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Evaluating the Strategies for Sustainable Traditional Medicine Development in Developing Countries: A Holistic Decision-Making Approach

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Abstract. Choosing the right options for sustainable traditional medicine development is a major challenge for healthcare policymakers and practitioners, especially with uncertainties introduced by political shifts and policy changes. A new approach is developed in this study to address this complex issue. Applying the alternative ranking using two-step logarithmic normalization (ARLON) based on picture fuzzy sets (PFS), this framework is the first of its kind in the literature. It helps identify the most appropriate strategies from options for sustainable traditional medicine development. The study combines the picture fuzzy ARLON approach with the FullEX technique to weigh criteria representing challenges to sustainable traditional medicine development. Sensitivity analysis scenarios and comparative analyses are conducted to test the approach's robustness. Results show that "Validation of safety, efficacy, and quality" and "Campaigns to highlight the positive aspects of TM" are the most appropriate alternatives for sustainable traditional medicine development.

2020 Mathematics Subject Classifications: 90B50, 03E72, 90C29
Key Words and Phrases: Sustainability, traditional medicine, FullEX, alternative ranking using two-step logarithmic normalization, multi-criteria decision-making

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1. Introduction

Traditional medicine (TM) refers to a wide range of indigenous medical systems and practices [1]. Examples include prominent systems like traditional Chinese as well as unknows systems, which are gaining popularity [2]. Across the world, there is a wealth of conventional knowledge concerning human and animal health [3]. The World Health Organization (WHO) recognition of TM as a main healthcare resource dates back to 1976 [3]. Initially, TM was defined as the accumulation of understandings and applications, regardless of their scientific explanation, utilized in health care and passed down through generations via practical experience and observation [4]. Currently, TM is understood as expertise and applications originating from cultural beliefs and experiences, employed in maintaining health and managing health conditions [5]. In Africa, traditional therapists and the use of medicinal plants are integral to community healthcare [6].

Traditional African healthcare systems have experienced a significant resurgence in the past twenty years, having previously been marginalized within the healthcare system [3]. Each African region has its distinct TM practices, which are frequently tailored to the socio-cultural circumstances of particular tribal communities, leading to variations [3]. These communities also exhibit diverse attitudes and behaviors toward health, disease, and treatment [3].

Herbal medicine (HM), a prevalent form of TM, significantly contributes to healthcare, especially in resource-constrained settings [7]. Natural products and their derivatives make up an estimated 50% of all drugs used in clinical settings [2]. The HM market was valued at US$ 216.40 billion in 2023 and is expected to reach US$ 371.45 billion by 2030, at a rate of 8.02% [2]. Sub-Saharan African countries, including Kenya, hold vast plant diversity, yet much remains unexplored [8]. This is despite the region facing numerous tropical diseases that affect both humans and animals [9]. As an agricultural nation, Kenya has rich resources in medicinal plants and knowledge of their usage [10]. Despite the evolution of TM, its development and utilization have been limited by various constraints.

Numerous studies have discussed the issues and tendencies related to integrating TM into formal health services [11–13]. These studies also evaluate the measures needed to ensure the affordable and advancement of TM. Several ongoing efforts to merge TM into formal health services are evident in various African countries, where joint initiatives focus on preventing and caring for ill patients [14]. These efforts serve as positive examples for merging TM into the formal system, particularly if supported by official coaching for practitioners involved in such partnerships. Some conventional health practitioner institutions, in conjunction with Ministries of Health, have consistently sought appropriate mechanisms for applying international statutes and laws related to TM at the local level. Their efforts have underscored the challenge of selecting appropriate strategies for the sustainable development of TM.

While different approaches exist for addressing issues in decision-making, multi-criteria decision-making (MCDM) methods are often utilized when handling numerous criteria [15–17]. The adoption of TM is declining rapidly due to various challenges, including safety issues and stigmatization. Therefore, the implementation of MCDM may be preferable for selecting appropriate strategies to eradicate these challenges. Several studies based on MCDM in the literature discuss the TM problem [18–20].

Nevertheless, it is important to highlight that there is currently no model for selecting strategies that specifically target the development of sustainable TM development in Africa. The objective of this study is to present a new integrated model for addressing the subject matter. The proposed MCDM model integrates the FullEX method, which involves considering an expert's reputation—a critical initial step in decision-making. Additionally, the study introduces the alternative ranking using two-step logarithmic normalization (ARLON) based on picture fuzzy sets (PFS) for the first time in the literature. This method aims to select the most appropriate alternative for sustainable TM development through group decision-making.

The motivation of the study is as follows. PFSs [21] are fuzzy sets [22] and intuitionistic fuzzy sets (IFSs) extensions [23]. They are used to model situations and advents that are not well represented by other sets (i.e. FS and IFS) [24]. The application of the picture fuzzy (PF) logic to represent unknown information is deemed more precise and pragmatic than FSs and IFSs [25]. PFS-related MCDM approaches are appropriate when decision-makers' opinions include various types of responses [26]. PFSs offer a superior approach to measuring objects, concepts, and ideas compared to other FS types [27]. In addressing uncertainty within sustainable TM development, PFSs present a strong solution. PFSs are defined by three membership levels; i.e. positive, negative, as well as neutral. They offer an effective means of expressing unknown information related to sustainable TM development, helping to minimize the loss of information. Despite these advantages, there is a lack of prior research applying a PFS-based MCDM approach to solve the sustainable TM development problem.

The approaches to weight criteria depend on the subjective opinions of decision-makers (DMs) [28]. The analytical hierarchy process (AHP), the stepwise weight assessment ratio analysis (SWARA), the best worst method (BWM), and the full consistency method (FUCOM) are some of these approaches that incorporate the personal viewpoints of DMs and assess each criterion concerning others via pairwise comparisons (PCs). The AHP method leverages experts' ideas to conduct PCs. By converting these ideas into numerical values (1–9-point scale), the significance of each criterion is determined by the method[29]. Conversely, the SWARA method removes criteria with approximately low significance and ranks those that are most significant[30]. The BWM is utilized when there are no objective measures accessible to evaluate criteria. It is centered around comparing pairs of criteria using best and worst references, which helps reduce the impact of anchoring bias [31]. The FUCOM method involves comparing each criterion with every other criterion using the scale in n-1 PCs[32]. Apart from subjective approaches, the introduction of objective and hybrid weighting techniques such as criteria importance through intercriteria correlation (CRITIC), indifference threshold-based attribute ratio analysis (**ITARA**), and root assessment method (RAM), including their fuzzy extensions. The CRITIC method calculates weights using both the interrelationships between criteria and the standard deviation of criterion value. Greater weight is attributed to criterion with little correlation with others and greater contrast intensity[33]. While CRITIC offers an objective measure that escapes focusing on experts' subjective input, it is greatly relying on the structure of accessible data and does not consider the heterogeneity of expert's ideas. Additionally, CRITIC-based weights can become unstable when criteria are hugely interrelated or in case of small dataset. The ITARA method is another weighting that assesses the criteria's significance based on the dispersion of attribute values while adopting an indifference threshold. This makes it effective in addressing huge problems and escaping exaggerated weights variations because of little variations of data. Although recent fuzzy extensions of ITARA have ameliorated its ability to overcome uncertainty; however, it still highlights attribute dispersion and neglect the varying qualities of expert contributions in group decision-making situations. The RAM approach and its fuzzy extensions take a different orientation for generating ranking-oriented assessments, where the focus is putted on the distance of alternatives from ideal or reference solutions. The RAM method is important for ranking alternatives, but they do not clearly produce criterion weights. This makes it complementary rather than substitutive to CRITIC or ITARA weighting methods. Furthermore, RAM assumes uniformity quality in expert's opinions and lacks mechanisms to include differential credibility among decision-makers. The FullEX technique sets itself apart from other subjective approaches by factoring in the esteem of experts, which includes their education level and life experience. This initial step is pivotal in making decisions, as these experts assess and prioritize criteria based on their significance. More knowledgeable experts are likely to make more accurate decisions, while a higher education level suggests a stronger conceptual foundation for making decisions. Unlike other subjective methods, these two crucial parameters have not been considered by them in the procedure of making decisions. The FullEX method combines Fuller's technique with expert reputation, illustrating how an expert's education and experience can remarkably impact the final decision. Unlike the BWM, FullEX produces varying rankings based on experts, while the BWM's results remain consistent regardless of expert reputation. Therefore, FullEX not only justifies its approach but also paves the way for new ideas in subjective approaches. However, there is a gap in research regarding the application of FullEX to assess challenges in sustainable TM development. This study addresses this gap by using FullEX to evaluate the weights of these challenges.

The alternative ranking using the ARLON method, introduced by Kara et al. [34], is distinctively outlined for decisional grids that contain various criteria and analysis units, and require effectiveness with exponential merits. The method stands out for its use of two normalization procedures and an aggregation operator, differentiating it from other approaches. Unlike PF-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and PF-Vlsekriterijumska Optimizacija I KOmpromisno Resenje (VIKOR), which relies on compromise ranking through utility and regret measures, the PF-ARLON approach directly includes a two-stage logarithmic normalization procedure that better addresses exponential and skewed data. PF-TOPSIS and PF-VIKOR perform well with relatively stabilized datasets but may generate unstable or biased rankings when extreme or unevenly distributed values are present, since they lack mechanisms to adjust the scale or symmetry of the data. By contrast, PF-ARLON compresses greatly large values and extends very little ones, transforming the dataset into a more symmetrical and normally distributed form before aggregation. This adjustment considerably diminishes distortions, enhances the comparability of criteria, and improves ranking stability. Moreover, its aggregation operator guarantees that no single criterion dominates disproportionately, which is a known limitation in PF-TOPSIS and PF-VIKOR when weights or scores of criteria vary widely. Therefore, PF-ARLON represents a methodological advancement over these existing PF-based approaches by providing more reliable, accurate and powerful rankings in complex decision environments. Despite these clear advantages, this novel alternative ranking method has not been previously adapted for use in a picture-fuzzy environment, making its adoption in this study a meaningful and original contribution.

The remainder of the article is organized as follows. Section 2 is the literature review, while Section 3 shows the novel methodology. Section 4 and Section 5 describe a case study as well as results and validation analysis, respectively. Section 6 and Section 7 are related to findings and discussion, and policy implications, respectively. The last section is about the conclusion.

2. Literature Review

TM is crucial in healthcare for its cultural relevance, accessibility, and holistic approach. It offers natural remedies, complements modern treatments, and helps preserve cultural knowledge. Integrating TM improves healthcare access and outcomes. Efficient use of TM requires thorough studies to identify and overcome challenges. For instance, Li et al. [35] determined the frequency of TM utilization and its influencing factors among healthy old women residing in Ibadan, Nigeria. Kwame [36] examined how healthcare consumers, traditional physicians, and biomedical doctors in Ghana view and propose integrating TM and healing practice. Pullen et al. [37] researched mental health and TM perspectives in Liberia. James et al. [38] studied how Ebola leftovers in Sierra Leone view traditional and complementary medicine (TCM) use. Malan et al. [39] studied Ehotile people's use of medicinal plants to add to a database of useful Ivorian plants. Fongnzossie Fedoung et al. [40] explored medicinal plants as COVID-19 supportive therapies.

Ndegwa et al. [41] explored medicinal plants used in Kenya for treating ailments. Nigussie et al. [42] studied the application of TM among Eastern Ethiopia residents. El Hajj et al. [43] explored Zambian women's use of TM during pregnancy. Mujinja & Saronga [44] assessed information, regulations, and issues among TM practitioners and regulators in Tanzania. Mothibe & Sibanda [45] described the favorable reception and recognition of African TM in healthcare. Mutombo et al. [46] examined how the Lubumbashi population perceives African TM and when they turn to these therapies.

Tan et al. [47] investigated the reasons for the widespread use of TM in Rwanda, a country where it has been incorporated into universal health coverage (UHC). Belhouala and Benarba [48] examined how Algerian traditional healers utilize medicinal plants to treat a variety of illnesses. Ajjoun et al. [49] offered pioneering scientific insights into the dermatological properties of medicinal plants in Morocco, potentially leading to new skin-issue treatments. Wannes & Marzouk [50] highlighted Tunisian medicinal plants' role in diabetes treatment, urging research into new drug conceptualizations.

Metwaly et al. [51] explored the basics, sources of data, remedy diseases, and therapeutics of Egyptian medicine, aiming to understand ancient Egyptian' TM. Agbodjento et al. [52] examined the present research landscape regarding Beninese medicinal plants. Ouoba et al. [53] studied TM use and unfavorable occurrences in Burkina Faso. Sanogo et al. [54] researched the enhancement of TM for contagious disorders in Mali. Alemu et al. [55] centered their study on the human medicinal plants along with their traditional usage in a specific Ethiopian region. Li et al. [56] reviewed the studies related the traditional Chinese medicine (TCM) for cancer therapy. Xi et al. [57] offers an extensive overview of the TCM development for the treatment of lung cancer.

The common approaches used in TM-related studies are indicated in Table 1. While these studies offer important insights into the application, perceptions, and documentation of TM across Africa and beyond, they are largely descriptive or exploratory in nature. Most focus on qualitative methods, ethnographics accounts, or cross-sectional survey which are successful for apprehending cultural practices and attitudes but fall short of providing structured assessment of sustainability challenges or practical strategies. Similarly, review-based and ethnobotanical studies contribute to knowledge preservation but do not translate into actionable decision-making frameworks. None of the existing works thoroughly assess and prioritize the complex, multi-dimensional challenges impeding the sustainable TM development. In this regard, our study advances the literature by introducing a holistic MCDM approach that integrateds expert opinions with objective ranking processes. This permiy not only the pinpointing of the most critical challenges but also the extensive evaluation and prioritization of strategies for sustainable TM development, thereby addressing a critical methodolofical and practical gap in the field.

Table 1: Approaches used for traditional medicine-related studies.

Authors	***Focus***	***Method***	***CA***	***SA***	***GDM***	***Location***
Li et al. [35]	Usage of TM	Multivariate logistic regression	No	No	Yes	Nigeria
Kwame [36]	Incorporate TM into a health system	Interpretive ethnographic qualitative research design	No	No	Yes	Ghana
Pullen et al. [37]	Understanding of behavior of healers of TM	Qualitative research design	No	No	Yes	Liberia
James et al. [38]	Attitude of TCM among people who survive Ebola	Quantitative cross-sectional study	No	No	Yes	Sierra Leone
Malan et al. [39]	Analysis of knowledge degree and usage of medicinal plants	Smith's index and informant consensus factor	No	No	Yes	Côte d'Ivoire
Fongnzossie Fedoung et al. [40]	Medicinal plants review	Review	No	No	No	Cameroon
Ndegwa et al. [41]	Exploration of natural products in Kenyan herbal medicine	Soxhlet extraction method	No	No	No	Kenya
Nigussie et al. [42]	Assessment of TM practice and related factors	Community-based cross-sectional study	No	No	No	East Ethiopia
El Hajj et al. [43]	Usage of TM assessment during pregnancy	Semi-structured interview	No	No	No	Zambia
Mujinja & Saronga [44]	Assessment of TCM issues and regulation awareness	In-depth interview	No	No	No	Tanzania
Mothibe & Sibanda [45]	Acceptance and recognition of African TM	Review	No	No	No	South Africa
Mutombo et al. [46]	Determination of the perception and use of TM	Semi-structured interview	No	No	No	DRC
Tan et al. [47]	Exploring why TM is popular	In-depth interview and participant observation	No	No	No	Rwanda
Belhouala & Benarba [48]	Assessment of medicinal plants to treat illness	Fidelity level, informant consensus factor	No	No	No	Algeria
Ajjoun et al. [49]	Evaluation of the dermatological characteristics of medicinal plants	Review	No	No	No	Morocco
Wannes & Marzouk [50]	Highlighting the significance of medicinal plants to cure diabetes	Review	No	No	No	Tunisia
Metwaly et al. [51]	Understanding the TM-related information	Review	No	No	No	Egypt
Agbodjento et al. [52]	Assessing the status of medicinal plants	Document	No	No	No	Benin
Ouoba et al. [53]	Estimating the frequency of usage of negative events related to TM	Population-based cross-sectional study	No	No	No	Burkina Faso
Sanogo et al. [54]	Valorizing TM via the generation of improved TM	Qualitative analysis	No	No	No	Mali
Alemu et al. [55]	Ethnobotanical study of TM plants	Semi-structured interviews	No	No	No	North Wollo Zone (Ethiopia)
Li et al. [56]	Integration of TCM into cancer therapy	Review	No	No	No	China
Xi et al. [57]	Integration of TCM into lung cancer treatment	Review	No	No	No	China
Our study	*Evaluating alternatives for sustainable TM development*	*FullEX-PF-ARLON*	*Yes*	*Yes*	*Yes*	*Kenya*

3. Proposed Methodology

This research follows a methodological framework consisting of three key phases. In the *first phase*, the research begins by defining the problem, where the most appropriate strategy for sustainable TM development is selected. This includes establishing the principles for selecting an expert group, determining the approach for criteria selection, and identifying the strategies for sustainable TM development. In the *development phase*, this research explains the FullEX-PF-ARLON integrated method designed for sustainable TM development. It begins by presenting the basics of the PFS. Then, the FullEX-PF-ARLON integrated model is detailed in two stages. Firstly, the FullEX method is used to calculate the weights of criteria in the decision-making process for sustainable TM development. Secondly, the PF-ARLON method is employed to rank the strategies for sustainable TM development. In the *robustness phase*, the research develops sensitivity analysis scenarios (SAS) and conducts a comparative analysis with other MCDM methods to test the developed model. Figure 1 illustrates these phases.

Figure 1: Flowchart of our methodology.

3.1. Experts, Criteria, and Alternatives Selection for Sustainable Traditional Medicine Development

Healthcare policymakers often choose sustainable TM development strategies intuitively, without in-depth research or expert consultation. This approach, while seeming effective short-term, can lead to long-term challenges. Timely and accurate policy implementation is crucial. To ensure sustainable TM development, policymakers must select the most appropriate strategy, as incorrect choices can impact this development. Therefore, selecting an alternative that fully supports TM development sustainability is critical. Healthcare policymakers should focus on choosing the proper DMs, defining the proper criteria, and properly identifying TM development strategies.

In selecting the expert group, it is essential to employ both strategic and operative techniques. The strategic technique entails including high-ranking executives capable of evaluating TM's long-term impact on public health. Meanwhile, the operative technique involves practitioners dealing directly with issues in the active usage of TM. To ensure effective selection, these techniques should be integrated, resulting in an expert group comprising both high-ranking executives and practitioners.

Defining criteria and strategies should include expert opinions and previous studies. Experts should validate these based on their experience. The next section proposes a model for selecting the appropriate strategy for sustainable TM development.

3.2. Establishing a Novel Integrated Model

This part describes the FullEX-PF-ARLON integrated method for selecting a sustainable TM development strategy. It begins with the preliminaries in Appendix A [21, 58, 59], followed by the FullEX steps in Appendix B [60, 61], and concludes with the PF-ARLON method steps in Appendix C [62].

4. Case Study

A case study was undertaken to assess the efficacy of the integrated FullEX-PF-ARLON method. The primary objective of this study was to devise a viable strategy for addressing the challenges that hinder the sustainable development of TM in Kenya. Initially, the study identified an expert group comprising health administrators and practitioners involved in TM. Subsequently, the study delineated the criteria (challenges) for sustainable TM development and their numbers. Following this, the study determined the alternatives for sustainable TM development in Kenya and their numbers. The subsequent parts elaborate on the expert group, define the criteria, as well as outline the alternatives for sustainable TM development. The implementation of the FullEX-PF-ARLON integrated method is then illustrated step by step.

4.1. Expert, Criteria, and Alternatives for Sustainable Traditional Medicine Development

4.1.1. Expert Determination

A group of experts, including healthcare administrators and experienced TM practitioners, should be formed to select the best approach for the sustainable development of TM. In a real-life case study, care was taken to ensure the panel represented diverse perspectives. Six experts agreed to participate in data collection after discussions and consultations.

4.1.2. Criteria Discovery and Definitions

After defining the research problem regarding selecting a strategy for sustainable TM development, the first step involved reviewing the literature on criteria selection. This focused on challenges hindering sustainable TM development in Kenya. The impact of these criteria on strategy selection was evaluated, and expert judgments were sought. Six criteria were identified through a literature review, recognizing their direct influence on decision-making. Each criterion was detailed to explain its role in affecting sustainable TM development. Their utilization in the literature was investigated, and discoveries were shown in Table 2. Additionally, the criteria are explained in Table 3.

Table 2: Criteria choice based on previous studies.

Criteria	*Criteria Type*	*References*
$\mho_1$: "Stigmatization due to poor perceptions and attitudes"	Benefit	[63]
$\mho_2$: "Inadequate conservation of medicinal plants and indigenous knowledge"	Benefit	[64, 65]
$\mho_3$: "Rapid modernization exposing the indigenous knowledge of TM to the risk"	Cost	[66]
$\mho_4$: "Intellectual property issues, inequitable benefits, and excessive exploitation of communities that own the knowledge"	Cost	[67]
$\mho_5$: "Unsubstantiated claims about the safety, efficacy, and quality of products of TM practice"	Benefit	[68]
$\mho_6$: "Irrational use of herbal medicine and lack of a national policy and regulatory framework"	Benefit	[69]

4.1.3. Alternatives for Sustainable Traditional Medicine Development

Experts were presented with five alternatives for sustainable TM development, identified through a literature review and experts' feedback. These alternatives are defined in Table 3.

5. Results and Validation Analysis

5.1. Weighting of Criteria using the FullEX Method

Steps 1-1 and 1-2. The experts compared two criteria and marked a better one based on their opinion by applying Fuller's triangle principle. After the experts' assessment, the input data matrix is formulated and presented in Table D1 in Appendix D.

Steps 1-3 and 1-4. The normalization of the input data with the expert weighted matrix is calculated using Eq. (B3) and Eq. (B4) and presented in Table D2 and Table D3, respectively.

Steps 1-5 and 1-6. Each element from the expert-weighted normalized input data matrix was divided by the optimal one ($V_{u\,\max}$) to obtain the optimal decision-making matrix (see Table 4).

Table 4: Optimal decision-making matrix.

Experts/Criteria	$\mho_1$	$\mho_2$	$\mho_3$	$\mho_4$	$\mho_5$	$\mho_6$
$\daleth_1$	0.0000	0.3601	0.3001	0.1500	0.7501	0.5538
$\daleth_2$	0.1999	0.3199	0.3999	0.1999	0.9997	0.7381
$\daleth_3$	0.2167	0.1734	0.4334	0.4334	0.8669	1.0000
$\daleth_4$	1.0000	0.8000	1.0000	0.3333	1.0000	0.6152
$\daleth_5$	0.1500	0.3601	0.3001	0.0000	0.7501	0.5538
$\daleth_6$	0.0000	1.0000	0.2500	1.0000	0.7500	0.4614
F_u	0.0851	0.1636	0.1457	0.1149	0.2778	0.2129

Table 3: Criteria and alternatives definition.

Criteria and alternatives	***Definitions***	***Refs.***
$\mho_1$	▷ Unfavorable views regarding TM. ▷ Media misrepresentation worsens perception. ▷ Disagreement on which Ministry should oversee TM (Health vs Cuture).	[12]
$\mho_2$	▷ Unsustainable harvesting and habitat destruction. ▷ Poverty-driven exploitation by untrained individuals. ▷ Unregulated sale and use of plants.	[70]
$\mho_3$	▷ The rapid loss of ancient knowledge due to aging custodians. ▷ Modernization threatens TM heritage.	[70, 71]
$\mho_4$	▷ Concerns regarding intellectual property and fair benefit distribution. ▷ Exploitation by unethical researchers/businessmen. ▷ Communities hesitant to share knowledge.	[72]
$\mho_5$	▷ Unverified assertions regarding healing and nutritional benefits. ▷ Lack scientific validation.	[73]
$\mho_6$	▷ Delays in policy finalization enable quackery. ▷ No clear integration with conventional medicine. ▷ Lack of mechanisms to enforce international TM laws.	[74]
$\wp_1$: "Campaigns to highlight the positive aspects of TM"	▷ Public/media campaigns to dispel myths. ▷ Lobby for TM recognition as a career. ▷ Introduce TM content into school curricula.	[75]
$\wp_2$: "Conservation of plants and knowledge"	▷ TM education for youth. ▷ Promote tree planting and sustainable harvesting. ▷ Strengthened forest protection and monitoring.	[76]
$\wp_3$: "Preserve traditions for younger generations"	▷ Document plant species and practices. ▷ Encourage family transmission of TM. ▷ Organize educational visit to rural areas.	[77]
$\wp_4$: "Validation of the safety, efficacy, and quality"	▷ Subject TM products to rigorous testing. ▷ Verify claims scientifically. ▷ Regulate practice and restrict informal sales.	[78]
$\wp_5$: "Development of national TM policy"	▷ Finalize Kenya's national TM policy. ▷ Integrate TM into healthcare system. ▷ Protect biodiversity and indigenous knowledge.	[79, 80]

Steps 1-7 and 1-8. All the values were summarized in the optimal decision-making matrix and the final importance of the criteria was calculated (Table 4). The final criteria weights (F_u) are calculated by applying Eq. (B8).The most critical challenge is the "unsubstantiated claims about the safety, efficacy, and quality of products of TM practice" ($\mho_5$). The rankings are $\mho_5 > \mho_6 > \mho_2 > \mho_3 > \mho_4 > \mho_1$.

Step 1-9. To confirm the result reliability, a second round of interviews with experts collected information on the percentage distribution of criteria importance. The results in Table 5 show a consistency rate below 0.1 (i.e. CI=0.09037) thus indicating satisfactory reliability.

Table 5: CI calculation.

Criteria	F_u	$\daleth_1$	$\daleth_2$	$\daleth_3$	$\daleth_4$	$\daleth_5$	$\daleth_6$	P_u	$\lvert F_u * 100 - P_u \rvert$
$\mho_1$	0.0851	5	5	10	20	10	10	10.0	1.4948
$\mho_2$	0.1636	15	10	10	20	18	15	14.6667	1.6939
$\mho_3$	0.1457	20	10	10	20	15	15	15.0	0.4310
$\mho_4$	0.1149	5	5	10	10	7	15	8.6667	2.8245
$\mho_5$	0.2778	40	35	35	20	20	20	28.3333	0.5538
$\mho_6$	0.2129	15	35	25	10	30	25	23.3333	2.0388

5.2. Alternatives Ranking

Steps 2-1. To evaluate the contribution levels of experts, the expertise levels of experts were evaluated according to Table C1. LVs and PFSs corresponding to the expertise levels of the experts are provided in Table 6.

Step 2-2. To derive precise values, the score functions outlined in Eq. (C1) are evaluated. The computed values of the score functions are recorded in Table 6.

Table 6: Significance levels by the panel of experts alongside the values obtained from the score functions.

Experts	***LVs***	***PFSs***	$\mathbb{S}(\daleth_v)$
$\daleth_1$	MI	(0.260, 0.260, 0.260)	0.5800
$\daleth_2$	I	(0.600, 0.260, 0.260)	0.8433
$\daleth_3$	I	(0.600, 0.260, 0.260)	0.8433
$\daleth_4$	VI	(0.700, 0.010, 0.010)	0.8933
$\daleth_5$	MI	(0.260, 0.260, 0.260)	0.5800
$\daleth_6$	VI	(0.700, 0.010, 0.010)	0.8933

Step 2-3. The computation of the weighting matrix for the experts ($\varpi = [\varpi_v]_{\mathcal{V}}$) was conducted utilizing Eq. (15) and is displayed in Table 7.

Table 7: The matrix illustrating the weights allocated by the experts.

Experts	$\daleth_1$	$\daleth_2$	$\daleth_3$	$\daleth_4$	$\daleth_5$	$\daleth_6$
ϖ_v	0.1252	0.1820	0.1820	0.1928	0.1252	0.1928

Step 2-4. Each expert conducted assessments of the alternatives according to the criteria utilizing the LVs outlined in Table C2. The evaluations made by the experts based on LVs are documented in Table D4. Subsequently, the LVs were converted into PF sets, resulting in the generation of initial decision matrices ($\tilde{\mathfrak{Q}}^{(\daleth_v)} = [\tilde{\mathfrak{Q}}_{tu}^{\daleth_v}]_{\mathcal{T}\times\mathcal{U}}$), presented in Table D5.

Step 2-5. The computation of the aggregated decision matrix ($\tilde{\mathfrak{Q}} = [\tilde{\mathfrak{Q}}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) was executed utilizing the PFWA operator, outlined in Eq. (C3), with the resulting matrix depicted in Table D6.

Step 2-6. The initial decision matrix for the criteria in its crisp form ($\mathfrak{Q} = [\mathfrak{Q}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) was derived by employing Eq. (C4), which incorporated the score functions ($\mathbb{S}(\tilde{\mathfrak{Q}}_{tu})$) .The resulting matrix is showcased in Table D7.

Step 2-7. By employing Eq. (17), the initial matrix for implementing the PF-ARLON method ($\mathfrak{T} = [\mathfrak{T}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) was computed (Table D8).

Step 2-8. Using Eq. (C6) and Eq. (C7), the first logarithmic normalization matrix ($\mathcal{N}^{1st} = [\mathcal{N}^{1st}{}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) and second logarithmic normalization matrix ($\mathcal{N}^{2nd} = [\mathcal{N}^{2nd}{}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) are calculated, and the results are provided in Table D9 and Table D10, respectively.

Step 2-9. The aggregated normalized decision matrix ($\mathcal{N}^{norm} = [\mathcal{N}^{norm}{}_{tu}]_{\mathcal{T}\times\mathcal{U}}$) was computed using the Heron Mean method (Eq. (C8)), with ($\xi = 0.5$) The results are elaborated in Table D11.

Step 2-10. By applying Eq. (C9), the calculation of the weighted aggregated normalization matrix ($\mathbb{W} = [\mathbb{W}_{tu}]_{\mathcal{T}\times\mathcal{U}}$)was conducted. The outcomes are furnished in Table D12.

Step 2-11. Through the utilization of Eq. (C10) and Eq. (C11), the computation of the cost-weighted aggregated normalized matrix ($\mathbb{W}^- = [\mathbb{W}_t^-]_{\mathcal{T}}$) and the benefit-weighted aggregated normalized matrix ($\mathbb{W}^+ = [\mathbb{W}_t^+]_{\mathcal{T}}$) were performed. The outcomes are presented in Table D13.

Step 2-12. Applying Eq. (C12), the conclusive ranking matrix for alternatives ($\Xi = [\Xi_t]_{\mathcal{T}}$) was computed with a ($\phi = 0.666$). The outcomes are presented in Table 8. Considering four benefit criteria out of a total of six, the k parameter is determined as 4 divided by 6, resulting in 0.666.

Table 8: The matrix indicating the rankings assigned to the alternatives ($\Xi = [\Xi_t]_{\mathcal{T}}$).

Alternative	$\wp_1$	$\wp_2$	$\wp_3$	$\wp_4$	$\wp_5$
Ξ_t	0.77130	0.76875	0.76647	0.77132	0.76773
Ranks	2	3	5	1	4

5.3. Sensitivity Analysis

To reinforce the robustness of the findings concerning the evaluation of alternatives using the PF-ARLON integrated model, two sensitivity analysis scenarios (SAS) were formulated. The SAS scenarios identified are outlined as follows:

- *SAS-1*: Observe the changes in alternative rankings when the last-ranked alternative is removed, and this process is repeated continuously.
- *SAS-2*: When different values within the range of 0-1 are assigned to parameter, how do alterations occur in alternative rankings?

The outcomes derived from executing each of the aforementioned scenarios are outlined as follows:

- The alternative rankings for SAS-1 are depicted in Table 9. An intriguing result here is that when the third and fifth alternative decisions are excluded from the model, the best alternative changes, with criterion $\wp_1$ becoming the most favorable.

Table 9: The alternatives ranking for SAS-1.

SAS-1	***Ranks***	***The best alternatives***	***The worst alternatives***
Research results	$\wp_4 > \wp_1 > \wp_2 > \wp_5 > \wp_3$	$\wp_4$	$\wp_3$
Removed $\wp_3$	$\wp_4 > \wp_1 > \wp_2 > \wp_5$	$\wp_4$	$\wp_5$
Removed $\wp_5$	$\wp_1 > \wp_4 > \wp_2$	$\wp_1$	$\wp_2$
Removed $\wp_2$	$\wp_1 > \wp_4$	$\wp_1$	$\wp_4$

- ·In SAS-2, different values were assigned to the parameter ξ. No variations were observed in the obtained alternative rankings. Alternative rankings are presented in Figure 2.

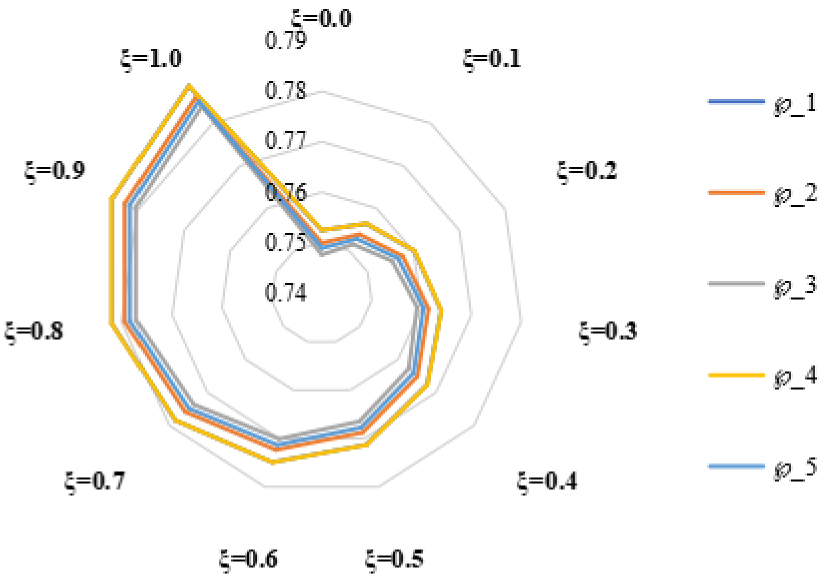

Figure 2: Alternative rankings for SAS-2.

5.4. Comparative Analysis

The findings obtained through the application of the PF-ARLON integrated method were supported by sensitivity analyses, demonstrating the robustness of the results. In comparing the outcomes of alternative ranking generated by the PF-ARLON method with those of other methods, various comparative analyses were conducted. Five different alternative ranking methods (ARTASI, MABAC, RAM, SAW, and TOPSIS) were employed to calculate alternative ranking values, which were then compared. The comparisons between these methods and the PF-ARLON method are outlined as follows:

- The ARTASI method involves standardizing the initial matrix, calculating the utility degrees of alternatives with respect to ideal and anti-ideal values, and subsequently deriving the final alternative ranking value by combining the utility degrees of alternatives. In contrast, the PF-ARLON method demonstrates alternative ranking values based on a two-step logarithmic normalization process.

- The MABAC method subjects the initial matrix to a single-step normalization process, computes the border approximation area, and determines alternative ranking values based on the distances of alternatives to this area. On the other hand, the PF-ARLON method utilizes a two-step logarithmic normalization process and calculates alternative ranking values based on weighted normalization value totals.

- The RAM method normalizes the initial decision matrix in a single step, weights it, and then calculates the ranking values of alternatives by summing the normalized values separately for cost and benefit criteria. In contrast, the PF-ARLON method employs a two-step logarithmic normalization process to calculate weighted normalization values. Subsequently, it computes the ranking values of alternatives based on whether the criteria are considered cost or benefit.

- The SAW method, after linear normalization, weighs the normalized decision matrix and computes the final alternative ranking values by summing the weighted values. Conversely, the PF-ARLON method normalizes the decision matrix after two different logarithmic normalization processes, weights it, and then determines the final alternative ranking values based on the evaluation of criteria as either cost or benefit.

- The TOPSIS method identifies ideal and anti-ideal alternatives in the normalized and weighted decision matrix. It then calculates positive and negative ideal distances through Euclidean distance calculations and determines alternative ranking values based on total proximity scores. In contrast, the PF-ARLON method considers the cost and benefit statuses of criteria to determine final alternative ranking values.

The calculations based on the initial decision matrix used in this research yielded results for each of the methods. The alternative ranking values are depicted in Figure 3, while the alternative ranking obtained are presented in Table 10.

According to these results, the alternative ranking results of the PF-ARLON method were found to be completely consistent with those of the RAM, SAW, and TOPSIS methods. However, discrepancies were observed in the rankings generated by the ARTASI and MABAC methods, particularly regarding the third and fourth alternative rankings in the PF-ARLON rankings. Thus, the comparative analysis results support the consistency of the PF-ARLON method with other alternative ranking methods.

Figure 3: Comparative analysis.

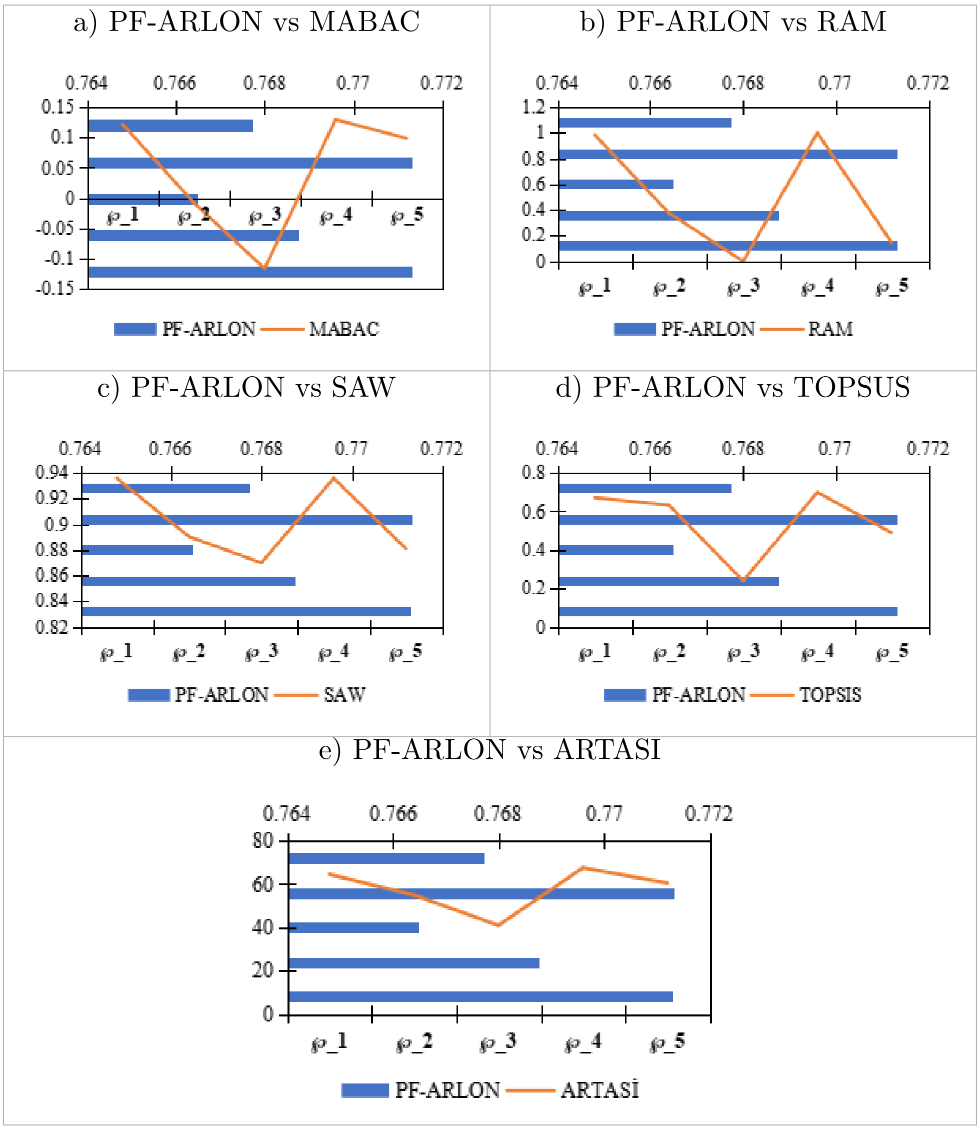

Table 10: Results of comparative analysis.

Methods	*Ranks*	*The best alternatives*	*The worst alternatives*
PF-ARLON	$\wp_4 > \wp_1 > \wp_2 > \wp_5 > \wp_3$	$\wp_4$	$\wp_3$
ARTASI	$\wp_4 > \wp_1 > \wp_5 > \wp_2 > \wp_3$	$\wp_4$	$\wp_3$
MABAC	$\wp_4 > \wp_1 > \wp_5 > \wp_5 > \wp_3$	$\wp_4$	$\wp_3$
SAW	$\wp_4 > \wp_1 > \wp_2 > \wp_5 > \wp_3$	$\wp_4$	$\wp_3$
RAM	$\wp_4 > \wp_1 > \wp_2 > \wp_5 > \wp_3$	$\wp_4$	$\wp_3$

6. Findings and Discussion

Drawing from previous research and expert opinions, it is evident that several challenges are obstructing the sustainable development of TM in Kenya. Three primary challenges were identified as potential threats to its sustainability. To gauge the importance of these challenges, a FullEX approach was employed to determine criterion weights.

The results highlight the most critical challenge as "unsubstantiated claims regarding the safety, effectiveness, and quality of TM products" ($\mho_5$), with a weight of 0.2778. This finding is consistent with Mssusa et al. [81], who noted the absence of reliable data on TM, leading to risks such as wastage of resources and potential harm from consuming unsafe substances. Adulteration compounds this challenge. Additionally, there are concerns about the competency of TM practitioners, with a growing number falsely advertising miraculous cures. The market is also saturated with unqualified practitioners and traders, exacerbating the problem. Additionally, van Wyk & Prinsloo [82] observed that most medicinal plants were gathered from the wild, where factors both within and outside the plants could cause variations in the levels of active compounds. Inadequate aggregations of these compounds can affect the effectiveness and safety of the medicines. Additionally, plants generate substances to protect themselves, some of which may be harmful to humans. Contaminants from natural or human sources can also compromise the quality of TM, leading to adverse effects and even death.

Addressing TM's safety, efficacy, and quality-related issues requires a comprehensive approach involving various stakeholders. Firstly, implementing and enforcing strict regulatory frameworks is crucial to ensure that claims are backed by scientific evidence. Secondly, educating the public about the risks of using TM without evidence and promoting seeking advice from qualified healthcare professionals is vital. Thirdly, establishing quality control measures to ensure products meet safety and efficacy standards, including testing for contaminants, is important. Fourthly, developing and enforcing professional standards for practitioners, including training and certification requirements, can ensure quality care. Fifthly, empowering consumers to make informed decisions by providing accurate information and labeling requirements is key. Lastly, regularly monitoring and evaluating regulations to address unsubstantiated claims is crucial for the safe use of TM.

"Irrational use of herbal medicine and lack of a national policy and regulatory framework" ($\mho_6$) is considered as the second most critical issue. According to Demeke et al. [83], several African countries, including Ethiopia, did not implement rational approaches to herbal medicine or establish clear policies and laws that could form the basis for an independent regulatory framework. Additionally, a significant number of respondents in an institution-based survey indicated the absence of defined policies, laws, or registration systems for herbal medicine. Addressing this issue therefore requires from one side, the development of a comprehensive national policy on herbal medicine essential to outline guidelines for its rational use, regulation, and integration into the healthcare system, and from another side, the implementation and enforcement of a regulatory framework for herbal medicine that includes standards for quality, safety, and efficacy, as well as registration and licensing requirements.

The third major challenge is the "inadequate conservation of medicinal plants and indigenous knowledge" ($\mho_2$). Chen et al. [64] found that this was due to habitat demolition, unprofessional harvesting, malfunction in traditional controls, unspecified land use rights, competition with other crops, profit-driven actions disregarding taboos, and the absence of data on plant populations. Addressing this issue requires a multifaceted approach. This includes protecting natural habitats where these plants grow, implementing sustainable harvesting practices, involving local communities in conservation efforts, and educating the public about the importance of conservation. Research and documentation of traditional knowledge and biodiversity are crucial, as is establishing legal frameworks to protect these resources. Cultural revitalization efforts can help preserve traditional practices, while collaboration among stakeholders is essential for developing and implementing effective conservation strategies.

The results obtained from the novel integrated FullEX-PF-ARLON method indicate that the most appropriate alternative is the "validation of the safety, efficacy, and quality" ($\wp_4$). Achieving this requires several key steps. First, a robust regulatory framework must be established and enforced to govern the production, labeling, and advertising of these products. Quality control measures should be implemented to monitor production processes and test for contaminants. Additionally, investing in research to evaluate the safety and efficacy of TM products and develop quality standards is essential. Education and training programs should be provided for TM practitioners to ensure they adhere to best practices and safety guidelines. Collaboration between practitioners, healthcare professionals, researchers, and regulatory authorities is crucial for knowledge sharing and best practice dissemination. Consumer awareness campaigns can help educate the public about the responsible use of TM and how to identify quality products. Establishing monitoring and evaluation systems will help assess the safety, efficacy, and quality of TM products on the market. Finally, integrating TM practices into the national healthcare system will ensure their safe and effective use alongside modern medicine.

"Campaigns to highlight the positive aspects of TM" ($\wp_1$) is the second most appropriate strategy for sustainable TM development. These campaigns can raise awareness among the public, healthcare professionals, and policymakers about the benefits of TM, leading to greater acceptance and utilization of these practices. Furthermore, such efforts can help preserve indigenous knowledge and practices that are at risk of being lost. By promoting the integration of TM into the mainstream healthcare system, campaigns can encourage more holistic and patient-centered care. Sustainable development of TM can also create economic opportunities for local communities, including TM practitioners and herbalists. Additionally, TM can help improve access to healthcare, especially in rural and underserved areas where conventional healthcare services may be limited. Promoting TM can also help preserve cultural identity and heritage, contributing to a sense of pride and identity among communities. Moreover, increased awareness can lead to more research and innovation in TM, resulting in the development of new treatments and practices. Lastly, campaigns can promote sustainable harvesting practices and the conservation of medicinal plants, contributing to environmental conservation efforts.

7. Policy implications

Based on the findings of the study, some policy priorities in the healthcare sector have been presented. First, an accurate regulatory framework should be adopted to direct the quality, safety, and effectiveness of TM products. Next, the rational utilization of herbal medicine and its integration within the formal healthcare system should be guided through the necessity of an extensive national TM policy. Then, protecting indigenous knowledge and conserving medicinal plants through community-based programs, habitat protection, and durable harvesting should be promoted. Finally, the TM practices should be validated through national awareness campaigns, practitioner training, and investment in research to increase public trust, and assist their effective and adequate integration into modern healthcare.

8. Conclusion

This study proposed a new integrated MCM approach to solve the challenge of selecting the most appropriate alternative for sustainable TM development in Kenya. While, unverified claims about TM product safety and efficacy, improper herbal medicine use due to the absence of a national policy and regulatory framework, and inadequate preservation of medicinal plants and indigenous knowledge are considered as the top three critical challenges to sustainable TM development, validating the safety, efficacy, and quality of medicinal plants and their products, as well as promoting the benefits of TM through focused campaigns are the most effective strategies to overcome these challenges.

Our study, while making significant impacts, is constrained by certain limitations. Firstly, our focus on a single country (Kenya), will unavoidably diminishes the extent to which the findings can be generalized, as socio-economic circumstances, policy contexts, and institutional arrangements often differ considerably across regions. Likewise, relying on only six experts, while important for producing detailed insights, restricts the variation of perspectives and raises the risks of bias in the weighting and ranking procedure. For these reasons, the current findings should be considered as exploratory rather than conclusive. To overcome these limitations, the scope should be expanded by including experts from various countries and regions to apprehend a larger range of contextual realities. The increase in the number and diversity of experts involved would also improve the representativeness and robustness of the results, offering powerful grounds for generalization and permitting significant cross-country comparisons. Additionally, the ARLON technique we employed has a limitation stemming from its assumption of equal impact degrees for both stages of the two-stage logarithmic normalization process during aggregation. This limitation could be mitigated through further complete studies and experimental research. Furthermore, our use of the FullEx approach has two constraints. Firstly, the results from its application may vary based on the distinctions of experts in various domains. Secondly, it is limited to crisp values. To address these limitations, future research should aim to incorporate the uncertain environment and extend the scope of analysis.

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