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ASSESSMENT OF ERGONOMIC RISK FACTORS FOR SUSTAINABLE AGRICULTURAL PRACTICES BASED ON PICTURE FUZZY LODECI-ARTASI APPROACH

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ABSTRACT

The implementation of proactive risk management from an occupational health and safety (OHS) perspective is of paramount importance in ensuring sustainable production and enhancing work efficiency among employees. This paper aims to develop an innovative occupational health and safety risk assessment (OHSRA) model for workers exposed to ergonomic risks during agricultural harvesting operations. The approach to achieving this objective is through the implementation and validation of two innovative methodologies: the LOgarithmic DEcomposition Of Criteria Importance (LODECI) and Alternative Ranking Technique based on Adaptive Standardized Intervals (ARTASI) methods. This study utilized an integrated approach, incorporating LODECI's weighting method and ARTASI's prioritization technique, based on picture fuzzy sets which employs Fine-Kinney risk parameters, to prioritize ergonomic risk factors affecting work-related musculoskeletal disorders (WMSDs). The validation of the proposed model is conducted through a sensitivity and comparative analysis. The research findings indicated that the five most significant hazards in harvesting operations are ERH_{11} (Land of harvesting area), ERH_{2} (Repetitive motion), ERH_{4} (Standing for a long time), ERH_{12} (Work stress) and ERH_{9} (Unsuitable climatic conditions), respectively. In finally concluding the paper, discussion is provided of potential future research directions.

Keywords: ARTASI, Ergonomic risk assessment, LODECI, Picture fuzzy sets, Sustainable agriculture, Work-related musculoskeletal disorders.

ABBREVIATIONS AND NOMENCLATURE

ARTASI	Alternative Ranking Technique based on Adaptive Standardized Intervals	$\widetilde{\mathfrak{R}}$	Initial decision risk matrix
LODECI	LOgarithmic DEcomposition Of Criteria Importance	$\mathbb{D}_{ij}$	Decomposition value
PFS	Picture fuzzy sets	$\mathbb{L}_j$	Logarithmic decomposition value
WMSDs	Work-related musculoskeletal disorders	$\mathbb{V}_{ij}^{+}$	The degree of usefulness of the ideal value
FST	Fuzzy Set Theory	$\mathbb{V}_{ij}^{-}$	The degree of usefulness of the anti-ideal value
OHSRA	Occupational Health and Safety Risk Assessment	P_i^{+}	The aggregate degree of utility for the ideal value
PFWA	Picture Fuzzy Weighted Averaging	P_i^{-}	The aggregate degree of utility for the anti-ideal value
IFS	Intuitionistic Fuzzy Sets	$\mathbb{F}_i$	The final utility functions value
OHS	Occupational Health and Safety	P	Probability
MCDM	Multi-Criteria Decision-Making	E	Exposure
PFNs	Picture fuzzy numbers	C	Consequence

1 INTRODUCTION

The OHSRA process is a proactive approach aimed at safeguarding workers' health and safety by preventing work-related accidents and occupational diseases caused by hazards in the workplace. The identification and evaluation of the major work-related hazards for the implementation of preventive measures constitutes a critical activity within the framework of the OHSRA [1]. The standard risk management process is comprised of four major phases: (i) the hazard determination, (ii) the classification of risk, (iii) the risk control measures implementation, and (iv) the regular review and monitoring of the implementation of the control measures [2].

Globally, musculoskeletal disorders impact a reported 1.71 billion people [3]. The prevalence of musculoskeletal pain in the world's working population is between 50% and 80% [4]. The aetiology of WMSDs is multifactorial, involving biomechanical, socio-demographic, managerial, and psychosocial risk aspects [5]. WMSDs are associated with a number of ergonomic risk factors, including non-neutral body postures, vibration, repetitive movements and heavy physical exertion [6]. The frequent occurrence of WMSDs has a significant impact on workers' productivity [7].

The prevalence of occupational hazards inherent in agricultural activities underscores the necessity for a comprehensive examination of their occupational health and safety implications for agricultural workers. Biomechanical and physical factors, such as noise and vibration from the equipment they use in their daily work, expose agricultural workers to the risk of WMSDs [8]. The repetitive nature of the work involved in the harvesting process is liable to induce fatigue in muscles, joints and nerves, and to cause WMSDs [9]. WMSDs are a category of occupational injury that may develop over time and are prevalent among agricultural workers [10]. The three main hazard factors for WMSDs in agriculture have been identified as: lifting and carrying heavy loads (more than 50 lb); continuous or repeated whole-body bending (stooping); and high levels of repetitive manual activity (e.g. clipping, cutting) [11, 12]. Furthermore, awkward postures, vibration-generating tools or equipment, cold working environments and locations of pressure are identified as ergonomic risk factors [13]. The literature's emphasis on the correlation between low job satisfaction and neck and back pain in agricultural workers, thereby suggesting the potential significance of psychosocial variables in the aetiology of musculoskeletal issues [14].

Conventionally, methodologies for conducting ergonomic risk assessments are based on observational techniques for the evaluation of workers' body posture [15]. Rapid Entire Body Assessment (REBA) [16, 17], Rapid Upper Limb Assessment (RULA) [18, 19], Ovako Working Posture Analysing System [20], Quick Exposure Check (QEC) [21], Occupational Repetitive Action (OCRA) [22], Loading on the upper body assessment (LUBA) [23].

The capacity of conventional methodologies for the assessment of ergonomic risks to address the multifaceted nature of risk factors which contribute to the occurrence of WMSDs in the field of agriculture is limited. These risk factors are complex and uncertain in nature and encompass physical, biomechanical, environmental, organizational, psychosocial, and demographic factors. A comprehensive assessment is required to fully determine their impact. In recent years, fuzzy multi-criteria decision-making (MCDM) studies have been conducted in the field of ergonomic risk assessment [24, 25, 26, 27]. The utilization of MCDM methodologies is recognized as a highly effective approach in scenarios where the decision-making process is characterised by a high degree of uncertainty. This research adopted the MCDM approach for the development of an innovative decision support model (DSM) within the scope of ergonomic risk assessment. In this study, Picture fuzzy sets (PFS) introduced by Cuong and Kreinovich [28] as an extension of intuitionistic fuzzy sets (IFS) [29] due to their advantages in expert evaluations.

Hazard analysis, when considered as a part of the risk assessment process, can be interpreted as a group decision-making procedure [30]. The Fine-Kinney technique is a quantitatively based methodology for the analysis of hazards [31]. In the original version of the Fine–Kinney methodology, the computation of risk value (RV) is achieved through the utilization of the following formula: $RV = P \times E \times C$, where P, E, and C represent probability, exposure, and consequence, respectively [32]. Nevertheless, the conventional Fine-Kinney technique is subject to limitations in practical application [30, 33, 34]: The first limitation pertains to the equal importance attributed to the effects represented by the risk parameters P, E, and C. However, it is important to note that these parameters may be evaluated differently in real-life scenarios. Secondly, defining the values of P, E and C with crisp numbers can cause significant challenges in practical application. Thirdly, the capacity to comprehensively address the various categories of uncertainty inherent in the information presented in the risk assessment provided by the expert is insufficient.

The present study proposes an MCDM approach, integrating PFS to develop a dynamic model for providing decision support in the context of risk assessment in relation to ergonomic factors. To address the shortcomings of the traditional Fine-Kinney approach concerning the expression of data pertaining to uncertain risk assessment, the utilization of PFS has been proposed in order to facilitate the description of such uncertainties. In the context of the MCDM framework, the utilization of PFS-LODECI-ARTASI, a hybrid model, is proposed for the purpose of evaluating the ergonomic risk priority. The LOgarithmic DEcomposition Of Criteria Importance (LODECI) [35] theoretical framework, which is based on PFS, is utilized to calculate weights for risk parameters P, E and C. The Alternative Ranking Technique based on Adaptive Standardized Intervals (ARTASI) [36] method is utilized in combination with PFS for the purpose of ranking hazards. Therefore, this study aims to provide a robust decision-support framework for related to ergonomic risk assessment by proposing a Fine-Kinney-based PFS-LODECI-ARTASI hybrid model.

The objective of this research is to devise a hybrid MCDM approach to prioritize hazards due to ergonomic risk factors that may affect WMSDs in harvesting operations carried out by agricultural workers. Whilst preceding studies in the relevant literature have, as a general rule, addressed the ergonomic risk assessment process by means of observational and statistical techniques, the present study aims to develop this research by using recently established techniques and emphasising the benefits of these techniques. The main focal point of this study is the introduction of a hybrid model for the ergonomic risk assessment framework, distinguished by the construction an algorithm that is specifically designed to this hybrid model. PFS are utilized in this hybrid model, along with Picture Fuzzy Weighted Averaging (PFWA) aggregation operator. The LODECI method is the preferred option for Fine-Kinney risk parameter weighting due to the efficiency with which it overcomes the instability that can be present in alternative methods of criterion weighting. In the context of hazard ranking, the ARTASI approach is preferred due to its two-step standardization procedure, which has been demonstrated to yield more effective results. The combination of these three methodological approaches with PFS results in the development of the Fine-Kinney-based PFS-LODECI-ARTASI (FK-PFLODAR) approach.

This paper makes significant contributions to the extant knowledge base on the following topics:

(i) *Construction of a Pioneering Ergonomic Risk Assessment Framework*: The paper proposes a pioneering ergonomic risk assessment framework, the FK-PFLODAR approach, for the ergonomic risk assessment process. The model integrates picture fuzzy sets, PFWA aggregation operations, Fine-Kinney, LODECI, and ARTASI methods, providing a new methodology within the existing literature.

(ii) *Harmonized Weighting of Criteria*: The LODECI approach is selected on the basis of its ability to stabilize situations that may be unstable in alternative approaches, thus rendering it an optimal choice for weighting risk parameters in the proposed model. This contributes to enhancing the model's robustness.

(iii) *Flexibly Designed Alternate Rating System*: The ARTASI approach in hazard ranking enables the extension of levels of uncertainty in the assessments of experts, thereby facilitating the development of more adaptable and flexible resolutions in the ergonomic risk assessment procedure.

1.1 The impetus of the study

Risk management is a process that involves evaluating the potential hazards and their associated risks, while also assessing the efficacy of preventive measures in order to determine the degree of acceptability of the risks [37]. The processing of information obtained from experts' experience and knowledge during the risk assessment process is a complex cognitive task [38]. As previously discussed, to overcome the limitations of the Fine-Kinney model and address uncertain information in risk assessment more comprehensively, a hybrid framework combining picture fuzzy modeling is proposed. Despite the study's primary orientation towards application and the lack of a conventional hypothesis testing framework, it is underpinned by a fundamental research question: The fundamental research question guiding this study is as follows: "Can integrating picture fuzzy MCDM methods into the Fine-Kinney process enhance the effectiveness, reliability, and adaptability of risk assessment practices in agricultural harvesting fields?" The exploration of this subject is of significance to both the advancement of academic knowledge and the practical endeavours aimed at enhancing safety in agricultural workplaces. The investigation provides valuable insights into the systematic integration of uncertainty into risk management methodologies.

1.2 The architecture of the study

This research is articulated into seven sections. Section 2 provides a comprehensive survey of the related literature. Section 3 presents a comprehensive overview of the methodological framework, within which detailed descriptions of PFS are provided. The FK-PFLODAR model is formulated in this section, including a detailed explanation of all the steps, and an algorithm is presented. In Section 4, a case study is conducted and information regarding the case study is provided. Thereafter, the implementation of the FK-PFLODAR model is demonstrated. Section 5 presents the validation results of the sensitivity analysis and comparative analysis. Section 6 of the paper discusses the managerial implications of the proposed risk assessment model, and the limitations of the research, and provides directions for future research. Finally, Section 7 concludes the paper.

2 LITERATURE SURVEY

2.1 Researchs on Ergonomic Risk Assessment

Non-ergonomic working conditions have been highlighted as a significant problem for employees in terms of occupational health and safety. The pervasiveness of musculoskeletal disorders (MSDs) within working environments constitutes a substantial problem [39]. In a multitude of developed countries, a considerable proportion of upper extremity and low back pain cases are attributable to identified risk factors, including physical exertion, repetitive motions, and prolonged exposure to awkward body postures [40]. In view of the significant economic and social costs of work-related musculoskeletal disorders (WMSDs), it is essential to identify the contributors to these injuries so that efficacious preventative measures can be formulated and executed [41]. Consequently, a plethora of WMSD exposure and risk assessment methodologies have been formulated.

Law et al. [42] employed the Rapid Entire Body Assessment (REBA) method to evaluate the potential for WMSDs in the healthcare sector during patient transfers. Ipaki et al.

[43] applied the Quick Exposure Check (QEC) method for the evaluation of physical and virtual prototype in the workstation design process. Cimino et al. [44] proposed a risk assessment framework that combines ergonomic methods with the Analytic Hierarchy Process (AHP) for lashing and unlashing operations at container terminals. De-Benavides-Jiménez et al. [45] utilized the Ovako Working Posture Analysing System (OWAS) and Rapid Upper Limb Assessment (RULA) methodologies due to the risk of WMSDs that agricultural workers are susceptible to as a consequence of forceful postures and repetitive motions.

2.2 PFS

The OHSRA can be considered as a subject within the MCDM paradigm, characterized by a fuzzy and complex framework, a consequence of factors such as uncertainty and inaccuracy in the evaluative processes of decision makers with regard to criteria and alternatives. It can thus be concluded that a fuzzy occupational risk assessment is a rational instrument for addressing uncertainty and imprecision in traditional occupational risk assessment approaches. Since Zadeh's pioneering work in 1965 [46], fuzzy set theory (FST) has been instrumental in resolving decision-making challenges in uncertain situations. Within the framework of Zadeh's FST, the degree of membership of each element of a fuzzy set is characterised by a membership function, which is delineated as a value ranging from 0 to 1. Subsequently, a plethora of extensions of fuzzy sets are discussed, with the purpose of dealing with uncertain information in real-life problems. Atanassov [29] proposed the intuitionistic fuzzy sets approach. IFSs have been applied to deal with the limitations of the fuzzy set by characterizing uncertainty in terms of degrees of membership, non-membership and hesitancy. In 2013, Cuong and Kreinovich [28] presented a proposal for a PFS that extended the IFS. The PFS is characterised by four distinct membership functions: positive membership, neutral membership, negative membership, and a refusal function. It is evident that the PFS provides a more comprehensive and meticulous account of information in comparison to the IFS. Consequently, numerous MCDM methodologies grounded in picture fuzzy sets have been devised to address decision-making challenges in contexts characterised by ambiguity and complexity: picture fuzzy Weighted Aggregated Sum Product Assessment (WASPAS) [47], picture fuzzy Measurement of Alternative and Ranking According to the Compromise Solution (MARCOS) [48], picture fuzzy Combined Compromise Solution (CoCoSo) [49], etc.

2.3 OHSRA Approaches Modelled on the Fine-Kinney Methodology

The assessment of occupational risks and the establishment of task priorities are of the utmost importance in the context of OHS management and the proactive prevention of potential hazards [34]. The Fine-Kinney model proposed by Kinney and Wiruth [50], provides a quantitative and comprehensive tool for the rating and control of risk within the OHSRA process. The assessment of risks is based on a combination of empirical observation and expert judgment in applying this model. This results in the risk assessment process being more complex, given that it inherently involves uncertain information. Consequently, to address the aforementioned limitations and uncertainties in evaluation, the researchers incorporated fuzzy sets into their proposed Fine-Kinney-based models. Gul et al. [51] used triangular fuzzy numbers (TrFNs) to represent the decision-makers' uncertainty regarding risk assessment. Ilbahar et al. [52] employed Pythagorean fuzzy set (PyFS) to address uncertainty and imprecision in the evaluation of occupational risks. Tang et al. [53] utilized interval-type 2 fuzzy set (IT2FS) to formulate uncertain risk values from various decision-makers. Seker [54] used interval-valued intuitionistic fuzzy set (IVIFS) to address uncertainty within the context of risk evaluation. Wang et al. [33] constructed a model based on Fermatean fuzzy set (FFS) with a view to processing uncertainty in risk assessment information provided by decision-makers with higher efficiency. Chen et al. [55] employed spherical fuzzy set (SFS) to manage the risk data provided by experts.

Within the framework of an OHS risk management strategy, it is critical for the decision-making procedure to consider multiple factors in order to ensure a comprehensive and effective evaluation of the situation. Risk prioritization is widely acknowledged as an MCDM problem. Therefore, in the OHSRA process, researchers implemented MCDM approaches with Fine-Kinney model. Wang et al. [30] developed a novel Fine-Kinney-based approach to risk evaluation, extending the MULTIMOORA (Multiple Multi-Objective Optimization by Ration Analysis) technique to determine the risk priority of hazards. Wang et al. [56] developed an interval 2-tuple linguistic ORESTE method-based risk priority computation model to improve the effectiveness of the Fine-Kinney procedure. Wang et al. [33] proposed a model for the assessment of occupational risk that is a hybrid model based on Fine–Kinney approach. The model utilizes an extended MARCOS (Measurement of Alternatives and Ranking to Compromise Solution) methodology. Chen et al. [55] proposed an approach to risk assessment that utilized an improved MABAC (Multi-Attributive Border Approximation Area Comparison) technique applied based on the Fine-Kinney framework.

2.4 Research Gaps

According to the above discussion, existing ergonomic risk assessment methods comprise processes based on observational techniques. The utilization of observational methods is inherently associated with the necessity for time-consuming and costly risk assessment procedures. Nonetheless, conventional observational ergonomic risk assessment methodologies predominantly concentrate on the analysis of workers' posture or movements. In addition to the acknowledged role physical factors, psychosocial factors and individual factors have been identified as contributing factors in the occurrence of WMSDs. In this context, there is a literature gap for ergonomic risk assessment that incorporates quantitatively and qualitatively determined factors in the risk decision-making process. Consequently, the most significant gap in the extant literature pertains to the absence of a holistic approach in ergonomic risk assessment frameworks.

In comparison to other industries, there has been a limited implementation of research on OHS risk assessment practices for the agricultural sector. Within the field of agricultural operations, the prevalence of WMSDs among workers is a salient issue, yet numerous studies have conspicuously failed to adequately address this salient issue. Therefore, this study highlights the literature gap in the need to develop preventive policies and increase these options for the affected agricultural workforce in relation to ergonomic issues.

Within the framework of conventional Fine-Kinney risk evaluation methodologies, the outcomes of risk scoring results may not always be rational due to the incapacity of decision makers to address uncertainty in their assessment. In this context, the capacity of PFSs to articulate uncertainty more comprehensively is advantageous for OHSRA.

In consideration of the aforementioned motivations, the paper posits a model of a hybrid picture fuzzy-based MCDM approach on the basis of Fine-Kinney that takes into account the uncertainties in decision-makers' judgments and can be an alternative to occupational ergonomic risk assessment tools.

In this research, the MCDM approach is adopted to construct an enhanced occupational risk assessment. Furthermore, due to their linguistic underpinnings, fuzzy sets are considered more suitable for utilization in expert evaluations. The OHSRA process is characterized by a substantial number of uncertain variables, which renders PFS a rational instrument with which to adequately represent DMs' fuzzy preferences. The weighting of risk parameters is enhanced by extending the LODECI method using PFS. The innovative PFS-LODECI approach offers the distinct advantage of computing the levels of stability of the risk parameter weights derived during the parameter weighted process. The ARTASI method is employed in combination via PFS for the purpose of ranking hazards. The proposed PFS-ARTASI approach is advantageous in that it offers a two-step standadization option derived from absolute maximum and minimum values. Therefore, this study proposes the utilization of the FK-PFLODAR approach to provide DSM for the problem of ergonomic risk assessment on the basis of MCDM.

3 METHODOLOGY

3.1 Preliminaries of PFS

PFS, an extension of IFS introduced by Cuong and Kreinovich [28], are widely utilized to address uncertainty in real-world problems. The following section provides a definition of PFS, along with a description of the relevant operations [28, 57, 58]:

Definition I: A PFS $\tilde{\mathfrak{P}}$ on a universe U is given by;

$$\tilde{\mathfrak{P}} = \left\{\left(\mathrm{u}, \mathfrak{a}_{\tilde{\mathfrak{P}}}(\mathrm{u}), \mathfrak{b}_{\tilde{\mathfrak{P}}}(\mathrm{u}), \mathfrak{c}_{\tilde{\mathfrak{P}}}(\mathrm{u})\right) | \mathrm{u} \in \mathrm{U}\right\} \tag{1}$$

where $\mathfrak{a}_{\tilde{\mathfrak{P}}}(u), \mathfrak{b}_{\tilde{\mathfrak{P}}}(u), \mathfrak{c}_{\tilde{\mathfrak{P}}}(u)$: $\mathrm{U} \rightarrow [0,1]$ is positive membership, neutral membership, and negative membership in the set $\tilde{\mathfrak{P}}$ respectively, with $0 \leq \mathfrak{a}_{\tilde{\mathfrak{P}}}(\mathrm{u}) + \mathfrak{b}_{\tilde{\mathfrak{P}}}(\mathrm{u}) + \mathfrak{c}_{\tilde{\mathfrak{P}}}(\mathrm{u}) \leq 1, \forall \mathrm{u} \in \mathrm{U}$.

For the set $\tilde{\mathfrak{P}}$, $\lambda_{\tilde{\mathfrak{P}}}(u) = 1 - (\mathfrak{a}_{\tilde{\mathfrak{P}}}(u) + \mathfrak{b}_{\tilde{\mathfrak{P}}}(u) + \mathfrak{c}_{\tilde{\mathfrak{P}}}(u))$ is referred as the refusal function in $\tilde{\mathfrak{P}}$.

Definition II: Mathematical operations for single-valued picture fuzzy sets are defined as follows [59];

$$\tilde{\mathfrak{P}}_1 \oplus \tilde{\mathfrak{P}}_2 = \left\{\mathfrak{a}_{\tilde{\mathfrak{P}}_1} + \mathfrak{a}_{\tilde{\mathfrak{P}}_2} - \mathfrak{a}_{\tilde{\mathfrak{P}}_1}\mathfrak{a}_{\tilde{\mathfrak{P}}_2}, \mathfrak{b}_{\tilde{\mathfrak{P}}_1}\mathfrak{b}_{\tilde{\mathfrak{P}}_2}, \mathfrak{c}_{\tilde{\mathfrak{P}}_1}\mathfrak{c}_{\tilde{\mathfrak{P}}_2}\right\} \tag{2}$$

$$\tilde{\mathfrak{P}}_1 \otimes \tilde{\mathfrak{P}}_2 = \left\{\mathfrak{a}_{\tilde{\mathfrak{P}}_1}\mathfrak{a}_{\tilde{\mathfrak{P}}_2}, \mathfrak{b}_{\tilde{\mathfrak{P}}_1} + \mathfrak{b}_{\tilde{\mathfrak{P}}_2} - \mathfrak{b}_{\tilde{\mathfrak{P}}_1}\mathfrak{b}_{\tilde{\mathfrak{P}}_2}, \mathfrak{c}_{\tilde{\mathfrak{P}}_1} + \mathfrak{c}_{\tilde{\mathfrak{P}}_2} - \mathfrak{c}_{\tilde{\mathfrak{P}}_1}\mathfrak{c}_{\tilde{\mathfrak{P}}_2}\right\} \tag{3}$$

$$\mathfrak{w}.\tilde{\mathfrak{P}}_1 = \left\{\left(1 - \left(1 - \mathfrak{a}_{\tilde{\mathfrak{P}}_1}\right)^{\mathfrak{w}}\right), \mathfrak{b}_{\tilde{\mathfrak{P}}_1}^{\mathfrak{w}}, \mathfrak{c}_{\tilde{\mathfrak{P}}_1}^{\mathfrak{w}}\right\} \quad \text{for } \mathfrak{w} > 0 \tag{4}$$

$$\tilde{\mathfrak{P}}_1{}^{\mathfrak{w}} = \left\{\mathfrak{a}_{\tilde{\mathfrak{P}}_1}^{\mathfrak{w}}, \left(1 - \left(1 - \mathfrak{b}_{\tilde{\mathfrak{P}}_1}\right)^{\mathfrak{w}}\right), \left(1 - \left(1 - \mathfrak{c}_{\tilde{\mathfrak{P}}_1}\right)^{\mathfrak{w}}\right)\right\} \quad \text{for } \mathfrak{w} > 0 \tag{5}$$

Definition III: The score function, denoted as $\mathbb{S}\mathbb{c}(\widetilde{\mathfrak{P}})$, can be calculated as follows [57];

$$\mathbb{S}\mathbb{c}(\widetilde{\mathfrak{P}}) = \mathfrak{a} - \mathfrak{c} + 1 + \frac{e^{\mathfrak{a}-\mathfrak{b}-\mathfrak{c}}}{1+\lambda}, \quad \mathbb{S}\mathbb{c}(\widetilde{\mathfrak{P}}) \in [e^{-1}, 2+e] \tag{6}$$

Definition IV: Picture Fuzzy Weighted Averaging (PFWA) aggregation operator. Concurrently, the relevant weight vector $w = (w_1, w_2, \dots, w_n)$; $w_j \in [0,1]$; $\sum_{j=1}^{n} w_j = 1$, is defined as follows [59];

$$\text{PFWA}_{w} = \left\{1 - \prod_{j=1}^{n}(1-\mathfrak{a}_{\widetilde{\mathfrak{P}}_j})^{w_j}, \prod_{j=1}^{n}\mathfrak{b}_{\widetilde{\mathfrak{P}}_j}^{w_j}, \prod_{j=1}^{n}\mathfrak{c}_{\widetilde{\mathfrak{P}}_j}^{w_j}\right\} \tag{7}$$

3.2 A Proposed Hybrid Ergonomic Risk Assessment Methodological Framework

This framework is comprised of two main phases. The first phase of this methodology details the utilization of PFS-LODECI for the weighting of Fine-Kinney risk parameters. In the subsequent phase, the procedures for ranking potential hazards related to WMSDs are performed utilizing PFS-ARTASI. Figure 1 provides a visualisation of the methodological framework underpinning the developed ergonomic risk assessment framework.

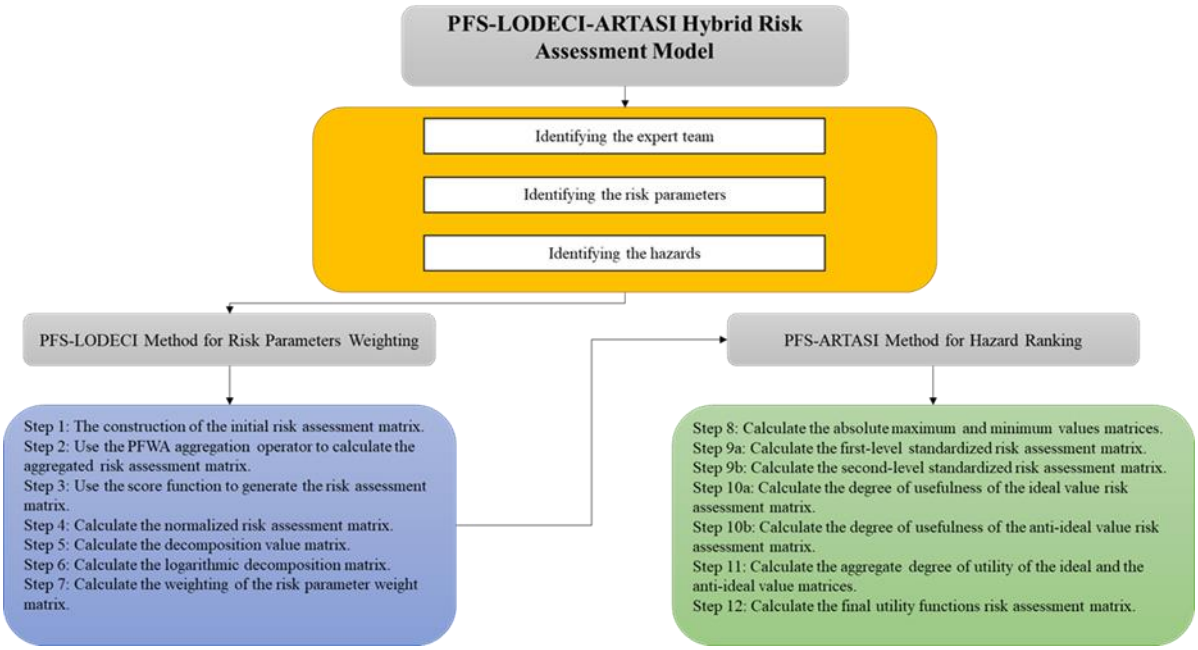

Figure 1. The flowchart of the methodological framework.

The problem of ergonomic risk assessment with picture fuzzy risk information is addressed by the FK-PFLODAR approach. Let $(ERH_i) = \{ERH_1, ERH_2, \dots, ERH_m\}(i = 1,2,\dots,m)$ be ergonomic hazards and n risk parameters $(RP_j) = \{RP_1, RP_2, \dots, RP_n\}(j = 1,2,\dots,n)$, and experts $(\mathbb{E}_k) = \{\mathbb{E}_1, \mathbb{E}_2, \dots, \mathbb{E}_q\}(k = 1,2,\dots,q)$ for the ergonomic risk assessment problem.

Phase 1. PFS-LODECI

The determination of the weighting of risk parameters by utilization of the PFS-LODECI method:

Step 1: The expert $(\mathbb{E}_k)$ evaluation of each ergonomic hazard (ERH_i) is conducted with reference to the linguistic terms (LTs) shown in Table 1, concerning each risk parameter (RP_j). Following the evaluation process, the LTs are converted into the matching PFSs, as outlined in Table 1, thereby establishing the initial risk assessment matrix $\left[\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}\right]_{mxn}$ where $\widetilde{\mathfrak{P}}_{\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}} =$

$$\left(\mathfrak{a}_{\widetilde{\mathfrak{P}}_{\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}}}(u), \mathfrak{b}_{\widetilde{\mathfrak{P}}_{\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}}}(u), \mathfrak{c}_{\widetilde{\mathfrak{P}}_{\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}}}(u)\right)(i = 1,2,\dots,m; j = 1,2,\dots,n; k = 1,2,\dots,q)$$

The initial decision risk matrix $\widetilde{\mathfrak{R}} = \left[\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}\right]_{mxn}$ for each expert k by using picture fuzzy numbers (PFNs).

$$\widetilde{\mathfrak{R}} = \left[\widetilde{\mathfrak{R}}_{ij}^{(\mathbb{E}_k)}\right]_{mxn} = \begin{matrix} & \begin{matrix} RP_1 & \cdots & RP_n \end{matrix} \\ \begin{matrix} ERH_1 \\ \vdots \\ ERH_m \end{matrix} & \begin{bmatrix} \Phi_{11}^k & \cdots & \Phi_{11}^k \\ \vdots & \vdots & \vdots \\ \Phi_{m1}^k & \cdots & \Phi_{mn}^k \end{bmatrix} \end{matrix} \tag{8}$$

where, $\Phi_{ij}^k = \widetilde{\mathfrak{P}}\left(\mathfrak{a}_{\Phi_{ij}^k}, \mathfrak{b}_{\Phi_{ij}^k}, \mathfrak{c}_{\Phi_{ij}^k}\right)$ refers the degree of positive membership, the neutral membership, and the negative membership of ergonomic hazards ERH_i regard to criterion RP_j (Fine-Kinney risk parameter; P, E, C) $(i = 1,2,\dots,m \; and \; j = 1,2,\dots,n)$.

Step 2. The aggregated risk assessment matrix $\widetilde{\mathfrak{R}} = \left[\widetilde{\mathfrak{R}}_{ij}\right]_{mxn}$ is derived through the utilization of the PFWA aggregation operator, as detailed in Eq. (9). In Eq. (9), the weight vector of the expert is denoted as $w_k = (w_1, w_2, \dots, w_q)$, for $w_k \epsilon [0,1]$ and $\sum_{k=1}^{q} w_k = 1$.

$$\begin{aligned} \text{PFWA}\left(\widetilde{\mathfrak{R}}^{(\mathbb{E}_1)}, \widetilde{\mathfrak{R}}^{(\mathbb{E}_2)}, \dots, \widetilde{\mathfrak{R}}^{(\mathbb{E}_q)}\right) &= \oplus_{k=1}^{q} w_k \widetilde{\mathfrak{R}}^{(q)} \\ &= \left\{1 - \prod_{k=1}^{q}\left(1 - \mathfrak{a}_{\widetilde{\mathfrak{R}}^{(k)}}(u)\right)^{w_k}, \prod_{k=1}^{q}\left(\mathfrak{b}_{\widetilde{\mathfrak{R}}^{(k)}}(u)\right)^{w_k}, \prod_{k=1}^{q}\left(\mathfrak{c}_{\widetilde{\mathfrak{R}}^{(k)}}(u)\right)^{w_k}\right\} \end{aligned} \tag{9}$$

Table 1. Linguistic terms used in the assessment of risk parameters and hazards (Mao et al. [58]).

Linguistic terms	Picture fuzzy numbers		
	$\mathfrak{a}$	$\mathfrak{b}$	$\mathfrak{c}$
Extremely high (EH)	0.90	0.00	0.10
Very high (VH)	0.80	0.10	0.10
High (H)	0.70	0.10	0.10
Medium high (MH)	0.60	0.20	0.20
Medium (M)	0.50	0.20	0.20
Medium low (ML)	0.40	0.20	0.30
Low (L)	0.30	0.30	0.30
Very low (VL)	0.20	0.30	0.50
Extremely low (EL)	0.10	0.30	0.60

Step 3. The utilization of the score function $\left(\mathbb{S}\mathfrak{c}(\tilde{\mathfrak{R}}_{ij})\right)$ as defined in Eq. (10) enables the calculation of the crisp values, and the subsequent generation of a crisp risk assessment matrix $\left(\mathfrak{D} = [\mathfrak{D}_{ij}]_{mxn}\right)$.

$$\mathbb{S}\mathfrak{c}(\tilde{\mathfrak{R}}_{ij}) = \mathfrak{a}_{\tilde{\mathfrak{R}}_{ij}} - \mathfrak{c}_{\tilde{\mathfrak{R}}_{ij}} + 1 + \frac{e^{\mathfrak{a}_{\tilde{\mathfrak{R}}_{ij}} - \mathfrak{b}_{\tilde{\mathfrak{R}}_{ij}} - \mathfrak{c}_{\tilde{\mathfrak{R}}_{ij}}}}{1 + \mathfrak{d}_{\tilde{\mathfrak{R}}_{ij}}}, \quad \mathbb{S}\mathfrak{c}(\tilde{\mathfrak{R}}_{ij}) \in [e^{-1}, 2 + e], \quad for\ (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{10}$$

Step 4. The calculation of the normalized risk assessment matrix $\left(\mathbb{N} = [\mathbb{N}_{ij}]_{mxn}\right)$ is achieved through the utilization of Eq. (11).

$$\mathbb{N}_{ij} = \begin{pmatrix} \dfrac{\mathfrak{D}_{ij}}{\mathfrak{D}_j^{max}}\ i\ fj \in benefit\ criteria \\ \dfrac{\mathfrak{D}_j^{min}}{\mathfrak{D}_{ij}}\ i\ fj \in cost\ criteria \end{pmatrix} for\ (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{11}$$

Step 5. The calculation of the decomposition value matrix $\left(\mathbb{D} = [\mathbb{D}_{ij}]_{mxn}\right)$ use Eq. (12).

$$\mathbb{D}_{ij} = max\{|\mathbb{N}_{ij} - \mathbb{N}_{rj}|\}\ for\ r \neq i\ and\ \times\ (r = 1,2, \dots, m; i = 1, \dots, m; j = 1, \dots, n) \tag{12}$$

Step 6. The calculation of the logarithmic decomposition matrix $\left(\mathbb{L} = [\mathbb{L}_j]_n\right)$ use Eq. (13).

$$\mathbb{L}_j = \ln\left(1 + \frac{\sum_{i=1}^{m} \mathbb{D}_{ij}}{m}\right) \tag{13}$$

Step 7. The determination of the risk parameter weight matrix $\left(\mathbb{W} = \left[\mathbb{W}_j\right]_n\right)$ is achieved through the utilization of Eq. (14).

$$\mathbb{W}_j = \frac{\mathbb{L}_j}{\sum_{j=1}^{n} \mathbb{L}_j} \; for \; (j = 1,2, \dots, n) \tag{14}$$

Phase 2. PFS-ARTASI

The calculation of the ranking of ergonomic hazards is achieved through the utilization of the PFS-ARTASI method:

Step 8. The crisp risk assessment matrix $\left(\mathfrak{D} = \left[\mathfrak{D}_{ij}\right]_{mxn}\right)$, calculated in accordance with the procedures delineated under Step 3, provides an initial risk assessment matrix relating to the PFS-ARTASI methodology. The crisp risk assessment matrix employed in order to calculate the absolute maximum values matrix$\left(\mathfrak{D}^{max} = \left[\mathfrak{D}_j^{max}\right]_n\right)$ and the absolute minimum values matrix $\left(\mathfrak{D}^{min} = \left[\mathfrak{D}_j^{min}\right]_n\right)$, as depicted the formulae provided in Eqs. (15) and (16), respectively.

$$\mathfrak{D}_j^{max} = \max_{1 \le i \le m} \mathfrak{D}_{ij} + \left\{\max_{1 \le i \le m} \mathfrak{D}_{ij}\right\}^{1/m} \; for \; (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{15}$$

$$\mathfrak{D}_j^{min} = \min_{1 \le i \le m} \mathfrak{D}_{ij} - \left\{\min_{1 \le i \le m} \mathfrak{D}_{ij}\right\}^{1/m} \; for \; (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{16}$$

Step 9. The subsequent step involves implementing the standardized risk assessment matrix via two sub-steps.

Step 9a. The first-level standardized risk assessment matrix $\left[\mathfrak{F}_{ij}\right]_{mxn}$ is computed utilizing Eq. (17).

$$\mathfrak{F}_{ij} = \frac{\mathcal{B}^u - \mathcal{B}^l}{\mathfrak{D}_j^{max} - \mathfrak{D}_j^{min}} \mathfrak{D}_{ij} + \frac{\mathfrak{D}_j^{max}.\mathcal{B}^l - \mathfrak{D}_j^{min}.\mathcal{B}^u}{\mathfrak{D}_j^{max} - \mathfrak{D}_j^{min}} \; for \; (i = 1,2, \dots, m; j = 1,2, \dots, n) \tag{17}$$

In the context of the aforementioned parameters, the absolute maximum value $\left(\mathfrak{D}_j^{max}\right)$ and the absolute minimum values $\left(\mathfrak{D}_j^{min}\right)$ are represented, while $\mathcal{B}^u$ and $\mathcal{B}^l$ denote the upper and lower limits of the standardized interval, respectively. $\left(\mathfrak{D}_{ij}\right)$ represents initial risk assessment matrix value. Additionally, the values in the standardized $[\mathcal{B}^l, \mathcal{B}^u]$ values are equivalent to $[1,\ 100]$ [36].

Step 9b. The second-level standardized risk assessment matrix $[\mathfrak{L}_{ij}]_{mxn}$ is computed utilizing Eq. (18).

$$\mathfrak{L}_{ij} = \begin{pmatrix} (\mathfrak{L}_{ij}) = \left(-\mathfrak{F}_{ij} + \underset{1\leq i\leq m}{max}\mathfrak{F}_{ij} + \underset{1\leq i\leq m}{min}\ \mathfrak{F}_{ij}\right); if\mathrm{j}\ \in cost\ criteria \\ (\mathfrak{L}_{ij}) = (\mathfrak{F}_{ij})\ ;\ if j\ \in benefit\ criteria \end{pmatrix} \quad (18)$$

Step 10. This step involves the calculation of the degree of usefulness of the hazards for the ideal and anti-ideal values through the employment of two sub-steps.

Step 10a. The degree of usefulness of the ideal value risk assessment matrix $\mathbb{V}^{+} = [\mathbb{V}_{ij}^{+}]_{mxn}$ is determined by the implementation of Eq. (19).

$$\mathbb{V}_{ij}^{+} = \left(\frac{\mathfrak{L}_{ij}}{\underset{1\leq i\leq m}{max}\ \mathfrak{L}_{ij}}\ \mathbb{W}_j\ \mathcal{B}^u\right) for\ (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (19)$$

where $\mathcal{B}^u = 100$ and $\mathbb{W}_j$ are criterion weights.

Step 10b. The degree of usefulness of the anti-ideal value risk assessment matrix $\mathbb{V}^{-} = [\mathbb{V}_{ij}^{-}]_{mxn}$ is determined by the implementation of Eq. (20).

$$\mathbb{V}_{ij}^{-} = -\mathfrak{U}_{ij} + \max_{1\leq i\leq m} \mathfrak{U}_{ij} + \min_{1\leq i\leq m} \mathfrak{U}_{ij}\ for\ (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (20)$$

where $\mathfrak{U}_{ij}$ is the degree of usefulness. $\mathfrak{U}_{ij}$ derived from Eq. (21).

$$\mathfrak{U}_{ij} = \left(\left(\frac{\min_{1\leq i\leq m} \mathfrak{L}_{ij}}{\mathfrak{L}_{ij}} \mathbb{W}_j\ \mathcal{B}^u\right)\right) for\ (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (21)$$

where $\mathcal{B}^u = 100$ and $\mathbb{W}_j$ are criterion weights.

Step 11. To calculate the aggregate degree of utility of the hazards for the ideal value matrix ($\mathrm{P}^{+} = [\mathrm{P}_i^{+}]_m$) and anti-ideal value matrix ($\mathrm{P}^{-} = [\mathrm{P}_i^{-}]_m$), the application of of Eqs. (22) and (23) is utilized, respectively.

$$\mathrm{P}_i^{+} = \sum_{j=1}^{n} \mathbb{V}_{ij}^{+}\ for\ (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (22)$$

$$\mathrm{P}_i^{-} = \sum_{j=1}^{n} \mathbb{V}_{ij}^{-}\ for\ (i = 1,2,\dots,m; j = 1,2,\dots,n) \quad (23)$$

Step 12. The final utility functions risk assessment matrix $\mathbb{F} = [\mathbb{F}_i]_m$ is determined through the utilization of the equation provided in Eq. (24). Subsequently, the highest value of the final utility functions risk assessment matrix represents the most significant hazard.

$$\mathbb{F}_i = \{P_i^+ + P_i^-\}\left\{\theta\, f(P_i^+)^\beta + (1-\theta).\, f(P_i^-)^\beta\right\}^{1/\beta};\ \theta \in [0,1];\ \beta \in [1,+\infty] \tag{24}$$

where $f(P_i^+)$ and $f(P_i^-)$ denote additive functions and calculated as $f(P_i^+) = \frac{P_i^+}{P_i^+ + P_i^-}$ and $f(P_i^-) = \frac{P_i^-}{P_i^+ + P_i^-}$, respectively.

4 CASE STUDY

The focus of this section is to apply the proposed risk assessment methodology for ergonomic hazards affecting workers during the harvesting of tea in the Eastern Black Sea region of Türkiye. Firstly, a group of three experts $\{\mathbb{E}_1, \mathbb{E}_2, \mathbb{E}_3\}$ with differing backgrounds is selected for the purpose of establishing the risk evaluation team, with the aim of addressing the risk assessment problem regarding the potential hazards utilizing the proposed framework. The weights of experts with different levels of experience are as follows: "$(w_1 = 0.4), (w_2 = 0.4), (w_3 = 0.2)$". Detailed information regarding the experts is given in Table 2. The Fine-Kinney risk parameters (RPs)—probability (P), exposure (E), and consequence (C)—are used within this case study to evaluate the hazards in order to provide a thorough and systematic evaluation. Each of the three risk parameters is regarded as a benefit criterion [60]. A comprehensive literature review and consultation of experts has identified thirteen potential ergonomic hazards (see Table 3). The aforementioned potential ergonomic hazards are denoted as $ERH = \{ERH_1, ERH_2, \ldots, ERH_{13}\}$.

Table 2. Information about the experts.

No	Area of expertise	Experience (year)	Academic degrees
$\mathbb{E}_1$	OHS specialist	15	Ph.D.
$\mathbb{E}_2$	Academician	20	Ph.D.
$\mathbb{E}_3$	OHS specialist	10	Master Degree

Table 3. The potential ergonomic hazards of the tea harvesting process.

No	The potential hazards	Description
ERH_1	Work posture	The manifestation of symptoms within the musculoskeletal system is characterised by the presence of fatigue and inflammation in muscular and articular tissues.
ERH_2	Repetitive motion	Musculoskeletal symptoms include tendinitis, tenosynovitis and carpal tunnel syndrome.
ERH_3	Exerting excessive force	Musculoskeletal symptoms lead to added stress on the postural muscles and other affected tissues.
ERH_4	Standing for a long time	The presence of musculoskeletal symptoms, characterised by muscular fatigue.
ERH_5	Using unsuitable tools and equipment	Symptoms affecting the muscles and joints, including fatigue and inflammation.
ERH_6	Weight	Symptoms affecting the muscles and skeleton in the lower extremity.
ERH_7	Height	Symptoms affecting the muscles and tendons in the upper extremity.
ERH_8	Experience	Musculoskeletal symptoms.
ERH_9	Unsuitable climatic conditions	Musculoskeletal symptoms.
ERH_{10}	Vibration	Symptoms related to the muscles and tendons; damage to the upper limbs.
ERH_{11}	Land of harvesting area	Symptoms and injuries affecting the muscles and skeleton.
ERH_{12}	Work stress	Musculoskeletal symptoms.
ERH_{13}	Organizational factor	Musculoskeletal symptoms.

Step 1. In this risk assessment process, each potential hazard is evaluated in regard to the RPs. The evaluation information derived from the experts using the LTs provided in Table 1 is displayed in Table 4.

Table 4. The linguistic terms based evaluations of potential hazards provided by experts.

$\mathbb{E}_1$	P	E	C	$\mathbb{E}_2$	P	E	C	$\mathbb{E}_3$	P	E	C
ERH_1	VH	H	M	ERH_1	VH	H	M	ERH_1	VH	H	M
ERH_2	EH	EH	MH	ERH_2	EH	EH	MH	ERH_2	EH	VH	M
ERH_3	H	ML	M	ERH_3	MH	L	M	ERH_3	H	L	M
ERH_4	EH	VH	M	ERH_4	EH	VH	MH	ERH_4	EH	VH	MH
ERH_5	ML	L	M	ERH_5	L	L	M	ERH_5	ML	L	M
ERH_6	M	M	M	ERH_6	ML	ML	M	ERH_6	M	M	MH
ERH_7	M	M	M	ERH_7	M	M	M	ERH_7	MH	M	MH
ERH_8	MH	M	M	ERH_8	M	M	M	ERH_8	MH	M	M
ERH_9	VH	ML	MH	ERH_9	H	VH	MH	ERH_9	VH	VH	M
ERH_{10}	VL	L	M	ERH_{10}	VL	L	M	ERH_{10}	VL	L	M
ERH_{11}	EH	H	H	ERH_{11}	EH	EH	H	ERH_{11}	EH	VH	VH
ERH_{12}	EH	EH	M	ERH_{12}	H	MH	M	ERH_{12}	M	M	MH
ERH_{13}	M	M	M	ERH_{13}	M	M	MH	ERH_{13}	M	M	M

Step 2. The PFWA aggregation operator, as described in Eq. (9), is utilized to compute the aggregated risk assessment matrix. The aggregated risk assessment matrix is shown in Table 5.

Table 5. The aggregated risk assessment matrix.

	P			E			C		
ERH_1	0.80	0.10	0.10	0.70	0.10	0.10	0.50	0.20	0.20
ERH_2	0.90	0.00	0.10	0.89	0.00	0.10	0.58	0.20	0.20
ERH_3	0.66	0.13	0.13	0.34	0.26	0.30	0.50	0.20	0.20
ERH_4	0.90	0.00	0.10	0.80	0.10	0.10	0.56	0.20	0.20
ERH_5	0.36	0.24	0.30	0.30	0.30	0.30	0.50	0.20	0.20
ERH_6	0.46	0.20	0.24	0.46	0.20	0.24	0.52	0.20	0.20
ERH_7	0.52	0.20	0.20	0.50	0.20	0.20	0.52	0.20	0.20
ERH_8	0.56	0.20	0.20	0.50	0.20	0.20	0.50	0.20	0.20
ERH_9	0.76	0.10	0.10	0.69	0.13	0.16	0.58	0.20	0.20
ERH_{10}	0.20	0.30	0.50	0.30	0.30	0.30	0.50	0.20	0.20
ERH_{11}	0.90	0.00	0.10	0.82	0.00	0.10	0.72	0.10	0.10
ERH_{12}	0.79	0.00	0.11	0.76	0.00	0.15	0.52	0.20	0.20
ERH_{13}	0.50	0.20	0.20	0.50	0.20	0.20	0.54	0.20	0.20

Step 3. The calculation of $[\mathfrak{D}_{ij}]_{mxn}$ is achieved through the utilization of the score function presented in Eq. (10). The matrix $[\mathfrak{D}_{ij}]_{mxn}$ is displayed in Table 6.

Table 6. The crisp risk assessment matrix.

	P	E	C
ERH_1	3.5221	3.0988	2.3047
ERH_2	4.0255	3.9457	2.5595
ERH_3	2.9215	1.7743	2.3047
ERH_4	4.0255	3.5221	2.4969
ERH_5	1.8242	1.6735	2.3047
ERH_6	2.1587	2.1587	2.3695
ERH_7	2.3695	2.3047	2.3695
ERH_8	2.4969	2.3047	2.3047
ERH_9	3.3640	2.9960	2.5595
ERH_{10}	1.2488	1.6735	2.3047
ERH_{11}	4.0255	3.6304	3.1909
ERH_{12}	3.4506	3.2957	2.3695
ERH_{13}	2.3047	2.3047	2.4336

The weights of RPs, as obtained by applying the Eqs. (11), (12), (13), and (14) in Steps 4, 5, 6 and 7, respectively, are presented in Table 7.

Table 7. The weights of the RPs.

$\mathbb{W}$	**P**	**E**	**C**
$\mathbb{W}_j$	0.394	0.355	0.251

After determining the weight of the RPs, the PFS-ARTASI steps are employed. As outlined in Step 8, Eqs. (15) and (16) are utilized to calculate the $\mathfrak{D}_j^{max}$ and the $\mathfrak{D}_j^{min}$, respectively. The matrices are provided in Table 8.

Table 8. The absolute maximum and minimum values.

$\mathfrak{D}$	P	E	C
$\mathfrak{D}_j^{max}$	5.1386	5.0571	4.2843
$\mathfrak{D}_j^{min}$	0.2316	0.6331	1.2384

The $\mathbb{F}_i$ value of potential hazards for the ideal value risk assessment matrix are computed $((\theta = 0.5)$ and $(\beta = 1))$ by applying the following steps of the PFS-ARTASI methodology: 9, 10, 11 and 12. The matrix $[\mathbb{F}_i]_m$ is given in Table 9. The maximum value of this matrix is indicative of the most serious potential hazard.

Table 9. $\mathbb{F}_i$ values and rankings of potential hazards.

Hazards	$\mathbb{F}_i$	Rank
ERH_1	78.9707	6
ERH_2	92.7671	2
ERH_3	58.9329	11
ERH_4	88.8070	3
ERH_5	46.1399	12
ERH_6	59.1833	10
ERH_7	63.1046	9
ERH_8	63.1777	8
ERH_9	80.9522	5
ERH_{10}	36.2905	13
ERH_{11}	97.7368	1
ERH_{12}	81.1756	4
ERH_{13}	63.5039	7

5 VALIDATION OF RESULTS

5.1 Sensitivity analysis

The proposed framework employs the Fine–Kinney parameters to signify the impact of the relationship between the data on risk rating and the results of hazard ranking. To investigate the effect of parameter value changes on the ultimate risk ranking, a sensitivity analysis was conducted by applying different values to these risk parameters. Therefore, the weight vectors of the Fine–Kinney parameters were changed. Given the three parameters inherent to the Fine–Kinney method, a total of six combinations were established in the context of this case study. In order to evaluate the robustness of the proposed model, five different weight scenarios (SC1, SC2, SC3, SC4, SC5) were constructed in addition to the original weight scenario (OSC), as displayed in Table 10. The effect of changes in the parameters on the hazard ranking was analyzed. The risk priority ranking of hazards from the sensitivity analysis is illustrated in Figure 2.

Table 10. The Fine–Kinney risk parameter weights for the chosen scenarios.

Scenario	Fine–Kinney parameter weight value		
	P	E	C
OSC	0.394	0.355	0.251
SC1	0.355	0.394	0.251
SC2	0.394	0.251	0.355
SC3	0.251	0.394	0.355
SC4	0.251	0.355	0.394
SC5	0.355	0.251	0.394

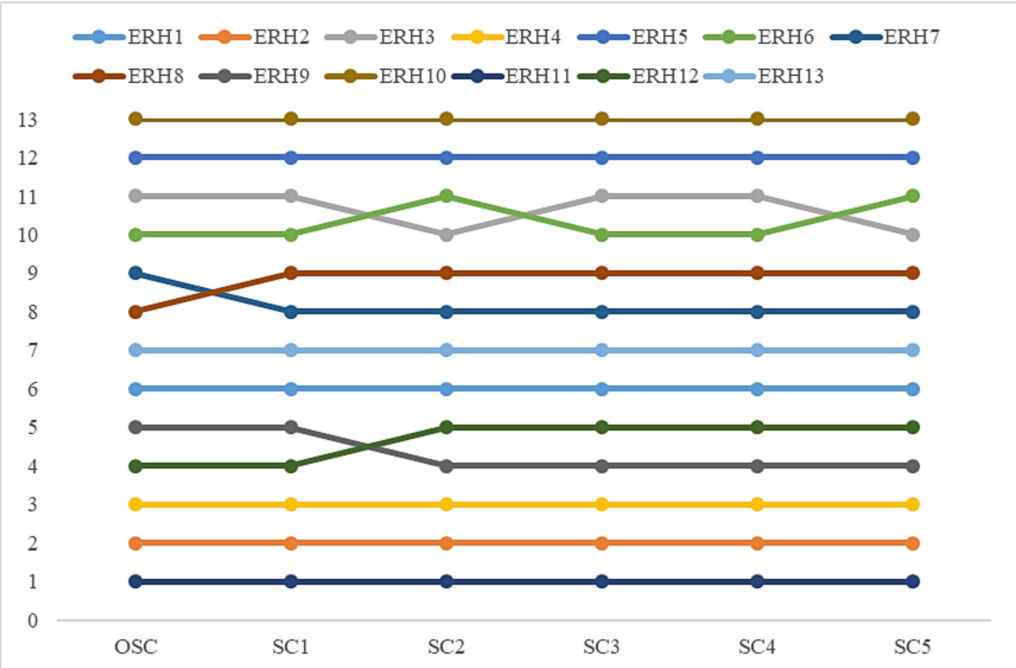

Figure 2. The results of sensitivity analysis.

As demonstrated in Figure 2, the final risk priority ranking results for hazards indicate that changes executed to the weight vector of the model's parameters have a negligible effect on the risk prioritization ranking. From Figure 2, there is a high correlation between the ranking results of hazards in different scenarios, and moreover, the ranking of critical hazards $(ERH_{11}, ERH_2, ERH_4, ERH_{12})$ remains consistent. The results of the conducted sensitivity analysis provide an indication of both the reliability and the applicability of the ranking results derived from the application of the established methodology.

5.2 Comparative analysis

A comparison with Fine-Kinney-based several conventional MCDM techniques, such as WASPAS, CoCoSo, EDAS, CODAS, and ARAS, has been conducted to illustrate the viability of the FK-PFLODAR model. The final hazard rankings from each of the above-mentioned methodologies are presented in Table 11. To provide a more lucid depiction delineated illustration of the results of the comparison study, the ranking order of each potential hazard as ascertained by alternative Fine-Kinney-based modelling approaches is also illustrated in Figure 3. Thereafter, the Spearman's rank correlation coefficients (SCC) for the results of the ranking obtained by the aforementioned employed approaches were calculated, as illustrated in the final row of Table 11.

Table 11. The result of the comparative analysis with conventional MCDM techniques.

	Based on Fine-Kinney					
	The proposed model	**PF-WASPAS**	**PF-CoCoSo**	**PF-EDAS**	**PF-CODAS**	**PF-ARAS**
	Ranking order					
ERH_1	6	5	5	5	5	5
ERH_2	2	2	2	2	2	2
ERH_3	11	10	10	10	8	10
ERH_4	3	3	3	3	3	3
ERH_5	12	12	12	12	12	12
ERH_6	10	11	11	11	11	11
ERH_7	9	8	8	8	9	8
ERH_8	8	7	7	7	7	7
ERH_9	5	6	6	6	6	6
ERH_{10}	13	13	13	13	13	13
ERH_{11}	1	1	1	1	1	1
ERH_{12}	4	4	4	4	4	4
ERH_{13}	7	9	9	9	10	9
SCC	1.00	0.97	0.97	0.97	0.94	0.97

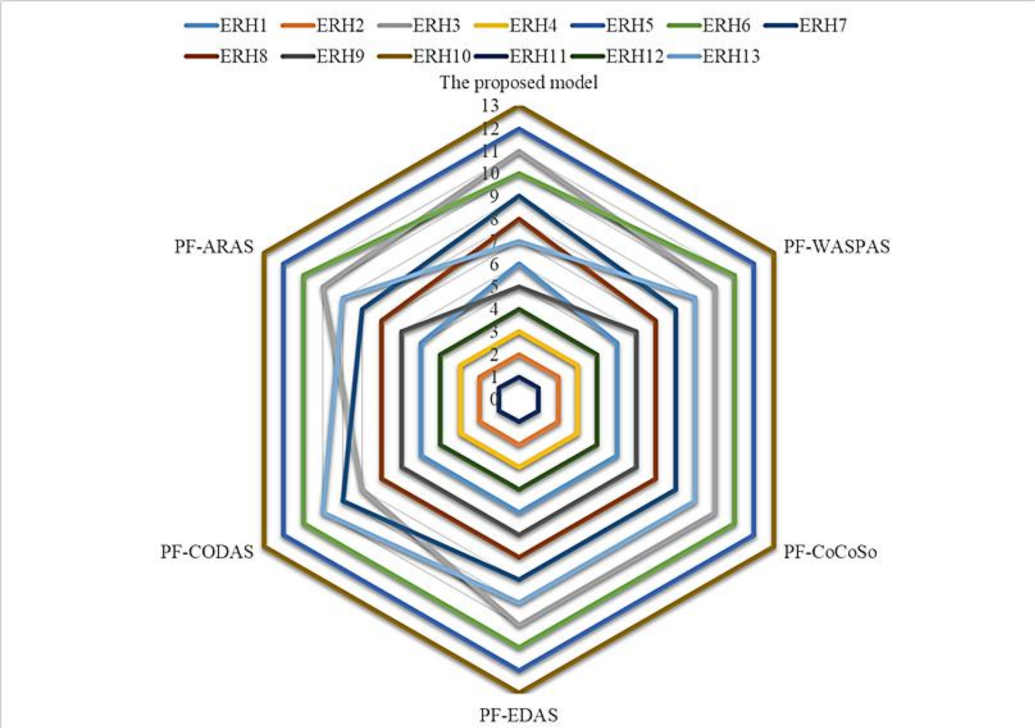

Figure 3. The presentation of the comparative analysis in graphical form.

The application of the WASPAS, CoCoSo, EDAS, CODAS, and ARAS methodologies yielded results that exhibited a strong correlation with the ARTASI approach.

6 DISCUSSION

6.1 Managerial Implications

The present model has been developed with the objective of facilitating a more exhaustive comprehension of the correlation between ergonomic risk factors and WMSDs. It is posited that this may engender beneficial insights with regard to the control of WMSD risk factors among agricultural workers in the operational field. Thus, a robust risk assessment model will empower authorities and stakeholders to act with greater alacrity and efficacy in response to significant potential occupational hazards. The developed FK-PFLODAR hybrid model, integrating PFS and advanced aggregation operator, provides useful practical information and managerial implications:

(i) Pioneering OHSRA Model: The conceptualization of the FK-PFLODAR hybrid model represents a significant innovation in the field of occupational risk assessment, providing a pioneering model for experts and practitioners engaged in ergonomic risk assessment. This pioneering approach transcends traditional methodologies to the field, incorporating recent advancements with a view to enhancing the OHSRA process.

(ii) Importance Evaluation of Amplified Risk Parameters: The employment of the LODECI method for risk parameters weighting provides a robust and reliable assessment of the relative importance of different criteria. This approach enables managers to make informed decisions by taking into account the sophisticated significance of each criterion.

(iii) Adaptable Option for Ranking: The ARTASI technique enables those tasked with decision-making processes to consider the inevitable uncertainties that arise during expert assessments. This adaptability in the ordering of alternatives allows the model to accommodate varying degrees of precision and divergent perceptions.

(iv) Reliability of Decisions and Resistance to Falsification: The integration of sensitivity analysis strategies within the validation process, in conjunction with their comparative evaluation against extant methodologies, ensures the resilience of the proposed model. These analyses constitute a framework for determining the model's efficaciousness. This insight facilitates the selection of the optimal decision support instrument in accordance with management requirements.

In conclusion, the FK-PFLODAR OHSRA framework, as posited in this paper, constitutes a sophisticated and pioneering instrument for practitioners intending to circumvent the complexity inherent in ergonomic risk assessment, thereby encouraging more systematic and strategic OHSRA processes.

6.2 Limitations and future directions

The aforementioned OHSRA model is subject to several limitations that could be the focus of future research. First, the OHSRA is a multifaceted decisional process that necessitates the involvement of a variety of experts. Given the heterogeneity of experts' backgrounds in terms of demographics, specialisms and professional experience, it is to be considered that opinions are frequently expressed that are both divergent and contradictory. This finding has the potential to have a significant impact on the classification of occupational hazards in terms of risk. Consequently, it is advised that a strategy be formulated for the mitigation of professional differences among experts associated with the OHSRA. Second, the proposed model determines risk priority based on only three parameters. Nevertheless, it is crucial to consider that various parameters, for example cost, can exert a substantial influence on the risk assessment process and its outcomes. Therefore, the integration of supplementary risk variables as additional dimensions within the Fine-Kinney approach may signify a viable direction for subsequent research endeavours. Finally, efficacy of the aforementioned model is dependent upon the incorporation of expert judgement in the assessment of risk variables and the delineation of hazard rankings. The inevitable subjectivity of expert evaluations may result in the presence of cognitive bias, and the robustness of the model's inferences may be contingent on the expertise and heterogeneity of the expert team engaged. In conclusion, the FK-PFLODAR model has been demonstrated to provide a robust OHS risk assessment tool; however, it is imperative to emphasise the limitations of the model, which are derived from the subjective evaluations of experts. It is suggested that future research efforts endeavours concentrate on incorporating Artificial Intelligence (AI) components to validate and improve model performance, with the aim of achieving a higher rate of accurate outcomes.

7 CONCLUSION

This study addressed the necessity to develop a DSM within the scope of ergonomic risk assessment, with a specific focus on prioritizing ergonomic risk factors affecting WMSDs among agricultural workers in terms of sustainable agriculture. Human factors/ergonomics possesses the capacity to contribute to processes that aim to combine both the human and financial dimensions in order to achieve sustainability, by optimizing the employees' performance and well-being [61].

The conventional Fine-Kinney model has been employed as a successful methodology in addressing the issue of occupational risk analysis. However, it is significant to emphasise that the model does possess some inherent limitations with regard to its capacity to manage uncertainty in expert judgements and the modelling of risk prioritization. Ergonomic risk factors are a major cause of WMSDs, which are known to have a significant impact on employee health and safety. The aim of ergonomic risk assessments, which are conducted to identify and evaluate the discrepancy between requirements of the workplace and the physical abilities of the workforce, is to prevent WMSDs [62]. This study proposes a hybrid ergonomic risk assessment model as a means to achieve the stated objective. This model integrates Fine-Kinney-based LODECI-ARTASI methods based on PFSs.

A total of 13 potential ergonomic hazards were identified in this study. The results demonstrate that the five most significant ergonomic hazards are ERH_{11} (Land of harvesting area), ERH_{2} (Repetitive motion), ERH_{4} (Standing for a long time), ERH_{12} (Work stress) and

ERH_9 (Unsuitable climatic conditions), respectively. The findings of the study demonstrate that ERH_{11} is the most significant potential hazard, necessitating the implementation of preventive and protective measures to ensure the health and safety of workers. The geography of the Eastern Black Sea region of tea plantations, characterized by slope, constitutes a significant hazard factor contributing to the prevalence of WMSDs. This is attributable to the physical demands of the work, which require workers to assume awkward postures during tea harvesting, resulting in potential musculoskeletal discomfort and injury. It is also important to note that ERH_{12} (Work stress) has been ranked among the most significant hazards. In the literature, psychosocial factors such as role conflict, low job control, job dissatisfaction and job insecurity are discussed as having an impact on WMSDs [63, 64]. The suggestion that psychological factors may be more influential on WMSDs than other factors is discussed in the literature [6]. A decline in the productivity of workers is likely to result in a corresponding decrease in the output of the agricultural sector of a nation, which, in turn, will have an impact on that country's GDP [7]. In order to manage the risk of WMSDs more effectively, it is essential that OHSRA practices address work-related psychosocial hazards [65]. In conclusion, this study provides beneficial implications for OHS professionals, decision-makers and practitioners in the control and prevention of ergonomic risks in the agricultural sector.

The proposed framework is acknowledged to have certain limitations, which are posited to be conducive to the suggestion of future directions. Firstly, it is important to note that only three risk parameters are included during the process of risk assessment. However, other factors such as cost or time might need to be taken into account in the event of more complicated risk assessment problems. Secondly, the proposed model was applied in agricultural studies. In such cases, its application can be diversified into various industries. Finally, the evaluation was conducted in accordance with the framework of three expert opinions in the current study. In future studies, the establishment oflarger decisional groups has the capacity to augment the efficacy of the model.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

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