussion

The ranking of the alternatives is based on the score values. Based on the criterial satisfaction by the expert's opinion the methods A1, A2, A3, A4 and A5 are ranked as A2 > A3 > A1 > A4 > A5. The method of Proliferative assay is feasible and compatible in comparison with other methods. The score values of necrosis assay and apoptosis assay are closer to each other and the score value of inflammatory assay is less. The scores do not reflect the inefficiency of the methods as generally the *in vitro* methods are highly vigorous in its applications but these scores represent the extent of satisfaction of the criteria by the methods. The assessment of nanotoxicity is indispensable for handling the nano materials at times

Table 3.5

	C1	C2	C3	C4	C5
A1	([0.453463, 0.496868],[0, 0.117588],[0.184224, 0.230662])	([0.434848, 0.497404],[0, 0.140809],[0.228012, 0.268404])	([0.468985, 0.51188],[0, 0.128804],[0.197976, 0.24552])	([0. 493377, 0. 568087], [0.189503,0. 233306],[0. 353463, 0. 385325])	([0.468985, 0.51188],[0, 0.128804],[0.197976, 0.24552])
A2	([0.364716, 0.41247],[0.129059, 0.157943],[0.322028, 0.345469])	([0.391794, 0.454993], [0.128804, 0.162172], [0.297899, 0.325667])	([0.434848, 0.497404],[0, 0.140809],[0.228012, 0.268404])	([0. 48249, 0. 542005], [0. 203105,0. 24296],[0. 389889, 0. 417873])	([0.403197, 0.483336],[0.117821, 0.153934], [0.262604, 0.293423])
A3	([0.453463, 0.496868],[0, 0.117588],[0.184224, 0.230662])	([0.434848, 0.497404],[0, 0.140809],[0.228012, 0.268404])	([0.468985, 0.51188],[0, 0.128804],[0.197976, 0.24552])	([0. 523246, 0. 580906], [0,0. 217682],[0. 316689, 0. 316689])	([0.468985, 0.51188],[0, 0.128804],[0.197976, 0.24552])
A4	([0. 37581, 0. 439343],[0. 117588, 0. 149575],[0. 282287, 0. 309825])	([0.434848, 0.497404],[0, 0.140809],[0.228012, 0.268404])	([0.403197, 0.483336],[0.117821, 0.153934], [0.262604, 0.293423])	([0. 48249, 0. 542005], [0. 203105,0. 24296],[0. 389889, 0. 417873])	([0. 391794, 0. 454993], [0. 128804, 0. 16217], [0. 297899, 0. 325667])
A5	([0. 37581, 0. 439343],[0. 117588, 0. 149575],[0. 282287, 0. 309825])	([0.380713, 0.428313], [0.140809, 0.170848], [0.337937, 0.361454])	([0. 391794, 0. 454993], [0. 128804, 0. 16217], [0. 297899, 0. 325667])	([0. 493377, 0. 568087], [0.189503,0. 233306],[0. 353463, 0. 385325])	([0.403197, 0.483336],[0.117821, 0.153934], [0.262604, 0.293423])

Table 3.6
Expert's opinion of the alternatives.

A1	([0.687836,	0.635883],	[0,	0.292385],	[0.386852,	0.444863])
A2	[0.719687,	0.671282],	[0	0.289737],	[0.375522,	0.436149])
A3	[0.683679,	0.634388],	[0	0.289737],	[0.375522,	0.436149])
A4	[0.722894,	0.666594],	[0	0.323103],	[0.452882,	0.48514])
A5	[0.724539,	0.673363],	[0.28505	0.329863],	[0.473797,	0.502134])

of its exposure to the environment. The inferences after assessment of the nano toxins will certainly facilitate in reducing the adverse effects by employing the optimal methods.

5. Conclusion

The proposed VIKOR method with score function using weighted average operator in Interval – valued Neutrosophic fuzzy environment is applied in ranking the nanotoxicity assessment methods to assist the production sectors in making decisions regarding the incorporation of assessment method. This method integrates score function with the methodology of VIKOR in determining the optimal ranking. The proposed method can be extended with linguistic Neutrosophic fuzzy sets and other multi criteria decision making models.

CRediT authorship contribution statement

Xavier Adaikalaraj: Data curation, Writing - original draft. **Nivetha Martin:** Conceptualization, Methodology, Software. **P. Pandiammal:** Investigation, Visualization. **N. Ramila Gandhi:** Software, Validation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ahamed, M., Siddiqui, M.A., Akhtar, M.J., Ahmad, I., Pant, A.B., and Alhadlaq, H.A. Genotoxic Potential of Copper Oxide Nanoparticles in Human Lung Epithelial Cells. Biochemical and Biophysical Research Communications, Volume:396, Issue:2, (2010), pp:578-583.
[2] K. Atanassov, Intuitionistic fuzzy sets, Fuzzy Sets Syst. 20 (1986) 87–96.
[3] Florentein Smarandache, Neutrosophy. Neutrosophic Probability, Set, and Logic. Amer. Res. Press, Rehoboth, USA, 105 p., 1998, 2000, 2002, 2005, 2006
[4] Foroozesh, N. & Gitinavard, H. & Vahdani, Behnam & Mousavi, S.M. Solving group decision-making problems in manufacturing systems by an uncertain compromise ranking method. International Journal of Applied Decision Sciences. (2018), 11. 1.
[5] Huang, Yu-Han & Wei, Gui-Wu & Wei, Cun. . VIKOR Method for Interval Neutrosophic Multiple Attribute Group Decision-Making. Information. 8. 144. (2017)10.3390/info8040144.
[6] Şahin, Rıdvan. Multi-criteria neutrosophic decision making method based on score and accuracy functions under neutrosophic environment. (2014), 10.5281/zenodo.22994.
[7] Takhar, Poonam & Mahant, Sheefali. In vitro methods for Nanotoxicity Assessment: Advantages and Applications.(2011). Arch Appl Sci Res. 3.
[8] Yalcin Enis, Ipek & Ozturk, Merve & Sezgin, Hande & Ismar Sir, Ezgi. . An overview of nanotoxicology. e-Journal of New World Sciences Academy. 12. (2017)57-65.
[9] Zadeh, L.A. Fuzzy sets, Information and Control, Vol. 8, No. 3, (1965), pp.338–353.

Further Reading

[1] H. Pouresmaeil, E. Shivanian, E. Khorram, H.S. Fathabadi, An extended method using TOPSIS and VIKOR for multiple attribute decision making with multiple decision makers and single valued neutrosophic numbers, Adv. Appl. Stat. 50 (2017) 261–292.
[2] V. Torra, Hesitant fuzzy sets, Int. J. Intell. Syst. 25 (6) (2010) 529–539.