International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Recommendation System using Neutrosophic Logic in Agriculture

Sitikantha Mallik[*1], **Suneeta Mohanty**[2], **Bhabani Shankar Prasad Mishra**[3]

Submitted:14/03/2024 **Revised**: 29/04/2024 **Accepted**: 06/05/2024

Abstract: For billions of people worldwide, agriculture provides food and a means of subsistence, making it an essential component of the global economy. Agriculture, one of the main industries, contributes to both economic stability and food security. To fulfill the expanding nutritional needs and maintain long-term resilience, however, innovation and sustainable techniques in agriculture are urgently needed as a result of the COVID-19 pandemic and continued climate change. Computational Intelligence is becoming more and more applicable in several automobile, industrial, and commercial sectors worldwide. Its ability to provide efficient and accurate functionalities attracts top companies to invest in A.I. because scientists and researchers believe that it will have a significant implication in the strife towards improving human life. Cultivating crops unsuitable to environmental conditions, such as soil and weather, is one of the main reasons behind the continuing decline in agricultural advances. One way to solve this problem is to apply the use of a recommendation system to predict favorable crops. Here, we are proposing a recommendation system based on neutrosophic logic. Neutrosophic logic is a promising tool for smart agriculture that can cope with the complexity and dynamism of agricultural systems. By incorporating neutrosophic logic into smart agriculture via IoT, it is possible to achieve more accurate, reliable, and robust solutions that can improve the quality and quantity of agricultural outputs while reducing the environmental and social impacts. The proposed model efficiently predicts the crop yield outperforming existing models like KNN, fuzzy logic, and neutrosophic logic.

Keywords: *crop recommendation system; uncertainty; soil texture; neutrosophic logic; fuzzy; indeterminacy*

1. Introduction

AI can handle it all, from self-driving cars and completing human-like tasks like playing computer games and preparing us for the next phases of technological advancement. A few decades ago, farms and agricultural businesses operated quite differently than they do now. This is mostly because of advancements in technology, including sensors, machinery, devices, and information technology. Cutting edge technologies like drones, GPS, aerial photography, and moisture and temperature sensors are often used in modern agriculture. With the help of smart agriculture technology, businesses can run more securely, sustainably, profitably, and efficiently. Smart agriculture can benefit from neutrosophic logic in several ways. For example, neutrosophic logic can help to analyze soil quality, crop health, weather conditions, pest infestation, and market demand by taking into account the uncertainty and imprecision inherent in these factors. Neutrosophic logic can also help to make optimal decisions based on multiple criteria and preferences that may be conflicting or ambiguous. Moreover, neutrosophic logic can enhance communication and collaboration among different stakeholders involved in smart agriculture, such as farmers, researchers, extension agents, consumers, and policymakers.

Integrating neutrosophic logic in smart agriculture has the potential to bring several significant benefits and impacts. Neutrosophic logic is an extension of traditional logic that helps us to depict and model imprecise, uncertain, and indeterminate information.

In most cases, the majority of the time, the process of clustering entails breaking the data up into different groups based on how similar or unlike the data is inside a cluster and between clusters. A cluster is a collection of related data objects that are grouped together, as opposed to how unique data pieces are divided into several categories [1]. Neutrosophy provides a new concept that considers an event or entity in the set. Indeterminacy was a brand-new idea that Smarandache added to the fuzzy set. Accordingly, we can define the neutrosophic set as an ordered triple N = (T, I, F), where T stands for the degree of truthiness, F for the degree of falsity, and I for the degree of indeterminacy. T, I, and F are also referred to here as neutrosophic components.[3]

The rest of the paper is organized as follows: section 2 illustrates the literature review of the existing works. Section 3 describes about the role of neutrosophic logic in agriculture. Section 4 presents the proposed neutrosophic model for agricultural yield prediction. Section 5 implies about experimental results and performance of proposed models over existing models. Section 6 wraps up with the conclusion and future work.

---

[1] *Research Scholar, School of Computer Engineering, KIIT Deemed to be University, Bhubaneswar, India*
ORCID ID : 0009-0003-0069-9560 Email: sitikanthamallik@gmail.com
[2] *Professor, School of Computer Engineering, KIIT Deemed to be University, Bhubaneswar, India.*
ORCID ID : 0000-0001-7137-629X Email: smohantyfcs@kiit.ac.in
[3] *Professor, School of Computer Engineering, KIIT Deemed to be University, Bhubaneswar, India. Email: bsmishrafcs@kiit.ac.in*
ORCID ID : 0000-0003-1656-4487
* *Corresponding Author Email:sitikanthamallik@gmail.com*

2. Related Works

Increasing crop production in agriculture is essential to meet the rapidly increasing food demand brought on by population growth. Crop productivity can rise by forecasting ecological conditions. Around majority of India's population makes their living from agriculture, therefore technology developments have the potential to have a widespread positive impact in this field. Crop quality is guaranteed based on information gathered from the agricultural field, including the temperature surrounding the crop and soil moisture content. The existing agricultural practices lack the ability to effectively handle uncertainty and imprecision in decision-making and data analysis, limiting the potential for improved efficiency and productivity. Smart agriculture refers to the integration of advanced technologies and data-driven techniques into agricultural practices. It is a new digital mode of farming. It utilizes various technologies such as sensors, automation, data analytics, and connectivity to optimize agricultural operations and improve productivity, sustainability, and efficiency in food production.

The significance of smart agriculture lies in its potential to address the challenges faced by traditional agriculture while meeting the increasing demands for food production:

1. **Improved Resource Management**: The exact and focused management of resources like water, fertilizer, and pesticides is facilitated by smart agriculture. Therefore, it is also called precision farming. Farmers may maximize resource use, cut waste, and lessen their environmental impact by tracking and evaluating real-time data on crop health, nutrient levels, and soil moisture.
2. **Enhanced Crop Yield and Quality:** The application of data analytics, predictive modeling, and remote sensing in smart agriculture enables better crop yield prediction, disease detection, and pest management. Farmers can make data-driven decisions to optimize planting patterns, irrigation schedules, and crop protection measures, resulting in improved crop yield and quality.[7]
3. **Cost Reduction and Efficiency:** Smart agriculture technologies automate repetitive tasks, streamline processes, and reduce labor requirements. This can lead to cost savings, increased operational efficiency, and improved overall profitability for farmers.
4. **Environmental Sustainability:** By minimizing resource wastage and optimizing inputs, smart agriculture practices contribute to environmental sustainability. Precision application of fertilizers and pesticides reduces pollution and runoff, while efficient irrigation practices conserve water resources.
5. **Data-Driven Decision-Making:** Smart agriculture generates a wealth of data from sensors, satellites, and other sources. Analyzing this data provides valuable insights and actionable information for farmers, empowering them to make intelligent decisions on risk reduction, allocation of resources, and handling of crops.
6. **Food Security:** With a growing global population and limited arable land, smart agriculture offers a pathway to achieve food security. By improving agricultural productivity, minimizing losses, and ensuring sustainable practices, it helps meet the increasing demand for food production without depleting natural resources.

In summary, smart agriculture has the ability to completely transform conventional farming methods by leveraging technology and data to optimize operations, increase productivity, reduce environmental impact, and contribute to global food security.

Smart agriculture relies heavily on data analytics since it harnesses the power of data to derive useful information and promote thoughtful decision-making. Computational intelligence techniques, such as neural networks and evolutionary algorithms, can be utilized in data analytics to improve predictive models and optimize solutions for complex problems. Together, data analytics and computational intelligence form a powerful combination that enables organizations to extract meaningful insights from their data, predict future trends, and make informed decisions for various applications across different industries. Computational Intelligence (C.I.) is a subfield of artificial intelligence (A.I.) that encompasses various techniques and methodologies designed to enable machines to mimic human intelligence in solving complex problems. It focuses on developing algorithms and models inspired by natural intelligence, including neural networks, evolutionary algorithms, and fuzzy systems.[8]

Neutrosophic logic is an extension of classical logic that allows for the representation and handling of imprecise, incomplete, and inconsistent information. It was introduced by Florentin Smarandache in the 1990s as a way to deal with uncertain and indeterminate knowledge. Neutrosophic logic extends the concept of truth values beyond just "true" and "false" to include a third value called "indeterminate" or "neither true nor false".[4]

Neutrosophic logic offers several advantages that make it a valuable and unique tool for handling uncertainty, ambiguity, and imprecision in information and decision-making. Some of the key advantages of neutrosophic logic include:

1. **Representation of Indeterminacy**: Neutrosophic logic introduces a third truth value, "indeterminate," which allows for a more accurate representation of situations where information is not completely true or false. It acknowledges the existence of ambiguity and uncertainty in real-world scenarios, which is often overlooked in classical logic.[5]
2. **Handling Contradictions:** Neutrosophic logic can handle situations where contradictory information coexists, enabling a more flexible and nuanced approach to decision-making. Instead of forcing a binary choice between true and false, it accommodates situations where both aspects might coexist to some degree.
3. **Fuzzy Set and Interval Set Integration**: Fuzzy sets and interval sets can be connected via neutrosophic logic, enabling a better representation of data that takes into account both membership and non-membership degrees.

3. Neutrosophic Logic in Agriculture

In neutrosophic logic, propositions, variables, and sets can have degrees of truth, falsity, and indeterminacy associated with them. This enables a more flexible representation and reasoning process, particularly in situations where traditional logic may struggle to capture the inherent uncertainty or vagueness. Neutrosophic logic is a branch of philosophy and mathematics that deals with the concept of neutrality, which means the existence of truth, indeterminacy, and falsity degrees in a proposition. Neutrosophic logic can be used to model uncertainty, vagueness, incompleteness, and inconsistency in various domains of knowledge.

By incorporating this logic into smart agriculture systems, the following advantages can be realized:

1. Handling uncertainty: Agricultural systems frequently have ambiguities and uncertainties, which neutrosophic logic can handle well. Numerous data sources are used in smart agriculture, including information on the weather, soil quality, and crop development patterns. This unclear information can be captured and processed with the aid of neutrosophic logic, resulting in more precise decision-making.[6]

2. Improved decision-making: Intelligent agriculture systems can make better decisions with neutrosophic reasoning. The systems can analyze and weigh several options using ambiguous and imprecise data, resulting in conclusions that are robust and dependable. This can improve the use of resources, crop management, pest management, and other farming practices.

3. Risk assessment and management: Neutrosophic logic can facilitate risk assessment and management in agriculture. By considering uncertainty factors, such as potential yield variations, market fluctuations, and environmental conditions, farmers and agricultural experts can assess risks more comprehensively. This makes it possible to take preventative action to reduce risks and possible losses.

4. **Precision agriculture:** Accurate data analysis is essential to precision farming techniques like spraying fertilizers and insecticides at different appropriate rates. Neutrosophic logic can enhance the accuracy of decision-making in precision agriculture systems by incorporating uncertainties related to soil composition, weather patterns, and crop health. This can result in optimized resource utilization, reduced environmental impact, and improved crop yields.[10]

5. **Adaptive systems:** Neutrosophic logic can contribute to the development of adaptive smart agriculture systems. These systems possess the ability to constantly learn and adjust to changing environmental conditions, market trends, and emerging agricultural knowledge. By incorporating neutrosophic logic, the systems can dynamically adjust their decision-making processes and strategies based on evolving uncertainties, leading to more resilient and efficient farming practices.[9]

6. Data fusion and integration: Smart agriculture relies on data from multiple sources, such as archives, orbiting satellites, and sensors. Neutrosophic logic can facilitate the fusion and integration of diverse data sets, even when they contain uncertainties and inconsistencies. This can lead to a more comprehensive and accurate understanding of the agricultural ecosystem, enabling more precise and effective management practices.[2]

In summary, integrating neutrosophic logic in smart agriculture can enhance decision-making, improve risk management, enable precision agriculture techniques, develop adaptive systems, and facilitate data fusion and integration. By leveraging neutrosophic logic, farmers and agricultural experts can make more informed and reliable decisions, leading to increased productivity, sustainability, and resilience in agricultural practices.

4. Methodology

The smart agriculture mechanism model incorporating neutrosophy theory combines the principles of smart agriculture and neutrosophic logic to create an intelligent and adaptive agricultural system. This model utilizes advanced technologies, data processing, and decision-making techniques to optimize agricultural practices while considering uncertainties and indeterminacies inherent in the domain. The model's operation is explained as follows :

1. **Data collection and processing**: The first step of the model involves gathering information from multiple

sources, including satellites, sensors, and old documents. This data contains details on market trends, pest infestations, crop growth patterns, soil properties, and weather. After the collection, the data is processed and represented using neutrosophic logic. Each data point is given a degree of truth, falsity, or indeterminacy.

2. **Neutrosophic rule base:** The model incorporates a rule base that includes neutrosophic rules derived from expert knowledge and domain-specific guidelines. These rules capture the relationships between different variables in the agricultural system and define the decision-making criteria. The rules consider the degrees of truth, falsity, and indeterminacy associated with the variables and provide a basis for inference and decision-making.[12]
3. **Uncertainty handling and analysis:** Neutrosophic logic allows the model to handle uncertainty and indeterminacy effectively. It considers degrees of truth, falsity, and indeterminacy associated with data and variables, enabling the system to reason and analyze the information in a more nuanced manner.[11] Uncertain and vague data are appropriately evaluated, and the model can assess the reliability and significance of the available information.
4. **Decision support system:** The smart agriculture mechanism model incorporates a decision support system that utilizes the principles of neutrosophic logic. The system evaluates multiple possibilities and potential outcomes based on the neutrosophic data representation and rule base. It considers the degrees of truth, falsity, and indeterminacy associated with different variables and uses them to make informed decisions. The decisions that are taken by support systems include allocating resources, managing crops, controlling pests, and implementing other agricultural techniques.
5. **Adaptability and learning**: The model is meant to be flexible and able to adjust to new situations and feedback. Based on recent information and user interaction, it continuously modifies the variables' degrees of truth, falsehood, and indeterminacy. This adaptability enables the model to dynamically adjust its decision-making processes and strategies, ensuring that it can respond effectively to evolving agricultural conditions and uncertainties.
6. **Integration with smart technologies**: The smart agriculture mechanism model integrates with various technologies, including sensor networks, data analytics platforms, and machine learning algorithms. This integration facilitates seamless data flow, analysis, and decision-making processes. The model leverages the benefits of neutrosophic logic in conjunction with other advanced technologies to enhance agricultural operations and optimize resource utilization.
7. **Evaluation and refinement:** The performance of the smart agriculture mechanism model incorporating neutrosophy theory is evaluated and refined through iterative processes. The precision, dependability, and efficacy of the model's decisions and outputs are evaluated by contrasting them with established facts or known understanding. The model is improved through feedback and validation findings resulting in improved performance and boosted capacity for making decisions.

By incorporating neutrosophic logic into the smart agriculture mechanism model, the agricultural system gains the ability to handle uncertainty, make more informed decisions, and adapt to changing conditions. This holistic approach allows for optimized resource allocation, increased crop yields, reduced environmental impact, and improved sustainability in agriculture.

5. Experimental Results Analysis And Discussion

This study assesses the classification performance of suggested neutrosophic models and current methods using MATLAB. The effectiveness of different machine learning and computational intelligence methods is evaluated and analyzed. The effectiveness of the prediction of crops might be evaluated using statistical measurements.

5.1. Dataset

The dataset that is used here for crop recommendation can be referred from https://www.kaggle.com/siddharthss/crop-recommendation-dataset/. This dataset was created by ICFA collecting information and data about the amount of rainfall, climatic conditions, and fertilizer. The crop recommendation dataset used in this study includes several factors that affect both crop yield and rainfall in a particular region. The variables phosphate (P), nitrogen (N), potassium (K), temperature, humidity, pH, precipitation, and label are all included in the crop recommendation dataset. Several constraints were placed on the selection of these instances from a larger database. The dataset is randomly divided into training and test sets while designing machine learning models, with the training set consisting of the largest quantity of data.

5.2. Parameters

In the experimental analysis, the parameters used for evaluating model performance include precision and recall, which are critical metrics in classification tasks. Precision measures the accuracy of positive predictions by calculating the ratio of true positive predictions to the total number of positive predictions, reflecting how many of the predicted positive instances are positive. Recall, also known as sensitivity or true positive rate, measures the ability of the model to identify all actual positive instances by calculating the ratio of true positive predictions to the total number of actual positives. Better crop recommendation is correlated with higher levels of precision and recall.

5.3. Experimental Setup

The Naïve Bayes, random forest, KNN, Fuzzy, and neutrosophic methods were implemented and executed using Python 3 on a PC equipped with an Intel Core i7 processor, 16GB of RAM, and running Windows 10 (64-bit).

5.4. Performance Comparison of Different Methods

To demonstrate the effectiveness of the suggested strategy for prediction, we performed several experiments using various methods including KNN, fuzzy logic, Naïve Bayes, and neutrosophic logic. These experiments were conducted on a crop recommendation dataset, which was created by combining data from the ICAR Institute on India's rainfall, climate, and fertilizer usage. Additionally, a sample of five rows from the dataset is demonstrated in Table 1.

The recall and precision comparative metrics are assessed for both the present and suggested approaches, as illustrated in Table 2. In terms of precision and recall, existing approaches like KNN algorithm offer lower accuracy whereas the neutrosophic strategy offers higher accuracy. As a result, by carefully choosing climate features, the suggested method has greater accuracy in the prediction of crops.

Table 1: Crop Recommendations

Sl. No.	*n*	*p*	*k*	*temperature*	*humidity*	*ph*	*rainfall*	*label*
1	88	35	40	23.57944	83.5876	5.853932	291.9857	rice
2	73	45	21	24.605322	73.588685	6.6368032	96.591953	maize
3	22	72	85	18.868056	15.658092	6.3911759	88.51049	chickpea
4	19	78	16	20.65376	23.10539	5.967533	67.71769	kidney beans
5	78	42	42	20.130175	81.604873	7.62873	262.71734	rice

Table 2: Comparison of Existing and Proposed System Metrics

Methods	**Metrics**	
	Recall	**Precision**
Naïve Bayes	0.968	0.9958181
KNN	0.95909	0.96538
SVM	0.96818	0.97151
Fuzzy	0.9467	0.9815
Neutrosophic	0.969	0.986

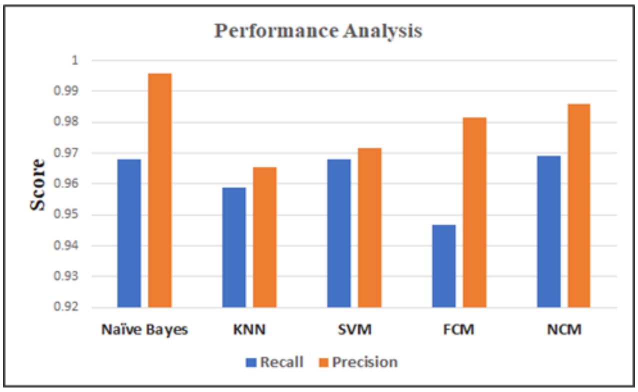

Fig 1. Performance Analysis Chart

The comparative performance of all models is shown in Figure 1, with an overall prediction accuracy ranging from 94% to 99% for both precision and recall. We experimented and eventually achieved a mean accuracy of 97% overall. All algorithms predict crop-type labels consistently, according to the testing results shown in Table 2. Notably, in terms of precision and recall, the Neutrosophic and Naïve Bayes algorithms performed better than the others.

Neutrosophic logic, used in crop recommendation, exhibits superior precision and recall compared to other algorithms, contributing to more accurate and reliable predictions.

6. Conclusion

Plant diseases contribute significantly to the output losses in contemporary agriculture. The severity of plant disease is a crucial statistic for determining crop disease's degree and can be used to forecast crop production. The severity of the disease will be quickly and accurately diagnosed, which will lessen yield losses. Experts have traditionally used visual inspection of plant tissue to assess the severity of plant diseases. The high expense and poor efficacy of manual plant disease evaluation impede the rapid development of modern agriculture. Artificial intelligence has the potential to revolutionize agriculture by providing a faster and more efficient analysis of farming crops and agricultural conditions Precision agriculture, smart greenhouses, and other applications have increasing demands for automated crop disease diagnosis models due to the proliferation of digital sensors and advancements in computer vision. They can also enhance the early detection of crop diseases which is not possible through the farmer's naked eyes and help make farming more accurate and sustainable. The application of Artificial Intelligence (AI) in agriculture holds great promise for enhancing food production, reducing crop wastage, increasing yields, and developing pest-resistant crops. One of the emerging approaches in this field is the use of neutrosophic sets, an extension of intuitionistic fuzzy sets.

Neutrosophic sets are particularly useful in handling indeterminacy and imprecision, which are common in agricultural data. They have been successfully applied to tasks such as clustering, segmentation, noise reduction, and image retrieval, all of which contribute to more accurate crop selection and improved yields.

The integration of neutrosophic sets into crop recommendation systems represents a promising advancement in agricultural AI. By leveraging these sets, we can handle the uncertainty and imprecision inherent in agricultural data more effectively, resulting in better recommendations and improved crop management strategies. This, in turn, supports the goal of enhancing food production and sustainability in agriculture. In our study, we explored various deep learning and machine learning models to predict crop adaptability and production, using a range of variables including temperature, humidity, pH, rainfall, nitrogen, phosphorus, and potassium. By incorporating neutrosophic sets into our methodology, we were able to improve the accuracy, recall, and precision of our predictions. This approach offers a robust framework for providing farmers with better crop recommendations, ultimately aiding in the selection of the right crops and fertilizers to maximize productivity and profitability.

Author contributions

Sitikantha Mallik: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation. **Suneeta Mohanty:** Investigation, Supervision, Writing- Reviewing and Editing. **Bhabani Shankar Prasad Mishra:** Investigation, Supervision, Writing- Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] F. Smarandache (Ed.), "Proceedings of the First International Conference on Neutrosophy, Neutrosophic Logic, Neutrosophic Set, Neutrosophic Probability and Statistics", University of New Mexico, Gallup Campus, Xiquan, Phoenix, 2002, pp. 147.

[2] Isaac Kofi Nti, Adib Zaman, Owusu Nyarko-Boateng, Adebayo Felix Adekoya, Frimpong Keyeremeh, A predictive analytics model for crop suitability and productivity with tree-based ensemble learning, *Decision Analytics Journal, Volume 8,2023,100311*, ISSN 2772-6622,https://doi.org/10.1016/j.dajour.2023.100311.

[3] F. Smarandache and M. Leyva-Vázquez, "Fundamentals of neutrosophic logic and sets and their role in artificial intelligence," *Neutrosophic Comput. Mach. Learn*., 2018.

[4] S. Kiruthika, D. Karthika, IOT-BASED professional crop recommendation system using a weight-based long-term memory approach, Measurement: Sensors, Volume 27,2023,100722, ISSN 2665-9174.https://doi.org/10.1016/j.measen.2023.100722.

[5] A. Q. Ansari, Ranjit Biswas, and Swati Aggarwal. 2013. Neutrosophic classifier: An extension of fuzzy classifier. Appl. Soft Comput. 13, 1 (2013), pp. 563–573. DOI: https://doi.org/10.1016/j.asoc.2012.08.002.

[6] Lacasta J, Lopez-Pellicer FJ, Espejo-García B, Nogueras-Iso J, Zarazaga-Soria FJ (2018) Agricultural recommendation system for crop protection. Comput Electron Agric 152(8):82–89. https://doi.org/10.1016/j.compag.2018.06.049.

[7] J. R, H. D and P. B, "A Machine Learning-based Approach for Crop Yield Prediction and Fertilizer Recommendation," 2022 *6th International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India*, 2022, pp. 1330-1334, doi: 10.1109/ICOEI53556.2022.9777230.

[8] Umberto Rivieccio, Neutrosophic logics: Prospects and Problems, *Fuzzy Sets and Systems, Volume 159, Issue 14,2008*, https://doi.org/10.1016/j.fss.2007.11.011.

[9] S. Bhanumathi, M. Vineeth and N. Rohit, "Crop Yield Prediction and Efficient use of Fertilizers," *2019 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2019, pp. 0769-0773, doi: 10.1109/ICCSP.2019.8698087*.

[10] K. P. K. Devan, B. Swetha, P. Uma Sruthi and S. Varshini, "Crop Yield Prediction and Fertilizer Recommendation System Using Hybrid Machine Learning Algorithms," 2023 IEEE 12th International Conference on Communication Systems and Network Technologies (CSNT), Bhopal, India, 2023, pp. 171-175, doi: 10.1109/CSNT57126.2023.10134662.

[11] Mallik, S., Mohanty, S., Mishra, B.S. (2022*)*. Neutrosophic Logic and Its Scientific Applications. *In: Dehuri, S., Prasad Mishra, B.S., Mallick, P.K., Cho, SB. (eds) Biologically Inspired Techniques in Many Criteria Decision Making. Smart Innovation, Systems and Technologies, vol 271. Springer, Singapore.* https://doi.org/10.1007/978-981-16-8739-6_38.

[12] Gafar, M.G., Elhoseny, M. & Gunasekaran, M. Modeling neutrosophic variables based on particle swarm optimization and information theory measures for forest fires. *J Supercomput* **76,** 2339–2356 (2020). https://doi.org/10.1007/s11227-018-2512-5.