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Information for Authors and Subscribers

*"***Neutrosophic Systems with Applications***"* has been created for publications on advanced studies in neutrosophy, neutrosophic set, neutrosophic logic, neutrosophic probability, neutrosophic statistics that started in 1995 and their applications in any field, such as the neutrosophic structures developed in algebra, geometry, topology, etc.
The submitted papers should be professional, in good English, containing a brief review of a problem and obtained results.
Neutrosophy is a new branch of philosophy that studies the origin, nature, and scope of neutralities, as well as their interactions with different ideational spectra.
This theory considers every notion or idea <A> together with its opposite or negation <antiA> and with their spectrum of neutralities <neutA> in between them (i.e., notions or ideas supporting neither <A> nor <antiA>). The <neutA> and <antiA> ideas together are referred to as <nonA>.
Neutrosophy is a generalization of Hegel's dialectics (the last one is based on <A> and <antiA> only). According to this theory every idea <A> tends to be neutralized and balanced by <antiA> and <nonA> ideas - as a state of equilibrium.
In a classical way <A>, <neutA>, <antiA> are disjointed two by two. But, since in many cases the borders between notions are vague, imprecise, Sorites, it is possible that <A>, <neutA>, <antiA> (and <nonA> of course) have common parts two by two, or even all three of them as well.
Neutrosophic Set and Neutrosophic Logic are generalizations of the fuzzy set and respectively fuzzy logic (especially of intuitionistic fuzzy set and respectively intuitionistic fuzzy logic). In neutrosophic logic a proposition has a degree of truth (T), a degree of indeterminacy (I), and a degree of falsity (F), where T, I, F are standard or non-standard subsets of $]^-0, 1^+[$.
Neutrosophic Probability is a generalization of the classical probability and imprecise probability.
Neutrosophic Statistics is a generalization of classical statistics.
What distinguishes neutrosophic from other fields is the <neutA>, which means neither <A> nor <antiA>.
<neutA>, which of course depends on <A>, can be indeterminacy, neutrality, tie game, unknown, contradiction, ignorance, imprecision, etc.
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Leveraging Neutrosophic Uncertainty Theory toward Choosing Biodegradable Dynamic Plastic Product in Various Arenas

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Abstract: Numerous studies in recent years have documented the negative effects of plastic waste on the environment and human wellness. Due to their widespread usage in daily life, particularly in packaging, and their rising direct or indirect discharge into the environment, plastics are recognized as an emerging environmental hazard. Thus, this point is considered the first problem in this study. As a result, efforts to replace traditional plastics with bioplastics have intensified. However, studies regarding the effects of conventional and bioplastics (BioPs) are also important. Hence, biodegradable polymers for industrial and commercial usage are essential in the present day as an alternative to traditional plastic. Another point considered in this study is packaging which entails the quest for new natural materials that may be included in the production of reusable, eco-friendly, and long-lasting flexible polymers. Prior studies demonstrated that starches from both tubers and grains may be processed into malleable biopolymers. Since the quality of the carbs from different vendors varies, choosing which one to work with presents a Multi-Criteria Decision-Making (MCDM) challenge. This paper proposed a neutrosophic MCDM methodology to select the best biodegradable dynamic plastic product (BDPP). The neutrosophic method is used to overcome uncertain data. The neutrosophic is integrated with the Additive Ratio Assessment (ARAS) method. The weights of the criteria are computed then the rank of BDPP is obtained by the neutrosophic ARAS method.

Keywords: Bioplastic; Biodegradable; MCDM; Neutrosophic Set; ARAS method.

1. Introduction

Throughout 2017 scholars of [1] demonstrated that 348 million tons of plastic were produced worldwide. The rationale behind that [2] Plastics are popular because they enable societies to get the merchandise they want for a bargain price. In light of its incredible traits in endurance, brightness, equilibrium, and affordable expenditures plastics have been utilized extensively in industrial and daily life since its inception. Due to [3]where the increasing usage of plastic, there is currently an issue with white pollution since a lot of plastic litter has been released into the environment globally. Shen et al. [1] coined the term "White pollution" to describe the problem of discarded plastics causing environmental contamination. The usage of plastic items like packing bags, agricultural mulch film, throwaway dinnerware, plastic bottles, etc. causes environmental and landscape damage. That is the case [4] given the accumulating evidence that plastic pollution harms living beings in terrestrial ecosystems alike. That is why as mentioned in [5] whereas the detrimental environmental repercussions of plastics are becoming more well-known among consumers.

As a result, several studies have looked at this negative impact in different contexts. For instance [6] discussed how it has a detrimental influence on society context whereas the negative effects of plastics on human society have gotten worse, including the immediate damage they do to the environment and the potential hazards that pose to humans and other living beings. Regarding the financial and economic context, in accordance with statistics in [7] 192 coastal nations and areas created 280 million tons of plastic debris in 2011, and roughly 8 million tons of that waste ended up in the seas.

For several decades, efforts have been made to lessen plastic waste and the ensuing contamination of land and marine areas. Whereas [8] illustrated that in 1975, the European Union generated Waste Framework Directives and a hierarchy of waste management practices, with prevention, reuse, recycling, recovery, and disposal ranked from most to least advantageous.

Conversely, [1] had a divergent scepticism on recycling depicted in two points. First one, Plastic recycling is limited by the high cost of these stages, the poor economic value of recovered plastics, and the low cost of raw materials. Second one, when plastic garbage is burned, harmful substances such as greenhouse gases (CO_2) and other irritating gases are released.

Thereby in light of the growing social, economic, and environmental crises , [1] illustrated efforts have been made to discover a workable solution to plastics. This solution is utilizing Bioplastics (BioPs) as a practical replacement for conventional plastics. Biops in [9] are described as polymers that meet one or both of the following requirements: they are made from bio-based and biodegradable.

BioPs are often produced as mentioned in [10] using renewable raw materials such lignin, cellulose, starch, and bioethanol. Thereby, [11]summarized biodegradable plastic as a plastic material that satisfies formal biodegradability standards, where a defined amount of breakdown must be experimentally verified within a specific timeframe and under specific circumstances.

Others as [12] demonstrated that in the near future, a viable alternative to petrochemical plastics might be provided by biobased and biodegradable plastic, which can be considered as one of the alternatives to achieve this sustainable expansion of the plastic sector. BioPs and biobased might be a potential long-term tackle to the issue of waste disposal and worldwide plastic pollution.

Ultimately, Environmental concerns about the non-biodegradability of viscoelastic plastics motivated researchers to look for a safer, more sustainable alternative. Starch, fiber, sodium alginate, and other chymotrypsinogen are the next most studied and used resources in the production of biodegradable polymers, respectively. Since there are many different manufacturers that may manufacture this amylase, selecting the one that is most suited to the intended use is essential. During this narrowing down process, it is important to consider the properties of the manufactured flexible polymers. Every carbohydrate source has to compromise on one or more of several desirable qualities since none of them can reliably provide every one of them [5].

Herein, this study volunteering the neutrosophic set to overcome the uncertain data between criteria and alternatives. This study used the single valued neutrosophic set (SVNSs) as a kind of neutrosophic set. The unpredictability and variety of the initial data make it challenging for Decision Makers (DMs) to communicate their judgments appropriately in real-world Multi-Criteria Decision Making (MCDM) scenarios. Smarandache proposed neutrosophic sets (NSs) to convey assessment values in complex systems, which are characterized by the truth-membership, indeterminacy-membership, and falsity-membership degrees concurrently, to deal with imprecise and ambiguous data. In the same way that the NSs is a generalization of the classic set, and fuzzy sets. So this study used additive ratio assessment (ARAS) method under NSs to rank the alternatives[13],[14].

2. Relevant Fundamental Tenets with Study

According to the conducted survey for prior studies which related to our interested scope, we illustrate the basic concepts and tenets which are important and serve our study.

2.1 Bioplastic Life Cycles

The environmental impacts of using bioplastics, such as the mitigation of climate change, are considered in this part, along with the full scope of the bioplastic's life cycle, from initial usage of land to the analysis of the unprocessed ingredients and final disposal options. The production of Biops entails several stages as seen in Figure 1, from harvesting raw materials to bio-refining to metabolism to plastic cleansing to injection or blow molding to finished products before distribution, usage, and disposal decisions. Recyclable, sustainable, and biodegradable are often used terms; it is useful to define them in light of this cycle [15].

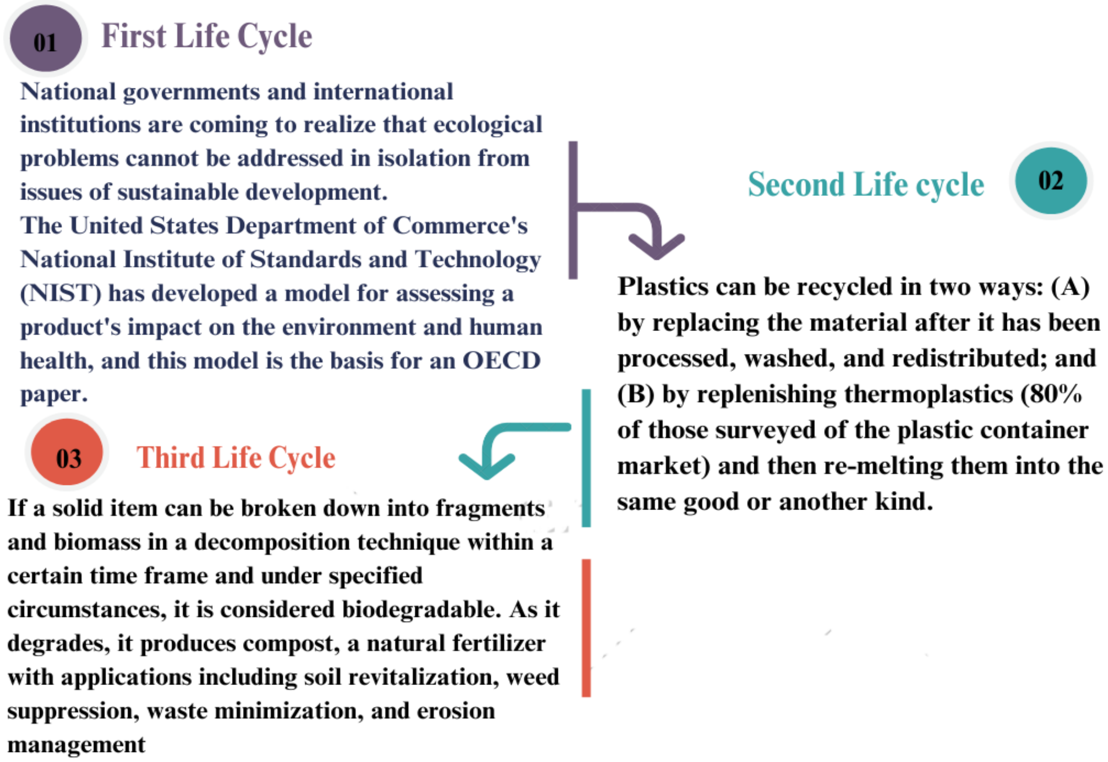

Figure 1. Bioplastic life cycles.

2.2 Biodegradable Plastics Productions

According to several studies as [16] both the terms "biodegradable" and "bioplastic" are commonly used interchangeably. Based on Fig 2 BioPs can be divided into two types.

Rising prices for biodegradable plastics are hard to predict because of how many variables affect consumption and how difficult it is to put a price tag on those variables. The generation of impact variables also involves a fair amount of difficulty. As people learn more about the need to conserve biodiversity and the environment, their interest in purchasing organic items increases. The manufacturing of BioPs stands to benefit from this [17].

As we've already shown, it's challenging to quantify the many influencing elements in order to apply them in an approach for forecasting interest in bioplastics. Time series data on the expense of crude oil, feedstock prices, and GDP provide the foundation for understanding the need for bioplastics. Many technical possibilities are being explored in previous research and in this paper because of the widespread ambiguity around their possible use. Future policy actions are particularly hard to assess since various policy initiatives have varying outcomes. Implementing national and international policies is problem-sensitive and may have varying outcomes. The perceptual impact will be harder to implement [18], [19]. Everything that helps keep bioplastic production prices low: Changes in technology and the results of education: Over time, more efficient processing techniques may be developed, and the price could go down as a result of the acquired effects.

Due to efficiencies of scale, businesses may generate more income at somewhat lower (unit) prices by increasing BioPs manufacturing. Manufacturing quantities for BioPs are still rather low, and the associated costs are quite expensive.

Effective environmental policy measures include but are not limited to: Price increases for conventional plastics may result from taxes imposed on products derived from fossil fuels. As a result, the price of BioPs would go down, increasing demand for them. Government subsidies allow bioplastic producers to cut their production costs and attract more customers.

The demand for bioplastic products would be bolstered if states banned the use of fossil plastics. Standardization may suffer, though, if the prohibitions are applied to all plastics, including bioplastics [20], [21]. The increasing need for bioplastics is strongly influenced by the price of crude oil. Since crude oil is used as the primary ingredient in the creation of conventional plastics, the cost is very variable. With the rising expense of both oil and traditional plastics, alternatives like BioPs have grown increasingly attractive. The need for bioplastics would rise in tandem with the cost of oil.

A rise in GDP has a multiplier effect on the manufacture and expansion of plastics, as well as on the use of BioPs. The market for BioPs will increase if market participants with better incomes spend more on green technologies. The costs of feedstock have a significant impact on the overall cost of producing bioplastics. Bioplastics are now manufactured mostly from maize starch or sugar cane. Manufacturing expenses, and hence BioPs prices, will rise if the cost of maize or sugar increases. In return, a decrease in bioplastic manufacturing follows price increases. The prices of both maize and sugar fluctuate wildly on the global market [22, 23].

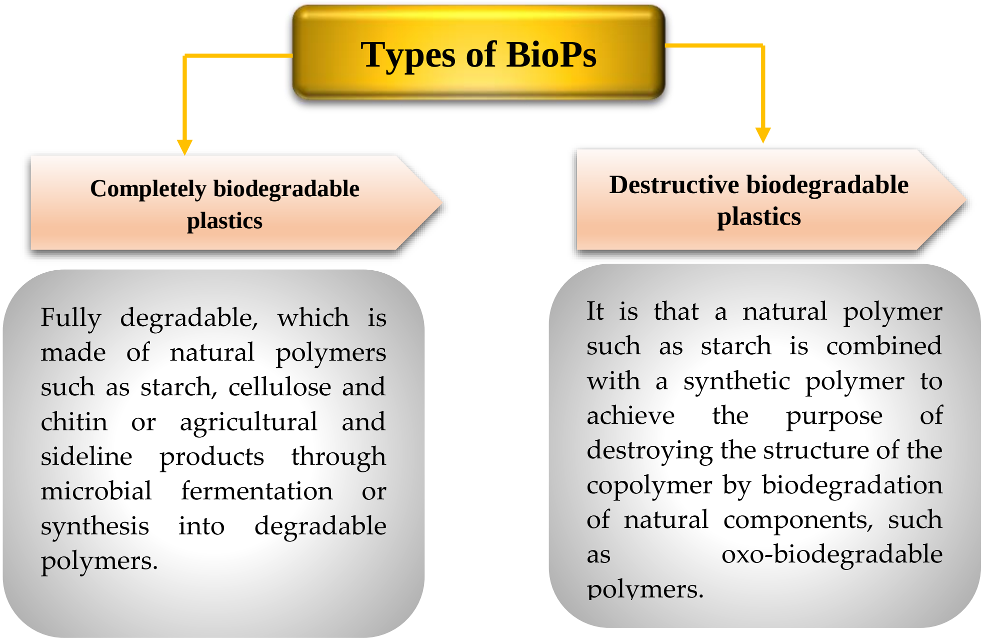

Figure 2. Bioplastic types.

3. Uncertainty Theory based Intelligent Ranker

Zavadskas and Turskis have presented a novel MCDM approach called ARAS. Its usefulness was quickly recognized, and it was quickly put to use in a variety of contexts [24]–[27]. This section introduces the ARAS method under single valued neutrosophic numbers. Figure 3 shows the steps of the proposed method.

Procedure 1: Build the decision matrix.

$$A_{aj} = \left(\prod_{k=1}^{r} A_{aj}^{k}\right)^{\frac{1}{r}} \quad (1)$$

$$A_{0j} = \max A_{aj} \quad (2)$$

Where j refers to the criteria and a refers to the alternatives.

Procedure 2: Normalize the decision matrix

$$NA_{aj} = \frac{A_{aj}}{\sum_{a=1}^{m} A_{aj}} \quad (3)$$

Procedure 3: Compute the weighted normalized decision matrix.

$$R_{aj} = w_{ij}^r \times NA_{aj} \quad (4)$$

Procedure 4: Compute the total performance for every option.

$$P_a = \sum_{j=1}^{n} R_{aj} \quad (5)$$

Procedure 5: Compute the utility degree.

$$U_a = \frac{P_a}{P_0} \quad (6)$$

Procedure 6: Rank the options.

The alternatives are ranked according to the highest value of U_a.

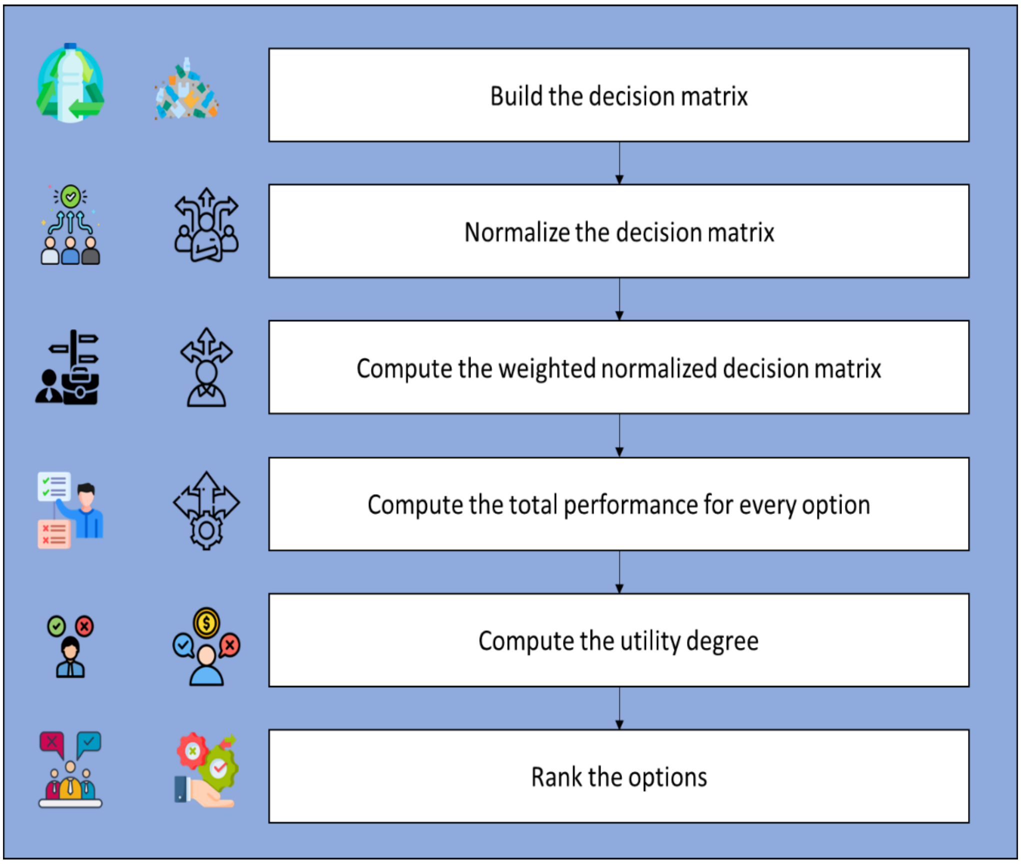

Figure 3. Procedures of uncertainty theory based intelligent ranker.

4. Verification and Results of Intelligent Ranker

Starch, often referred to as amylum, is a polymeric foodstuff composed of numerous glucose units joined together by hydroxylation. This material is synthesized throughout most stages of photosynthesis and used to store energy. Packaged types of corn, potatoes, rice (corn), maize, and cassava all have high concentrations of this nucleotide, making them some of the most common foods eaten across the world. Natural starch, a white, odorless, and flavorless powder, is insoluble in cold ethanol. Branched amyloid and symmetrical alpha helix starch are the two main components. Starch contains 20–25% amylase and 75–80% lipase by weight, based on the kind of plant. According to reports, ethanol may be made by fermenting cereal grains into glucose, which is subsequently used in the creation of alcoholic drinks, scotch, and biodiesel. Refined sugars derive almost entirely from glucose that has been synthesized in a laboratory. Pastes may be prepared from a variety of carbohydrates by mixing them with hot water. Corn starch paste is one example. It has adhesive and stiffening properties. Starch's most common non-food use in industry is as a glue in the papermaking process. Textile flour, applied before boiling, may stiffen most textile materials. The starch business uses a series of processes including a wet grinder, washing, sifting, and drying to collect and purify carbohydrates from seeds and potatoes.

This section introduces the results of the neutrosophic ARAS method. The ARAS method applied into eight criteria and seven alternatives as shown in Figure 4. The initial matrix is built by the decision matrix by using Eqs. (1), (2). Then compute the weights of criteria. The criterion 4 is the highest weight and criterion 8 is the least criteria. Then normalize the decision matrix by using Eq. (3) as shown in Table 1. Then compute the weighted normalized decision matrix by using Eq. (4) as shown in Table 2. Then compute the total performance of each alternative by using Eq. (5). Then compute the utility degree by using Eq. (6) as shown in Figure 5. Alternative 2 is the best and alternative 7 is the worst.

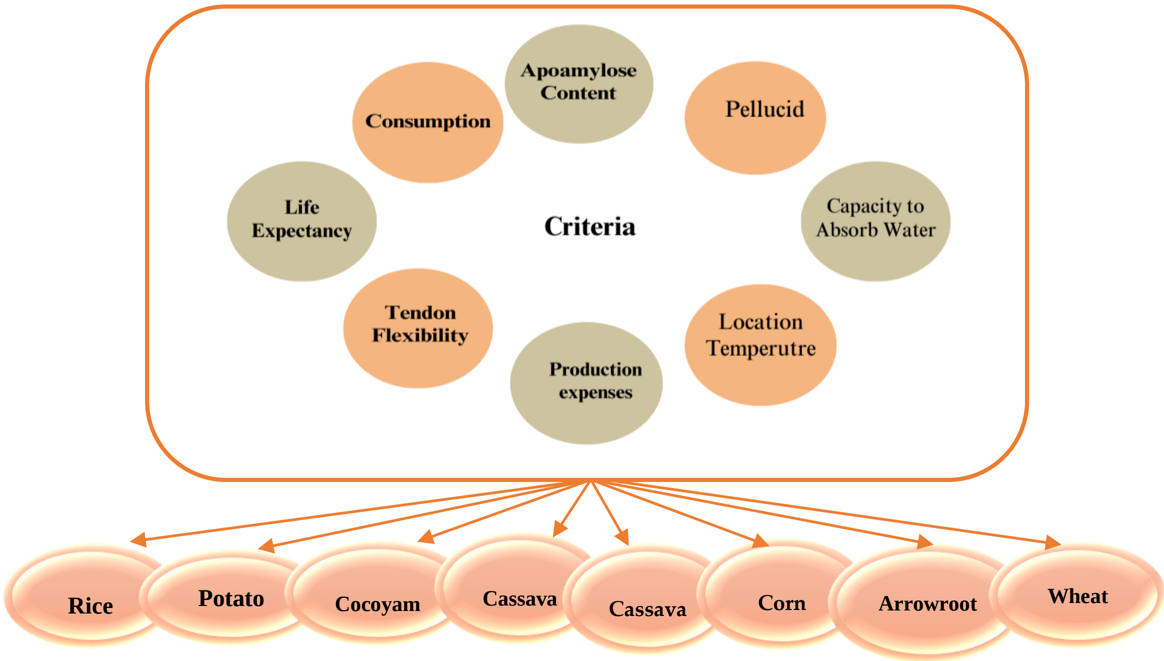

Figure 4. Utilized criteria and alternatives.

Table 1. The normalized decision matrix.

	PPC$_1$	**PPC$_2$**	**PPC$_3$**	**PPC$_4$**	**PPC$_5$**	**PPC$_6$**	**PPC$_7$**	**PPC$_8$**
PPA$_1$	0.120497	0.107723	0.120841	0.247223	0.164112	0.167586	0.184546	0.067845
PPA$_2$	0.154779	0.110416	0.119325	0.132211	0.070185	0.065549	0.2589	0.198847
PPA$_3$	0.222317	0.226308	0.186571	0.091723	0.190541	0.195694	0.098692	0.138438
PPA$_4$	0.129896	0.258027	0.186571	0.132211	0.101165	0.125159	0.068469	0.210163
PPA$_5$	0.222317	0.110416	0.11978	0.132211	0.064949	0.125159	0.257562	0.190764
PPA$_6$	0.074521	0.076693	0.186571	0.132211	0.245648	0.125159	0.06312	0.066282
PPA$_7$	0.075672	0.110416	0.080342	0.132211	0.1634	0.195694	0.06871	0.127661

Table 2. The weighted normalized decision matrix.

	PPC$_1$	PPC$_2$	PPC$_3$	PPC$_4$	PPC$_5$	PPC$_6$	PPC$_7$	PPC$_8$
PPA$_1$	0.007485	0.012045	0.008971	0.052985	0.030513	0.016449	0.039552	0.002653
PPA$_2$	0.009615	0.012347	0.008858	0.028335	0.013049	0.006434	0.055487	0.007776
PPA$_3$	0.013811	0.025305	0.01385	0.019658	0.035427	0.019208	0.021152	0.005414
PPA$_4$	0.008069	0.028852	0.01385	0.028335	0.01881	0.012285	0.014674	0.008219
PPA$_5$	0.013811	0.012347	0.008892	0.028335	0.012076	0.012285	0.055201	0.00746
PPA$_6$	0.004629	0.008576	0.01385	0.028335	0.045673	0.012285	0.013528	0.002592
PPA$_7$	0.004701	0.012347	0.005964	0.028335	0.030381	0.019208	0.014726	0.004992

Figure 5. The values of utility degrees.

5. Conclusion

This study aims firstly to display and aggregate various prior studies 'perspectives which related to sustainability and problems threatening it. Thus, this study concluded that biodegradable polymers can be used in place of conventional plastics, to enhance the environment and ensure the long-term availability of petroleum resources. Also, BioPs are a significant breakthrough in the modern era.

Secondly, the primary problem with the MCDM was deciding which flexible plastic manufacturing method would be the most sustainable, and this was solved using the ARAS approach. Then using empirical research results, a fair weighting of the requirements has been determined. This study investigated the sustainability of environmentally friendly biodegradable polymers. This study's use of neutrosophic MCDM methodology emphasizes the inherent uncertainty in developing biodegradable plastics due to the wide range of environmental variables that must be considered at each stage. This research contributes to our knowledge of green product innovation and the process of creating bioplastic products. The evaluation's clarity was rated higher than its other factors. This study used the single valued neutrosophic set to overcome the uncertain data. The neutrosophic ARAS method is used to compute the rank of alternatives. Alternative 2 is the best and alternative 7 is the worst.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Integrated Neutrosophic Best-Worst Method for Comprehensive Analysis and Ranking of Flood Risks: A Case Study Approach from Aswan, Egypt

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Abstract: This paper presents a comprehensive framework for the analysis and ranking of flood risks with respect to regional variations and data uncertainties under a Neutrosophic environment. The research introduces a novel approach to flood risk mitigation and management, bringing together the scientifically robust Best-Worst Method (BWM) and single-valued Neutrosophic set for the first time. The unique application of a single-valued Neutrosophic set allows us to better illustrate and manage uncertainty, imprecision, and vagueness in data. Additionally, we employ BWM, a multi-factor decision-making method, for discerning and ranking the most influential flood risk factors. Together, the integrated methodologies provide a balanced, comprehensive guide for decision-makers and risk handlers, showcasing efficient and effective mitigation strategies. The paper emphasizes the importance of mitigating flood risks to save lives and properties and to manage and conserve environmental resources efficiently. A case study was conducted in Aswan, Egypt, to assess flood susceptibility. The results revealed that 12.60% of the study area exhibited very high susceptibility to flooding, 18.77% showed high susceptibility, 23.94% exhibited moderate susceptibility, 22.91% registered a low susceptibility, and the remaining 21.78% showed very low susceptibility to flooding.

Keywords: Best Worst Method; Single Valued Neutrosophic Set; Flood Risks; Risk Management.

1. Introduction

Natural hazards, such as floods, pose a significant threat to communities around the globe, causing widespread socio-economic and environmental damage [1]. Increased human activity coupled with effects of climate change has led to an escalation of these hazards, placing more people and properties at risk. Flood susceptibility, in particular, plays a critical role in the burgeoning hazard scape. Particularly in regions like Egypt, the impact of flooding can be devastating due to its unique geographical features and growing population [2, 3]. Aswan, Egypt, stands as one of the areas with a growing need for effective flood risk management strategies, considering the frequent and increasing intensity of flood events in the region[4]. Despite the crucial need to manage and mitigate flood risks, this area lacks a comprehensive and in-depth analysis of flood susceptibility—a gap this study aims to fill. Understanding and managing these risks necessitates a comprehensive, nuanced, and sophisticated set of tools. This research proposes to widen the scope of traditional risk analysis by introducing a neutrosophic environment, providing a platform for analyzing and ranking flood risks based on more fluid and less precise data. The science of Neutrosophy, developed by Florentin Smarandache [5] in the late 90s, offers a potent tool for quantifying and dealing with uncertainty, imprecision, and vagueness in data. Meanwhile, the Best-Worst Method (BWM), as a versatile multi-factor decision-making technique, is particularly well-suited for discerning and ranking the most influential risk factors. Unfortunately, these analytic strategies have remained largely disparate. Thus, there's a growing need to introduce integrated strategies, unifying the robustness of BWM with the uncertainty-ridden reality as captured by Neutrosophy for improved flood risk mitigation and management. An approach which not only acknowledges the uncertainty that permeates flood risk prediction but, additionally, transforms this alleged limitation into a strategic advantage.

1.1 Problem Statement

The increasing frequency and intensity of flood events underscore the acute need for effective flood risk management [6, 7]. Currently, the application of diverse regional characteristics and data uncertainties in flood risk analysis is insufficient, leading to a significant gap in the creation of resourceful mitigation and management strategies. The disconnection between the science of Neutrosophy and the BWM further exacerbates this issue. Despite Neutrosophy's potential for precisely quantifying and handling uncertainty, imprecision, and vagueness in data, and BWM's efficiency at identifying and ranking pivotal risk factors, these two analytical strategies have scarcely been integrated in the domain of flood risk management. This overlooked integration signifies a pressing problem: the potential for improved flood risk management strategies using these methodologies remains largely untapped. This paper aims to address this specific issue. This study will propose an innovative approach that unifies the robustness of BWM with the uncertainty-ridden reality as encapsulated by Neutrosophy, hence creating a comprehensive strategy for flood risk prediction, mitigation, and management. It poses to transform the limitation of uncertainty into a strategic advantage for efficient decision-making and resource allocation in flood risk management.

1.2 Paper objectives

The objectives of this paper can be defined as follows:

1. To integrate the principles of Neutrosophy and the BWM in the field of flood risk management. This goal addresses the current lack of integration and seeks to leverage the strengths of both methodologies.
2. To create a novel strategy for efficient flood risk prediction, mitigation, and management. This strategy will be grounded in the fusion of Neutrosophy and BWM, presenting a comprehensive approach to handling the diverse regional characteristics and data uncertainties that populate flood risk analysis.
3. To transform the conceptualization of data uncertainties, viewing them not as hindrances, but as strategic advantages that can aid in robust decision-making and efficient resource allocation. This objective is tied to the distinctive ability of Neutrosophy to precisely quantify and manage uncertainty, vagueness, and imprecision in data.

Overall, this paper will make strides towards improving flood risk management by harnessing the potential of Neutrosophy and BWM.

1.3 Methodology overview

This paper employs a systematic approach for the analysis, ranking, and mitigation of flood risks, centering on the integration of the BWM and single valued Neutrosophic set for the first time in this domain.

The methodology comprises of three main stages:

1. Single Valued Neutrosophic Set: This part involves capturing and illustrating uncertainty, imprecision, and vagueness in regional characteristics and flood data. By assuming an approach rooted in Neutrosophic logic, the truth-membership degree (T), indeterminacy-membership (I), and falsity-membership degree (F) of each point or parameter in the study area can be realistically depicted [8].
2. Best-Worst Method: In this stage, using BWM—a multi-factor decision-making method—the influential flood risk factors are identified and prioritized. To conduct this, we collect expert opinions on the best and worst factor based on their judgments of which factor is the most

desirable (best) and which is the least desirable (worst). This ranking contributes to discerning the relative weight of each risk factor and contributes to the development of robust mitigation strategies.

3. Weighted Overlay: within the ArcGIS suite was incorporated as a key step in our methodology. This tool allows us to combine multiple raster datasets, representing various flood risk factors, into a single dataset with an assigned importance or weightage for each factor[9]. After applying the Single Valued Neutrosophic Set and Best-Worst Method to identify and rank flood risk factors, the Weighted Overlay process will be implemented as described below:
   - Defining input layers and weights: Each identified risk factor (such as slope, rainfall, elevation, soil type, etc.) is represented through a raster layer. Based on our BWM ranking, we assign a weight to each factor, indicating its significance in influencing flood risk.
   - Reclassification of raster layers: Each raster layer is reclassified into a common scale (for example, 1-10). This ensures that the input layers are compatible, allowing meaningful combination and comparison.
   - Application of weights: The reclassified risk factor layers are then overlaid, and a weighted sum is calculated to produce the final output raster. This final output clearly indicates regions of varying flood susceptibility, providing critical spatial understanding for risk management.

By integrating these three steps methodology, the proposed methodology constructs a balanced and detailed landscape of flood risks, facilitating improved decision making. To validate this approach, a case study was carried out in Aswan, Egypt, assessing the level of flood susceptibility. The findings confirmed the robustness and reliability of this integrated methodology in defining and treating flood risks.

1.4 Paper contributions

This paper has several meaningful contributions:

1. Methodological Contribution: This paper innovates methodologically by combining the BWM with a Single Valued Neutrosophic Set for flood risk analysis, enhancing the robustness of risk assessment.
2. Incorporation of Weighted Overlay: The integration of Weighted Overlay within ArcGIS in our proposed methodology assists in merging spatial aspects with deciding factors, which is a novelty in flood risk management research.
3. Addressing Uncertainty: This methodology addresses uncertainty, vagueness, and imprecision in flood risk factors in a significant way through Neutrosophic logic, enhancing the soundness of the resulting analysis.
4. Practical Implications: A practical testing in Aswan, Egypt presented as a case study validates the efficacy of the proposed methodology, demonstrating applied value in real-world scenarios.
5. Enabling Informed Decisions: The prioritized ranking of flood risk factors aids in the better design of flood mitigation strategies, creating the potential for more informed decision-making.

In sum, the paper contributes to both theoretical understanding and practical application in flood risk management.

1.5 Paper structure

The structure this paper is as follows:

Introduction: a brief overview of flood risks, the importance of managing them, the state of current research, and the focus of this paper (risk analysis and ranking factor for flood mitigation). **Review of Literature**: Detailed examination of existing studies on flood risk analysis and management **Methodology:** The proposed approach using a single-valued Neutrosophic Set, the best-Worst Method, and a weighted overlay within ArcGIS is explained. The reasons for method selection and their sequence are explained. **Case Study Application**: results and **Discussions:** The proposed methodology and tools are applied to a real-world scenario (e.g., Aswan, Egypt), and the process and the findings are explained. Results analysis and discussion of their implications on flood risk management are also explained. **Conclusion**: The paper's findings are summarized, the potential impact is discussed, and future research directions are laid out. **References**: Citation of all the studies and sources referred to throughout the paper.

2. Literature Review

2.1 Understanding Flood Risks

Flood risks emerge from a complex interplay of environmental, socioeconomic, and infrastructural factors [10]. At the heart of flood risk analysis lies the understanding of these risks - their sources, their potential impact, and effective strategies for their management. The primary concern regarding flood risks is their sheer unpredictability and potential to cause extensive damage to life, property, and the environment [11]. Previous case studies have shown the exacerbating effect of factors such as urbanization, climate change, and inadequate infrastructure on increasing flood risks [12]–[14]. Management strategies for flood risks also vary significantly. They range from built interventions like flood barriers and levees to natural solutions such as wetland conservation and reforestation. In recent years, scientists and policy-makers have recognized the importance of using a combination of different strategies, tailored to the specific conditions of each region, to reduce flood risks [15, 16]. Developing effective flood risk management strategies also requires understanding and integrating local community views and experiences, creating a cooperative environment for proactive preparation and response. Recent literature indicates a trend toward the development of more sophisticated tools for flood risk analysis [17, 18]. These tools incorporate probabilistic risk assessment, decision trees, and geographic information systems (GIS) to analyze flood patterns, simulate flood scenarios and devise effective risk mitigation strategies [19, 20].

2.2 Existing Methodologies in Flood Risk Analysis

The landscape of flood risk analysis is incredibly diverse, characterized by the use of various scientific methods, analytical models, and socio-economic analysis. These methodologies aim to identify, assess, and foresee flood risks, ultimately guiding the design and implementation of effective flood risk management strategies. In the interest of precision, several scientific models have been developed to quantify flood risks. Hydrological models, for example, simulate water cycle components within a defined specific area, aiding in the prediction of possible flood events [21]. Hydraulic models, conversely, are employed to understand the movement of water across landscapes during flood events [22]. In parallel, the application of GIS has revolutionized flood risk analysis [23]. This tool allows for spatial analysis of flood risks, overlays of flood scenario models over existing maps, and the creation of detailed flood risk maps, proving critical in land use planning and flood mitigation efforts. According to various case studies, climate models combined with socio-economic data have proven significantly helpful in long-term flood risk prediction and management [24, 25]. Socio-economic analysis serves in ascertaining the vulnerability and adaptability of communities to flood events, paving the way for community-specific flood risk management strategies [26]. Research indicates an increasing emphasis on integrated methodologies that blend scientific modeling, socio-economic considerations, and local knowledge to create robust and inclusive flood risk management strategies. However, these methods are not without their challenges and limitations, warranting further research and advancement in this realm.

2.3 Role of Neutrosophic Logic in Risk Mitigation

Neutrosophic logic, a branch of multi-valued logic, is a novel approach used in uncertain and indeterminate problem-solving instances, offering new avenues in flood risk mitigation [27]. Notably, it operates on the idea that every notion has its anti-notion and a degree of neutralities, ranging from truth, and indeterminacy, to falsity. Applying neutrosophic logic in flood risk mitigation involves the use of neutrosophic sets, which handle uncertainty by providing membership, non-membership, and indeterminacy functions [28]. This range of possibilities allows neutrosophic sets to capture a more comprehensive picture of the complex reality of flood risks, thereby enabling a more robust analysis. Neutrosophic logic also aids in decision-making processes relevant to flood risk mitigation. These involve crucial elements with varying degrees of certainty, ambiguity, and subjectivity. With neutrosophic multi-factor decision-making tools, such as Neutrosophic Analytic Hierarchy Process (AHP) and Neutrosophic Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), it is easier to rank and prioritize various flood mitigation strategies based on different factors [29]. Therefore, the integration of neutrosophic logic in flood risk analysis could potentially yield more precise, flexible, and adaptable flood mitigation and risk management strategies, making it a valuable tool in investigations within neutrosophic environments.

2.4 The Implementation of the Best-Worst Method in Environmental Research

The BWM technique is an increasingly popular decision-making method used in environmental research [30, 31]. It assists in identifying both the most and least significant factors among a set of alternatives. By evaluating the maximum and minimum differences together in a unified model, BWM generates more reliable and optimal results [32]. In environmental research like flood risk management, BWM is utilized in establishing a hierarchy or ranking of possible mitigation measures based on their effectiveness, economic feasibility, and environmental impact [33]. For instance, BWM could be employed to prioritize flood risk reduction strategies such as dam construction, river dredging, and floodplain zoning, considering diverse factors like cost, social consequences, ecological impact, etc. Moreover, BWM's comparative approach allows for a more objective assessment of different environmental strategies. It helps stakeholders to weigh the pros and cons of each mitigation method and make informed decisions based on systematic comparison rather than personal bias or single-factor consideration. Despite its strengths, the implementation of BWM in environmental research is not without challenges. As it involves relatively complex calculations, the process may require advanced knowledge of mathematics or the use of specific software tools. Moreover, the decision-making process can be affected by the quality of input data and requires effective communication among stakeholders. Thus, while BWM holds great potential in environmental research, its deployment must be carefully managed to ensure maximum benefits.

While previous research has applied multi-factor decision-making methods to flood risk analysis, few if any have incorporated the BWM into their analytical frameworks. In addition, while uncertainties in flood risk data are widely recognized, there is a lack of detailed methods for effectively managing these uncertainties. Furthermore, existing methods usually apply classical logic, but cannot effectively deal with the uncertainty, imprecision, and vagueness inherent in flood risk assessment data. Also, flood risk mitigation strategies are not always sufficiently tailored to specific, local risks due to lacking detailed, localized flood risk analysis. This research bridges these gaps by incorporating a single-valued Neutrosophic set in BWM for the first time, providing a novel approach to flood risk mitigation and management.

3. Methodology

3.1 Study Area

Aswan is a city located in the southern part of Egypt and is the capital of the Aswan Governorate [34]. Aswan is geographically located on the eastern bank of the Nile River at the first cataract, approximately 899 kilometers south of Cairo, Egypt's capital city. It is situated near the Tropic of Cancer, in the southernmost part of Egypt as shown in Figure 1. Latitude and longitude coordinates for Aswan are approximately 24.0889° N and 32.8998° E respectively. Aswan is surrounded by the Eastern Desert, which is characterized by hills and rugged highlands. To the southwest of the city lies Lake Nasser, one of the largest artificial lakes in the world, created by the Aswan High Dam. Aswan's geographic location and its proximity to critical natural features like the Nile River and the Eastern

Desert contribute significantly to its climate, hydrological conditions, and accordingly, its flood risk profile. It is one of the driest inhabited places in the world and is noteworthy for its significant geologic and geographic features. From the perspective of this study, important attributes of Aswan include its geographic location along the Nile River, its climate, geology, and hydrology. This city experiences high temperatures in the summer and mild winters. The Nile River has a significantly influential role in shaping the city's flood risk profile; its seasonal fluctuations, driven by the African monsoons, provide flood risks. Moreover, the Aswan High Dam, situated near Aswan city, plays a pivotal role in controlling the flow of the Nile River and subsequently affecting the flood risk in the area. The city also contains a high concentration of structures and populations, increasing potential flood vulnerability. These factors combined present the city as a suitable study area for this research.

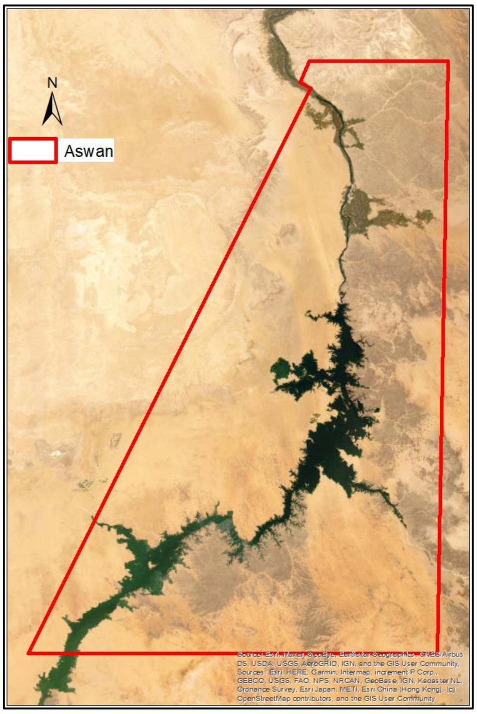


Figure 1. Study area.

3.2 Flood Susceptibility Factors

In this paper, the neutrosophic BWM method is used to utilize nine factors. These factors are instrumental in understanding and assessing the flood risks associated with the geographic and topographic characteristics of the study area. The factors for flood susceptibility in this study are detailed in Table 1 and shown in Figure 2. The spatial and attribute data used in this investigation were obtained from secondary data sources. The various data sources used are discussed in further detail in the phrases that follow. Slope and aspect were developed using ArcGIS Pro software tools and a global digital elevation model (DEM) produced by the United States Geological Survey (USGS). The FAO Soil Portal website provided the information for the soil-type map. The Egyptian National Authority for Remote Sensing and Space Sciences (NARSS) collects data on both rivers and roads. The remaining data are created with the aid of various analysis tools found in ArcGIS Pro 2.6, including the raster calculator, curvature, aspect, and slope.

Table 1. Factors for flood susceptibility assessment.

Factor	Description	Classes	Class Classification	Class Rank	Cost/ Benefit	Factor Weight (%)
		WB	Very Low	1		5

Soil Type (FRF1)	Different soil types can influence the radius and speed of floodwater. For example, sandy soil with high permeability can quickly absorb water, decreasing flood risks, while clay soil with low permeability may cause water to pool on the surface, increasing flood risks.	E	Low	2	Benefit(Maximize)	
		SCS	Moderate	3		
		SS	High	4		
		SC	Very High	5		
Slope (FRF2)	Slope can influence the speed and direction of floodwater. Steeper slopes can lead to faster water flow and could possibly aggravate soil erosion, while gentle slopes may slow water flow and decrease flood risks.	0 - 2.866623164	Very High	5	Cost(Minimize)	17
		2.866623165 - 6.775654752	High	4		
		6.775654753 - 12.76950319	Moderate	3		
		12.7695032 - 21.10877057	Low	2		
		21.10877058 - 66.45353699	Very Low	1		
Distance from Road (FRF3)	Roads can divert or block natural water courses, potentially leading to flooding. The proximity to roads can therefore determine the flood susceptibility of a region.	0 - 0.029141037	Very High	5	Cost(Minimize)	8
		0.029141037 - 0.0751532	High	4		
		0.0751532 - 0.128834057	Moderate	3		
		0.128834057 - 0.197852302	Low	2		
		0.197852302 - 0.391103387	Very Low	1		
Distance from Drainage (FRF4)	The distance from drainage can significantly affect flood risk, as locations closer to drainage channels may have higher flood risks due to potential overflow.	0 - 0.312295608	Very High	5	Cost(Minimize)	13
		0.312295608 - 0.624591216	High	4		
		0.624591216 - 0.976924722	Moderate	3		
		0.976924722 - 1.345273388	Low	2		
		1.345273389 - 2.041932821	Very Low	1		
Distance from Dams	Dams retain large volumes of water. If a dam overflows or breaches, areas downstream and close to the dam face significant flood risks.	0 - 0.562840344	Very Low	1	Benefit(Maximize)	2
		0.562840344 - 0.979759117	Low	2		
		0.979759117 - 1.427946798	Moderate	3		
		1.427946799 - 1.87613448	High	4		
		1.876134481 - 2.65785718	Very High	5		
Distance from River (FRF6)	The closer a location is to a river, the higher the flood risk, particularly in cases of river overflow.	0 - 0.110352123	Very High	5	Cost(Minimize)	13
		0.110352123 - 0.258756701	High	4		
		0.258756701 - 0.418577017	Moderate	3		
		0.418577017 - 0.605034051	Low	2		
		0.605034051 - 0.970337629	Very Low	1		

SuFRFace Curvature (FRF7)	This defines the convexity or concavity of the surface, influencing how water collects or disperses, thereby affecting flood susceptibility.	-273,456,005,100 - -8,767,064,907	Very Low	1	Benefit(Maximize)	8
		-8,767,064,906 - -2,149,841,402	Low	2		
		-2,149,841,401 - 4,467,382,103	Moderate	3		
		4,467,382,104 - 15,496,087,950	High	4		
		15,496,087,960 - 289,007,992,800	Very High	5		
DEM (FRF8)	A DEM can determine the potential flood path, as water typically flows from higher to lower areas.	60 - 190	Very High	5	Cost(Minimize)	13
		190.0000001 - 247	High	4		
		247.0000001 - 310	Moderate	3		
		310.0000001 - 389	Low	2		
		389.0000001 - 661	Very Low	1		
Aspect (FRF9)	The direction a slope faces (north, south, east, and west). This could influence the microclimate and in turn, the propensity for heavy rainfall and potential flooding.	-1 - 57.01191071	Very High	5	Cost(Minimize)	21
		57.01191072 - 136.2476912	High	4		
		136.2476913 - 211.2386977	Moderate	3		
		211.2386978 - 284.8147796	Low	2		
		284.8147797 - 359.8057861	Very Low	1		

3.3 Best Worst Mwthod

The BWM method is a multi-criteria decision-making method developed by Rezaei (2015) [35]. The key strength of this method lies in its simplicity: it only requires a small number of pairwise comparisons.

Here are the steps in applying the Best-Worst Method:

1. Identify the Factor/Alternatives: The first step involves identifying the factor or alternatives that will be used for decision-making.
2. Determine the Best and Worst Factors: Identify the best and worst factors or alternatives among those identified. The 'best' refers to that with the greatest benefit or highest importance, while the 'worst' refers to that with the least benefit or lowest importance.
3. Perform Pairwise Comparisons: Compare the best factor to all other factors, the worst factor to all other factors, and then the best to the worst. These comparisons yield a consensus estimate of the relative importance of the best and worst factors.
4. Calculate Weights: Utilizing a mathematical model, calculate the weights of all the factors. These weights offer a measure of the relative importance of each criterion compared to all the others.
5. Check Consistency: It's crucial to ensure the consistency of the responses provided in the pairwise comparisons. If the Consistency Ratio (CR) is less than 0.1, the preference weights are acceptable; if not, the pairwise comparisons need to be revised.
6. Rank Alternatives: Finally, use the calculated weights to rank the alternatives and make the decision. The alternative with the highest weight is usually considered the best choice.

3.4 Best Worst Method under Neutrosophic Set

BWM's excellent consistency and data adaptability in regard to computations with the least comparability matrix has led to its widespread use [36, 37]. This section introduces the BWM under the single-valued neutrosophic set. We used the single-valued neutrosophic numbers to evaluate the factor. These numbers can deal with vague data.

Step 1. Determine the factors of flood risks

In this step, the factors used for flood susceptibility are identified as shown in Figure 3.
Step 2. Identify the most important factor and least important factors.
We pose the question, "Which factor or sub-factor is the most significant and least significant for the flood risks?" to elicit opinions on which factors are most and least relevant in this context.
Step 3. Compare the most significant factors with other factors.
After settling on the best factor (F), participants are required to assess its importance relative to the other factor on a single-valued neutrosophic scale. The final product of this process is the (FM) vector, which consists of the following values:

$X_F = (x_{F1}, x_{F2}, x_{F3} \dots \dots \dots x_{Fn})$

Step 4. Compare the rest of factors with the least important factor.
Participants are then asked to rank the remaining factor from least to most essential, with single valued neutrosophic number 1 representing the same importance as the poorest criterion (L) and single valued neutrosophic number 9 representing the utmost importance. The resulting vector, others-to-worst (FL), was calculated as follows:

$X_L = (x_{1L}, x_{2L}, x_{3L} \dots \dots \dots x_{nL})^T$

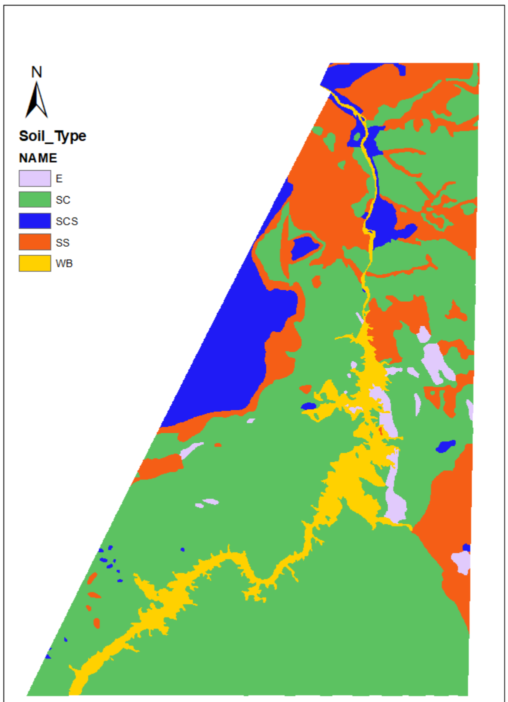
Step 5. Compute the weights of each factor.

$$\begin{cases} X_M^k \mid e^k \quad \left(\frac{1}{e^k}\right), \forall k = 1,2,3 \dots k \\ X_L^k \mid e^k \quad (e^k), \forall k = 1,2,3 \dots k \\ e^k \mid e^* \quad Dir(\alpha \times e^*), \forall k = 1,2,3 \dots k \end{cases}$$

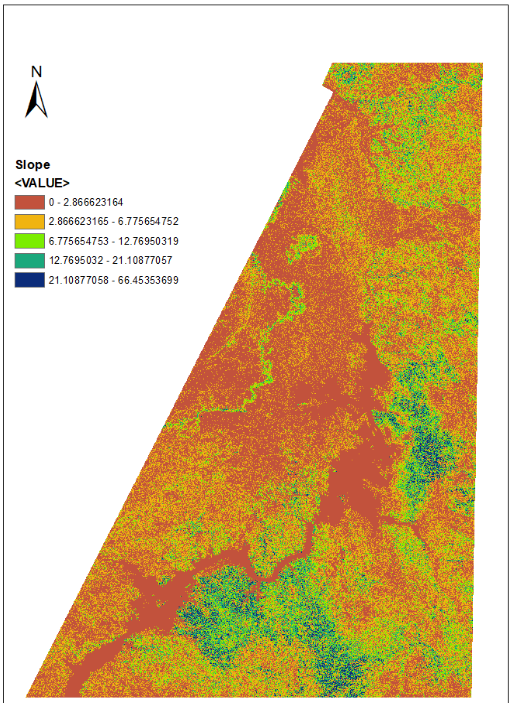
Step 6. Compute the final weights of each factor.

$G_i = \sum e_j * a_{ij}^{nor}$

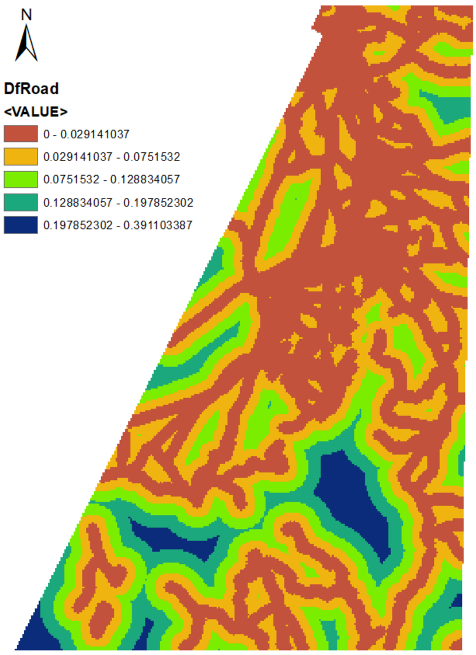
j=1, a_{ij}^{nor} refers to the normalization value



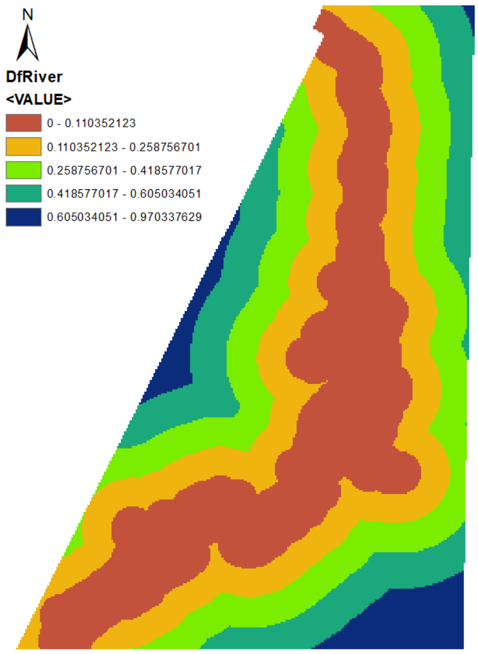
2.1 Soil_Type



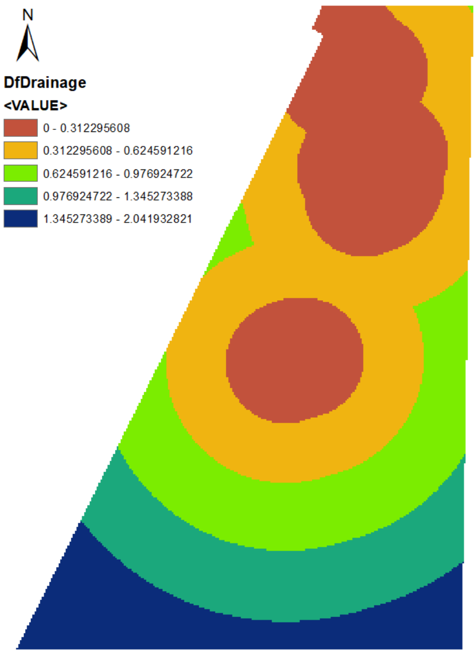
2.2 Slope



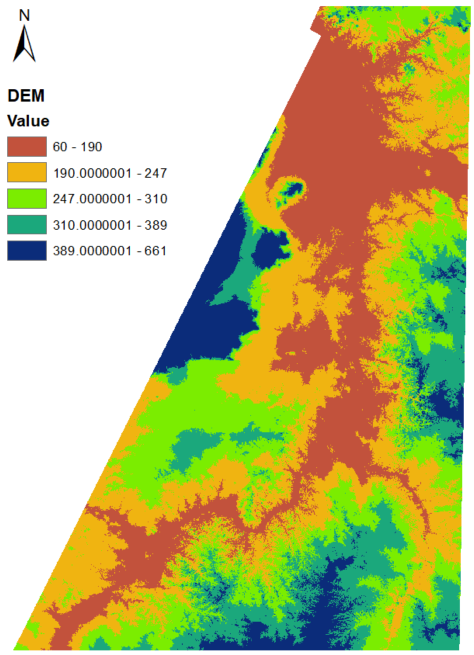
2.3 Distance from Road



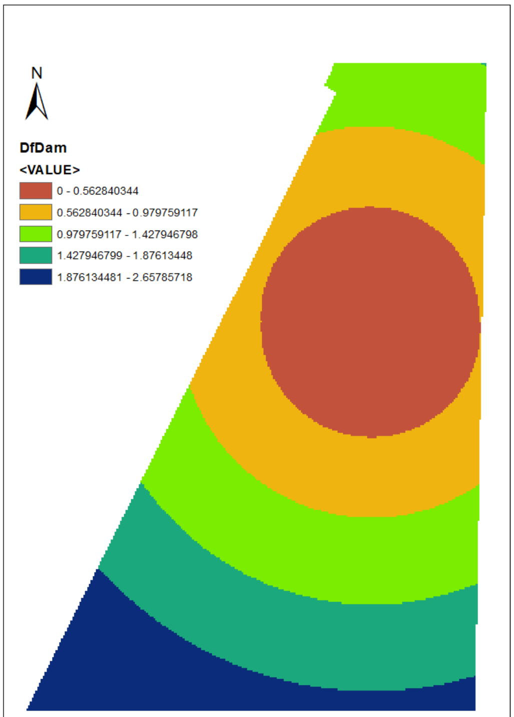
2.4 Distance from River



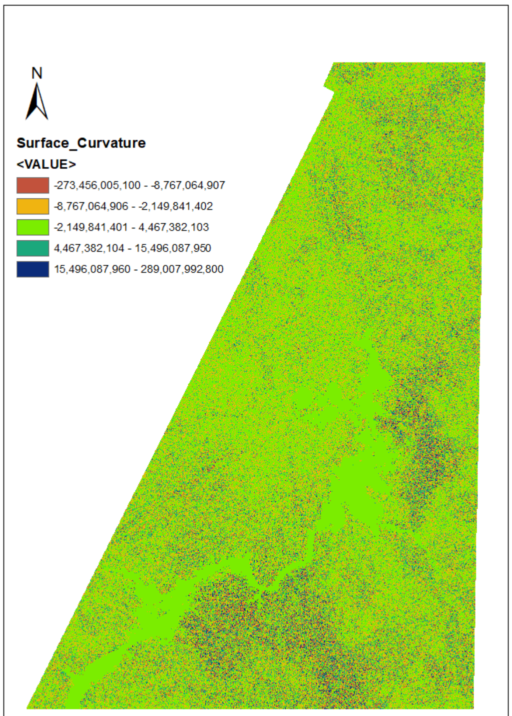
2.5 Distance from Drainge



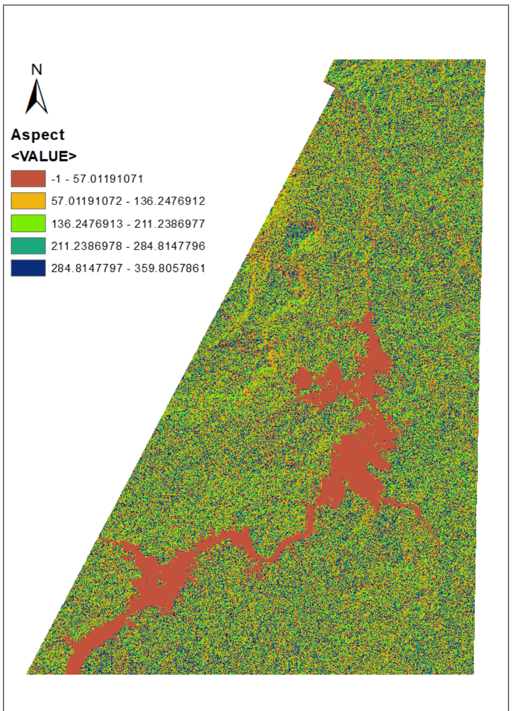
2.6 DEM



2.7 Distance from Dams



2.8 Surface_Curvature



2.9 Aspect

Figure 2. Factors map layers using ArcGIS Pro 2.9.

4. Case Study Application: Results and Discussion

The N-BWM was used to develop the weights for the factors. The main factors evaluations are exhibited in Table 2.

Table 2. Evaluation of flood risks factors using Single Valued neutrosophic numbers

	FRF_1	FRF_2	FRF_3	FRF_4	FRF_5	FRF_6	FRF_7	FRF_8	FRF_9
FRF_1	1	(0.9,0.1,0.2)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.3,0.75,0.65)	(0.8,0.2,0.3)	(0.9,0.1,0.2)
FRF_2	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.7,0.3,0.4)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_3	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.7,0.3,0.4)	(0.3,0.75,0.65)	(0.3,0.75,0.65)	(0.6,0.4,0.5)
FRF_4	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1/(0.9,0.1,0.2)	1	(0.8,0.2,0.3)	(0.9,0.1,0.2)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_5	1/(0.7,0.3,0.4)	1/(0.25,0.75,0.80)	1/(0.25,0.75,0.80)	1/(0.8,0.2,0.3)	1	(0.6,0.4,0.5)	(0.3,0.75,0.65)	(0.9,0.1,0.2)	(0.7,0.3,0.4)
FRF_6	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1/(0.7,0.3,0.4)	1/(0.9,0.1,0.2)	1/(0.6,0.4,0.5)	1	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.6,0.4,0.5)
FRF_7	1/(0.3,0.75,0.65)	1/(0.7,0.3,0.4)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_8	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1/(0.7,0.3,0.4)	1/(0.8,0.2,0.3)	1	(0.9,0.1,0.2)
FRF_9	1/(0.9,0.1,0.2)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.9,0.1,0.2)	1
	FRF_1	FRF_2	FRF_3	FRF_4	FRF_5	FRF_6	FRF_7	FRF_8	FRF_9
FRF_1	1	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_2	1/(0.25,0.75,0.80)	1	(0.9,0.1,0.2)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_3	1/(0.6,0.4,0.5)	1/(0.9,0.1,0.2)	1	(0.9,0.1,0.2)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.3,0.75,0.65)	(0.6,0.4,0.5)
FRF_4	1/(0.25,0.75,0.80)	1/(0.25,0.75,0.80)	1/(0.9,0.1,0.2)	1	(0.25,0.75,0.80)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.8,0.2,0.3)
FRF_5	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1/(0.6,0.4,0.5)	1/(0.25,0.75,0.80)	1	(0.6,0.4,0.5)	(0.3,0.75,0.65)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
FRF_6	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1	(0.6,0.4,0.5)	(0.6,0.4,0.5)	(0.6,0.4,0.5)
FRF_7	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1	(0.8,0.2,0.3)	(0.8,0.2,0.3)
FRF_8	1/(0.8,0.2,0.3)	1/(0.6,0.4,0.5)	1/(0.3,0.75,0.65)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1	(0.25,0.75,0.80)
FRF_9	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.7,0.3,0.4)	1/(0.6,0.4,0.5)	1/(0.8,0.2,0.3)	1/(0.25,0.75,0.80)	1

The weights of these factors were calculated utilizing the neutrosophic Best-Worst Method (BWM). The findings are displayed in Figure 3. According to these, the weight distribution among the factors is as follows: Soil Type (FRF1) at 5%, Slope (FRF2) at 17%, Distance from Road (FRF3) at 8%, Distance from Drainage (FRF4) at 13%, Distance from Dams at 2%, Distance from River (FRF6) at 13%, Surface Curvature (FRF7) at 8%, Digital Elevation Model (DEM) (FRF8) at 13%, and Aspect (FRF9) at 21%.

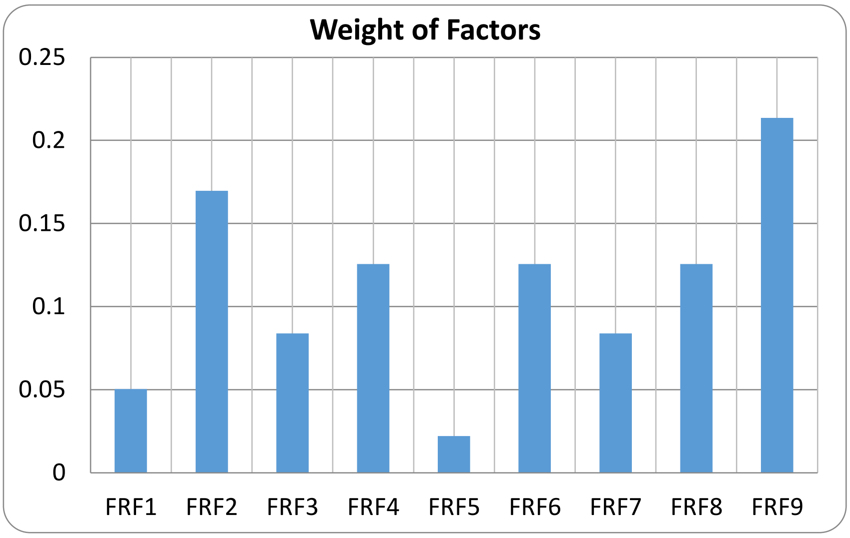


Figure 3. The weights of factors of flood risks.

The weights of these factors, calculated using the neutrosophic Best-Worst Method (BWM), were used in conjunction with the spatial layers collected via ArcGIS Pro 2.9 software's weighted overlay tool, to arrive at the flood susceptibility analysis of the study area. The results, as depicted in Figure 4, revealed that, Very Low susceptibility to flooding denotes areas that are least likely to experience flood events based on the chosen factors. These areas, constituting 21.78% of the study region, are typically situated at higher ground levels, further from bodies of water such as rivers or dams, and often exhibit favorable soil types and slopes contributing to better water runoff. It should be noted, however, that while these areas have the lowest susceptibility among the categories, it doesn't suggest they are completely immune to flooding, but rather they are less prone to flood risks compared to other regions in the study area, Areas classified as Low susceptibility to flooding represent 22.91% of the study area. These regions are more resistant to flooding compared to those in higher susceptibility categories. They typically include features such as gentle slopes that aid in water drainage, specific types of soil that absorb more water, greater distance from bodies of water like rivers or dams, and sufficient storm water management infrastructure such as roads or drainage systems. They still maintain a slight risk of flooding, particularly during severe weather events or in cases of infrastructure failure, but are generally less likely to experience flood-related problems under normal circumstances, Moderate susceptibility regions, accounting for 23.94% of the study area, are characterized by an intermediary risk of flooding. These areas neither have the most nor the least predisposition towards flooding. They often include varied slopes, soil types that have average absorption capabilities, and locations that are neither extremely close nor far from water bodies like rivers or dams. While their risk is not as heightened as in high or very high susceptibility areas, they still possess a notable risk, particularly in the event of severe weather occurrences or unexpected environmental changes. As such, continuous monitoring and effective flood mitigation measures are required in these regions, High susceptibility regions, which make up 18.77% of the study area, are more prone to flooding. These areas often have features that exacerbate flood risks, such as steep slopes which hinder effective water runoff, soil types that do not absorb water well, or proximity to water bodies like rivers or dams. Additionally, these regions could be closer to infrastructures which, when compromised, could boost the flood hazard. Incidences of flooding in these areas are more common, especially during severe weather conditions. Therefore, advanced flood monitoring and robust mitigation strategies are necessary for these areas., and The areas with Very High susceptibility to flooding, representing 12.60% of the study area, have the highest likelihood of experiencing flood events. These regions are often characterized by features such as very steep slopes reducing water absorption, soil types with poor absorption capacities, or close proximity to large water bodies like rivers or dams. These areas might also be in locations where storm water infrastructure is insufficient or compromised. Flooding is likely to occur in these places, even outside of extreme weather conditions, making continuous monitoring and aggressive flood mitigation measures a necessity for these locations. These results categories are detailed in Table 3.

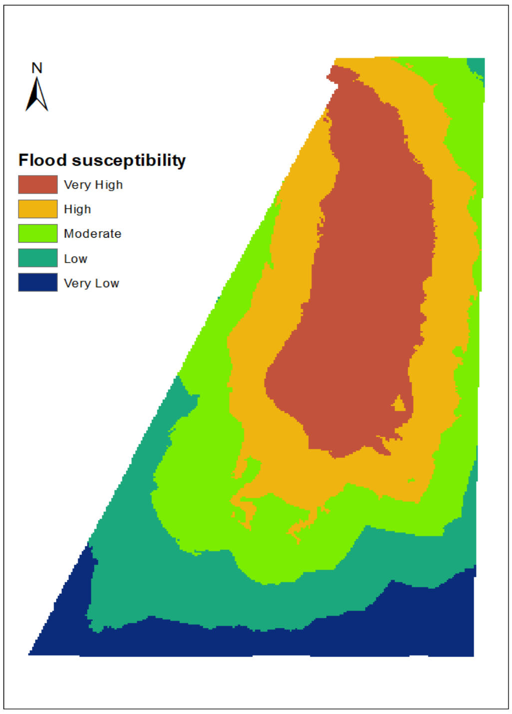


Figure 4. Flood susceptibility map.

Table 3. Flood Susceptibility classes.

Category	Interpretation	Color Scheme
Very Low	Areas that are least likely to experience flood events	
Low	Areas generally less likely to experience flood-related problems under normal circumstances.	
Moderate	Areas characterized by an intermediary risk of flooding.	
High	Areas more prone to flooding	
Very High	Areas have the highest likelihood of experiencing flood events.	

5. Conclusion

In conclusion, the analysis of flood susceptibility in the study area under the neutrosophic environment has been conducted and the areas are classified into five categories: Very Low, Low, Moderate, High, and Very High. This classification provides insights into predicting and managing flood conditions in diverse regions. Future studies could benefit from more quantifiable data, enhanced flood prediction models, and advanced flood mitigation techniques. Additionally, the integration of more layers, such as variations in climate change scenarios, could contribute to a better predictive model. The efficacy of the neutrosophic decision-making process could be further tested in various other disciplines and research fields to verify its broad applicability and robustness. Overall, a better understanding of flood patterns will aid in the strategic and targeted allocation of resources for flood risk management.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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A Neutrosophic Framework for Assessment of Distributed Circular Water to Give Neighborhoods Analysis to Prepare for Unexpected Stressor Events

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Abstract: The global water issue is caused by a number of factors, including extreme weather, population increase, and industrial activity. One of the reasons we're running out of water as a planet is because of the outdated take-make-use-throw-away linear paradigm of handling water. It has been suggested that the circular economy may help alleviate water shortages by inspiring a fundamental change in municipal water infrastructure. Reduced consumption, recovered natural resources, and minimal waste are the three pillars of a circular water supply. A dispersed water supply is more adaptable and robust than a centralized one because it gives communities more time to be ready for emergencies. Nonetheless, there have been no extensive studies of the most important elements that influence the choice to build distributed water supplies. In order to better inform the planning process, this research seeks to identify critical selection factors that influence the evaluation of viable choices. This study proposed the triangular neutrosophic set with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to compute the weights of criteria. The neutrosophic set is used to deal with uncertain data.

Keywords: Triangular Neutrosophic Set; Water Management; Distributed Circular Water; DEMATEL Method.

1. Introduction

By 2020, 3.6 billion individuals will still be without availability to basic sanitation and 2 billion would be without safe drinking water. By 2030, the gap between global water needs and supply is expected to widen to 40 percent. This means that just 81% of people will have availability to clean drinking water by the year 2030, leaving an estimated 1.6 billion individuals in need. Global warming, population increase, and the demands of agriculture and industry all contribute to a global water crisis.

For instance, the water cycle is being impacted by climate change-related phenomena including rising global temperatures and severe weather occurrences. There will be a greater need for reliable water management systems when the world's population approaches 9.8 billion in 2050. Commercial operations, which account for 19% of global water usage, produce wastewater that may be dumped without sufficient therapy, further endangering the world's already dire water situation [1, 2].

Problems with water supply may have far-reaching effects on economies, ecosystems, and societies, making them critically important to people everywhere. Increasing urbanization brings with it a host of water-related difficulties that need a rethinking and rebuilding of urban water infrastructure. In light of the present water crisis, proponents of the sustainable economy have pushed for its implementation as a means of shifting the existing water policy mindset. A "take-make-use-dispose" linear framework is often used for the administration of water resources. To put it another way, it is already difficult to get access to securely managed water supplies using the conventional linear strategy since water is repeatedly removed without being replaced[3]–[5].

For both financial and ecological reasons, the linear fluid paradigm must be abandoned. However, a circular economy strategy may provide a more sustainable, egalitarian, resilient, and effective means of addressing water-related issues. Reducing waste, reusing materials, and cutting down on consumption are all positive outcomes that might result from implementing circular economy ideas into urban water supplies [6, 7].

There has been growing interest in studying circular water structures due to the potential advantages of adopting such a paradigm. Scientists have created a broad range of centralized and distributed circular water structures using state-of-the-art technology. Centralized water systems may meet more demand, but they are more expensive to set up and take longer to begin providing service.

Large-scale water infrastructure is less likely to replenish supplies and uses more power. In contrast, establishing decentralized water supplies takes less time and money and may be tailored to meet the specific requirements of a certain neighborhood or community. Cities may better prepare for stresses and shocks when dispersed systems continue to operate as intended even when a centralized system is disturbed. Therefore, the focus of this study is on the implementation of decentralized, closed-loop water systems on a community level [8, 9].

2. Water Systems

There have been enormous advantages to cities from the traditional, centralized approach of urban water management, which brings 'large pipes in' from numerous water supplies to urban areas and pushes 'huge pipes out' to discharge urban effluent. Cities across the globe benefit from this "hard path" of water in many ways, including a steady supply of clean water, better health care, more effective wastewater treatment, and streamlined administration. However, there are several risks and costs associated with this route, including ecological damage, societal interference, and high cost of capital.

Water availability is shifting rapidly as a result of the impact of global warming on various water source types as well as aging, increasingly vulnerable, large facilities inadequate leadership structures, limited financing possibilities for new infrastructure projects, and other factors. Threats on the supply side, such as growing urbanization, demographic shifts, and altered client behaviors, are frequently not handled by responsive policy adjustments [10, 11].

In light of this, urban areas are beginning to realize they must rethink their approach to water management and undertake a radical reimagining of their use of freshwater. As a substitute to the traditional linear management approach, which relies on a big central architecture and a limited number of decentralized water solutions applied at various spatial scales inside the city, a new, circular flow of water is envisaged.

Decentralized neighborhood-level measures are planned to supplement the distribution system with regional supplies like rainwater or the soil, and to regenerate wastewater to cover some of the urban demands, in addition to water-aware appliances used in individual homes to reduce individual demands. By integrating numerous distributed technological advances options, this circular urban water supply system decreases, recycles, and reclaims, as opposed to the traditional model of extracting, transporting, and disposing of wastewater. The proposed paradigm change is very reminiscent of bigger socio-economic shifts that attempt to achieve sustainability, like the development of a system of circular economy [12, 13].

This desired decentralization of urban fluid, however, will not come without difficulty, as it introduces a greater degree of network complexity and necessitates collaboration and co-design of efficient execution and uptake models among sectoral organizations, water utilities, neighborhoods, and businesses. Also, the complex interplay among various decentralized technologies at various scales and across various urban water cycle areas, like potable water, sewage, and stormwater, must be factored into decision support systems that were originally developed with the assumption of a centralized, outside-provided water system [14, 15].

3. Circular Water Economy

Water's significance as a public good essential to human survival and an essential human right cannot be emphasized. Agricultural output, energy generation, industrial output, and manufacturing output all rely on water to function. It is fundamental to equitable growth since it has roots in economic, ecological, and social variables. Conflicts and economic instability, particularly in sectors that supply essential services, may result from unchecked competition for water resources [16, 17].

The lack of water to cool thermal power stations has had a negative impact on the production and quality of crops. People expansion, increasing agricultural activity, urbanization (75% of Europe's population now resides in cities and metropolitan regions), and the variable weather induced by climate change have all contributed to a worldwide rise in the demand for water. Vanishing snow, increasing sea levels, and erratic rainfall patterns are all results of the hydrological cycle being altered by the greenhouse gas influence of global warming. The hydrological cycle demonstrates the cyclical nature of water; nevertheless, human actions over the last century have impeded the natural flow of the planet's water supply [18, 19].

4. Neutrosophic DEMATEL Method

The authors of this work utilize neutrosophic Decision-Making Trial and Evaluation Laboratory (DEMATEL) to calculate weights and create a causal diagram of causes impacting digitalization in distributed circular water. DEMATEL's use of neutrosophic numbers allows it to accommodate uncertainties brought on by human choice. However, grey theory and fuzzy logic are often used to deal with such issues. It is explained that fuzzy logic has problems with uncertainty and lack of membership. Cases in the actual world may be represented as neutrophilic sets, which are compilations of decision-making dimensions including truth, indeterminacy, and falsehood. utilized extensively in MCDM issues; pioneered the neutrosophic method. In addition, presented and used the neutrosophic DEMATEL technique for vendor choice. This research adds to the existing body of knowledge by taking a neutrosophic approach to distributed circular water using the DEMATEL technique [20]–[24]. Figure 1 shows the proposed method.

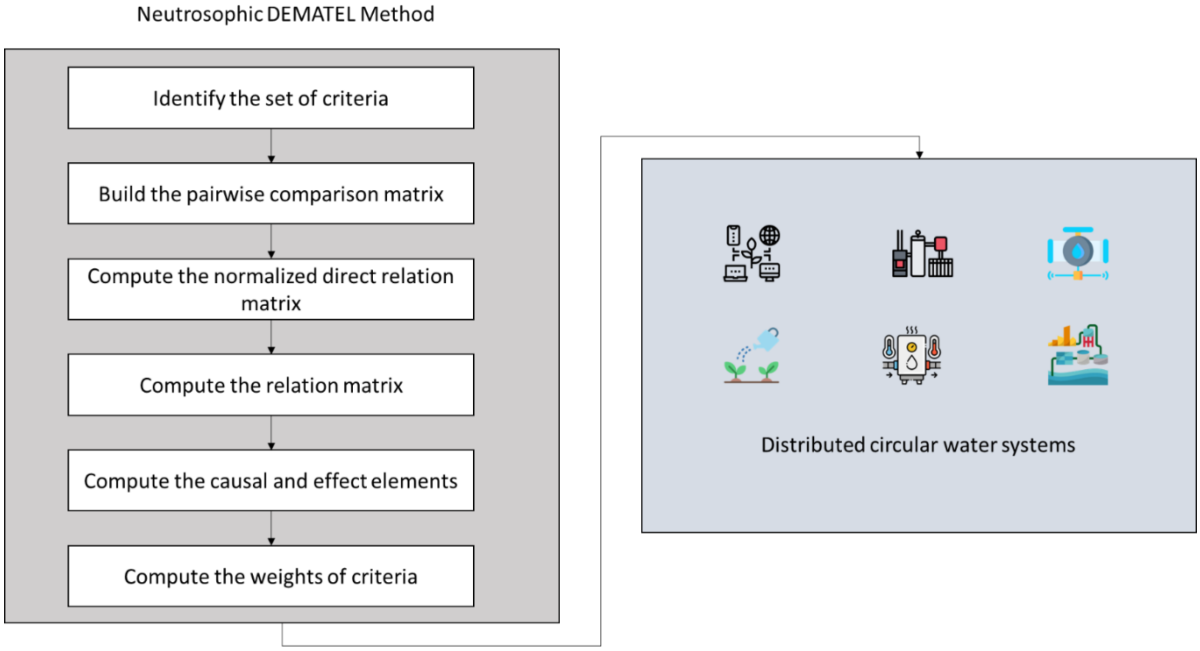

Figure 1. The neutrosophic DEMATEL method steps.

Step1. Identify the set of criteria.
Step2. Build the pairwise comparison matrix.
Step3. Compute the normalized direct relation matrix.

$$N = \frac{1}{\max \sum_{j}^{m} x_{ij}} \quad (1)$$

$$R = N * X \quad (2)$$

Where X refers to the pairwise comparison matrix.
Step4. Compute the relation matrix.

$$L = R(I - R)^{-1} \quad (3)$$

Where I refers to the Identity matrix.
Step5. Compute the causal and effect elements.

$$A = \left[\sum_{j=1}^{f} l_{ij}\right]_{f \times 1} \quad (4)$$

$$B = \left[\sum_{j=1}^{f} l_{ij}\right]_{1 \times f} \quad (5)$$

Step6. Compute the weights of criteria

$$w_j = \sqrt{(A+B)^2 + (A-B)^2} \quad (6)$$

5. Results and Discussion

This section introduces the application of the neutrosophic DEMATEL method to compute the weights of criteria.

By recycling and reusing water on a local level, a distributed circular water system may help cut down on overall water use and waste. Instead of transporting water from a single location, this method recycles the water already present in a given region.

In the circular water system, wastewater from sources including irrigation systems, factories, and toilets is collected, purified, and reused for non-drinking needs. The water is cleansed and reused in a natural cycle after being returned to the environment.

The advantages of this method include: Less water is used because less freshwater is needed from a centralized source when water is reused on a local level. Less untreated water is released into the environment thanks to wastewater treatment and reuse, resulting in less pollution. The water security of communities is improved when they use water from nearby sources rather than depending on distant sources. Less energy is required to transport water from a central source when it can be treated and reused on a local level. Because it needs less infrastructure and maintenance, the dispersed circular water system may be less expensive than centralized water systems. As a whole, a distributed circular water system is an eco-friendlier and effective method of water management that may cut down on water waste and save money for communities.

These are some of the requirements for distributed circular water systems:

Rainwater, groundwater, and surface water are all good examples of local water supplies that might be tapped into by the system.

The system should be able to treat and recycle wastewater to a high enough level that the recycled water is of sufficient quality for its intended use.

The system needs a well-thought-out distribution network to provide clean water to residents quickly and easily.

Water supply and demand swings may be smoothed out if the system has enough storage space.

Water quality and quantity should be monitored in real-time, and the system should be controlled so that any problems can be addressed immediately.

Successful implementation of the system requires active community involvement. To make sure the community is aware of the system's advantages and is eager to participate, it must have an effective communication and engagement plan.

Considering the initial investment, continuing maintenance cost, and possible cost savings from decreased water usage and waste, the system should be economically viable and sustainable.

Water security can be improved, water consumption can be reduced, and environmental effects can be mitigated if a distributed circular water system is planned and built with these goals in mind. Also, social, technical, and ecological are criteria used in this paper.

Applying the steps of the triangular neutrosophic DEMATEL method. Table 1 presents the triangular neutrosophic numbers between criteria. Then compute the normalization direct relation matrix as shown in Table 2. Then compute the total relation matrix. Then compute the casual and effects elements. Then compute the weights of criteria as shown in Figure 2.

Table 1. Direct relation matrix

	DWC_1	DWC_2	DWC_3	DWC_4	DWC_5	DWC_6	DWC_7	DWC_8	DWC_9	DWC_{10}
DWC_1	1	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}
DWC_2	1/{(0,1,2); 0.30, 0.75, 0.70}	1	{(1,2,3); 0.80, 0.15, 0.20}	{(4,4,4); 1.00, 0.00, 0.00}	{(4,4,4); 1.00, 0.00, 0.00}	{(1,2,3); 0.80, 0.15, 0.20}	{(0,1,2); 0.30, 0.75, 0.70}	{(2,3,4); 0.90, 0.10, 0.10}	{(1,2,3); 0.80, 0.15, 0.20}	{(1,2,3); 0.80, 0.15, 0.20}
DWC_3	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1	{(2,3,4); 0.90, 0.10, 0.10}	{(0,1,2); 0.30, 0.75, 0.70}	{(4,4,4); 1.00, 0.00, 0.00}	{(4,4,4); 1.00, 0.00, 0.00}	{(4,4,4); 1.00, 0.00, 0.00}	{(1,2,3); 0.80, 0.15, 0.20}	{(4,4,4); 1.00, 0.00, 0.00}
DWC_4	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/ {(2,3,4); 0.90, 0.10, 0.10}	1	{(4,4,4); 1.00, 0.00, 0.00}	{(2,3,4); 0.90, 0.10, 0.10}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(4,4,4); 1.00, 0.00, 0.00}	{(0,1,2); 0.30, 0.75, 0.70}
DWC_5	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1	{(0,1,2); 0.30, 0.75, 0.70}	{(2,3,4); 0.90, 0.10, 0.10}	{(1,2,3); 0.80, 0.15, 0.20}	{(0,1,2); 0.30, 0.75, 0.70}	{(2,3,4); 0.90, 0.10, 0.10}
DWC_6	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/ {(2,3,4); 0.90, 0.10, 0.10}	1/{(0,1,2); 0.30, 0.75, 0.70}	1	{(1,2,3); 0.80, 0.15, 0.20}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}	{(0,1,2); 0.30, 0.75, 0.70}
DWC_7	1/{(0,1,2); 0.30, 0.75, 0.70}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(2,3,4); 0.90, 0.10, 0.10}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1	{(2,3,4); 0.90, 0.10, 0.10}	{(0,1,2); 0.30, 0.75, 0.70}	{(1,2,3); 0.80, 0.15, 0.20}
DWC_8	1/{(0,1,2); 0.30, 0.75, 0.70}	1/{(2,3,4); 0.90, 0.10, 0.10}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(2,3,4); 0.90, 0.10, 0.10}	1	{(1,2,3); 0.80, 0.15, 0.20}	{(4,4,4); 1.00, 0.00, 0.00}
DWC_9	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1	{(0,1,2); 0.30, 0.75, 0.70}
DWC_{10}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(2,3,4); 0.90, 0.10, 0.10}	1/{(0,1,2); 0.30, 0.75, 0.70}	1/ {(1,2,3); 0.80, 0.15, 0.20}	1/ {(4,4,4); 1.00, 0.00, 0.00}	1/{(0,1,2); 0.30, 0.75, 0.70}	1

Table 2. Normalization direct relation matrix

	DWC_1	DWC_2	DWC_3	DWC_4	DWC_5	DWC_6	DWC_7	DWC_8	DWC_9	DWC_{10}
DWC_1	0.034187	0.010891	0.010891	0.010891	0.010891	0.010891	0.010891	0.010891	0.010891	0.010891
DWC_2	0.107313	0.034187	0.062818	0.15384	0.15384	0.062818	0.010891	0.103842	0.062818	0.062818
DWC_3	0.107313	0.018605	0.034187	0.103842	0.010891	0.15384	0.15384	0.15384	0.062818	0.15384
DWC_4	0.107313	0.007597	0.011255	0.034187	0.15384	0.103842	0.010891	0.010891	0.15384	0.010891
DWC_5	0.107313	0.007597	0.011255	0.007597	0.034187	0.010891	0.103842	0.062818	0.010891	0.103842
DWC_6	0.107313	0.018605	0.007597	0.011255	0.107313	0.034187	0.062818	0.010891	0.010891	0.010891
DWC_7	0.107313	0.107313	0.007597	0.011255	0.011255	0.018605	0.034187	0.103842	0.010891	0.062818
DWC_8	0.107313	0.011255	0.007597	0.011255	0.018605	0.107313	0.107313	0.034187	0.062818	0.15384
DWC_9	0.107313	0.018605	0.018605	0.007597	0.107313	0.107313	0.107313	0.018605	0.034187	0.010891
DWC_{10}	0.107313	0.018605	0.007597	0.107313	0.011255	0.107313	0.018605	0.007597	0.107313	0.034187

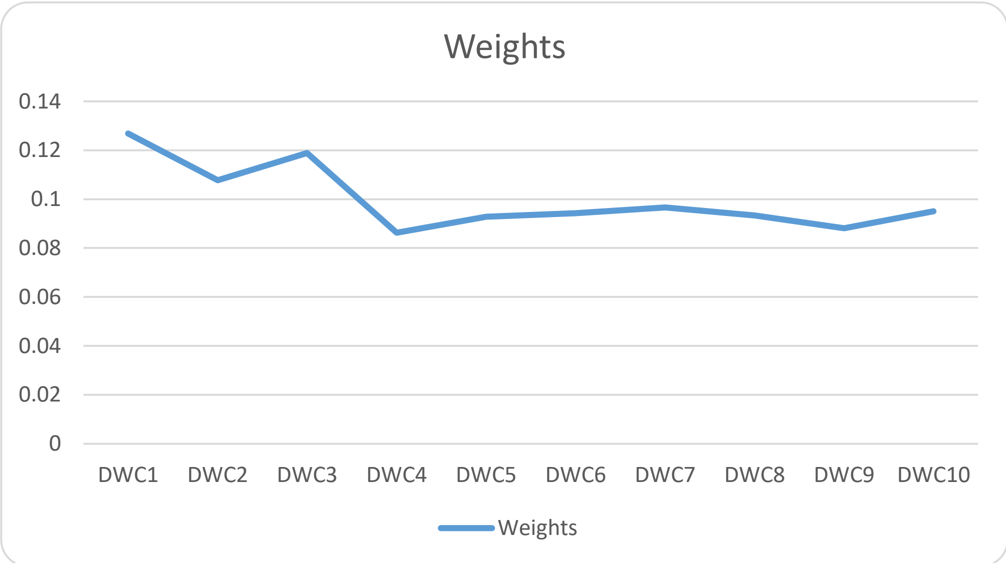

Figure 2. The weights of distributed circular water criteria.

6. Conclusion

The worldwide water crisis is becoming worse because of things like climate change, population growth, and industrial activity. The circular economy has been advocated as a solution to water shortage because it can help bring about a fundamental shift in the way water is managed. Eliminating waste, recovering assets, and cutting consumption are all possible results of incorporating circular economy ideas into urban water supplies. Greater resilience and greater service delivery versatility are provided by distributed water supply systems. Distributed systems continue to operate in the face of a failure at the central node, giving societies time to be ready for the unexpected. This paper used the triangular neutrosophic DEMATEL method to analyze the weights of water system criteria. We used the ten criteria in this study. We achieved the treatment capacity as the highest criterion. To ensure that recycled water is of sufficient quality for its intended use, a distributed circular water system must have sufficient treatment capacity. This is crucial because the quality of the recycled water is crucial to the system's performance, and contaminated water may have detrimental effects on human health and the surroundings.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Energy Efficiency and Material Cost Savings by Evolution of Solar Panels Used in Photovoltaic Systems under Neutrosophic Model

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Abstract: Traditional applications of solar panels have been limited to smaller-scale energy production, such as that required by single houses or apartment complexes. Researchers from all around the globe have been working together to develop creative, efficient goods, increase the energy efficiency of solar panels, and build new, ground-breaking practices using photovoltaic system design. Solar photovoltaic (PV) system planning demands a strategic decision-making approach to socioeconomic growth in many nations due to the rising understanding of the financial, social, and ecological aspects. The primary goal of this study is to provide a novel, adaptable method of Multi-Criteria Decision Making (MCDM) for government decision-makers (DMs) to use in evaluating solar PV panel manufacturers using various variables. This paper used the single-valued neutrosophic set to deal with the vague data. The neutrosophic set is used with the Characteristic Objects Method (COMET). The COMET method is an MCDM method. It is used to compute the rank of alternatives. The application of the proposed method is introduced with eleven criteria and ten solar panels in PV.

Keywords: Solar Panels; Photovoltaic System; Energy Efficiency; Neutrosophic Set.

1. Introduction

Photovoltaic (PV) systems, which utilize sunlight to generate electricity, are one of the most popular forms of renewable energy generating. Solar PV energy has the greatest electricity density and requires the least amount of preservation contrasting to other renewable energy sources. It also produces no harmful emissions during operation and helps mitigate global warming. Despite the PV technological many benefits, the transformation system is vulnerable to a number of environmental factors that might reduce its performance, including hail, dust, and high surface operating temperatures [1, 2].

The outermost temperature of a photovoltaic panel is often affected by exogenous meteorological conditions, including wind speed, atmospheric humidity, temperatures, collected dust, and sunlight. The effectiveness of a solar panel decreases by 0.5% for every 1°C increase in its outermost temperature. Therefore, as a result of the increase in temperature, the efficiency with which solar energy is transformed into electrical power decreases. The leftover solar energy is turned into heat, which satisfies the law of preservation of energy. The total conversion efficiency suffers as a result of this lost heat [3]–[5].

For solar systems to convert energy to be a practical option, they need to increase their efficiency. In order for this to be a workable option, we need to figure out how to reduce the impact of the temperature rise on the conversion effectiveness.

With the goal of boosting the overall effectiveness of the solar converting system, only a few writers have attempted to compile and perform an exhaustive study of alternative technologies that may be used to cool the operational surface of solar panels [6, 7].

Options, standards, and the expert's assessment of the importance of the criteria and the extent to which the requirements are satisfied by other options all make up the decision-making procedure. Ambiguity and unpredictability play a role in the process of prioritizing options by taking criteria into account. Fuzzy decision-making technologies are used to address such cases [8]–[10].

Zadeh is widely regarded as the father of fuzzy set theory, which has since been expanded to include interval-valued fuzzy sets by Turksen, intuitionistic fuzzy sets by Atanssov, hesitant sets by Tora, and Neutrosophic fuzzy sets by Florentin Smarandache. Many different approaches to making decisions have been developed by scholars, from group consensus to the use of many factors [11, 12].

2. Suitability Energy

Critical concerns influencing global sustainability include warming temperatures and the development of environmentally friendly energy systems. Important topics, such as climate change and air pollution, were discussed at the United Nations Climate Change Conference (COP25) in 2019. The dangers of airborne contaminants to human health were discussed, in addition to the present severity of anomalous climates and warm temperatures throughout the globe. Machines have gradually replaced humans in the workplace and made it possible to extract and use natural resources (such as coal, oil, natural gas, and different minerals) at an unprecedented scale since the nineteenth-century industrial period [13, 14].

While the rise of industry and its repercussions were vital to economic growth in many nations, they also left behind a legacy of contamination of the environment and other difficulties as a result of massive amounts of CO2. This has triggered irreversible, aberrant climatic conditions (such as severe cold, extreme heat, floods, and drought) and exacerbated worldwide warming and environmental degradation. Climate calamities will only become worse if action isn't taken. Many island states may not survive if conditions persist at their current levels.

According to IPCC's (a United Nations organization) 2019 annual report, global temperatures are now around 1°C higher than they were during the industrialization era. As global temperatures rise, so do the natural disasters that result from them. Natural catastrophes will have a bigger effect on human life and property when the temperature rise reaches 1.5°C; when it reaches 1.5-2 °C, the world will be swept with both predictable (such as stored-grain infestations, rising temperatures, droughts, and changes of forest environmental systems) and unpredictable catastrophes due to climate change.

High CO2 emissions are a critical ecological management problem that the world must face as a cost of economic success and fast technological progress. It's unclear whether we'll be able to stop the world from becoming warmer. Temperatures exceeding 20 degrees Celsius were recorded in Antarctica in February of the year 2020, signaling an acceleration in the rate at which ice is melting and sea levels are increasing [15, 16].

3. Solar Panels

Traditional applications of solar panels have been limited to smaller-scale energy production, such as that required by single houses or apartment complexes. There are two crystal kinds, polycrystalline and monocrystalline, that provide these panels with a wide efficiency range. Polycrystalline displays are often less efficient than monocrystalline panels owing to the existence of just one crystal, but they are less costly. The overall price of a solar panel is based on its power output (in watts), manufacturer, dimensions, expected lifespan, and approvals.

Choosing a panel only based on its price is not a good idea since it may not work in the intended location, might not be certified to qualify for government rebates, and might not have a long enough warranty to cover the cost of installation and maintenance in a timely manner. Solar panels have a longer payback period than other power generation methods due to the high cost per kilowatt-hour of electricity generated. Consumers are unlikely to adopt solar system technologies with a lengthy payback time. The sooner an investor may recoup their initial investment via the sale of excess power to the grid or the use of a 'free' source of electricity, the better the efficiency of their solar panels. Therefore, choosing these solar panels is a crucial step in developing a photovoltaic system [17, 18].

4. Renewable Energy

Energy is crucial to the continued development of countries. Fossil fuels have been the world's primary energy source for decades. However, global energy use has been placed under considerable pressure as a result of rapid population growth, increasing levels of living, and the proliferation of power-consuming enterprises in both established and developing countries. The fast increase in emissions of environmental pollutants such as carbon dioxide and methane as a consequence of this trend has highlighted two major concerns: the decline of the most readily accessible energy sources (primarily oil) and the issue of climate change. The globe is confronting the issue of combating climate change and warming temperatures via the use of safe and cost-effective renewable energy (RE) sources. The International Renewable Energy Agency (IRENA) predicts a 50% growth in RE-based potential worldwide between 2019 and 2024, amounting to an additional 1220 Gigawatts [19, 20].

Energy harvested from the sun, rainfall, wind, tides, and geothermal radiation are all examples of renewable energy. When compared to conventional sources of energy (e.g. coal, oil, and petroleum), the environmental effect of green energy is negligible, and there are no byproducts of carbon dioxide. Therefore, green energies seem to be the most viable option for addressing ecological issues and worries about energy security. The sun provides a source of a great deal of renewable energy. Solar energy has emerged as the most promising RE source because of its widespread availability, adaptability, and very simple deployment with negligible land-use impacts. Harvesting the sun's rays and using them as a source of power is what is meant by the phrase "solar energy." A large portion of the global demand for energy may be met by harnessing the sun's daily output of power (such as in one hour, the planet gets 172 000 TWh of power from the sun) [21, 22].

Solar PV systems and concentrating solar-thermal power (CSP) systems, which use heat from the sun to turn traditional turbines, are two methods for harnessing the sun's energy for electrical production.

5. Photovoltaic Systems

These days, PV systems are among the most widely used means of producing electrical power. The global PV energy industry is growing rapidly, but many countries, especially those with densely populated cities, are running out of room. That is to say, it is getting more difficult to find enough space for the installation of additional PV panels, which are normally roof- or ground-mounted. PV systems are inefficient; hence a large plot of land is required (about 10 square meters per kilowatt peak). To deal with these issues and free up space for farming, housing, and other uses, solar energy plants may be installed on water bodies including lakes, dam reservoirs, waterways, and rivers. Furthermore, the effectiveness of solar panels is increased by the cooling effect of water on floating solar power plants (FPVSs) [23, 24]. A PV system is comprised of a PV panel or array, the main part that transforms solar energy into direct current (DC) power, as well as auxiliary parts that serve for storing and disseminating the energy. It can be seen in Figure 1 that there are four main parts to a typical solar power plant. These parts are the PV module (or PV array), the battery, the charge controller, and the inverter. As the PV modules generate more energy than is immediately needed, the excess is stored in batteries for use at night or on periods with low sunshine or overcast weather. The life of the batteries is prolonged by the charge controller, which prevents them from being overloaded or completely depleted. Then the neutrosophic Characteristic Objects Method (COMET) is applied to select the best solar panels.

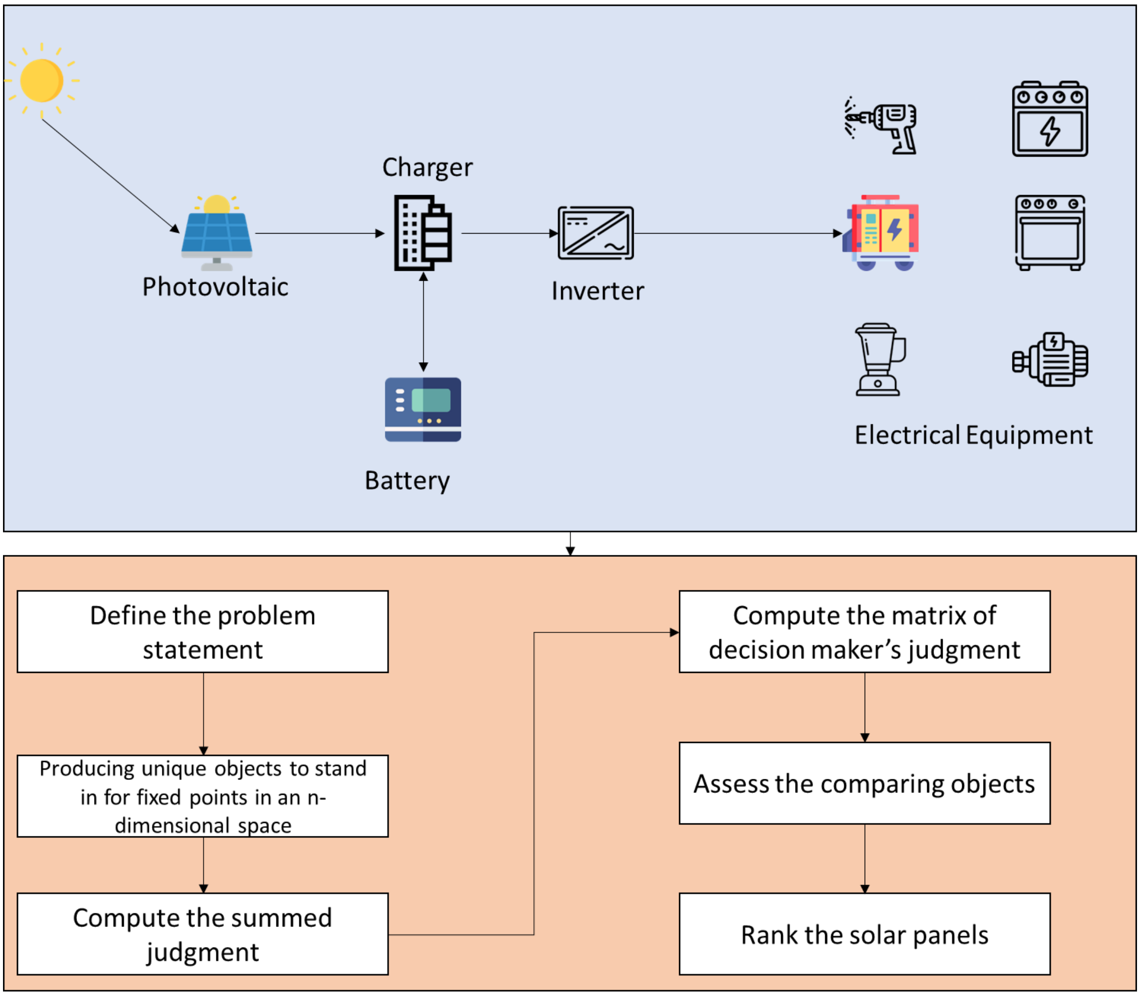

Figure 1. Photovoltaic system and solar panels selection.

6. Neutrosophic COMET Method

The COMET is a novel method for resolving decision-making issues by the identification of several criteria using an expert decision-making model [25, 26]. The novel approach presented here has the major benefit of being completely resistant to the order of solar panels. The steps of this process are outlined below.

i. Define the problem statement

The problem is defined by gathering the set of criteria and set of alternatives based on solar panels. These criteria and alternatives are gathering from previous studies, and evaluated by the single valued neutrosophic numbers.

ii. Producing unique objects to stand in for fixed points in an n-dimensional space.

These things could really exist in the world, or they might just be hypothetical.

$$O_1 = \left(SPC(SPC_{11}), SPC(SPC_{21}), \dots \dots . . SPC(SPC_{r1})\right) \quad (1)$$

$$O_2 = \left(SPC(SPC_{11}), SPC(SPC_{21}), \dots \dots . . SPC(SPC_{r2})\right) \quad (2)$$

$$O_3 = \left(SPC(SPC_{11}), SPC(SPC_{21}), \dots \dots . . SPC(SPC_{r3})\right) \quad (3)$$

$$O_4 = \left(SPC(SPC_{11}), SPC(SPC_{21}), \dots \dots . . SPC(SPC_{r4})\right) \quad (4)$$

$$O_t = \left(SPC(SPC_{1SPC1}), SPC(SPC_{2SPC1}), \dots \dots . . SPC(SPC_{rSPC1})\right) \quad (5)$$

Where SPC refers to the criteria of solar panels.

iii. Compute the matrix of decision maker's judgment.

The criteria and alternatives are evaluated by the decision makers with the single valued neutrosophic numbers.

$$MX = \begin{bmatrix} x_{11} & \cdots & x_{1t} \\ \vdots & \ddots & \vdots \\ x_{t1} & \cdots & x_{tt} \end{bmatrix} \quad (6)$$

Where x_{11} refers to the comparing (SPC_i) and (SPC_j)

iv. Assess the comparing objects.

$$x_{ij} = \begin{cases} 0, & s_{exp}(SPC_i) < s_{exp}(SPC_j) \\ 0.5, & s_{exp}(SPC_i) = s_{exp}(SPC_j) \\ 1.0, & s_{exp}(SPC_i) > s_{exp}(SPC_j) \end{cases} \quad (7)$$

Where s_{exp} refers to the function of decision makers with the judgment.

v. Compute the summed judgment (JU)

The JU is computing by the vertical vector as:

$$JU = \sum_{j=1}^{t} x_{ij} \quad (8)$$

7. Solar Panels Results

This section ranks the solar panels based on various criteria. These paper used ten alternatives and eleven criteria like Open Circuit Voltage, Short Circuit Current, Module Efficiency, Peak Power, Cost, Weight, Area, Material, Service support, Spare part, and Reliability.

Using alternative energy sources extensively to satisfy increasing energy needs not only saves money as opposed to alternatives such as fossil fuels but also lessens the country's reliance on imported goods, which in turn helps the economy thrive. Particularly in poor nations, where the cost of installing and maintaining solar PV systems is cheap, utilizing them to produce power raises GDP and the quality of life. Levelized cost of electricity (LCOE), capacity factor, and overall installed price of a solar photovoltaic structure, weighted globally.

This section offers the result of the single valued neutrosophic COMET method. The experts are evaluated the criteria and alternatives. Then we replace their opinions by the single valued neutrosophic numbers. Then assessing the objects by the comparison as shown in Tables 1-3. Then compute the scores of summed judgments as shown in Figure 2. The option 10 is the best and alternative 8 is the worsts.

Table 1. The Assessment of the comparing first and second object.

	SPC_1	SPC_2	SPC_3	SPC_4	SPC_5	SPC_6	SPC_7	SPC_8	SPC_9	SPC_9	SPC_{10}
SPA_1	1	0	0	1	0	0	1	1	0	0.5	1
SPA_2	1	0	0	1	0	0	0	1	0	0	1
SPA_3	1	0	0	1	0	0	0	1	1	0	1
SPA_4	1	0	0	1	0	0	0.5	1	0	0.5	1
SPA_5	1	0	0	1	1	0	1	1	0	0.5	1
SPA_6	0.5	0	0	1	0	0	0.5	1	0.5	0	1
SPA_7	1	0	0	1	0.5	0	0.5	1	0	0.5	1
SPA_8	1	0	0	1	0	0	0.5	1	0	0.5	1
SPA_9	0.5	0.5	0.5	0.5	0.5	0	0	0.5	0	1	0.5
SPA_{10}	1	1	1	1	1	1	1	1	1	1	1

Table 2. The Assessment of the comparing second and third object.

	SPC_1	SPC_2	SPC_3	SPC_4	SPC_5	SPC_6	SPC_7	SPC_8	SPC_9	SPC_9	SPC_{10}
SPA_1	0.5	1	1	0.5	1	1	0.5	0.5	1	0.5	0.5
SPA_2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SPA_3	1	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SPA_4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5
SPA_5	0.5	0.5	0.5	1	0.5	0.5	0.5	1	0.5	0.5	0.5
SPA_6	1	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5
SPA_7	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	1	0.5	0.5
SPA_8	0.5	0.5	0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5
SPA_9	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SPA_{10}	0.5	1	1	0.5	1	0.5	0.5	0.5	0.5	1	0.5

Table 3. The Assessment of the comparing third and fourth object.

	SPC_1	SPC_2	SPC_3	SPC_4	SPC_5	SPC_6	SPC_7	SPC_8	SPC_9	SPC_9	SPC_{10}
SPA_1	0.5	1	1	0.5	1	1	1	0.5	1	1	0.5
SPA_2	0.5	1	0.5	0.5	1	0.5	1	0.5	1	1	1
SPA_3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SPA_4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	1
SPA_5	0.5	1	0.5	0.5	0.5	0.5	1	1	0.5	1	0.5
SPA_6	0.5	0.5	0.5	0.5	1	0.5	1	0.5	1	1	0.5
SPA_7	0.5	1	0.5	0.5	0.5	0.5	1	0.5	1	0.5	1
SPA_8	0.5	1	0.5	0.5	1	0.5	1	0.5	0.5	1	0.5
SPA_9	0.5	1	0.5	0.5	1	0.5	1	0.5	1	1	0.5
SPA_{10}	0.5	1	1	0.5	1	0.5	0.5	0.5	1	1	0.5

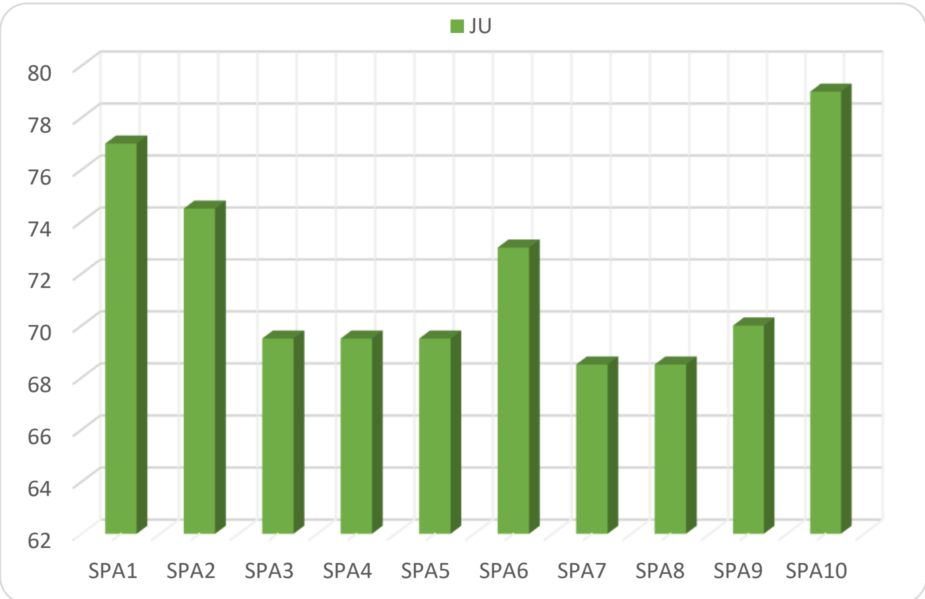

Figure 2. The scores of summed judgments (JU).

8. Conclusion

Developments in international energy sources raise greenhouse gas emissions and fossil fuel costs in response to rising energy demand. Solar energy is a clean, renewable energy source that may cover energy needs at lower costs and presents economic opportunities, especially in rural regions.

Because of the enormous opportunity for solar energy, policymakers have been focusing more on solar energy expenditures in recent years. This paper proposed a single-valued neutrosophic set with the COMET method to deal with uncertain data and rank the alternatives. This paper used 11 factors and 10 alternatives.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Neutrosophic MCDM Methodology for Risk Assessment of Autonomous Underwater Vehicles

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Abstract: Due to its usefulness in several industries and the military, researchers have concentrated on developing autonomous underwater vehicles (AUVs). However, AUV navigation continues to be a difficult challenge to solve owing to the variety of underwater settings. The usage of AUVs, or autonomous underwater vehicles, is not without dangers like malfunction, ecological risks, loss of communications, cybersecurity risks, collisions, and others. There are many criteria to assess these risks technical, operational, economic, and regulatory. So, the methods of multi-criteria decision-making (MCDM) is used to deal with these various criteria. The analytical hierarchy process (AHP) method is an MCDM methodology, that can be used to compute the weights of criteria. The AHP is integrated with the single-valued neutrosophic set (SVNS) to deal with uncertain data in the assessment process. The risks of AUVs are ranked after computing the weights of the criteria. The results show that malfunctions are the highest risk.

Keywords: Neutrosophic Set; Autonomous Underwater Vehicles; Risks Analysis; MCDM.

1. Introduction

Many nations and people throughout the globe have taken an interest in the ocean and its inhabitants in recent years. As a result, it's crucial to learn more about these places and the lessons they can teach us. Since the oceans and seas cover most of the surface of the planet, their significance for resource extraction, scientific inquiry, and economic gain should come as no surprise. From a scientific perspective, the ocean offers a plethora of study options for a deeper comprehension of our planet, which may help several research sectors and scientific organizations [1, 2].

Moreover, due to the high worth of the ocean's resources, many scholars and researchers have put in long hours undertaking in-depth research to find the best uses for them. As part of this shift, nations have been racing to perfect maritime monitoring tools that can operate at different depths and in different environments, including the air. One such tool is the autonomous underwater vehicle (AUV), which is used for surveillance and other forms of crucial surveillance. In 1957, Stan Murphy, Bob Francois, and Terry Ewart from the University of Washington in the United States created the first AUV at the university's applied physics laboratory.

Among the many applications for AUVs are maritime rescue, data collecting, seafloor discovery, and the search for objects underwater. In order to preserve and safeguard our oceans as one of our most important natural assets, these types of boats have grown more popular for a variety of uses, including mapping seabed geography, evaluating marine pastures, and checking undersea oil pipelines. The emergence of the AUV sector is a direct result of the proliferation of cutting-edge technology. Examples of recent developments that have contributed to the growth of the AUV sector include improvements in software and design elements [3, 4].

Think about how AUVs have improved their data collection and processing thanks to new and improved sensors and software. Because of these developments, AUVs may now carry out activities including underwater visualization, pipeline assessment, and rescue efforts. AUVs have also advanced in design thanks to the incorporation of new technologies in areas like propulsion, navigation, and connectivity. These developments in technology have made AUVs safer in operation, as well as more flexible and able to adjust to different environments.

The AUV market is expected to expand at a rapid clip of 22.8% CAGR during 2022 and 2027 as a direct consequence of these developments. Demand for AUVs in industries such as offshore oil and gas development, oceanographic research, and military surveillance is projected to be a major factor in this expansion. It is anticipated that this expansion will be fueled in part by the AUV industry's commitment to technological advancement, which in turn will open up promising new avenues of business [5, 6].

Since the introduction of the fuzzy theory by Zadeh, several methods have been created to cope with ambiguity. Atanassov introduces intuitionistic fuzzy sets, a generalization of fuzzy sets that takes truth and falsity participation into account. To better deal with ambiguity, Smarandache devised neutrosophic logic. Incorporating the "ambiguity" that comes with making any kind of human judgment, "Neutrosophic Logic" has recently emerged [7, 8].

Constraints are passed on to the choice. The need to limit the total number of trainees is a key limitation. This restriction might be based on available funds or the greater work burden experienced because of an absence. This component also has to be included. It is crucial to the technique to define the factors that will be taken into account. The Analytic Hierarchy Process (AHP) has been shown in recent research to be an effective, rigorous, and stable technique for generating and measuring subjective judgments in MCDM. The benefits of AHP, however, are reduced due to the bi-comparison of parameters and possible discrepancies, as stated in the same research. Potential solutions include hybrid techniques that combine AHP with other methodologies [9, 10].

This study proposed the single-valued neutrosophic AHP MCDM method to rank the AUVs risks and compute the weights of the list of criteria.

2. Autonomous Underwater Vehicle Building

The AUV's bodywork construction is crucial because it protects the vehicle's mechanical and electrical parts from water damage. The fluid-structure relationship between the AUV and the water influences its motion dynamics. AUVs take their torpedo shapes directly from boats.

Extremely maneuverable, UVs can swiftly navigate intricate routes and reach out-of-the-way places. In addition to these straightforward designs, AUVs are now also being built in sophisticated forms with hydrofoil shapes to boost performance and decrease drag. AUV P-SURO Similar AUVs include those described by Li et al. and the ones provided by Alam et al. These many AUVs have a common waterproof close-frame construction despite their varying body forms. Due to the lower drag force at low speeds, open-frame constructions are often used by AUVs.

In addition to these man-made devices, AUVs have also been designed to seem like fish or other marine life. These bio-mimetic AUVs are not only useful for exploration and other submerged tasks but also for studying and understanding marine creatures in their natural habitat. Among the bio-mimetic AUVs, fish robots have proven to be the most well-liked [11, 12].

Modular body construction is becoming more common in modern AUVs. The entire AUV is made up of modular components, including the engine and sensor modules, that can be rapidly and easily swapped out in the event of a malfunction or upgraded to meet new mission needs. These AUVs are more cost-effective to maintain and have a high degree of adaptability.

As it moves through the water, an AUV encounters drag and lift forces from the friction between its body and the water. These forces are significantly impacted by the framework of the body. Predicting drag and lift requires studying the fluid-structure relationship between the AUV and the nearby water. The performance of the AUVs may be improved by minimizing these loads utilizing various numerical and optimization techniques. The creation of a reliable dynamic framework for steering and control benefits from estimates of drag and lift as well.

3. Autonomous Underwater Systems

AUVs are autonomous underwater systems that are not tied to the surface, unlike manned undersea robots and remotely controlled vehicles. Costs associated with operations and issues of human safety (such as mine reconnaissance) may be minimized with the use of untethered and unmanned characteristics. In 1957, researchers at the University of Washington created the first AUV, dubbed the Self-Propelled Underwater Research Vehicle (SPURV). The SPURV resembles a torpedo in design. It has a range of up to 3000 meters, a maximum speed of 2.3 meters per second, and a working time of roughly 4 hours. The use of AUV technology has grown exponentially during the last 60 years. Some specifics of AUV methods are shown below.

Due to their autonomous navigation and control capabilities, AUVs can complete missions without human intervention. The sensors aboard collect data from the settings in which these devices operate. Most AUVs need a few fundamental systems, including navigation, power, and sensor technology [13, 14].

4. Navigation System of AUVs

One of the most crucial components of an AUV is its navigation system. The following is a presentation of navigational systems, which includes navigational methods and navigational hardware:

Due to the quick degradation of GPS signals in the ocean, navigation presents a difficult difficulty. Researchers have proposed a number of navigation approaches over the last several decades to address this issue. In order to function, some antiquated methods need surface boats or beacons to be pre-positioned in a certain area. Different lengths of baseline are used for each of these methods: ultrashort (USBL), short (SBL), and long (LBL). Both USBL and SBL setups have a vessel on the surface. The LBL network relies on stationary beacons. A beacon is an instrument that sends out periodic signals to direct autonomous underwater vehicles.

Both a transceiver and an antenna are components of a USBL system. A transceiver is an item with the ability to send and receive electromagnetic waves. Three or more signal-generating transducers are included in a USBL transceiver, and their baseline separation is less than 10 centimeters. Distances between transducers serve as the baseline. A transponder is an item that takes in one signal and immediately sends out another. Transceiver and transponder are both mounted on autonomous underwater vehicles. A USBL technology monitors relative orientations and distances between the outermost vessel and the AUV to determine its location. The variation in phase of acoustic signals measured at the transducer array is used to calculate relative orientations. The distance between two points may be determined by timing the travel time of a sound wave from its source to its destination [15, 16].

5. Communication System of AUVs

The acoustic communicators used by AUVs make underwater interaction possible. Sound signals are sent and received by acoustic modems, which transform electrical power into sound energy and back again. Designers of modems work hard to boost data transfer rates and ensure consistent connectivity. Increasing time delays among frames decreases interference from multipath, and certain companies use spread-spectrum methods to improve the proportion of packets delivered in multipath surroundings, leading to higher processing speeds in those cases. We summarise a variety of modern modem solutions from various vendors to provide a general understanding of the capabilities of acoustic modems.

Batteries dominate AUV power systems. Lead-acid and silver-zinc batteries are the two most common kinds of conventional batteries. Lead-acid batteries are less expensive than silver-zinc ones, although the latter can store twice as much energy. AUVs, like mobile phones and laptops, now often employ lithium batteries. Recharging is possible with lithium batteries. Using this function can save a ton of money.

However, there is still a restriction due to insufficient battery life. Some AUVs are designed with removable batteries to get around this problem, allowing for quick battery swaps and subsequent return to duty [17, 18].

AUVs may serve as sensor systems, allowing for the installation of a wide variety of sensors. Images may be captured using digital cameras, digital video recorders, synthetic aperture sonars, and side-scan sonars. Swath bathymetry seabed overlays are possible with the use of sub-bottom investigators and multi-beam sonars. Distances may be determined using tools like echo sounders and underwater laser scanners. Avoiding danger is made easier with forward-looking sonars. The electrical conductivity, temperature, and stress of saltwater may be measured using a conductivity temperature thickness. There is already a plethora of sensors available to do a wide range of tasks [19, 20].

6. Risks Analysis of AUVs

The distinctions between a malfunction, a problem, and an error are crucial. When a part or system stops working as it should, we call it a failure. A fault is any anomalous situation or flaw that has the potential to cause a failure. The term "error" is used to describe a deviation from the expected value, situation, or human action. It often happens when actual performance falls short of expectations, which may lead to failure.

There has been a progressive movement towards human operator risk assessment as AUV technology has developed. Human variables, which are crucial but somewhat difficult to measure, are garnering more interest in the AUV risk control method as a means to thoroughly limit the risk of AUV installations. When people become involved, AUVs lose some of their independence. We may categorize how much control a system has over its own actions on a scale from totally human-operated to entirely human-assisted to fully human-delegated to completely human-supervised to a fully human-mixed initiative to fully human-operated again. The degree of autonomy indicates how little interference from humans there will be throughout the operation. The current generation of AUV systems falls under level (ii), level (iii), and level (iv), with level (v) and degree (vi) possible in the not-too-distant future. While modern AUV systems have some degree of autonomy, employees are still necessary in a supervisory capacity. Human beings are primarily involved in the design process (figuring out mission plans), the deployment and retrieval of the vehicle, decision-making in the face of crises, and so on [21, 22].

Underwater habitats where AUVs are often used include open ocean, sea ice or shelf ice, and coastal regions. Subsea settings are dynamic and dangerous, making it difficult to guarantee a safe installation. Thus, it is critical to determine what aspects of the underwater environment pose threats to AUVs and to learn how to mitigate such risks. In this part, we draw on previous research to examine four important environmental elements connected to risk: sea ice or shelf ice; underwater currents; the surrounding temperature; and water density [23, 24].

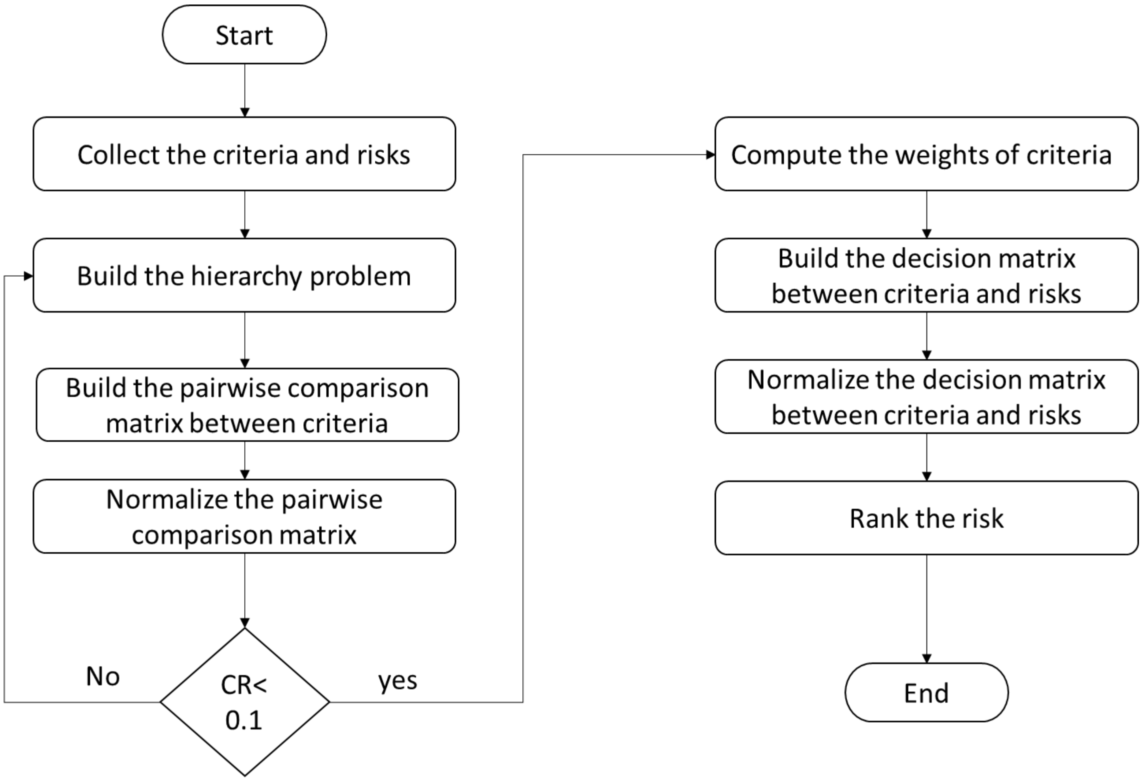

Figure 1. The steps of the neutrosophic AHP method.

7. Neutrosophic MCDM Methodology

In AHP, the decision-makers' past actions are translated into values for the criterion. AHP is a technique that maps the expertise of decision-makers onto the relative importance of certain criteria. The outputs of an AHP analysis are the relative values of the various criteria. Each condition has a weight, and their total is 1. crisp is the original AHP.

However, humans make judgements with a certain amount of fuzziness. Therefore, FAHP is produced by combining fuzzy logic with AHP. Van Laarhoven and Pedrycz provide the first way to combine fuzzy logic with AHP. The purpose of using AHP in making decisions is to account for the ambiguity that comes with using human reasoning. Fuzzy theory is included into AHP in FAHP[25], [26]. The suggested approach incorporates a novel model that combines Neutrosophic Sets with AHP. Figure 1 shows the steps of the neutrosophic AHP method.

Step 1. Build the pairwise comparison matrix between criteria.

Step 2. Normalize the pairwise comparison matrix.

Step 3. Compute the consistency ratio.

$$CR = \frac{CI}{RI}$$

$$CI = \frac{\lambda_{max}-n}{n-1}$$

Step 4. Compute the weights of criteria.

$$w_j = \frac{x_j}{n}$$

Step 5. Build the decision matrix between criteria and risks.

Step 6. Normalize the decision matrix between criteria and risks.

Step 7. Rank the risk.

The risks are ranked with the highest value in multiplying the weights of criteria by the normalization matrix.

8. Results of AUVs Risks Analysis

This section introduces the assessment the risks analysis of the AUVs. This section introduces the application of the single-valued neutrosophic AHP method. The AHP is used to compute the weights of criteria. The AHP is used to rank the risks of the AUVs. There are seven risks are introduced is this paper. AUVs pose hazards similar to those of any other technological advancement. Threats associated with AUVs include:

In the event of a failure, the AUV may become unresponsive or unable to carry out its mission since it relies on a number of complicated electrical and mechanical components. Dangers in the Natural World: Underwater currents, rocks, and other barriers may all pose a threat to the AUV's health and safety. Disconnection: AUVs depend on their communication systems to receive instructions from their operators and relay any collected data back to them. If the AUV loses contact with its base, it may get disoriented and unable to continue its mission. Hacking, a kind of cyberattack, is one example of how AUVs' data and control systems might be jeopardized by their increasing interconnectedness with other systems. Accidental collisions with other vehicles, marine creatures, or submerged objects pose a significant threat to the health and safety of AUVs. Remote AUV operations provide room for human error in mission planning, navigation, and data interpretation, increasing the risk of the AUV being lost, destroyed, or unable to perform its intended purpose. The use of AUVs may have negative consequences for the marine ecosystem, such as the destruction of habitats and the introduction of foreign objects and contaminants.

Thera are six criteria to assess the AUVs risks. The parameters used to evaluate the dangers posed by AUVs may be broken down into numerous classes, such as: In terms of technological criteria, we'll be looking at things like how well the AUV's sensors, navigation, communication, and propulsion systems work and how long they last. Evaluating the AUV's software and control systems, such as its level of autonomy and any built-in redundancies, is another technical criterion. Environmental criteria include taking into account the water depth, temperature, and current, as well as any other environmental parameters that may have an effect on the AUV's performance and safety, while it is in operation. The possible effect of the AUV's operation on marine life and ecosystems must also be considered among the environmental requirements. In terms of operational criteria, we'll be looking at things like how well the mission was planned and carried out, how well the AUV was maintained, and how well the AUV was equipped with safety features to prevent accidents. Cybersecurity Criteria: This includes assessing the likelihood of cyber-attacks, data breaches, and other cybersecurity threats in relation to the AUV's operation. Compliance with safety and environmental legislation, as well as industry standards and best practices, are all part of the regulatory criteria that must be considered while operating an AUV. Evaluating the economic hazards of operating an AUV, such as the cost of development and operation and the potential for financial losses due to system failures, accidents, or other unanticipated occurrences, is part of this criterion.

Table 1. AUVs data between criteria and alternatives.

	$AUVC_1$	$AUVC_2$	$AUVC_3$	$AUVC_4$	$AUVC_5$	$AUVC_6$
$AUVR_1$	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.90, 0.10, 0.10)
$AUVR_2$	(0.10, 0.90, 0.90)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.90, 0.10, 0.10)
$AUVR_3$	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)
$AUVR_4$	(0.90, 0.10, 0.10)	(0.20, 0.85, 0.80)	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.90, 0.10, 0.10)	(0.20, 0.85, 0.80)
$AUVR_5$	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.10, 0.90, 0.90)
$AUVR_6$	(0.20, 0.85, 0.80)	(0.20, 0.85, 0.80)	(0.30, 0.75, 0.70)	(0.20, 0.85, 0.80)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)
$AUVR_7$	(0.90, 0.10, 0.10)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.10, 0.90, 0.90)	(0.20, 0.85, 0.80)	(0.90, 0.10, 0.10)

Table 2. AUVs data normalization between criteria and alternatives.

	$AUVC_1$	$AUVC_2$	$AUVC_3$	$AUVC_4$	$AUVC_5$	$AUVC_6$
$AUVR_1$	0.2641	0.2032	0.0997	0.0721	0.1362	0.2731
$AUVR_2$	0.0354	0.1471	0.0516	0.1924	0.051	0.2731
$AUVR_3$	0.0685	0.0761	0.1376	0.1393	0.0987	0.0366
$AUVR_4$	0.2641	0.1471	0.3844	0.1924	0.3806	0.0708
$AUVR_5$	0.0354	0.2032	0.0516	0.1924	0.0987	0.0366
$AUVR_6$	0.0685	0.1471	0.1376	0.1393	0.1362	0.0366
$AUVR_7$	0.2641	0.0761	0.1376	0.0721	0.0987	0.2731

The experts are evaluated the criteria and risks of the AUVs by using linguistic terms of single valued neutrosophic set. Then we used the single valued neutrosophic numbers instead of the linguistic terms as shown in Table 1. Then apply the steps of the AHP method on the single valued neutrosophic numbers to compute the weights of criteria and rank the risks. Then normalize the pairwise comparison matrix. Then compute the weights of criteria. Figure 2 shows the highest importance criteria. Then compute the rank of the risks by normalize the data between criteria and risks as shown in Table 2. Then multiply the weights of criteria by the normalization data. Then sum of each row as shown in Figure 3. The malfunction is the highest risk in all risks.

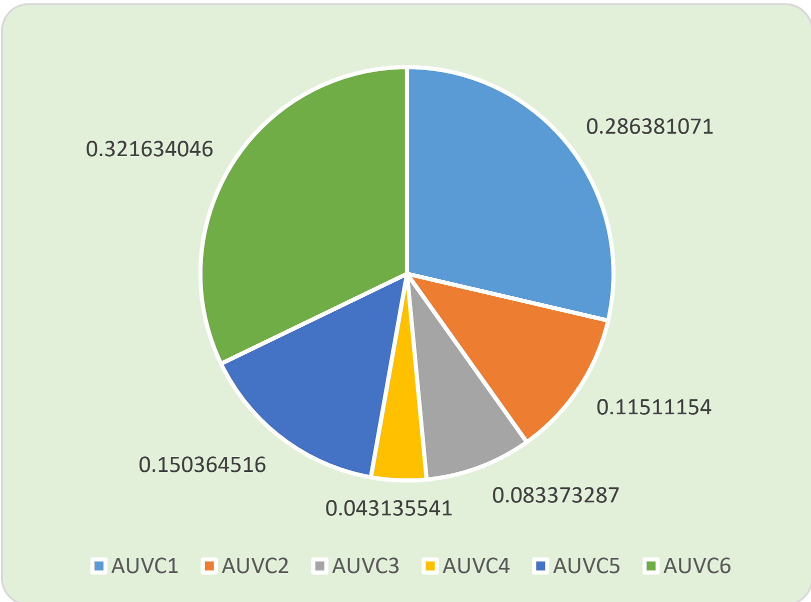

Figure 2. The importance criteria risks of AUVs.

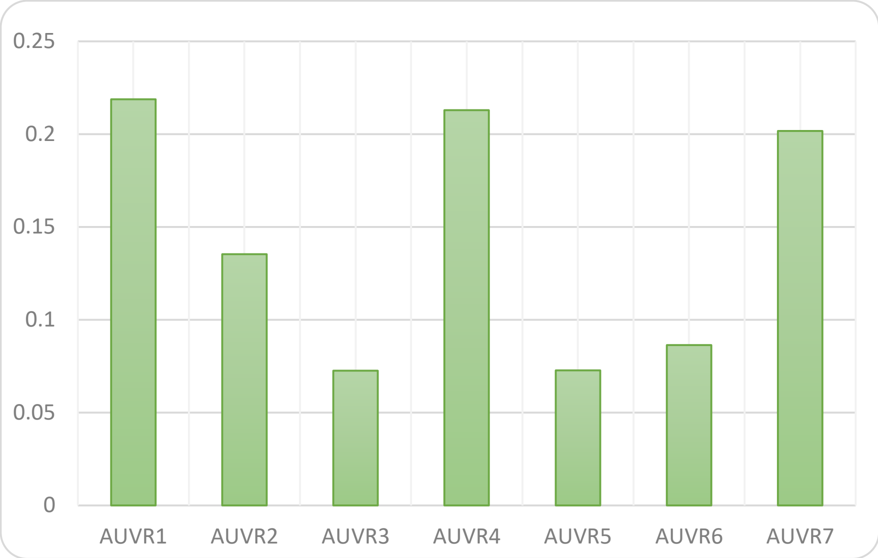

Figure 3. The rank of seven risks of AUVs.

9. Conclusion

AUVs are useful platforms for taking automated measurements without human involvement in harsh environments like the ocean or beneath the ice. But the AUVs have many risks threat it. So, this study collected and ranked these risks based on various criteria by using the concept of the MCDM method. The AHP method is used to compute the weights of criteria and rank the risks. The AHP is integrated with the single-valued neutrosophic set to deal with uncertain data. The malfunctions are the highest risk. The possibility of malfunction is a major threat while using AUVs. The sensors, navigation, communication, and propulsion systems of the AUV are all susceptible to failure. If the AUV has a problem, it may become unresponsive or unable to fulfill its mission, leading to either the loss of the AUV or the information it has gathered.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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