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Sustainable Plastic Waste Management in Thanjavur District: An Evaluation Using Fuzzy AHP and Neutrosophic TOPSIS

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Abstract:

Introduction: The amount of plastic garbage has increased in tandem with the steady growth in the use of plastic products worldwide. Since plastics are lightweight, inexpensive, and durable, they are highly appreciated in a variety of industries, including electronics, building, packaging, healthcare, and agriculture). Plastic's cost, adaptability, resistance to corrosion, durability, and ease of production all contribute to its rising demand.With changes to the Plastic Waste Management Rules, India has made managing single-use plastics a top priority.

Objectives: The research provides an extensive examination of the methods used to manage plastic garbage in Thanjavur's rural villages. Examining household behaviors and waste production trends, it reveals a wide range of plastic kinds, including polystyrene (PS), polypropylene (PP), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyethylene terephthalate (PET).

Methods: The research uses a Multi-Criteria Decision Making (MCDM) approach that combines the Neutrosophic Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) for alternative ranking with the Fuzzy Analytic Hierarchy Process (FAHP) for criteria weighting. Although it uses fuzzy logic to address ambiguity and uncertainty in decision-making processes, the Fuzzy AHP approach is applied in a manner similar to that of AHP.

Results: Egestas diam in arcu cursus euismod quis viverra nibh. Convallis aenean et tortor at risus viverra. Sit amet justo donec enim diam. Sem et tortor consequat id. Purus gravida quis blandit turpis. Consectetur adipiscing elit duis tristique sollicitudin nibh sit amet commodo. Eget duis at tellus at urna condimentum mattis pellentesque. Auctor elit sed vulputate mi sit amet.

Conclusions: This study determines that, among the available options, Polyethylene Terephthalate (PET) is the best option by applying the fuzzy analytic hierarchy process (Fuzzy AHP) to balance these criteria. PET exhibits potential because of its economic and environmental advantages, but its effective application necessitates customized strategies that take into account the infrastructure constraints and socioeconomic characteristics of the local area. Programs for raising community knowledge and participation are crucial in promoting sustainable waste management techniques, as the study emphasizes.

Keywords: Plastic Waste Management, Fuzzy AHP, Neutrosophic TOPSIS, Thanjavur.

1. Introduction

Inadequately disposed waste," as defined by Prabha & Lily (2021), refers to waste that was originally destined for a landfill or dumpsite but was not managed properly. The term "plastic" originates from the Greek word "plasticos," meaning "capable of being shaped or molded by heat." The global use of plastic products has grown steadily, resulting in a corresponding increase in plastic waste. Plastics are valued for their practical qualities such as lightness, affordability, and durability (Thompson et al., 2009), making them indispensable in various sectors including electronics, construction, packaging, healthcare, and agriculture (Sharuddin et al., 2016). The demand for plastic continues to rise due to its affordability, versatility, resistance to corrosion, durability, and ease of production (Wong et al., 2015). Developed countries like those in Europe, North America, Australia, New Zealand, Japan, and South Korea typically dispose of their plastic waste in secure, controlled landfills, even materials that are not suitable for incineration or recycling, due to their effective waste management systems. In these countries, very little plastic waste is considered inadequately managed (Marchand, 2019).

However, according to recent projections from the MNRE Report, India is expected to see a significant rise in waste generation, increasing from approximately 145 million tons per year to an estimated 260-300 million tons per day by 2047 (Kumar & Agrawal, 2020).

In India, the management of single-use plastics has been a primary focus through revisions to the Plastic Waste Management Rules in 2016 and 2018, as well as a proposed amendment in 2021. These regulations categorize plastics by polymer type and recommend recycling methods accordingly. According to research by the Centre for Science and Environment (CSE), plastics like polystyrene (PS) and others in similar categories are non-recyclable and environmentally harmful. It emphasizes the need for attention not only to post-consumer waste but also to pre-consumer waste generated by industries. Globally, various sectors produce millions of tons of plastic waste annually, with packaging being the largest contributor. In India, plastics fulfill 40% of the packaging demand, as per analysis by FICCI. Achieving sustainable Plastic Waste Management (PWM) requires all stakeholders—government, corporate sectors, communities, and organizations—to adopt circular economy strategies. This approach aims to reduce the volume of plastic waste ending up in landfills, thereby mitigating significant threats to the economy, ecology, and public health.

2. Literature Review

Land filling remains a cost-effective and straightforward waste management solution suitable for urban areas, with careful consideration of various criteria when selecting appropriate sites, ensuring compliance with relevant laws and regulations. Studies indicate that only 6% of available areas are highly suitable for landfill development, while 22% are moderately suitable (Muhaiminul et al., 2020). Improper disposal of waste generated externally contributes to numerous health, safety, and environmental challenges. In the realm of waste management innovation, this study utilizes the Internet of Things (IoT) to enhance energy efficiency and waste management practices in smart homes. Employing an estimative-computational research design, experts collected and processed data using computational methods facilitated by tools like STATA and MATLAB. Fuzzy logic calculations and MATLAB software were instrumental in data representation and processing. The study highlights the substantial energy savings achieved through IoT-enabled smart homes (Ehsanifar et al., 2023). For sustainable solid waste management (SWM), optimizing landfill technology is crucial as it represents the final step in waste disposal.

The application of Remote Sensing (RS) techniques has gained popularity for its practicality in developing environmentally friendly waste management systems and data-driven waste regulations (Karimi et al., 2023). Factors such as cost-effectiveness, reputation, and quality play pivotal roles in selecting green service providers committed to sustainable waste management practices.In the realm of environmental protection, addressing these demands requires a multi-criteria decision-making (MCDM) approach that integrates both quantitative and qualitative assessments. The complexity of the MCDM problem in selecting green suppliers necessitates methods that can impartially and effectively handle expert-provided data, avoiding biases inherent in conventional research methods. Recent analyses have compared computational results using traditional TOPSIS and AHP-TOPSIS methods, demonstrating that advanced approaches can offer unbiased evaluations of real-world scenarios for green supplier selection (Chung et al., 2023).

A sustainable Zero Waste Management (ZWM) system can significantly benefit from integrating data into mathematical waste management models. Enhanced source separation of waste components leads to higher yields of quality secondary products and promotes resource conservation during disposal processes. The study assumes highly efficient source separation, where waste is individually collected and routed to appropriate treatment facilities. Future efforts should incorporate stakeholder feedback to inform waste generation and handling within proposed models, prioritizing resource conservation-oriented ZWM over consumption-based waste hierarchies. Research findings emphasize the readiness of existing infrastructure, such as collection trucks and containers, to support the development of new municipal solid waste (MSW) collection systems. Stakeholders' expert assessments validate the sustainability of these waste management systems. Surveys, whether conducted in person or online, are crucial for gathering input on waste management practices from relevant parties and integrating this data into mathematical models for sustainable ZWM (Apaydin et al., 2023).

In analyzing and benchmarking solid waste management systems across Canadian provinces, an integrated methodology combining efficiency analysis and Fuzzy Analytic Hierarchy Process (FAHP) was employed. Economic variables such as GDP ratios, GDP across industries, and sector-specific GDPs were scrutinized to assess system performance among nine provinces. The efficacy approach prioritized provinces based on these variables, while FAHP evaluated the impact of each indicator on system effectiveness. The study illuminates the economic efficiencies of each Canadian province individually and collectively, utilizing a newly proposed integrated decision-making framework (FAHP and efficacy approach). This framework was developed with input from experts and data sourced from government agencies, incorporating provincial statistics, literature reviews, and professional insights to select indicators and options. By combining these methods, the decision-making process becomes more straightforward and less ambiguous (Kabir et al., 2022).

In a practical case study from the Casablanca region, an integrated methodology was demonstrated to select landfill sites considering Political, Economic, Environmental, and Social (PEES) variables. Qualitative and quantitative criteria influencing landfill location selection were explored using literature reviews and expert interviews. Alternative locations were ranked, and criteria weights were determined using fuzzy TOPSIS and fuzzy AHP algorithms, respectively (Hanine et al., 2016). In multi-criteria decision-making processes for waste management, environmental and economic criteria are frequently prioritized. However, socially acceptable practices are increasingly essential in sustainable waste management due to emerging social regulations and concerns. Research indicates that social impact is not fully integrated into decision-making despite its importance in solid waste management (Gutierrez-Lopez et al., 2023). Pamucar et al. (2022) introduced a novel decision-making paradigm to evaluate integrated solid waste management effectiveness at the regional level. Their framework comprehensively addresses all aspects of solid waste management over time and their environmental impacts, employing the fuzzy MACBETH multi-criteria decision-making model to handle uncertainties and inefficiencies. In selecting materials for heat storage utilizing industrial waste heat, a multi-criteria decision-making process integrates qualitative and quantitative datasets. This method employs MATLAB software, graph theory, and matrix methodologies to generate a target-based material appropriateness index, accommodating both objective and subjective considerations (Housouli et al., 2023). Using goal programming and fuzzy AHP, Nirmala & Uthara (2018) evaluated five plastic waste management strategies against five criteria. Mechanical recycling emerged as the preferred technique based on survey responses, with ecological impact deemed the most critical criterion.

Elkhrachy et al. (2023) developed a comprehensive framework for landfill suitability mapping in Najran, Saudi Arabia, integrating multiple remote sensing datasets and decision-making techniques. Thematic layers included surface elevation, slope, groundwater depth, land use, drainage density, road network, soil type, and proximity to residential and protected areas. This approach categorized the landfill appropriateness index into five groups based on traditional and satellite data, facilitating informed decision-making for landfill site selection. Selecting appropriate landfill sites is a critical challenge in solid waste management, as improper disposal methods can severely impact the environment and quality of life. A comprehensive framework is essential for streamlining the process of identifying suitable landfill sites, involving criteria weighting, standardization, and robust data collection. An example of this approach was demonstrated in selecting the Abha-Khamis-Mushyet dump site in Aseer using an integrated GIS-based fuzzy-AHP-MCDA approach (Javed Mallick, 2021).

Urban drainage infrastructures face significant challenges due to inadequate construction practices, inappropriate designs, and insufficient asset management and maintenance. Mengistu et al. (2023) conducted an analytical hierarchy process (AHP) qualitative multicriteria decision model to analyze the causes and implications of drainage system failures. Their findings highlighted solid wastes and debris as major contributors, with correlation values of 0.93 and 0.95 respectively, accounting for approximately 35.5% and 28.6% of system failures. In minimizing concrete waste on construction sites, Mdallal & Hammad (2019) utilized a multi-criteria decision-making technique known as the Holistic Fuzzy AHP approach. This method integrates fuzzy sets theory to address uncertainties in expert judgments, considering technical, social, economic, and environmental factors to evaluate alternatives like prefabrication, landfilling, and recycled concrete aggregates. For emerging nations facing increasing urbanization and population growth, finding suitable landfill locations is crucial for effective solid waste management. Makonyo & Msabi (2021) employed geographic information systems (GIS) and multi-criteria decision analysis to identify potential dump sites in Dodoma, highlighting the importance of strategic location decisions for waste management infrastructure. Water resources are under pressure from rapid urbanization and industrial development, necessitating the construction of sewage treatment plants to ensure sustainable water management. Wu et al. (2023) utilized an enhanced Best Worst Method (BWM) and fuzzy comprehensive assessment to evaluate the safety of municipal sewage treatment plants, considering human, material, environmental, and management factors. In municipal solid waste (MSW) management, selecting geographic locations for landfill activities involves complex decision-making processes handled by relevant authorities (Hanine et al., 2016). Cities, as major contributors to global energy consumption and carbon emissions, play a critical role in addressing water and climate crises (Demircan & Yetilmezsoy, 2023). Addressing uncertainty in performance metrics in plastic waste management, Abdel-Basset et al. (2018) explored the application of neutrosophic TOPSIS, extending from intuitionistic fuzzy sets, to optimize decision-making models. This approach considers indeterminacy and non-membership, effectively replicating real-world decision challenges in uncertain environments.

3. Methods

The paper makes several significant contributions:

Data Collection: It gathered numerical experimental data from 190 households in Thanjavur District using a structured questionnaire. This data collection provides empirical insights into local perspectives and practices regarding the management of solid waste, offering a foundation for informed decision-making.

FAHP Framework for Criteria Evaluation: The study employed the Fuzzy Analytic Hierarchy Process (FAHP) framework to determine the relative performance weights of criteria. This approach facilitates a structured and systematic assessment of criteria importance, enhancing the robustness and objectivity of decision-making in solid waste management.

Neutrosophic TOPSIS Validation: The paper utilized the Neutrosophic Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method to validate the proposed ranking methodology. This validation step ensures that the ranking of alternatives in waste management solutions considers the complexities and uncertainties inherent in real-world decision environments, providing a more comprehensive and reliable basis for practical application.

These contributions collectively enhance understanding and application in the field of solid waste management, offering methodological advancements that address both quantitative data collection and qualitative decision-making frameworks.

2. Neutrosophic sets

In this section, we give definitions involving neutrosophic sets, single valued neutrosophic sets, triangular neutrosophic numbers,and operations on triangular neutrosophic numbers.

Definition 2.1. (Smarandache, F., 1998.)

Let E be a universe. A neutrosophic set A in E is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$. $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard elements of [0,1]. It can be written as $A = \{< x, (T_A(x), I_A(x), F_A(x)) >: x? E; T_A(x), I_A(x), F_A(x)?\ ]0^-, 1^+[\ \}$. There is no restriction on the sum of $T_A(x), I_A(x)$, and $F_A(x)$. So $0 = T_A(x), I_A(x), F_A(x) = 3^+$.

Definition 2.2. (Smarandache, F., 1998.)

Let E be a universe. A single valued neutrosophic set A, which can be used in real scientific and engineering applications, in E is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$. $T_A(x), I_A(x), F_A(x)$ are real standard elements of [0,1]. It can be written as $A = \{< x, (T_A(x), I_A(x), F_A(x)) >: x? E; T_A(x), I_A(x), F_A(x)? [0, 1]\ \}$.

Definition 2.3. (Mahdi et al, (2002).

Let $(\alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}) \in [0,1]$ and $a_1, a_2, a_3 ? R$ such that $a_1 = a_2 = a_3$. Then a single valued triangular neutrosophic number $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ is a special neutrosophic set on the real line set R, whose truth-membership, indeterminacy-membership and falsity-membership functions are given as follows

$$T_{\tilde{a}}(x) = \begin{cases} \alpha_{\tilde{a}}\left(\dfrac{x - a_1}{(a_2 - a_1)}\right) & \text{if } a_1 \leq x \leq a_2 \\ \alpha_{\tilde{a}} & \text{if } x = a_2 \\ \alpha_{\tilde{a}}\left(\dfrac{a_3 - x}{a_3 - a_2}\right) & \text{if } a < x \leq a_3 \\ 0 & \text{otherwise} \end{cases}$$

$$I_{\tilde{a}}(x) = \begin{cases} \dfrac{(a_2 - x + \theta_{\tilde{a}}(x - a_1))}{(a_2 - a_1)} & \text{if } a_1 \le x \le a_2 \\ \theta_{\tilde{a}} & \text{if } x = a_2 \\ \dfrac{(x - a_2 + \theta_{\tilde{a}}(a_3 - x))}{(a_3 - a_2)} & \text{if } a_2 < x \le a_3 \\ 1 & \text{otherwise} \end{cases}$$

$$F_{\tilde{a}}(x) = \begin{cases} \dfrac{(a_2 - x + \beta_{\tilde{a}}(x - a_1))}{(a_2 - a_1)} & \text{if } a_1 \le x \le a_2 \\ \beta_{\tilde{a}} & \text{if } x = a_2 \\ \dfrac{(x - a_2 + \theta_{\tilde{a}}(a_3 - x))}{(a_3 - a_2)} & \text{if } a_2 < x \le a_3 \\ 0 & \text{otherwise} \end{cases}$$

Where $\alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}$ denote the maximum truth-membership degree, minimum indeterminacy-membership degree and minimum falsity-membership degree respectively. A single valued triangular neutrosophic number $\breve{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ may express an ill-defined quantity about α, which is approximately equal to α.

Definition 2.4. (Mahdi et al, 2002)

Let $\breve{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ and $\breve{b} = \langle (b_1, b_2, b_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ be two single valued triangular neutrosophic numbers and ? ? 0 be any real number. Then,

$$\breve{a} + \breve{b} = \langle (a_1 + b_1, a_2 + b_2, a_3 + b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle$$

$$\breve{a} - \breve{b} = \langle (a_1 - b_3, a_2 - b_2, a_3 - b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle$$

$$\breve{a}.\breve{b} = \begin{cases} \langle (a_1 b_1, a_2 b_2, a_3 b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if } (a_3 > 0, b_3 > 0) \\ \langle (a_1 b_3, a_2 b_2, a_3 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if } (a_3 < 0, b_3 > 0) \\ \langle (a_3 b_3, a_2 b_2, a_1 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if } (a_3 < 0, b_3 < 0) \end{cases}$$

$$\gamma\breve{a} = \begin{cases} \langle (\gamma a_1, \gamma a_2, \gamma a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if } (\gamma > 0) \\ \langle (\gamma a_1, \gamma a_2, \gamma a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if } (\gamma > 0) \end{cases}$$

$$\frac{\breve{a}}{\breve{b}} = \begin{cases} \dfrac{a_1}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_3}{b_1}; \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \text{ if } (a_3 > 0, b_3 > 0) \\ \dfrac{a_3}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_1}{b_1}; \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \text{ if } (a_3 < 0, b_3 > 0) \\ \dfrac{a_3}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_1}{b_1}; \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \text{ if } (a_3 < 0, b_3 < 0) \end{cases}$$

3. Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is an extension of the Analytic Hierarchy Process (AHP) introduced by Thomas L. Saaty in 1987, further developed with fuzzy logic theory by researchers such as Zamani Sabzi et al. (2016). This method is employed similarly to AHP but

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incorporates fuzzy logic to handle uncertainty and vagueness in decision-making processes. The steps involved in the Fuzzy AHP method are as follows:

1. Developing a fuzzy comparison matrix

First the scale of linguistics is determined. The scale used is the triangular fuzzy number (TFN) scale from one to nine are shows in Table 1.

Table 1. Scale of Interest

Scale of Interest	Linguistic Variable	Membership Function
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Strongly more important	(4,5,6)
7	Very strongly important	(6,7,8)
9	Extremely important	(8,9,10)

Then, by using equation (1) to make the fuzzy comparison matrix.

$$\bar{A} = \begin{bmatrix} 1 & \cdots & \overline{a_{1n}} \\ \vdots & \ddots & \vdots \\ \overline{a_{n1}} & \cdots & 1 \end{bmatrix} \quad (1)$$

2. Define the Fuzzy Geometric Mean

The fuzzy geometric mean is then calculated using Equation (2).

$$\bar{x_i} = \left(\bar{a}_{(i1)} \otimes \bar{a}_{(i2)} \otimes \ldots \otimes \bar{a}_{(in)}\right)^{\frac{1}{n}} \quad (2)$$

Where a_{in} is a value of fuzzy comparison matrix from criteria I to n. Result from the fuzzy geometric mean will be referred to later as local fuzzy number.

3. Find the weight of fuzzy of each dimension

The next step is to calculate the global fuzzy number for each evaluation dimension with Equation (3).

$$\tilde{w}_i = \tilde{x}_1 \otimes (\tilde{x}_1 \oplus \tilde{x}_1 \oplus \ldots \oplus \tilde{x}_1)^{-1} \quad (3)$$

4. Define the best non fuzzy performance (BNP)

The value of the best BNP from the fuzzy weight in each dimension is then determined using Equation (4) after the global fuzzy number has been converted to a crisp weight value using the Centre of Area (COA) approach.

$$\mathrm{BNP}_{wi} = \frac{[(u_{wi} - l_{wi}) + (m_{wi} - l_{wi})]}{3} + l_{wi} \quad (4)$$

3.1. Proposed Neutrosophic Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Approach

The framework of neutrosophic TOPSIS method, as applied in your study, involves several key steps after obtaining the weighted criteria from the Fuzzy Analytic Hierarchy Process (FAHP). Here's an outline of how neutrosophic TOPSIS is typically implemented:

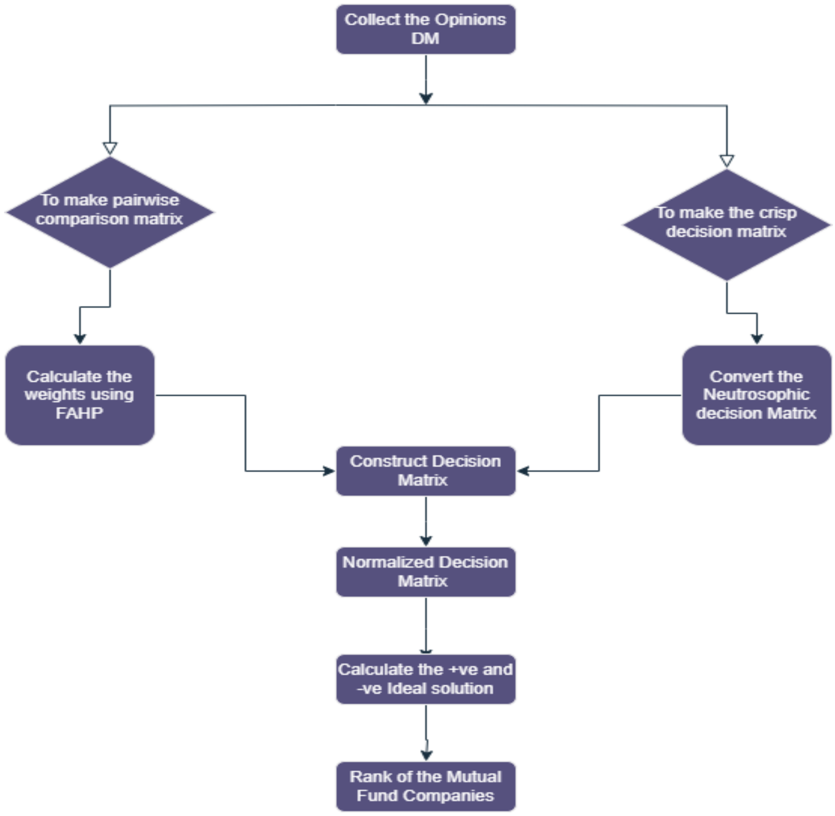

Fig.1 The proposed the neutrosophic TOPSIS

Step 1: After founding the criteria values, these values are given to one experts. Expert opinions on language variables like absolutely crucial, very strongly important, equally important, slightly important, and so on are provided. Translate the terms used in language into the triangular neutrosophic scale, as indicated in Table 2.

Convert the neutrosophic scales to crisp values by using equation

4. To formulate the decision matrix take the average value for the expert's opinion crisp

values. The decision matrix as follows:

$$X = \begin{bmatrix} a_{11} & ? & a_{ln} \\ ? & ? & ? \\ a_{ml} & ? & a_{mn} \end{bmatrix} \quad (11)$$

Step 2: The normalize the decision matrix using equation (12)

$$Y = y_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^{n} a_{ij}^2}}, j = 1,2, \dots, n; i = 1,2, \dots, m \quad (12)$$

Step 3: Using the equation (13), obtain the weighted normalized decision matrix vi j taking into account the fact that each criterion has a different weight (obtained from steps 1 to 9, in

FAHP).

$$v_{ij} = y_{ij} \times W_j, j = 1,2, \dots, n; i = 1,2, \dots, m. \quad (13)$$

Step 4: Calculate the positive ideal solution (PIS) and negative ideal solutions (NIS).

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$$

$$\{(\max_j v_{ij} | i ? I), (\min_j v_{ij} | j ? I) \quad (14)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}$$

$$\{(\max_j v_{ij} | i ? I), (\min_j v_{ij} | j ? I) \quad (15)$$

Step 5: Calculate the separation measures using positive and negative ideal solutions.

$$S(v_{0j}^+, v_{ij}) = v\left(?_{i=1}^{n}(v_{ij} - v_i^+)^2\right) \quad (16)$$

$$S(v_{0j}^-, v_{ij}) = v\left(?_{i=1}^{n}(v_{ij} - v_i^-)^2\right) \quad (17)$$

(20)

Step 6: Then the closeness coefficient CC_i is determined

$$CC_i = \frac{S_i^+(x)}{S_i^+(x) + S_i^-(x)} \quad (21)$$

Step 7: Alternatives are ranked in the decreasing order of CC_i value.

The study employs a Multi-Criteria Decision Making (MCDM) technique that integrates Fuzzy Analytic Hierarchy Process (FAHP) for criteria weighting and Neutrosophic Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) for ranking alternatives. Here’s a detailed outline of the methodology used:

Overview

Data Collection:

A questionnaire was administered to gather numerical experimental data from 160 participants in Thanjavur. This data collection phase provided quantitative insights into various parameters related to solid waste management.

Expert Evaluation:

Experts reviewed the questionnaire responses and validated the collected data to ensure reliability and accuracy before proceeding with further analysis.

Criteria Identification:

Several criteria were identified for evaluating solid waste management strategies, including: polyethylene terephthalate (PET) (C1), high-density polyethylene (HDPE) (C2), and low-density polyethylene (LDPE) (C3), polypropylene (PP) (C4). These criteria were selected based on their relevance to the study objectives and their impact on environmental factors.

Fuzzy AHP for Criteria Weighting:

Fuzzy Analytic Hierarchy Process (FAHP) was utilized to determine the relative weights of the criteria. This involved pairwise comparisons of criteria by experts, which were then converted into fuzzy scales to accommodate uncertainties and subjective judgments.

Alternative Evaluation:

Six locations within Thanjavur District were considered as alternatives for implementing solid waste management strategies: Vallam (A1), Palani Samy (A2), Thirukattupalli (A3), Thiruvananthapuram (A4), Ammapettai (A5), and Pattukottai (A6). These locations were evaluated based on their suitability and performance regarding the identified criteria. The MCDM procedure as follows

4. Results

Determining the weights of the criteria by FAHP Approach

Step1: Construct the pairwise comparison matrix

	C1	C2	C3	C4	C5	C6
C1	1	3	2	9	7	6
C2	1\3	1	3	5	9	6
C3	1\2	1\3	1	4	6	9
C4	1\9	1\5	1\4	1	4	7
C5	1\7	1\9	1\6	1\4	1	5
C6	1\6	1\6	1\9	1\7	1\5	1

Step2: The fuzzy geometric mean shall be calculated by the following equation.

	C1	C2	C3	C4	C5	C6
C1	1.6515	1.7043	1.7497	1.6515	1.7043	1.7497
C2	1.6182	1.6664	1.7091	1.6182	1.6664	1.7091
C3	1.5820	1.6255	1.6683	1.5820	1.6255	1.6683
C4	1.4562	1.4994	1.5377	1.4562	1.4994	1.5377
C5	1.3159	1.3544	1.3902	1.3159	1.3544	1.3902
C6	1.0865	1.0996	1.1155	1.0865	1.0996	1.1155

Step3: Criteria weight calculated as follows:

Criteria	C1	C2	C3	C4	C5	C6
Fuzzy Weights	0.1902	0.1861	0.1817	0.1674	0.1513	0.1234
Rank	1	2	3	4	5	6
Crisp Weights	0.3740	0.2689	0.1921	0.0877	0.0496	0.0274
Rank	1	2	3	4	5	6

Ranking the alternatives by Neutrosophic TOPSIS Approach

After measuring the weight of the criteria, we use the neutrosophic TOPSIS model to rank the alternative set of places with the set of weighted criteria obtained from the FAHP process. The proposed model of the neutrosophy TOPSIS method is shown in Fig. 2. Moreover, selecting the best company from six places using neutrosophy TOPSIS is discussed as follows

Table 1. The Neutrosophic Triangular scale value

Explanation	Scale	Scale Neutrosophic Triangular Scale
Equally important	1	((1,1,1);0.5,0.5,0.5))
Slightly important	3	((2,3,4);0.3,0.75,0.70))
Strongly important	5	((4,5,6);0.80,0.15,0.20))
very strongly important	7	((6,7,8);0.9,0.10,0.10))
Absolutely important	9	((8,9,9);1.00,0.00,0.00))
Sporadic values between two close scales	2	((1,2,3);0.4,0.6,0.65))
	4	((3,4,5);0.35,0.6,0.4))
	6	((5,6,7);0.7,0.25,0.3))
	8	((7,8,9);0.85,0.1,0.15))

Step1: Neutrosophic decision matrix DM1 to provide intangible criteria

	C1	C2	C3	C4	C5	C6
	DM1					
A1	EI	MI	I3	MDI	MI	SI
A2	I1	EI	MDI	EI	SI	EI
A3	MI	SI	EI	MDI	I4	I3
A4	SI	EI	SI	MDI	EI	MDI
A5	SI	i3	I1	MI	MDI	MI
A6	EI	i4	L1	EI	MDI	EI

Step2: Neutrosophic decision matrix DM1 to provide intangible criteria

	C1	C2	C3	C4	C5	C6
	1	5	6	3	5	7
A1	2	9	3	9	7	9
A2	5	7	9	3	8	6
A3	7	9	7	3	9	3
A4	7	6	2	5	3	5
A5	9	8	2	1	3	1
A6	1	5	6	3	5	7

Step3: Decision-matrix

	C1	C2	C3	C4	C5	C6
	0.1667	23.3333	26.8333	4.4000	20.0000	61.6000
A1	1.0000	79.2000	2.9333	0.0000	0.0000	0.0000
A2	18.0000	37.3333	79.2000	0.0000	0.0000	0.0000
A3	42.9333	79.2000	0.0000	4.0000	79.2000	4.0000
A4	41.0667	40.8333	0.0000	23.3333	4.0000	23.3333
A5	72.0000	64.4000	0.8333	0.1667	4.6667	0.1833
A6	0.1667	23.3333	26.8333	4.4000	20.0000	61.6000

Step4: Normalized decision matrix

	C1	C2	C3	C4	C5	C6
	0.0018	0.1638	0.3207	0.1827	0.2441	0.9334
A1	0.0105	0.5559	0.0351	0.0000	0.0000	0.0000
A2	0.1893	0.2620	0.9465	0.0000	0.0000	0.0000
A3	0.4516	0.5559	0.0000	0.1661	0.9668	0.0606
A4	0.4320	0.2866	0.0000	0.9690	0.0488	0.3536
A5	0.7573	0.4520	0.0100	0.0069	0.0570	0.0028
A6	0.0018	0.1638	0.3207	0.1827	0.2441	0.9334

Step5: Calculate the separation measures from positive and negative ideal solution

	S+	S-	Vi	Rank
A1	0.1193	0.1972	0.3165	3
A2	0.0305	0.2182	0.2487	1
A3	0.0305	0.1211	0.1516	6
A4	0.1193	0.1815	0.3008	4
A5	0.1692	0.1895	0.3588	2
A6	0.0219	0.1713	0.1931	5

The Waste Management Palace was evaluated using the Neutrosophic-TOPSIS method, which calculates relative proximity values. According to this technique, the optimal choice should be farthest from the negative ideal solution while being closest to the ideal response. Specifically, A1, A4, A6, and A3 exhibited notably low performance levels, resulting in rankings of 3, 4, 5, and 6 respectively. Notably, A6's ranking dropped significantly, indicating its poor performance. In response, both the public and government have implemented measures based on the developed

MCDM approach to address these issues. These methods facilitate selecting the most suitable locations for waste management.

5. Discussion

The study offers a comprehensive analysis of plastic waste management strategies in rural communities of Thanjavur. It examines household practices and waste generation patterns, revealing significant diversity in plastic types such as Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS). Quantification of daily plastic waste production per household underscores the scale of the issue and the urgency for effective management solutions. Evaluation of municipal solid waste management techniques, based on criteria including financial viability, social acceptance, environmental impact, and practical feasibility, highlights the complexity of addressing plastic waste in rural contexts. Using the fuzzy analytic hierarchy process (Fuzzy AHP) to weigh these criteria, the study identifies Polyethylene Terephthalate (PET) as the optimal choice among available techniques. While PET shows promise due to its environmental and economic benefits, successful implementation requires tailored approaches considering local socio-economic conditions and infrastructure limitations. The study underscores the importance of community engagement and awareness programs to foster sustainable waste management practices. Collaboration among policymakers, environmental agencies, and local authorities is essential to develop integrated waste management strategies encompassing efficient collection, recycling, and disposal methods for various types of plastic waste. This holistic approach aims to minimize environmental pollution, conserve natural resources, and promote a circular economy model. Future research could explore innovative technologies and incentives to enhance plastic recycling rates and reduce overall waste generation in rural communities. Long-term sustainability goals should prioritize education initiatives and capacity-building programs to empower residents with knowledge and tools for active participation in waste reduction efforts. In conclusion, while challenges persist, the study emphasizes the potential for effective plastic waste management in rural areas through strategic planning, stakeholder collaboration, and community-driven initiatives. By implementing evidence-based solutions and adapting to local contexts, cleaner and healthier environments can be achieved, advancing sustainable development goals for rural communities in Thanjavur and beyond.

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