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Original paper

Designing a sustainable development model for agricultural sector under critical circumstances (COVID-19 Pandemic): A fuzzy approach

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Abstract

The COVID-19 pandemic has affected health, economic, and social factors and harmed the distribution and sales of agricultural products. It has become a crucial factor in agricultural development. The purpose of the present study is to design a sustainable development model in the agricultural sector under circuital circumstances (i.e., the COVID-19 pandemic). To achieve this goal of used a combined methodology of grounded theory, the Fuzzy Delphi Method (FDM), the Fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method, and the Fuzzy decision-making trial and evaluation laboratory-based analytic network process (FDANP) method. The criteria of higher importance were identified using grounded theory and FDM. Then, the fuzzy DEMATEL method was carried out to identify internal relationships, effects, and dependencies of the main criteria. Finally, the weight of the main criteria of the model has been calculated with the Fuzzy DANP method. According to the results of the Fuzzy DEMATEL method, Critical circumstances (COVID-19), environmental factors, educational factors, health factors, and economic factors had the highest effects. The critical circumstances criterion (COVID-19) had the largest effect and strongest relationship with the other criteria. On the other hand, the results of the Fuzzy DANP method show that environmental factors (MC7), social factors (MC2), critical circumstances (COVID-19) (MC5), health factors (MC1), entrepreneurial factors (MC8), are the most important criteria of the sustainable development model of the agricultural sector under critical circumstances. Therefore, to move on the path of sustainable development in the agricultural sector, one should focus on the factors that have a higher influence and importance.

Keywords: Sustainable development, agricultural sector, COVID-19, Iran, fuzzy DEMATEL, criterion identification.

1 Introduction

Sustainable development involves economic, environmental, and social aspects to protect life on earth for both the current and future generations. GAIAs definition of sustainable development implies restrictions on human activities and insists on making better use of resources and technologies. However, the COVID-19 pandemic impacts economies and societies and threatens sustainable development. Although it is not a permanent challenge, it can disturb the process and leave long-lasting consequences. GAIA also focuses on mutual relationships between all living creatures on earth and seeks an integrated approach to bring a trade-off between the economic, social, and environmental impacts of the COVID-19 pandemic [50] A review of agricultural capabilities and potentials in Iran indicates that Iranian agriculture has significant capacities, and efficient agricultural activity would enable other sectors to progress and provide sustainability in Iran [42]. National development includes agricultural contributions to, for example, the development of the other sectors through economic surplus (financing, providing energy, and raw materials of handicrafts, and industry), financing in economic growth, foreign currency supply, workforce storage, industrial goods market, agricultural self-sufficiency to avoid foreign dominance, rational immigration change across Iran, and agricultural tourism in rural areas

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[14]. Agriculture plays a key role in supporting human livelihood and national economic development. Agricultural practices determine the food production level and, to a great extent, environmental status [61]. On the other hand, the analysis of statistical evidence indicates that the consumption and export of agricultural and food products in Iran have lost about 7.8 % and 10 % of their value, respectively, due to the effects of the prevalence of COVID - 19. The amount of damage in March 2019 is estimated at 131 million dollars. It was estimated by about 108 million dollars in consumption and 23 million dollars in the export section. The agricultural sector is the main pillar in providing food security and its instability will create many challenges in the path of growth and development of Iran's economy. Iran's agricultural sector is vulnerable to natural events, but it is the most resistant economic sector to artificial events. Considering the central role of the agricultural sector as the driver of many economic sub-sectors of Iran such as industry (food industry, meat industry, textile, and clothing industry, etc.) and services (trade, hotel, and restaurant, transportation, warehouse), Targeting for this sector should be in such a way that in the current conditions (COVID-19 Pandemic) and the possibility of its continuation, the agricultural sector provided the requirements of sustainable production by optimally using all software and hardware capacities. Although severe sanctions have been imposed on Iran's economy in the years of 2009 - 2019, the agricultural sector has grown by 43%. Therefore, the agricultural sector can contribute to the resilience of Iran's economy in critical situations [44].

Sustainability in different Iranian agricultural systems has been investigated in the form of case studies [4, 11, 13, 18, 21, 30, 31, 32, 33, 39, 43, 51, 55]. However, a localized sustainable development model remains yet to be proposed for Iran. It is important to develop a localized sustainable development model for the COVID-19 pandemic to push the global agricultural sector toward sustainable development. Thus, the present paper aims to design a sustainable development model for the agricultural sector for the critical circumstances of the COVID-19 pandemic. The rest of the study is organized as follows. Section 2 reviews the research literature. In Section 3, we introduce the basic aspects of our research materials and methods. In Section 4, implementation and findings are described. In Section 5, the experimental results are demonstrated. Finally, Section 6 contains some concluding remarks and discussions on the limitations of this research and the development of future research that can be done.

2 Literature review

Many studies on sustainable development in the agricultural sector and the effects of the COVID-19 pandemic have been conducted in Iran [6, 15, 40, 42, 56, 60] and other countries of the world [17, 19, 37, 52, 53, 60, 62, 65], which are reviewed below.

[6] Explored the role of rural management in sustainable development with an emphasis on livability. They sought to evaluate the contributions of rural management to livability enhancement and achieving sustainable rural development in villages with a minimum of 100 households in Soltanieh County, Iran. They selected ten villages as case studies based on topography and population classification. The statistical population consisted of 5434 rural households in the county. The sample size was calculated to be 241 using the modified Cochran formula. They conducted applied research and adopted a descriptive-analytical methodology. Data were collected using literature reviews and field studies (questionnaires and interviews). The reliability of the variables was calculated to be 0.823 using Cronbach's alpha. To analyze the data, the one-sample t-test, multivariate regression, and cluster analysis were carried out. The findings revealed that rural management significantly affected all the livability factors of the villages under study. Furthermore, cluster analysis suggested a direct relationship between rural management performance and livability coefficient (0.658). The path analysis indicated that rural management performance in institutional physical and managerial factors had the largest effects on village livability (0.374 and 0.371, respectively).

[15] Analyzed the influences of geographical advantages on sustainable rural development in Khorramabad County, Iran. They adopted a scale-based quantitative methodology. The statistical population consisted of the villages in the county. A total of 150 villages were employed as samples using stratified random sampling. Data were collected using a literature review (secondary data) and a researcher-made questionnaire (distributed among village authorities). The correlation test, stepwise analysis, and a neural network were employed to analyze the data. It was found that, among geographical advantage variables, active population, public investment, private investment, skilled and expert population, farmlands, water quantity, urban place access, and tourist arrival were the most important predictors of sustainable rural development in Khorramabad County.

[40] Studied the efficiency of Iranian higher education in achieving sustainable development. The sustainable development efficiency of Iranian higher education was analyzed using data envelopment analysis (DEA) from an environmental perspective. Then, an autoregressive distributed lag (ARDL) model was employed to evaluate the efficiency of Iranian higher education in achieving sustainable development in terms of continuous growth during 1990-2015. The DEA model indicated that Iranian higher education was inefficient for sustainable development. The ARDL model suggested

that productivity enhancement in Iranian higher education had a positive, significant effect on economic growth and that investing in academic education with two lags would have a positive influence on economic growth.

[42] Conducted a comparative analysis of agricultural development policies in Gilan Province, Iran, in the past two decades, with an emphasis on sustainable development. They sought to identify the agriculture organization policies with significant relationships with sustainable rural economic development indices. The statistical population consisted of the dwelling villages of Roodsar County. Based on the 2015 Census, Roodsar has 395 dwelling villages. The sample size was estimated to be 195 using the Cochran formula. The relationship between the independent and dependent variables was evaluated using the Pearson correlation coefficient. The correlation coefficient indicated that sustainable economic development had a significant relationship with agricultural policies ($p=0.009$). The correlation coefficient was reported to be 0.772.

[56] Studied the roles of climate finance in economic growth and sustainable development. They primarily focused on climate finance and investment in this field and explored climate finance's impacts on the economy and economic growth. The novelty of their work included the novelty of the topic and a comprehensive perspective. The necessity of their work lay in the destructive consequences of neglecting climate finance.

[69] Investigated direct foreign investment as a sustainable development determinant in developing countries and emerging market economies. They sought to realize whether the attraction of direct foreign investments to developing and emerging economies would lead to high value-added employment opportunities, whether such investments would not harm the environment, and whether the sustainable direct foreign investment would ensure achieving sustainable development in developing countries. The impacts of direct foreign investment on the sustainable development process of selected developing economies during 2000-2018 were explored through an econometric model based on empirical-panel data. The empirical results implied that direct foreign investment had a significant spillover effect on the sustainable development indices of the selected countries, whereas environmental pollution was found to have a negative, significant impact on sustainable development.

[17] Analyzed the effects of the COVID-19 pandemic on the production of vegetables and consequent measures from an agricultural insurance perspective. They used a survey and interviewed 46 agriculture corporations in Shanghai, China, to explore how the pandemic influenced the production of vegetables and proposed suggestions on agricultural insurance. It was found that:

(a) The pandemic affected almost the entire vegetable supply chain; however, it posed the largest impact on sales.

(b) The risks of the vegetable production market had substantially increased, with the gap between the farm price and retail price increasing. The sales price difference between traditional channels and e-commerce was significant.

(c) The income of farmers decreased due to the COVID-19 pandemic in general, and small-scale traditional farmers suffered from larger losses.

(d) Agricultural insurance plays a key role in the sustainable supply of vegetables to cities. To minimize the impact of the pandemic on the production of vegetables and the sustainability of urban market baskets and farmer income, it is necessary to pay further attention to agricultural insurance, specifically providing insurance for market risks.

[19] Examined the role of the future flexibility of sustainable energy under the COVID-19 pandemic in Europe. The results suggested a need for energy flexibility as countries encountered a triple challenge of the COVID-19 crisis, a consequent economic crisis, and a climate crisis. With a focus on Europe, it was found that flexibility could bring a trade-off between power generation and power demand and enable the energy sector to reliably exploit low-carbon renewable energy resources, and ensure a more sustainable energy future and sustainability. They proposed five emergency policies for Europe that evaluated the possible impacts of COVID-19 on the socioeconomic prerequisites of flexibility in energy systems.

[37] Investigated the influence of COVID-19 on the exports of agricultural products. They employed unique firm-level survey data to measure COVID-19 impacts on Chinese agricultural exporting firms. Although agricultural jobs experienced reduced exports on average, the exports of some crops, particularly cereals and oil, were high and even increased. This suggests a substantial demand for the main food during the pandemic. However, some crops (e.g., edible mushrooms and garden crops) dramatically declined in exports. Furthermore, the COVID-19 pandemic was found to have larger impacts on small firms than on larger ones in general.

[52] studied increased concerns about the production of agricultural products under the spread of COVID-19 in China. They discussed the impacts of COVID-19 on the production of crops in China and the responses of the government to reduce the negative impacts. It was found that irrational restrictions blocked output channels of agricultural products, impeded necessary inputs, destroyed production cycles, and reduced production capacity. The experiences of China are expected to provide warnings and suggestions, particularly to developing countries, to protect domestic crop production.

[53] Studied the COVID-19 and climate change challenges in agriculture and food security in Southern Asia. They argued that climate change had become an emergency in the south of Asia as it would destroy agriculture and threaten food security. The novel coronavirus disturbed many agricultural activities and supply chains in Southern Asia and increased the complexity of food security and livelihood sustainability challenges. They concluded that South Asian countries should collectively share their experiences and improve disturbed agrifood supply chains. Strategies and approaches would be required to cope with the COVID-19 pandemic and climate crises. Today, there is a unique opportunity to exploit COVID-disruptive forces and marketing-related policies to accelerate the shift into more sustainable and robust food systems. Some short-term support for handling COVID-19 challenges could be associated with investing in natural capital to improve productivity and long-term flexibility and achieve long-term food production.
[60] Evaluated a framework for PESTEL dimensions in the sustainable management of COVID-19 healthcare waste. They analyzed sustainable healthcare waste management dimensions using several approaches, including PESTLE analysis (political, economic, social, technological, environmental, and legal factors), interpretive structural modeling (ISM), and fuzzy MICMAC. The framework provided seventeen PPESTEL factors in the sustainable management of healthcare waste during the COVID-19 pandemic via a literature review and expert discussions. Then, ISM developed a hierarchy of the seventeen sustainable healthcare waste management dimensions based on mutual relationships. Fuzzy MICMAC analysis classified the seventeen PESTEL dimensions into four groups. It was concluded that the policymaking framework should be urgently considered by governments and health authorities across the world for political, legal, and environmental targeting. Waste control and environmental regulation compliance (output dimensions) should be regularly tracked to ensure cleaner production in healthcare services.
[62] Developed and validated an agricultural sustainability measure. A multi-stage process was employed to develop and validate the measure. The statistical population consisted of Iranian wheat growers. The data were analyzed using multivariate statistical methods, i.e., principal component analysis (PCA) and confirmatory factor analysis (CFA). The PCA classified agricultural sustainability indices into four components/criteria, including "social justice and welfare," "durability," "sustainability and adaptation," and "productivity and efficiency." The factor structure of the agricultural sustainability measure was subjected to CFA and proved the fit indices of the measurement model. Finally, a total of 23 principal components were introduced to measure agricultural sustainability.
[65] Evaluated the impacts of COVID-19 on food security, agriculture, and livelihood in developing countries. They argued that COVID-19 would have extensive consequences for health and livelihood in developing countries. Food security is the most aspect of sustainable development. The agricultural sector is the backbone of economies, and a major fraction of developing countries are dependent on agriculture for revenue. Thus, a disruption in food security and the agricultural sector would strongly impact such countries. The COVID-19 impacts on agriculture and food security were comprehensively evaluated.
Previous studies mostly emphasized certain aspects of sustainable development in the agricultural sector, and papers evaluated COVID-19 impacts on agriculture in case studies. For example, the influences of the COVID-19 pandemic on the production and exports of crops have been analyzed. However, no study fundamentally added new concepts based on the domestic and global COVID-19 circumstances to the existing sustainable development concepts. The novelty of the present work lies in pioneering the design of a comprehensive sustainable development model for the agricultural sector under COVID-19 circumstances. The results could indeed identify many ambiguous and unknown aspects of sustainable development and fundamentally alter the concepts and definitions of sustainability, which would require a fundamental change in the attitude of authorities. Therefore, it can be said that the novelty of the present work primarily includes the novel topic, extracting a model based on expert views through a fuzzy approach, considering the COVID-19 circumstances and their impact on sustainable development, and integrating quantitative and qualitative research to extract the model.

3 Materials and methods

The present study is basic research in terms of objectives as it sought to propose new objects and carried out modeling. Qualitative research is used in modeling. The qualitative phase was implemented based on grounded theory. The present work adopted a hybrid quantitative-qualitative methodology. The statistical population consisted of experts, and snowball sampling was employed to select participants. The interviewees introduced other experienced individuals, and the samples of the qualitative phase were developed by communicating with the introduced individuals. Sampling was continued until theoretical saturation was achieved. Experts were those with high levels of knowledge and experience, agreed to participate in the research, and had active contributions to the topic under study. The methodology consisted of two stages and seven sub-stages, including:

A) Stages

Stage 1: The qualitative stage was implemented in two sub-stages. In the first sub-stage, grounded theory was adopted to identify the criteria. In the second sub-stage, interviews were employed as a complementary instrument to identify the criteria in grounded theory. The interviewees were selected using snowball sampling. The criteria were extracted based on the interviews using the Fuzzy Delphi method (FDM).
Stage 2: Once the important criteria and sub-criteria had been identified, the effects of the criteria on each other and their contributions were analyzed using the Fuzzy DEMATEL and expert views. Then, using the Fuzzy DANP method, the effective weight of each criterion is determined.

B) The sub-stages are depicted in Fig. 1.

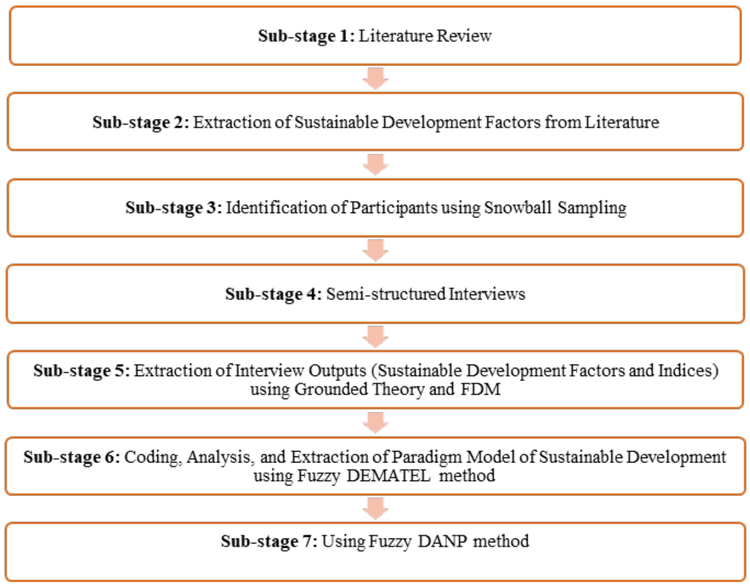


Figure 1: The Sub-stages of the applied methodology

3.1 Qualitative phase

The qualitative phase was analyzed in MAXQDA based on FDM and grounded theory. This theory is a general, inductive, and interpretive methodology proposed by [16]. The data-driven theory is an inductive and exploratory methodology that enables researchers in various fields to develop theories rather than adopting existing theories. These theories are developed systematically based on real data. The term "grounded" implies that each theory developed using this methodology is grounded in documented real data. Grounded theory is a methodology to acquire an understanding of the topic under study, investigating topic(s) that have not been comprehensively studied and topics whose knowledge is limited. The grounded theory steps include:

- Research design
- Data collection
- Three stages of coding: (a) open coding, (b) axial coding, and (c) selective coding
- Noting: recording interpretations of the data
- Developing a theory

3.2 Quantitative phase

The present study adopted a quantitative-qualitative methodology to analyze the data. Grounded theory and FDM were employed in the qualitative phase. Fuzzy DEMATEL was used in the quantitative phase to evaluate the effects and dependencies between the criteria. Cronbach's alpha was employed to measure the reliability of the questionnaire, whereas face validity and expert interviews were exploited to evaluate the validity of the questionnaire.

3.3 Fuzzy set theory and DEMATEL method

The basics of fuzzy set theory and the Fuzzy DEMATEL method are described below.

3.3.1 Fuzzy set theory

The theory of fuzzy sets was first introduced by Zadeh [67, 71]. In fuzzy theory, each member in a fuzzy set is assigned a membership degree, which is usually [0,1]. Trapezoidal, monotone, and triangle are common types of fuzzy membership functions [59]. A triangular fuzzy number (TFN) is used to simplify calculations in fuzzy environments. Definitions of fuzzy logic are described below [25].

Definition 3.1. *A fuzzy set $\tilde{A}$ is a subset of a universe of discourse X, which is characterized by a membership function le $\mu_{\tilde{A}}(x)$ representing a mapping $\mu_{\tilde{A}}:\ X \to [0,1]$. The function value of $\mu_{\tilde{A}}(x)\,\tilde{A}$ is called the membership value, which represents the degree of truth that x is an element of a fuzzy set $\tilde{A}$. It is assumed that $\mu_{\tilde{A}}(x)\,\epsilon[0,1]$, where $\mu_{\tilde{A}}(x) = 0$ reveals that x belongs completely to $\tilde{A}$, while indicates that x does not belong to the fuzzy set $\tilde{A}$.*

Definition 3.2. *A fuzzy set $\tilde{A}$ of the universe of discourse X is convex if and only if*

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)\,x_2) \geq \min\left(\mu_{\tilde{A}}(x_1),\ \mu_{\tilde{A}}(x_2)\right),\ \forall_x \in [x_1, x_2],\ \lambda \in [0,1]. \tag{1}$$

Definition 3.3. *A fuzzy set $\tilde{A}$ of the universe of discourse X is normal if*

$$max\mu_{\tilde{A}}(x) = 1. \tag{2}$$

Definition 3.4. *The α-cut of the fuzzy set $\tilde{A}$ of the universe of discourse X is defined as*

$$\tilde{A}_\alpha = \{x \in X \mid \mu_{\tilde{A}}(x) \geq \alpha\}. \tag{3}$$

where $\alpha \in [0,1]$.

Definition 3.5. *A fuzzy number $\tilde{N}$ is a fuzzy subset in the universe of discourse X, which is both convex and normal.*

Definition 3.6. *Let $\tilde{N}$ be a fuzzy number and $\tilde{N}_\alpha$ be the a-cut of $\tilde{N}$. If the lower bound of $\tilde{N}_\alpha$, > 0 for $\alpha \in$ [0,1], then $\tilde{N}$ is called a positive fuzzy number.*

Definition 3.7. *A triangular fuzzy number $\tilde{N}$ can be defined as a triplet (l, m, u), and the membership function $\mu_{\tilde{N}}(x)$ is defined as:*

$$\mu_{\tilde{N}}(x) = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0, & x > u \end{cases} \tag{4}$$

where l, m, and u are real numbers and $l \leq m \leq u$. See Fig. 2.

Theorem 3.8. *Let $\tilde{N} = (l, m, u)$ be a triangular fuzzy number and k > 0 a crisp number, then*

$$k \times \tilde{N} = (kl,\ km,\ ku). \tag{5}$$

Theorem 3.9. *Let $\tilde{N}_1 = (l_1, m_1, u_1)$ and $\tilde{N}_2 = (l_2, m_2, u_2)$ be two triangular fuzzy numbers. The addition operations of $\tilde{N}_1$ and $\tilde{N}_2$, denoted by $\tilde{N}_1 \bigoplus \tilde{N}_2$ yield another triangular fuzzy number.*

$$\tilde{N}_1 \bigoplus \tilde{N}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2). \tag{6}$$

Theorem 3.10. *Let $\tilde{N}_1 = (l_1, m_1, u_1)$ and $\tilde{N}_2 = (l_2, m_2, u_2)$ be two triangular fuzzy numbers. The multiplication of $\tilde{N}_1$ and $\tilde{N}_2$, denoted by $\tilde{N}_1 \otimes \tilde{N}_2$, is defined by the membership function $\mu_{\tilde{N}_1 \bigotimes \tilde{N}_2}$ as follows [34]:*

$$\begin{cases} 0 & ; x \leq l_1 l_2 \\ \frac{2l_1l_2 - l_1m_2 - l_2m_1 + \sqrt{[l_1(m_2-l_2) - l_2(m_1-l_1)]^2 + 4x(m_1-l_1)(m_2-l_2)}}{2(m_1-l_1)(m_2-l_2)} & ; l_1l_2 \leq x \leq m_1m_2 \\ \frac{2u_1u_2 - u_1m_2 - u_2m_1 + \sqrt{[u_1(u_2-m_2) - u_2(u_1-m_1)]^2 + 4x(u_1-m_1)(u_2-m_2)}}{2(u_1-m_1)(u_2-m_2)} & ; m_1m_2 \leq x \leq u_1u_2 \\ 0 & ; x \geq u_1u_2 \end{cases} \tag{7}$$

$\tilde{N}_1 \otimes \tilde{N}_2$ is not a triangular fuzzy number. However, the following property provides an approximation formula to regard $\tilde{N}_1 \otimes \tilde{N}_2$ as a triangular fuzzy number.

Theorem 3.11. *Let $\tilde{N}_1 = (l_1, m_1, u_1)$ and $\tilde{N}_2 = (l_2, m_2, u_2)$ be two positive triangular fuzzy numbers, $\tilde{N}_1 \otimes \tilde{N}_2$ approximates a triangular fuzzy number $(l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$ [63], i.e.,*

$$\tilde{N}_1 \bigotimes \tilde{N}_2 \cong (l_1 + l_2, m_1 + m_2, u_1 + u_2). \tag{8}$$

See Fig. 3.

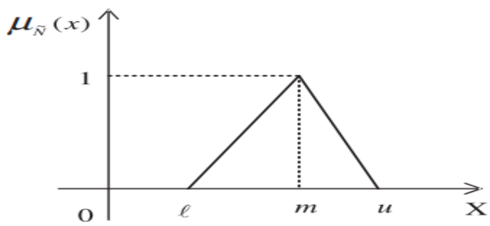


Figure 2: A triangular fuzzy number $\tilde{N}$

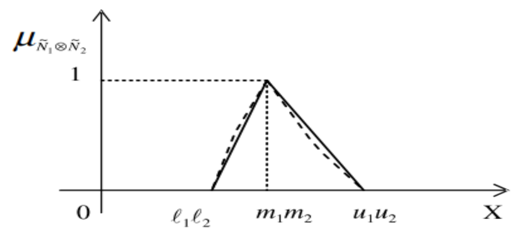


Figure 3: Membership function of $\tilde{N}_1 \bigotimes \tilde{N}_2$ and its approximation

Definition 3.12. *Linguistic variables are used as variables whose values are not numbers but linguistic terms [68].*

The linguistic-variable approach is usually employed by decision-makers to express their assessments, which is very useful in dealing with ill-defined situations in traditional quantitative expressions. Linguistic values can be represented with fuzzy numbers. In particular, triangular fuzzy numbers are commonly used.

As with that fuzziest model, we had to convert the final fuzzy data into a crisp value. Here, we used the CFCS method proposed by [46] for defuzzification. This method has the advantages of giving a greater crisp value with a greater membership function and distinguishing two symmetrical triangular fuzzy numbers with the same mean.

3.4 Fuzzy Delphi method

The Fuzzy Delphi method was first introduced by Kaufmann and Gupta [24] and then developed by Ishikawa et al [23]. The Fuzzy Delphi method is a combination of the Delphi method and fuzzy set theory. In this method, linguistic variables are used by experts. [45] found that the use of the Fuzzy Delphi method for group decisions can lead to a common understanding of the opinions of experts [23, 45]. In this research, first, a triangular fuzzy numerical assignment was collected from the expert's point of view according to the language word chosen by them to collect the opinions of the decision-making group. Then, to calculate the evaluation value, the triangular fuzzy number of each criterion was used, which was given to that criterion by experts [5].

Step 1. gathers fuzzy expert opinions, E_i; i = 1, …, n, In the fuzzy method, qualitative variables are usually defined as triangular or trapezoidal fuzzy numbers. Suppose definite numbers are defined as trapezoidal fuzzy numbers such as the following:

$$\tilde{A}^{(i)} = \left(a_1^{(i)},\ a_2^{(i)},\ a_3^{(i)},\ a_4^{(i)}\right),\ i = 1, \ldots, n. \tag{9}$$

Step 2. Fuzzy average method is used for the aggregation of experts' opinions. The mean $\tilde{A}_m$ of all $\tilde{A}^{(i)}$ is computed. Hence

$$\tilde{A}^{(i)} = (a_{m1}, a_{m2}, a_{m3}, a_{m4}) = \left(\frac{1}{n}\sum_{i=1}^{n} a_1^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_2^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_3^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_4^{(i)}\right). \tag{10}$$

In this relationship, $\tilde{A}^{(i)}$ represents the expert point of view, and $\tilde{A}_m$ represents the average of the experts' views, and the difference between any expert's opinion and the average of opinions is calculated and the fuzzy Delphi cycle is repeated.

Then for each expert E_i the differences

$$\left(a_{m1} - a_1^{(i)}, a_{m2} - a_2^{(i)}, a_{m3} - a_3^{(i)}, a_{m4} - a_4^{(i)}\right) = \left(\frac{1}{n}\sum_{i=1}^{n} a_1^{(i)} - a_1^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_2^{(i)} - a_2^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_3^{(i)} - a_3^{(i)}, \frac{1}{n}\sum_{i=1}^{n} a_4^{(i)} - a_4^{(i)}\right). \tag{11}$$

are found and sent back to the expert E_i for reexamination.

Step 3. Each expert E_i presents a revised trapezoidal fuzzy number

$$\tilde{B}^{(i)} = \left(b_1^{(i)}, b_2^{(i)}, b_3^{(i)}, b_4^{(i)}\right),\quad i = 1, \ldots, n. \tag{12}$$

This process starts with Step 2 and is repeated. The average $\tilde{B}_m$ is calculated by the formula (10) with the differences that now a $a_1^{(i)},\ a_2^{(i)},\ a_3^{(i)},\ a_4^{(i)}$ are substituted correspondingly by $b_1^{(i)}, b_2^{(i)}, b_3^{(i)}, b_4^{(i)}$. If it still necessary new trapezoidal fuzzy numbers $\tilde{C}^{(i)} = \left(c_1^{(i)}, c_2^{(i)}, c_3^{(i)}, c_4^{(i)}\right)$ are presented, and their average $\tilde{C}_m$ is calculated. The process could be repeated again and again until successive means $\tilde{A}_m$, $\tilde{B}_m$, $\tilde{C}_m$, ... become reasonably close (we can define the distance of two fuzzy numbers, $d_i \leq 0.2$).

Step 4. At a later time, the same process may reexamine the ratings, if there is important information available due to new discoveries. The fuzzy Delphi steps used in this study are:

Step I. Identification of the criteria through a comprehensive review of the theoretical foundations and expert interviews (in MAXQDA)

Step II. Collecting the views of decision-making experts; to screen the criteria and evaluate whether they were relevant, questionnaires were delivered to experts so that they would linguistically evaluate the importance of each criterion, as shown in Table 1.

Table 1: Linguistic expressions and FDM numbers [41]

Linguistic terms	Abbreviations	Triangular fuzzy numbers
Very low	VL	(0, 0, 0.25)
Low	L	(0, 0.25, 0.50)
Medium	M	(0.25, 0.50, 0.75)
High	H	(0.50, 0.75, 1)
Very high	VH	(0.75, 1, 1)

Step III. Verification and screening of the criteria

Step IV. Completion of FDM; the FDM procedure would be completed once the mean difference between two consecutive rounds decreased below 0.1 [9].

3.5 DEMATEL method

The DEMATEL method is a decision method that is used to solve multi-criteria decision problems [35]. This method identifies the factors in a system according to experts and is based on directional diagrams. This method uses graph theory to derive cause-and-effect relationships between factors [3].

3.5.1 Comparison with Other MCDM Methods

The DEMATEL method has been compared with some other MCDM methods to show its advantages and disadvantages. We choose the most commonly used methods in MCDM, that is, analytic hierarchical process (AHP), grey relational analysis (GRA), Technique for order performance by similarity to ideal solution (TOPSIS), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), ELECTRE (Elimination Et Choix Traduisant la REalite) and analytic network process (ANP), to compare the procedural basis of these MCDM methods [57]. In the AHP, a hierarchy considers the distribution of a goal among the elements being compared and judges which element has a greater influence on that goal [27, 29]. The GRA is an impact evaluation model that measures the degree of similarity or difference between two sequences based on relation grade [12]. The VIKOR method introduces the ranking index based on the particular measure of "closeness" to the ideal solution by using linear normalization [47]. The basic principle of the TOPSIS is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution [70]. The ELECTRE is a prominent outranking MCDM technique, which selects the best action from a proposed set of ones based on multiattribute utility theory [54]. Compared with these MCDM methods, the DEMATEL method has the following advantages: It effectively analyzes the mutual influences (both direct and indirect effects) among different factors and understands the complicated cause and effect relationships in the decision-making problem. It can visualize the interrelationships between factors via an IRM and enable the decision maker to clearly understand which factors have mutual influences on one another. The DEMATEL can be used not only to determine the ranking of alternatives but also to find out critical evaluation criteria and measure the weights of evaluation criteria. Although the AHP can be applied to rank alternatives and determine criteria weights, it assumes that the criteria are independent and fails to consider their interactions and dependencies. The ANP, an advanced version of the AHP, can deal with the dependence and feedback between criteria; but as indicated in [28, 38], the assumption of equal weight for each cluster to obtain a weighted supermatrix in the ANP is not reasonable in practical situations.

On the other hand, in comparison to other MCDM methods, the possible disadvantages of the DEMATEL method may be the following: It determines the ranking of alternatives based on interdependent relationships among them, but other criteria are not incorporated in the decision-making problem. The relative weights of experts are not considered in aggregating personal judgments of experts into group assessments. It cannot take into account the aspiration level of alternatives as in the GRA and VIKOR methods or obtain partial ranking orders of alternatives as in the ELECTRE approach. Therefore, the DEMATEL has been integrated with other MCDM methods to combine their desired properties in the literature. Next, we will discuss the situations in which it is more appropriate to use the DEMATEL method before some other methods [57].

3.5.2 Fuzzy DEMATEL method

In the original DEMATEL, the relationships of decision factors are assessed by crisp values to establish a structural model. To deal with the uncertainty and ambiguity in the verbal expressions of the respondents, the fuzzy approach of the DEMATEL method is used. This method is used with the fuzzy set theory presented in Fig. 4 [1].

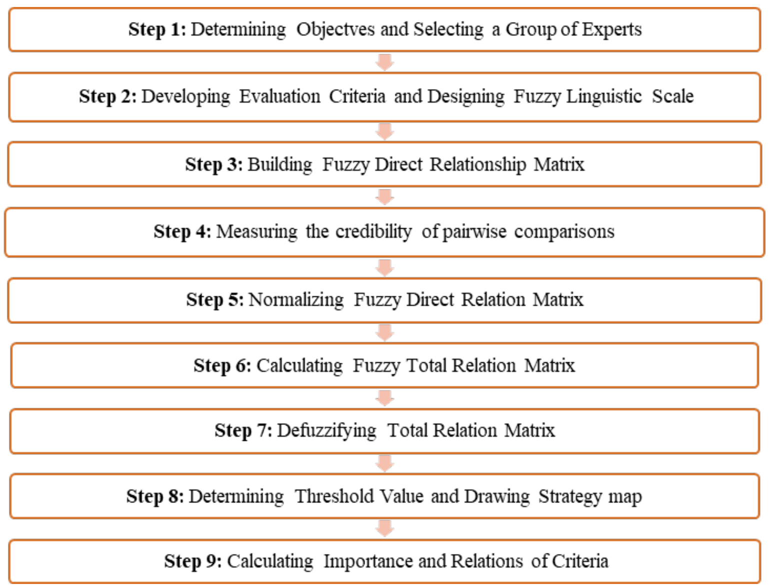


Figure 4: Fuzzy DEMATEL algorithm

The fuzzy DEMATEL method is summarized as follows [36].

Step 1. Set a goal and form a group of experts to gather their group knowledge to solve the problem [20, 47].

Step 2. Develop evaluation criteria and design the fuzzy linguistic scale: In this step, the dimensions and components of the research are identified using the opinions of experts. The criteria to be evaluated will be selected according to the areas under study. The linguistic scales used in this method and their corresponding values are given in Table 2. The fuzzy numbers used in this study are of the triangular fuzzy type [7].

Table 2: The fuzzy linguistic scales for evaluation in the Fuzzy DEMATEL method [7].

Linguistic terms	Definitive equivalent	Triangular fuzzy numbers
No influence (No)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.50)
Low influence (L)	2	(0.25, 0.50, 0.75)
High influence (H)	3	(0.50, 0.75, 1)
Very high influence (VH)	4	(0.75, 1, 1)

Step 3. Building a fuzzy matrix of initial direct relations based on expert views. To measure the relations between criteria, it is required to organize the criteria in a square matrix to undergo pairwise comparisons based on expert views. The experts would express their views based on Table 2. For n criteria and p experts, there would be a total of p fuzzy matrices $Z^1,\ Z^2,\dots,\ Z^{(P)}$, each corresponding to the views of one expert with triangular fuzzy numbers as their elements. Matrix $\tilde{Z}^{(k)}$ is written as:

$$\tilde{Z}^{(k)}=\begin{bmatrix} 0 & \cdots & \tilde{z}_{1n}^{(k)} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{n1}^{(k)} & \cdots & 0 \end{bmatrix};k=1,2,\dots,P, \tag{13}$$

where $\tilde{z}_{ij}^{(k)} = \left(l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}\right)$. Without loss of generality, elements $\tilde{z}_{ij}^{(k)} (i = 1, 2, \ldots, n)$ will be regarded as a triangular fuzzy number (0, 0, 0) whenever it is necessary. Fuzzy matrix $Z^{(k)}$ is called the initial direct-relation fuzzy matrix of expert k.

Step 4. After taking the experts' opinions, the credibility of pairwise comparisons should be checked. To measure the level of credibility of the data, first, the inconsistent rate (g) is obtained from the following relationship. The (g) value obtained should be less than 5%. [64].

$$g = \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{|z_{ij}^{p} - z_{ij}^{p-1}|}{z_{ij}^{p}} \times 100. \tag{14}$$

Credibility is also obtained from the following relationship

$$Credibility = 1 - g. \tag{15}$$

Step 5. Acquire the normalized direct-relation fuzzy matrix. Let $\tilde{a}_{ij}^{(k)}$ be the triangular fuzzy numbers,

$$\tilde{a}_{ij} = \sum_{j=1}^{n} \tilde{z}_{ij}^{(k)} = (\sum_{j=1}^{n} l_{ij}^{(k)}, \sum_{j=1}^{n} m_{ij}^{(k)}, \sum_{j=1}^{n} u_{ij}^{(k)}) \ and \ r^{(k)} = \max_{1 \le i \le n} (\sum_{j=1}^{n} u_{ij}^{(k)}) \ . \tag{16}$$

The linear scale transformation is then used as a normalization formula to transform the criteria scales into comparable scales. The normalized direct-relation fuzzy matrix of expert k, denoted as $\tilde{X}^{(k)}$, is given by

$$\tilde{X}^{(k)} = \begin{bmatrix} \tilde{x}_{11}^{(k)} & \cdots & \tilde{x}_{1n}^{(k)} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{n1}^{(k)} & \cdots & \tilde{x}_{nn}^{(k)} \end{bmatrix} ; k = 1, 2, \ldots, p, \tag{17}$$

where

$$\tilde{x}_{ij}^{(k)} = \frac{\tilde{z}_{ij}^{(k)}}{r^{(k)}} = \left(\frac{l_{ij}^{(k)}}{r^{(k)}}, \frac{m_{ij}^{(k)}}{r^{(k)}}, \frac{u_{ij}^{(k)}}{r^{(k)}}\right). \tag{18}$$

Step 6. Calculating the fuzzy total relation matrix. The fuzzy total relation matrix $\widetilde{T_c}$ is calculated as:

$$\widetilde{T_c} = \lim_{k \to +\infty} (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \cdots \oplus \tilde{x}^k) \ . \quad \text{and} \quad \widetilde{T_c} = \begin{bmatrix} \tilde{t}_{11} & \cdots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \cdots & \tilde{t}_{nn} \end{bmatrix}. \tag{19}$$

where $\tilde{t}_{\mathrm{ij}} = (l\ ''_{\mathrm{ij}}, \mathrm{m}\ ''_{\mathrm{ij}}, \mathrm{u}\ ''_{\mathrm{ij}})$, then

$$\text{Matrix}[l\ ''_{ij}] = X_l \times (I - X_l)^{-1}, \tag{20}$$

$$\text{Matrix}[m\ ''_{ij}] = X_m \times (I - X_m)^{-1}, \tag{21}$$

$$\text{Matrix}[u\ ''_{ij}] = X_u \times (I - X_u)^{-1}. \tag{22}$$

Step 7. Defuzzification of the total relation matrix. The Converting Fuzzy data into Crisp Scores (CFCS) defuzzification method was used. The CFCS output is a matrix of crisp scores. The defuzzification stages are:

Stage I. normalization

$$l_{ij}^{n} = \frac{\left(l_{ij}^{t} - min\ l_{ij}^{t}\ \right)}{\Delta_{min}^{max}}. \tag{23}$$

$$m_{ij}^{n} = \frac{(m_{ij}^{t} - min\ l_{ij}^{t})}{\Delta_{min}^{max}}. \tag{24}$$

$$u_{ij}^{n} = \frac{(u_{ij}^{t} - min\ l_{ij}^{t})}{\Delta_{min}^{max}}. \tag{25}$$

So that:

$$\Delta_{min}^{max} = max\ u_{ij}^{t} - min\ l_{ij}^{t}\ . \tag{26}$$

Stage II. Calculating the upper and lower bounds of the normal scores

$$l_{ij}^{s} = m_{ij}^{n}/(1 + m_{ij}^{n} - l_{ij}^{n}). \tag{27}$$

$$u_{ij}^{s} = u_{ij}^{n}/(1 + u_{ij}^{n} - l_{ij}^{n}). \tag{28}$$

Stage III. Calculating the total normalized crisp scores

$$x_{ij} = \frac{[l_{ij}^{s}\left(1 - l_{ij}^{s}\right) + u_{ij}^{s} \times u_{ij}^{s}]}{[1 - l_{ij}^{s} + u_{ij}^{s}]}. \tag{29}$$

Stage IV. Calculating the crisp scores

$$T_c = min\ l_{ij}^{n} + (x_{ij} \times \Delta_{min}^{max}). \tag{30}$$

Step 8. Determining the threshold value and drawing the strategy map. The crisp values of the defuzzified total relation matrix that are smaller than the mean total relation matrix are identified and set to 0 using Eq. (29). In other words, those relations are not considered to be causes. Finally, a strategy map is drawn based on the relations.
where T_C: Crisp total relation matrix

$$T_c = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nn} \end{bmatrix}; i, j = 1, 2, \ldots, n. \tag{31}$$

$$TS = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} t_{ij}}{m \times n}. \tag{32}$$

$$U_{ij} = \begin{cases} t_{ij} & t_{ij} \geq TS \\ 0 & \text{Others} \end{cases} \tag{33}$$

Step 9. Calculating the importance and relations of the criteria. The sum of the rows D and the sum of the columns R in the defuzzified total relation matrix is obtained as:

$$D_i = \sum_{j=1}^{n} t_{ij}\ (i = 1,\ 2,\ \ldots,\ n). \tag{34}$$

$$R_j = \sum_{i=1}^{n} t_{ij}\ (j = 1,\ 2,\ \ldots,\ n). \tag{35}$$

Then, D+R and D-R are calculated, which represent the interaction and influence of the factors, respectively.

3.5.3 Fuzzy DANP method

The combined method of Fuzzy decision-making trial and evaluation laboratory (FDEMATEL)-based analytic network process (ANP) is known as the Fuzzy DANP method. The mist of the interrelations among sustainable development model of the agricultural sector under critical circumstances (COVID-19) criteria is fulfilled by the Fuzzy DEMATEL method, which illustrates the behavior of the criteria within the complex framework. It demonstrates the existence of every relationship as well as the influence degrees of any relationship. The next stage is to weight the important level of each criterion by the Fuzzy DANP method. are shown and explained briefly in Fig. 5 [10, 22, 49, 58, 66].
In Step 9, the degrees of influence of criteria are different from each other. The fuzzy ANP method can be used to obtain the weight of the criteria and their prioritization, as well as to compare with the results of the Fuzzy DEMATEL method. But the cluster-weighted supermatrix that was obtained by using the traditional average method (equal cluster-weighted) in ANP is irrational [64]. Therefore, to solve this problem, the normalized matrix $\tilde{T}_c$ which is obtained influential cluster-weighted by DEMATEL method results, is combined with the procedure of the ANP method in this study. The Fuzzy DANP method is summarized as follows [2, 8, 10, 26, 49, 48, 58, 64].

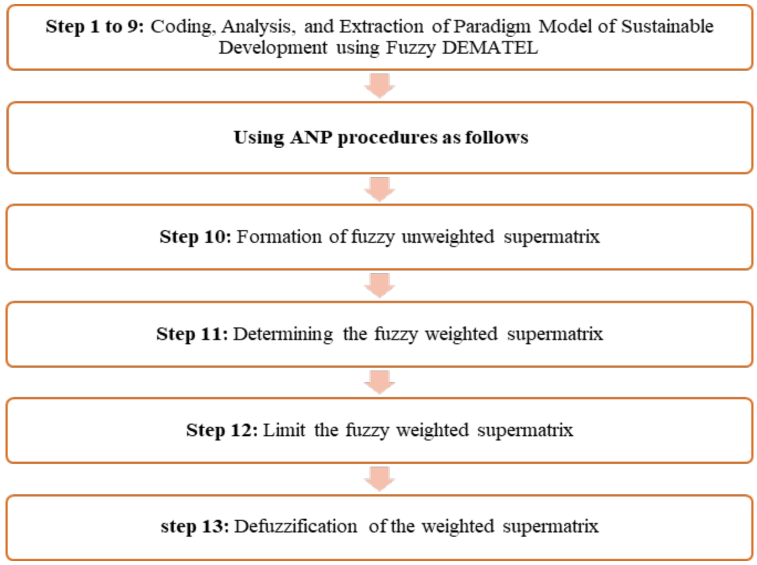


Figure 5: Fuzzy DANP algorithm

We call the fuzzy total relation matrix $\tilde{T}_c = [\tilde{t}_{ij}]_{n\times n}$ obtained by criteria and $\tilde{T}_D = [\tilde{t}^D_{ij}]_{m\times m}$ obtained by dimension from $\tilde{T}_c$. Then, we normalize the supermatrix $\tilde{T}_c$ for the ANP weights of dimension by using the relation matrix $\tilde{T}_D$.

Step 10 Formation of fuzzy unweighted supermatrix. The fuzzy total relation matrix $(\tilde{T}_c)$ will be obtained from Fuzzy DEMATEL. Each row will sum for normalization.

$$\tilde{T}_c = \begin{array}{c c} & \begin{array}{ccc} D_1 & D_j & D_n \\ c_{11}\dots c_{1m_1}\cdots & c_{j1}\dots c_{jm_j}\cdots & c_{n1}\dots c_{nm_n} \end{array} \\ \begin{array}{cc} D_1 & c_{11} \\ \vdots & \vdots \\ & c_{1m_1} \\ & c_{i1} \\ D_i & \vdots \\ \vdots & c_{im_i} \\ & c_{n1} \\ D_3 & \vdots \\ & c_{nm_n} \end{array} & \begin{bmatrix} \tilde{T}_c^{11} & \dots & \tilde{T}_c^{1j} & \dots & \tilde{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{T}_c^{i1} & \dots & \tilde{T}_c^{ij} & \dots & \tilde{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{T}_c^{n1} & \dots & \tilde{T}_c^{nj} & \dots & \tilde{T}_c^{nn} \end{bmatrix} \end{array} \tag{36}$$

After normalizing the fuzzy total relation matrix $\tilde{T}_c$ by dimensions, we will obtain a new matrix $\tilde{T}_c^{\alpha}$ which is shown in Eq. (37).

$$\tilde{T}_c^{\alpha} = \begin{array}{c c} & \begin{array}{ccc} D_1 & D_j & D_n \\ c_{11}\dots c_{1m_1}\cdots & c_{j1}\dots c_{jm_j}\cdots & c_{n1}\dots c_{nm_n} \end{array} \\ \begin{array}{cc} D_1 & c_{11} \\ \vdots & \vdots \\ & c_{1m_1} \\ & c_{i1} \\ D_i & \vdots \\ \vdots & c_{im_i} \\ & c_{n1} \\ D_3 & \vdots \\ & c_{nm_n} \end{array} & \begin{bmatrix} \tilde{T}_c^{\alpha 11} & \dots & \tilde{T}_c^{\alpha 1j} & \dots & \tilde{T}_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{T}_c^{\alpha i1} & \dots & \tilde{T}_c^{\alpha ij} & \dots & \tilde{T}_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ \tilde{T}_c^{\alpha n1} & \dots & \tilde{T}_c^{\alpha nj} & \dots & \tilde{T}_c^{\alpha nn} \end{bmatrix} \end{array} \tag{37}$$

In addition, an explanation for the normalization of $\tilde{T}_c^{\alpha 11}$ is shown as Eqs. (39), (40), and other $\tilde{T}_c^{\alpha nn}$ are as above.

$$\tilde{d}_{cj}^{11} = \sum_{i=1}^{m_1} \tilde{t}_{ij}^{11},\ j = 1,\ 2,\ \dots,\ m_1, \tag{38}$$

$$\tilde{T}_c^{\alpha 11} = \begin{bmatrix} \tilde{t}_{c11}^{11}/\tilde{d}_{c1}^{11} & \cdots & \tilde{t}_{c1j}^{11}/\tilde{d}_{c1}^{11} & \cdots & \tilde{t}_{c1m_1}^{11}/\tilde{d}_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{ci1}^{11}/\tilde{d}_{cj}^{11} & \cdots & \tilde{t}_{cij}^{11}/\tilde{d}_{cj}^{11} & \cdots & \tilde{t}_{cim_1}^{11}/\tilde{d}_{cj}^{11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{cm_11}^{11}/\tilde{d}_{cm_1}^{11} & \cdots & \tilde{t}_{cm_1j}^{11}/\tilde{d}_{cm_1}^{11} & \cdots & \tilde{t}_{cm_1m_1}^{11}/\tilde{d}_{cm_1}^{11} \end{bmatrix} = \begin{bmatrix} \tilde{t}_{c11}^{\alpha 11} & \cdots & \tilde{t}_{c1j}^{\alpha 11} & \cdots & \tilde{t}_{c1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{ci1}^{\alpha 11} & \cdots & \tilde{t}_{cij}^{\alpha 11} & \cdots & \tilde{t}_{cim_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{cm_11}^{\alpha 11} & \cdots & \tilde{t}_{cm_1j}^{\alpha 11} & \cdots & \tilde{t}_{cm_1m_1}^{\alpha 11} \end{bmatrix}. \tag{39}$$

Let the fuzzy total relation matrix match and fill into the interdependence clusters. It is called fuzzy unweighted supermatrix is shown as Eq. (40). which is based on transposing the normalized fuzzy total relation matrix $\tilde{T}_c^{\alpha}$ by dimensions (clusters), i.e., $\tilde{W}_c = (\tilde{T}_c^{\alpha})$

$$\tilde{W}_c = (\tilde{T}_c^{\alpha}) = \begin{array}{cc} & \\ D_1 & \begin{array}{c} c_{11} \\ \vdots \\ c_{1m_1} \end{array} \\ D_i & \begin{array}{c} c_{j1} \\ \vdots \\ c_{jm_j} \end{array} \\ D_3 & \begin{array}{c} c_{n1} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \overset{\begin{array}{ccc} D_1 & D_j & D_n \\ c_{11}\ldots c_{1m_1}\cdots & c_{i1}\ldots c_{im_i}\cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \tilde{W}_c^{11} & \cdots & \tilde{W}_c^{1i} & \cdots & \tilde{W}_c^{n1} \\ \vdots & & \vdots & & \vdots \\ \tilde{W}_c^{1j} & \cdots & \tilde{W}_c^{ij} & \cdots & \tilde{W}_c^{nj} \\ \vdots & & \vdots & & \vdots \\ \tilde{W}_c^{1n} & \cdots & \tilde{W}_c^{in} & \cdots & \tilde{W}_c^{nn} \end{bmatrix}}. \tag{40}$$

If the matrix $\tilde{W_c}^{11}$ is blank or 0 which is shown as Eq. (41) means the matrix between the clusters or criteria is independent and with no interdependent, and the other $\tilde{W_c}^{nn}$ are as above.

$$\tilde{W_c}^{11} = \begin{array}{c} C_{11} \\ \vdots \\ C_{1j} \\ \vdots \\ C_{1m_1} \end{array} \overset{\begin{array}{ccccc} C_{11} & \cdots & C_{1i} & \cdots & C_{1m_1} \end{array}}{\begin{bmatrix} \tilde{t}_{c11}^{\alpha 11} & \cdots & \tilde{t}_{ci1}^{\alpha 11} & \cdots & \tilde{t}_{cm_11}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{c1j}^{\alpha 11} & \cdots & \tilde{t}_{cij}^{\alpha 11} & \cdots & \tilde{t}_{cm_1j}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_{c1m_1}^{\alpha 11} & \cdots & \tilde{t}_{cim_1}^{\alpha 11} & \cdots & \tilde{t}_{cm_1m_1}^{\alpha 11} \end{bmatrix}}. \tag{41}$$

Step 11. Determining the fuzzy weighted supermatrix. For obtaining the Fuzzy weighted Supermatrix, each row will sum for normalization as Eq. (42).

$$\tilde{T}_D = \begin{bmatrix} \tilde{t}_D^{11} & \cdots & \tilde{t}_D^{1j} & \cdots & \tilde{t}_D^{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_D^{i1} & \cdots & \tilde{t}_D^{ij} & \cdots & \tilde{t}_D^{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_D^{n1} & \cdots & \tilde{t}_D^{nj} & \cdots & \tilde{t}_D^{nn} \end{bmatrix}. \tag{42}$$

We normalized the fuzzy total relation matrix $\tilde{T}_D$ and obtained a new matrix $\tilde{T}_D^{\alpha}$ shown as Eq. (44). where

$$\tilde{d}_j = \sum_{i=1}^{n} \tilde{t}_D^{ij}, j = 1,\ 2,\ \ldots,\ n, \tag{43}$$

$$\tilde{T}_D^{\alpha} = \begin{bmatrix} \tilde{t}_D^{11}/\tilde{d}_1 & \cdots & \tilde{t}_D^{1j}/\tilde{d}_j & \cdots & \tilde{t}_D^{1n}/\tilde{d}_j \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_D^{i1}/d_j & \cdots & \tilde{t}_D^{ij}/\tilde{d}_j & \cdots & \tilde{t}_D^{in}/\tilde{d}_j \\ \vdots & & \vdots & \vdots & \\ \tilde{t}_D^{n1}/\tilde{d}_n & \cdots & \tilde{t}_D^{nj}/\tilde{d}_j & \cdots & \tilde{t}_D^{nn}/\tilde{d}_j \end{bmatrix} = \begin{bmatrix} \tilde{t}_D^{\alpha 11} & \cdots & \tilde{t}_D^{\alpha 1j} & \cdots & \tilde{t}_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_D^{\alpha i1} & \cdots & \tilde{t}_D^{\alpha ij} & \cdots & \tilde{t}_D^{\alpha in} \\ \vdots & & \vdots & \vdots & \\ \tilde{t}_D^{\alpha n1} & \cdots & \tilde{t}_D^{\alpha nj} & \cdots & \tilde{t}_D^{\alpha nn} \end{bmatrix}. \tag{44}$$

Let the normalized fuzzy total relation matrix $\tilde{T}_D^{\alpha}$ fill into the fuzzy unweighted supermatrix to obtain the fuzzy weighted supermatrix.

$$\tilde{W}^{\alpha} = \tilde{T}_D^{\alpha}\tilde{W}_c = \begin{bmatrix} \tilde{t}_D^{\alpha 11} \times \tilde{W}_c^{\,11} & \cdots & \tilde{t}_D^{\alpha 1j} \times \tilde{W}_c^{\,1j} & \cdots & \tilde{t}_D^{\alpha 1n} \times \tilde{W}_c^{\,1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{t}_D^{\alpha i1} \times \tilde{W}_c^{\,i1} & \cdots & \tilde{t}_D^{\alpha ij} \times \tilde{W}_c^{\,ij} & \cdots & \tilde{t}_D^{\alpha in} \times \tilde{W}_c^{\,in} \\ \vdots & & \vdots & \vdots & \\ \tilde{t}_D^{\alpha n1} \times \tilde{W}_c^{\,n1} & \cdots & \tilde{t}_D^{\alpha nj} \times \tilde{W}_c^{\,nj} & \cdots & \tilde{t}_D^{\alpha nn} \times \tilde{W}_c^{\,nn} \end{bmatrix}. \tag{45}$$

Step 12. Limit the fuzzy weighted supermatrix by raising it to a sufficiently large power k, until the fuzzy supermatrix has converged and become a long-term stable supermatrix to get the global priority vectors, called ANP weights, Eq. (46).

$$\tilde{w} = \lim_{k\to\infty} \left(\tilde{W}^{\alpha}\right)^{k}. \tag{46}$$

Step 13. Defuzzification of the weighted supermatrix. At this step, the fuzzy numbers are transformed into crisp values by the center of area method. Defuzzification by the center of area method is simple and practical. It determines the best-defuzzified value (BDV) of fuzzy numbers [22]. The BDV value of the triangular fuzzy number $\mu_{\tilde{A}}(x)$ can be constructed with Eq. (47).

$$w = BDV = \frac{1}{3}(l + m + u). \tag{47}$$

4 Implementation and findings

4.1 Selection of experts through snowball sampling

To select the panel participants, snowball sampling was employed. Two experts (Experts in economics, extension, and sustainability of agriculture) were first identified and asked to introduce other experts with relevant knowledge. A list of 28 experts was obtained. Then, a form of the subject, objective, and time and number of rounds was delivered to the experts, and they were asked to express their consent to participate in the panel. A total of 20 experts agreed to participate in the study. A list of agricultural sustainable development factors was identified by reviewing earlier works and interviewing the experts, and the questionnaires were delivered in closed and open forms to the experts to score the factors and add other factors that would impact sustainable development in the agricultural sector under critical circumstances (COVID-19 pandemic). This was continued until the experts no longer had new factors to propose (i.e., theoretical saturation).

4.2 Identification of factors using FDM and grounded theory

The literature was reviewed to provide a list of factors affecting sustainable development in the agricultural sector. Then, the experts were subjected to an interview of seventeen questions, as shown in Table 3.

Table 3: Interview questions

1. How do you define sustainable development?
2. How do you define sustainable development in the agricultural sector?
3. How do you define sustainable development under critical circumstances (COVID-19)?
4. How do you define sustainable development in the agriculture sector under critical circumstances (COVID-19)?

5. What are the factors and indices (criteria and sub-criteria) of sustainable development in the agricultural sector?
6. How can sustainable development be expanded in the agricultural sector to protect the environment and prevent the degradation of non-renewable resources?
7. How do you describe the general agricultural sustainable development policies of national and international agriculture-related organizations?
8. How do you describe the influence of farming smartification on agricultural sustainable development?
9. What are the economic, social, and environmental outcomes of sustainable development in agriculture?
10. How do you describe agricultural development, particularly sustainable development, in Iran?
11. What are the climatic and ecosystem capacities of Iran for sustainable agriculture?
12. What are the challenges currently encountered by agriculture, particularly sustainable agriculture, during the COVID-19 pandemic in Iran?
13. What organizations can contribute to sustainable development in agriculture under critical circumstances (COVID-19)?
14. What are the important infrastructural factors and indices (criteria and sub-criteria) in proposing a sustainable development model for agriculture under critical circumstances (COVID-19)?
15. How and why are the above-mentioned factors prioritized?
16. How do these factors relate to each other?
17. How do you describe the agricultural sustainable development model under critical circumstances (COVID-19)?

The interview responses were coded and classified using open and axial coding. Table 4 reports open coding, whereas Table 5 provides axial and selective coding.

Table 4: Open codes

Expressed Evidence (Interviews)	Extracted Concepts (Initial Codes)	Interviewee
Supporting the youth, women, and knowledge-based companies to establish novel businesses	Entrepreneurship, agricultural and rural collaborations, sustainable employment, science and technology, supportive policies	A01
Resilience improvement of the healthcare system to cope with emerging diseases and epidemics	Healthcare, mobilization of facilities, science, and technology, supportive policies	A04
International joint economic agreements in critical circumstances	Robust markets, supply chain, food security, farmer loss minimization, agricultural trade development	A07

Table 5: Axial and selective codes

Axial Code	Codes (Extracted Concepts)
Entrepreneurial Factors	Promoting entrepreneurial culture, skill-based training, and employment of agriculture graduates
Health Factors	Rural health houses, public vaccination, healthy village, medical insurance for critical circumstances
Economic Factors	Facilitating crop exports in critical circumstances, crop insurance status in critical circumstances, the proportion of medicine and treatment costs in the total farmer income

A total of 80 factors were extracted from earlier works and interviews using MAXQDA. A questionnaire was designed based on the factors and delivered to the respondents (A sample of 20 people from Experts in economics, extension, and sustainability of agriculture). They were requested to express to what extent they agreed with the factors using the linguistic indices (Table 1). A total of 72 sub-criteria were identified. Table 6 provides the 10 main criteria and 72 sub-criteria.

Table 6: main Criteria and sub-criteria

Main Criteria	Sub-criteria	Symbol
Health factors (MC1)	Public vaccination status	SC1-1
	Free healthcare services	SC1-2
	Number of rural health houses	SC1-3
	Access to doctors	SC1-4
	Access to medicines	SC1-5
	Access to hospitals	SC1-6
	Medical insurance for critical circumstances	SC1-7
	Healthcare plan updating rate for critical circumstances	SC1-8
	Establishment and enhancement of infrastructures to produce raw materials, medicines, vaccines, bioproducts, and medical equipment at international quality levels	SC1-9
	Sustainable financing in healthcare	SC1-10
	Enhancement of mental health and happy life in society	SC1-11

	Importance of prevention preference over treatment	SC1-12
	Promoting the cultivation of medicinal plants under the Ministry of Agriculture	SC1-13
Social factors (MC2)	Individual development of farmers	SC2-1
	Compliance with health protocols in critical circumstances	SC2-2
	Professional ethics of farmers (preference of social interests over personal interests)	SC2-3
	Importance of meritocracy in the agricultural sector	SC2-4
	Individual and social life skills of farmers	SC2-5
	Immigration of the rural population in critical circumstances	SC2-6
	Number of agricultural collaboration communities of the youth and women in villages	SC2-7
Economic factors (MC3)	Facilitation of crop exports in critical circumstances	SC3-1
	Crop insurance status in critical circumstances	SC3-2
	The proportion of medicine and treatment costs in total farmer income	SC3-3
	Support for the knowledge-based economy of the agricultural sector	SC3-4
	The agricultural business development rate	SC3-5
	Agricultural border market development	SC3-6
	Agricultural tourism income	SC3-7
	The purchasing power of farmers in critical circumstances	SC3-8
	The unemployment rate in the agricultural sector	SC3-9
	Gross domestic product of agriculture in critical circumstances	SC3-10
Educational factors (MC4)	Specialized agricultural knowledge in education centers	SC4-1
	Education-employment relevance in the agricultural sector	SC4-2
	Specialized consultation services provided to farmers	SC4-3
	Crisis management training of farmers	SC4-4
	Training farmers to use state-of-the-art technologies	SC4-5
	Organic farming training	SC4-6
	Farmer education	SC4-7
	Farmers' financial knowledge	SC4-8
Critical circumstances (COVID-19) (MC5)	Natural crisis (drought)	SC5-1
	Environmental crisis (climate change)	SC5-2
	Financial and economic crisis (inflation, recession)	SC5-3
	Political crisis (sanctions and war)	SC5-4
	Technological crisis (hardware and software failure)	SC5-5
	Health crisis (COVID-19)	SC5-6
Technology factors (MC6)	Number of digital agricultural platforms (e.g., websites and applications)	SC6-1
	Use of emerging digital technologies, e.g., artificial intelligence (AI), blockchain, cloud computing, and the internet of things (IoT) in the agricultural sector	SC6-2
	Number of startups in the agricultural sector	SC6-3
	Number of agricultural knowledge-based companies	SC6-4
	Access to and presence of conversion industries	SC6-5
	Crop processing rate	SC6-6
Environmental factors (MC7)	Hospital waste management status (COVID-19)	SC7-1
	The average social cost of pollutant emissions	SC7-2
	Areas under cultivation and cultivable land area	SC7-3
	Quantity of distributed fertilizers	SC7-4
	Fertilizer sales	SC7-5
	Forest area	SC7-6
	Attention to desert greening	SC7-7
Entrepreneurial factors (MC8)	Promotion of entrepreneurial culture	SC8-1
	Attention to skill-based training	SC8-2
	Agricultural self-employment facilities	SC8-3
	Employment rate or agriculture graduates	SC8-4
Spatial factors (MC9)	Geographical spillover effects	SC9-1
	Economic spillover effects	SC9-2
	Technological spillover effects	SC9-3
	Political spillover effects	SC9-4
	Sociocultural spillover effects	SC9-5
	Environmental spillover effects (pollution)	SC9-6

Policy factors (MC10)	Consideration of sustainable development in macroeconomic policies	SC10-1
	Consideration of sustainable development in domestic and international environmental policies	SC10-2
	Consideration of sustainable development in sociocultural policies (population and family)	SC10-3
	Consideration of sustainable development in health policies	SC10-4
	Consideration of sustainable development in science and technology policies	SC10-5

Fig. 6 illustrates the proposed sustainable development model for the agricultural sector under critical circumstances (COVID-19).

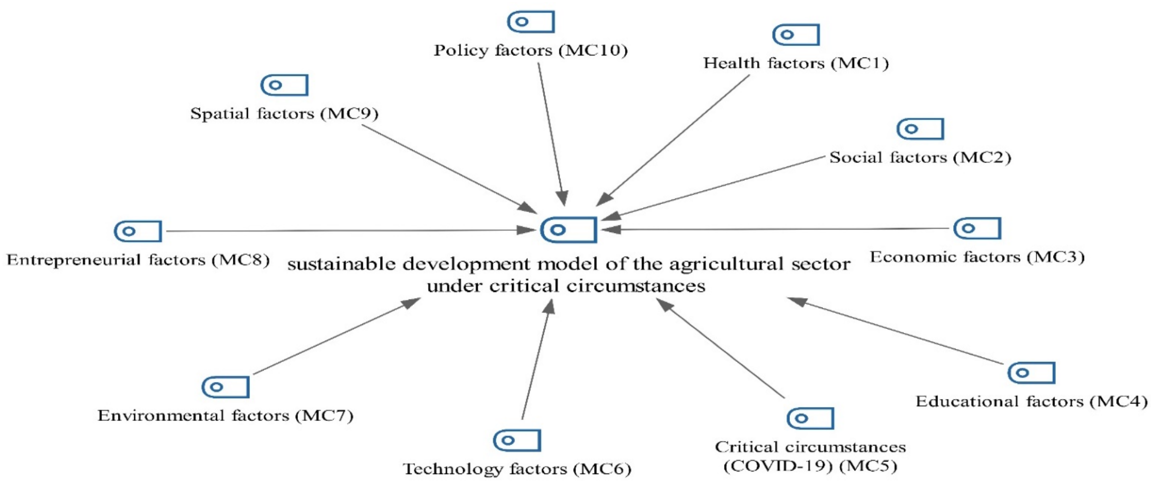


Figure 6: Conceptual model in MAXQDA

4.3 Implementation of Fuzzy DEMATEL method

To identify the internal relationships between the main criteria, twenty experts (A sample of 20 people from Experts in economics, extension, and sustainability of agriculture) were selected as respondents (Step 1).
Then, a list of the agricultural sustainable development main criteria under critical circumstances (COVID-19) was delivered to the respondents in the form of a fuzzy DEMATEL questionnaire (Step 2). Table 7 provides the coding of the main criteria.

Table 7: coding of the main criteria

Main Criteria	code
Health factors	MC1
Social factors	MC2
Economic factors	MC3
Educational factors	MC4
Critical circumstances (COVID-19)	MC5
Technology factors	MC6
Environmental factors	MC7
Entrepreneurial factors	MC8
Spatial factors	MC9
Policy factors	MC10

The criteria were subjected to pairwise comparisons based on the five-point Likert scale. Then, the respondents' linguistic views of the criteria influencing sustainable development in the agricultural sector under critical circumstances were collected.
Drawing on the fuzzy linguistic scale proposed by [7], the linguistic variables were translated into fuzzy numbers [36].

Step 3. Building the fuzzy direct relation matrix

The fuzzy direct relation matrix $\tilde{Z}^{(k)}$ was built using the simple average of the responses, as shown in Table 8.

Table 8: Fuzzy direct relation matrix

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	(0.000,0.000,0.000)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.375,0.625,0.875)	(0.500,0.750,1.000)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.125,0.375,0.625)	(0.250,0.500,0.750)
MC2	(0.125,0.375,0.625)	(0.000,0.000,0.000)	(0.000,0.250,0.500)	(0.125,0.375,0.625)	(0.375,0.625,0.875)	(0.125,0.375,0.625)	(0.500,0.750,1.000)	(0.375,0.625,0.875)	(0.000,0.125,0.375)	(0.125,0.375,0.625)
MC3	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.000,0.000,0.000)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.000,0.250,0.500)	(0.500,0.750,1.000)
MC4	(0.500,0.750,1.000)	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.000,0.000,0.000)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.250,0.500,0.750)
MC5	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.000,0.000,0.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
MC6	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.000,0.000,0.000)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.125,0.375,0.625)	(0.125,0.375,0.625)
MC7	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.500,0.750,1.000)	(0.000,0.250,0.500)	(0.000,0.000,0.000)	(0.125,0.375,0.625)	(0.375,0.625,0.875)	(0.125,0.375,0.625)
MC8	(0.000,0.250,0.500)	(0.500,0.750,1.000)	(0.500,0.750,1.000)	(0.125,0.375,0.625)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.000,0.000,0.000)	(0.000,0.250,0.500)	(0.125,0.250,0.500)
MC9	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.250,0.500,0.750)	(0.125,0.375,0.625)	(0.375,0.625,0.875)	(0.125,0.375,0.625)	(0.000,0.000,0.000)	(0.375,0.625,0.875)
MC10	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.375,0.625,0.875)	(0.375,0.625,0.875)	(0.250,0.500,0.750)	(0.000,0.000,0.000)

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

Step 4. Measuring the credibility of pairwise comparisons

Inconsistent rate (%) $= g = \frac{1}{10(10-1)} \sum_{i=1}^{10} \sum_{j=1}^{10} \frac{|z_{ij}^{20} - z_{ij}^{19}|}{z_{ij}^{20}} \times 100 = 4.17\% < 5\%$

Credibility (%) = (1 - 4.17%) ×100 = 95.83%

Step 5. Normalizing the fuzzy direct relation matrix

The normalized fuzzy direct relation matrix $\tilde{X}^{(k)}$ was calculated using Eq. (18), as shown in Table 9.

Table 9: Normalized fuzzy direct relation matrix

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	(0.000,0.000,0.000)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.042,0.069,0.097)	(0.056,0.083,0.111)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.014,0.042,0.069)	(0.028,0.056,0.083)
MC2	(0.014,0.042,0.069)	(0.000,0.000,0.000)	(0.000,0.028,0.056)	(0.014,0.042,0.069)	(0.042,0.069,0.097)	(0.014,0.042,0.069)	(0.056,0.083,0.111)	(0.042,0.069,0.097)	(0.000,0.014,0.042)	(0.014,0.042,0.069)
MC3	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.000,0.000,0.000)	(0.028,0.056,0.083)	(0.028,0.056,0.083)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.000,0.028,0.056)	(0.056,0.083,0.111)
MC4	(0.056,0.083,0.111)	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.000,0.000,0.000)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.028,0.056,0.083)
MC5	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.000,0.000,0.000)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.056,0.083,0.111)
MC6	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.000,0.000,0.000)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.014,0.042,0.069)	(0.014,0.042,0.069)
MC7	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.028,0.056,0.083)	(0.056,0.083,0.111)	(0.000,0.028,0.056)	(0.000,0.000,0.000)	(0.014,0.042,0.069)	(0.042,0.069,0.097)	(0.014,0.042,0.069)
MC8	(0.000,0.028,0.056)	(0.056,0.083,0.111)	(0.056,0.083,0.111)	(0.014,0.042,0.069)	(0.028,0.056,0.083)	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.000,0.000,0.000)	(0.000,0.028,0.056)	(0.014,0.028,0.056)
MC9	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.028,0.056,0.083)	(0.014,0.042,0.069)	(0.042,0.069,0.097)	(0.014,0.042,0.069)	(0.000,0.000,0.000)	(0.042,0.069,0.097)
MC10	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.028,0.056,0.083)	(0.042,0.069,0.097)	(0.042,0.069,0.097)	(0.028,0.056,0.083)	(0.000,0.000,0.000)

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

Step 6. Calculating the fuzzy total relation matrix

The fuzzy total relation matrix $\tilde{T}_c$ was developed, as shown in Table 10.

Table 10: Fuzzy total relation matrix

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	(0.016,0.072,0.322)	(0.056,0.140,0.421)	(0.039,0.119,0.382)	(0.054,0.132,0.396)	(0.069,0.153,0.433)	(0.053,0.131,0.390)	(0.044,0.130,0.414)	(0.029,0.111,0.382)	(0.023,0.094,0.331)	(0.039,0.116,0.372)
MC2	(0.023,0.097,0.343)	(0.012,0.061,0.289)	(0.010,0.082,0.319)	(0.022,0.094,0.331)	(0.051,0.126,0.377)	(0.021,0.092,0.325)	(0.064,0.138,0.391)	(0.049,0.121,0.363)	(0.007,0.058,0.272)	(0.021,0.089,0.319)
MC3	(0.055,0.139,0.417)	(0.058,0.143,0.430)	(0.014,0.069,0.313)	(0.041,0.122,0.391)	(0.044,0.131,0.417)	(0.053,0.132,0.397)	(0.057,0.144,0.432)	(0.055,0.138,0.413)	(0.009,0.082,0.325)	(0.065,0.141,0.402)
MC4	(0.069,0.151,0.429)	(0.045,0.131,0.418)	(0.028,0.109,0.379)	(0.014,0.070,0.315)	(0.058,0.143,0.430)	(0.053,0.132,0.397)	(0.057,0.144,0.433)	(0.055,0.137,0.413)	(0.037,0.108,0.350)	(0.039,0.117,0.379)
MC5	(0.076,0.172,0.494)	(0.079,0.178,0.508)	(0.073,0.166,0.475)	(0.074,0.166,0.476)	(0.026,0.100,0.407)	(0.072,0.164,0.469)	(0.079,0.179,0.512)	(0.076,0.170,0.488)	(0.066,0.148,0.426)	(0.072,0.161,0.462)
MC6	(0.055,0.137,0.412)	(0.057,0.142,0.425)	(0.040,0.120,0.385)	(0.053,0.133,0.398)	(0.057,0.142,0.424)	(0.013,0.066,0.304)	(0.057,0.142,0.427)	(0.055,0.136,0.408)	(0.023,0.094,0.333)	(0.026,0.103,0.362)
MC7	(0.053,0.133,0.398)	(0.054,0.136,0.409)	(0.038,0.115,0.372)	(0.039,0.116,0.372)	(0.068,0.149,0.421)	(0.012,0.089,0.344)	(0.015,0.073,0.325)	(0.026,0.106,0.370)	(0.049,0.116,0.346)	(0.026,0.101,0.351)
MC8	(0.010,0.086,0.335)	(0.065,0.140,0.393)	(0.062,0.131,0.369)	(0.022,0.094,0.334)	(0.038,0.114,0.368)	(0.036,0.106,0.341)	(0.026,0.103,0.361)	(0.011,0.058,0.279)	(0.005,0.069,0.285)	(0.022,0.079,0.312)
MC9	(0.039,0.115,0.371)	(0.026,0.106,0.369)	(0.037,0.111,0.357)	(0.024,0.099,0.346)	(0.039,0.118,0.381)	(0.023,0.096,0.340)	(0.053,0.132,0.396)	(0.024,0.101,0.354)	(0.007,0.047,0.244)	(0.050,0.120,0.359)
MC10	(0.056,0.139,0.417)	(0.044,0.131,0.417)	(0.054,0.134,0.402)	(0.054,0.134,0.402)	(0.044,0.130,0.417)	(0.040,0.120,0.385)	(0.057,0.143,0.432)	(0.055,0.137,0.412)	(0.036,0.108,0.349)	(0.013,0.065,0.302)

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

Step 7. Defuzzification of the total relation matrix
Table 11 reports the defuzzified total relation matrix.

Table 11: Crisp total relation matrix (T_c)

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	0.114	0.183	0.159	0.172	0.191	0.17	0.173	0.153	0.131	0.155
MC2	0.136	0.1	0.12	0.132	0.164	0.129	0.178	0.159	0.094	0.126
MC3	0.18	0.186	0.11	0.163	0.172	0.172	0.187	0.179	0.121	0.18
MC4	0.192	0.175	0.151	0.111	0.184	0.172	0.187	0.179	0.145	0.157
MC5	0.216	0.223	0.208	0.208	0.149	0.205	0.225	0.214	0.186	0.202
MC6	0.179	0.185	0.16	0.173	0.182	0.106	0.185	0.177	0.131	0.144
MC7	0.173	0.178	0.155	0.156	0.187	0.13	0.115	0.148	0.151	0.14
MC8	0.126	0.179	0.168	0.133	0.153	0.143	0.145	0.096	0.104	0.118
MC9	0.155	0.147	0.15	0.138	0.158	0.135	0.173	0.141	0.081	0.157
MC10	0.181	0.174	0.174	0.174	0.172	0.16	0.187	0.178	0.144	0.105

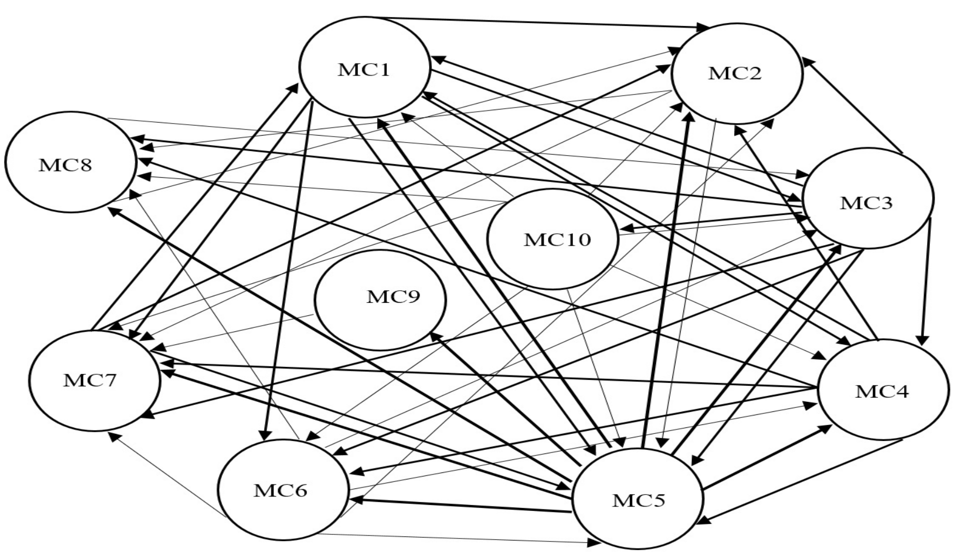
Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

Step 8. Determining the threshold value and drawing the strategy map
Table 12 shows the total relation matrix, in which values below the threshold are excluded. Fig. 7 depicts the cause-effect relations between the components. The threshold (TS) was obtained to be 0.1590.

Table 12: Crisp total relation matrix with under-threshold values excluded

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	0	0.183	0.159	0.172	0.191	0.17	0.173	0	0	0
MC2	0	0	0	0	0.164	0	0.178	0.159	0	0
MC3	0.18	0.186	0	0.163	0.172	0.172	0.187	0.179	0	0.18
MC4	0.192	0.175	0	0	0.184	0.172	0.187	0.179	0	0
MC5	0.216	0.223	0.208	0.208	0	0.205	0.225	0.214	0.186	0.202
MC6	0.179	0.185	0.16	0.173	0.182	0	0.185	0.177	0	0
MC7	0.173	0.178	0	0	0.187	0	0	0	0	0
MC8	0	0.179	0.168	0	0	0	0	0	0	0
MC9	0	0	0	0	0	0	0.173	0	0	0
MC10	0.181	0.174	0.174	0.174	0.172	0.16	0.187	0.178	0	0

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).



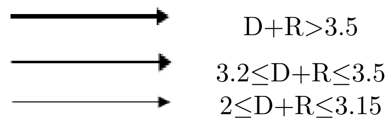


Figure 7: Strategy map

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

The strategy map was drawn based on the importance of the main criteria calculated by D+R in Step 7; D+R>3.5, 3.2≤D+R≤3.5, and 2≤D+R≤3.15 represented very high, high, and relatively high importance, respectively. A larger thickness of the lines would stand for the higher importance of the corresponding criterion. Critical circumstances (COVID-19) (MC5) were found to have very high importance. Also, environmental factors (MC7), health factors (MC1), educational factors (MC4), and economic factors (MC3) were inferred to have high importance. The importance of technology (MC6), factors (MC10), social (MC2), entrepreneurial (MC8), and spatial (MC9) factors is relatively high.

Step 9. Calculating the importance of criteria and their relationships

Table 13 provides D+R and D-R.

Table 13: Importance and relationships of the criteria

Main criteria	R	D	D+R	D-R
MC1	1.652	1.601	3.253	-0.051
MC2	1.730	1.338	3.068	-0.392
MC3	1.555	1.650	3.205	0.095
MC4	1.560	1.653	3.213	0.093
MC5	1.712	2.036	3.748	0.324
MC6	1.522	1.622	3.144	0.100
MC7	1.755	1.533	3.288	-0.222
MC8	1.624	1.365	2.989	-0.259
MC9	1.288	1.435	2.723	0.147
MC10	1.484	1.649	3.133	0.165

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

Fig. 8 depicts the significant relationships in the form of a graph in which the horizontal axis represents D+R, while the vertical axis stands for D-R. The position and relationships of each criterion are represented by points (D+R, D-R).

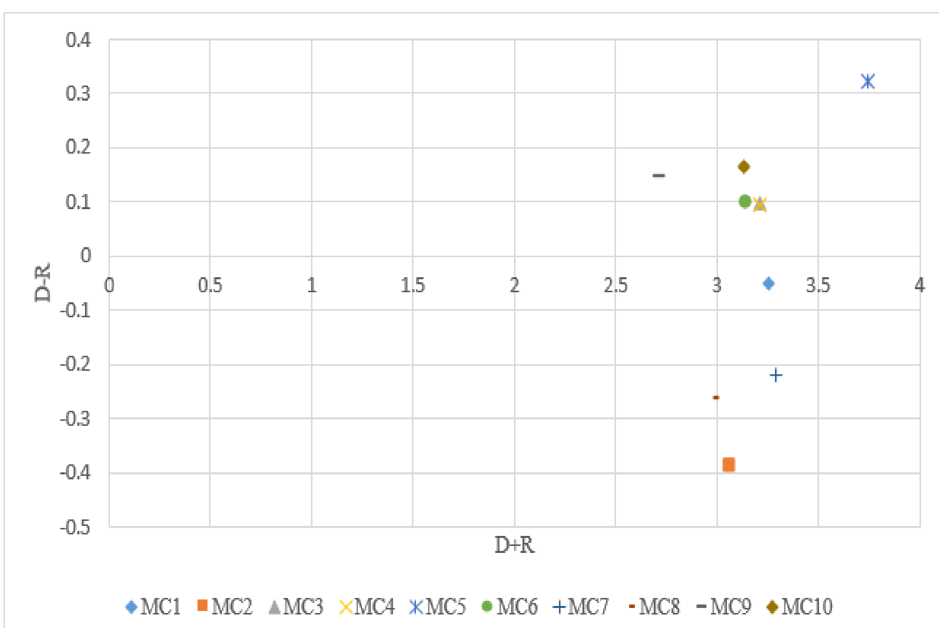


Figure 8: cause and effect diagram. Using the different symbols for the main criteria: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

4.4 Implementation of fuzzy DANP method

After determining the relationship structure between the factors of the sustainable development model of the agricultural sector under critical circumstances by the Fuzzy DEMATEL method, the ANP method is applied to obtain criteria weights. To avoid increasing the volume of the paper, only the result of step 13 is presented.

Step 13. Defuzzification of the weighted supermatrix

Table 14: Defuzzification of the stable matrix of ANP when power $w = \lim_{k\to\infty} \left(\tilde{W}^{\alpha}\right)^k$

	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8	MC9	MC10
MC1	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034	0.1034
MC2	0.1092	0.1092	0.1092	0.1092	0.1092	0.1092	0.1092	0.1092	0.1092	0.1092
MC3	0.0979	0.0979	0.0979	0.0979	0.0979	0.0979	0.0979	0.0979	0.0979	0.0979
MC4	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982	0.0982
MC5	0.1058	0.1058	0.1058	0.1058	0.1058	0.1058	0.1058	0.1058	0.1058	0.1058
MC6	0.0962	0.0962	0.0962	0.0962	0.0962	0.0962	0.0962	0.0962	0.0962	0.0962
MC7	0.1097	0.1097	0.1097	0.1097	0.1097	0.1097	0.1097	0.1097	0.1097	0.1097
MC8	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028	0.1028
MC9	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829
MC10	0.0937	0.0937	0.0937	0.0937	0.0937	0.0937	0.0937	0.0937	0.0937	0.0937

Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

5 Experimental results

5.1 Results of fuzzy DEMATEL method

The criteria were analyzed in aspects, including:

(i) Effect: The sum of the elements of each row (D) represents the effect of the corresponding main criterion on the other main criteria. According to Table 15, critical circumstances (COVID-19) (MC5) were found to have the strongest effect.

Table 15: Effects of the main criteria

Main criteria	D	Rank
Critical circumstances (COVID-19) (MC5)	2.036	1
Educational factors (MC4)	1.653	2
Economic factors (MC3)	1.650	3
Policy factors (MC10)	1.649	4
Technology factors (MC6)	1.622	5
Health factors (MC1)	1.601	6
Environmental factors (MC7)	1.533	7
Spatial factors (MC9)	1.435	8
Entrepreneurial factors (MC8)	1.365	9
Social factors (MC2)	1.338	10

(ii) Dependence: the sum of the column elements (R) stands for the dependence of the corresponding main criterion on the other main criteria of the system. Environmental factors (MC7) were found to have the largest dependence, as shown in Table 16.

Table 16: Dependence of the main criteria

Main criteria	R	Rank
Environmental factors (MC7)	1.755	1
Social factors (MC2)	1.730	2
Critical circumstances (COVID-19) (MC5)	1.712	3
Health factors (MC1)	1.652	4
Entrepreneurial factors (MC8)	1.624	5
Educational factors (MC4)	1.560	6
Economic factors (MC3)	1.555	7
Technology factors (MC6)	1.522	8
Policy factors (MC10)	1.484	9
Spatial factors (MC9)	1.288	10

(iii) The horizontal axis (D+R) represents the effect and dependence of each main criterion in the system. A larger D+R suggests a higher interaction of the corresponding main criterion with the other main criteria. According to Table 17, critical circumstances (COVID-19) (MC5) had the highest effect and importance.

Table 17: Importance of the main criteria

Main criteria	D+R	Rank
Critical circumstances (COVID-19) (MC5)	3.748	1
Environmental factors (MC7)	3.288	2
Health factors (MC1)	3.253	3
Educational factors (MC4)	3.213	4
Economic factors (MC3)	3.205	5
Technology factors (MC6)	3.144	6
Policy factors (MC10)	3.133	7
Social factors (MC2)	3.068	8
Entrepreneurial factors (MC8)	2.989	9
Spatial factors (MC9)	2.723	10

(iv) The vertical axis (D-R) indicates the effects of the main criteria. A positive D-R stands for a cause, whereas a negative D-R represents an effect.
According to Table 18, critical circumstances (COVID-19) (MC5), policy factors (MC10), spatial factors (MC9), technology factors (MC6), economic factors (MC3), and educational factors (MC4) were found to be causal factors, while health factors (MC1), environmental factors (MC7), entrepreneurial factors (MC8), and social factors (MC2) were effect factors.

Table 18: Relationships of the main criteria

Main criteria	D-R	Type
Critical circumstances (COVID-19) (MC5)	0.324	cause
Policy factors (MC10)	0.165	cause
Spatial factors (MC9)	0.147	cause
Technology factors (MC6)	0.100	cause
Economic factors (MC3)	0.095	cause
Educational factors (MC4)	0.093	cause
Health factors (MC1)	-0.051	effect
Environmental factors (MC7)	-0.222	effect
Entrepreneurial factors (MC8)	-0.259	effect
Social factors (MC2)	-0.392	effect

5.2 Results of fuzzy DANP method

Following the analysis presented in Section 4.3, the fuzzy total influence relation matrices $\tilde{T}_c$ based on the criteria and $\tilde{T}_D$ based on the dimension were generated.
After that, the fuzzy weighted supermatrix was determined and the fuzzy numbers were transformed into crisp values following the analysis presented in Section 3.5.3. Table 19 shows the final results of the prioritization within among main criteria.

Table 19: Prioritization within among main criteria

Main criteria	Weights	Weights (%)	rank
Environmental factors (MC7)	0.1097	10.9730	1
Social factors (MC2)	0.1091	10.9183	2
Critical circumstances (COVID-19) (MC5)	0.1058	10.5833	3
Health factors (MC1)	0.1034	10.3440	4
Entrepreneurial factors (MC8)	0.1028	10.2822	5
Educational factors (MC4)	0.0982	9.8245	6
Economic factors (MC3)	0.0979	9.7936	7
Technology factors (MC6)	0.0961	9.6187	8
Policy factors (MC10)	0.0937	9.3720	9
Spatial factors (MC9)	0.0829	8.2904	10

The analysis of the Fuzzy DANP method revealed that the weights of the sustainable development model criteria in the agricultural sector are close to each other. Therefore, it can be the list of sustainable development model criteria for the agricultural sector can be divided into two groups, which are the minor group and the main group. Specifically, five criteria with overall weights less than 10% are considered as the minor group; and the other criteria with overall weights higher than 10% are considered as the main group. A dotted line labeled "SL" (separation line) illustrates the differential between the two groups in Fig. 9, where all rankings are presented. five sustainable development criteria of the agricultural sector on the left side of the SL, environmental factors (MC7), social factors (MC2), critical circumstances (COVID-19) (MC5), health factors (MC1), entrepreneurial factors (MC8), are the most important criteria of the sustainable development model of the agricultural sector under critical circumstances. In contrast, the five criteria on the right side of the SL are the important criteria.

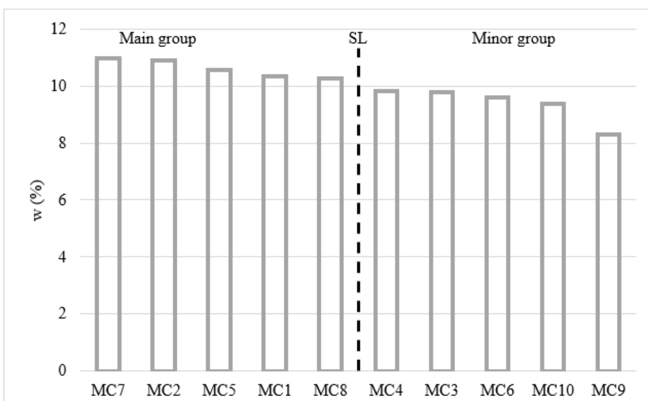


Figure 9: Illustration of criteria prioritization. Note: Health factors (MC1), Social factors (MC2), Economic factors (MC3), Educational factors (MC4), Critical circumstances (COVID-19) (MC5), Technology factors (MC6), Environmental factors (MC7), Entrepreneurial factors (MC8), Spatial factors (MC9), Policy factors (MC10).

5.3 Comparison of results

Table 20 shows the results of the comparison of the two methods of Fuzzy DEMATEL and Fuzzy DANP based on the values of D+R and weights.

Table 20: Prioritization within based D+R and weights among criteria

Main criteria	D+R	rank	Weights	rank
Health factors (MC1)	3.253	3	0.1034	4
Social factors (MC2)	3.068	8	0.1092	2
Economic factors (MC3)	3.205	5	0.0979	7
Educational factors (MC4)	3.213	4	0.0982	6
Critical circumstances (COVID-19) (MC5)	3.748	1	0.1058	3
Technology factors (MC6)	3.144	6	0.0962	8
Environmental factors (MC7)	3.288	2	0.1097	1
Entrepreneurial factors (MC8)	2.989	9	0.1028	5
Spatial factors (MC9)	2.723	10	0.0829	10
Policy factors (MC10)	3.133	7	0.0937	9

Based on the results of the comparison of FDEMATEL and FDANP methods in the main group of criteria based on FDANP classification, environmental factors (MC7), health factors (MC1) (3.2≤D+R≤3.5) and critical circumstances (COVID-19) (MC5) (D+R≥3.5) have more than 10% importance and are highly influential, but social factors (MC2) and entrepreneurial factors (MC8) (2≤D+R≤3.15) has more importance than 10%, but they are relatively high influential. In the minor group of criteria, educational factors (MC4) and economic factors (MC3) (3.2≤D+R≤3.5), have an importance of less than 10% and are highly influential. On the other hand, the criteria of technology factors (MC6), policy factors (MC10), and spatial factors (MC9) (2≤D+R≤3.15) have an importance of less than 10% and are relatively highly influential.

6 Conclusion and future research

The present study adopted an integrated methodology of grounded theory, FDM, and Fuzzy DEMATEL to develop a sustainable development model in the agricultural sector under critical circumstances (COVID-19). Also, to compare the results, the combined method of Fuzzy DANP was used. A total of eighty factors were identified using grounded theory. They were classified into ten main criteria and seventy-two sub-criteria using FDM. The internal relationships, effects, and dependencies of the criteria were identified through the Fuzzy DEMATEL method. Then, using the Fuzzy DANP method, the effective weight of each criterion was determined. The results of the Fuzzy DEMATEL method show, that critical circumstance (COVID-19), environmental factors, educational factors, health factors, and economic factors were found to have the strongest effects. Critical circumstances (COVID-19) had the largest effect and strongest interaction with the other main criteria. On the other hand, based on the results of the Fuzzy DANP method, environmental factors (MC7), social factors (MC2), critical circumstances (COVID 19) (MC5), health factors (MC1), entrepreneurial factors (MC8), are the most important criteria of the sustainable development model of the agricultural sector under critical circumstances. Therefore, to move on the path of sustainable development in the agricultural sector, one should focus on the factors that have a higher influence and importance.

The findings can help countries focus on the essential factors discussed in the present work to predict the most effective factors for sustainable development in the agricultural sector. Critical circumstances (COVID-19) were found to have the highest effect among the main criteria of sustainable development in the agricultural sector. Researchers have argued that critical circumstances are the most influential main criterion in an agricultural sustainable development model. The consideration of critical circumstances (COVID-19) could effectively help develop a sustainable development model in the agricultural sector as it may, directly and indirectly, influence the other agricultural sustainable development criteria. Educational, economic, policy, technology, and health factors were also found to have high importance. As the second-most important main criterion, environmental factors influence health factors, social factors, and critical circumstances. They have been reported to be the most dependent main criterion (an effect criterion). This suggests that environmental protection is essential for sustainable development in the agricultural sector. Health factors represented the third-most important main criterion in the agricultural sustainable development model. This implies that health factors are necessary for sustainable development in the agricultural sector. Education affects health, social, environmental, and entrepreneurial factors and critical circumstances (COVID-19). This suggests that educational factors play a key role in the sustainable development model of the agricultural sector. Economic factors were found to have strong interactions with the other main criteria. Therefore, economic factors also play a key role in agricultural sustainable development.

This paper identified the main criteria and sub-criteria that influence sustainable development in the agricultural sector. The strategy map of the main criteria was drawn using the Fuzzy DEMATEL method. A strategy map finds interdependencies among the main criteria. These main criteria can potentially contribute to sustainable development in agriculture. This study may provide sustainable development criteria of the agricultural sector under critical circumstances (COVID-19) to countries so that they could analyze their agricultural sustainable development.

Finally, it should be said that some limitations of this study require further examination: for example, As the sample size in this study was relatively small, later studies can increase the number of respondents to deepen their understanding of the complexity of the sustainable development model criteria in the agricultural sector. as the criteria are determined by decision-makers judgmentally, using a structured, scientific method like artificial intelligence or Partial Least Square - Structural Equation Modeling (PLS-SEM), can be helpful; In our future study, we are going to address this problem.

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