Research Article

A Proposed Comparative Algorithm for Regional Crop Yield Assessment: An Application of Characteristic Objects Method

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The agriculture sector plays a vibrant role in the economic prosperity of advanced and developing countries. It is a crucial source of revenue for the majority of the population. Nevertheless, unfortunately, in Pakistan, the share of the agricultural sector in Gross Domestic Product (GDP) is gradually declining. Therefore, comprehensive strategies and actions need to be developed and implement to enhance the agricultural productivity of Pakistan. In this study, an attempt has been made to examine the crop yield revenue of Punjab, Pakistan, by ranking the districts according to their contribution to the agricultural GDP of Pakistan’s economy. A Multi-Criteria Decision Making (MCDM) technique, namely, characteristic objects method (COMET), which is entirely free of the rank reversal paradox, is used for this purpose. However, to make a fair comparison, in this research, a comprehensive framework is proposed to normalize the crop yield revenue of Punjab under probabilistic nature. The proposed framework is applied to various districts of Punjab, Pakistan, from 1992 to 2019. It is concluded that Jhang, Faisalabad, and Rahim Yar Khan (RYK) are the highest-ranked districts, while Nankana Sahib, Rawalpindi, and Islamabad are the lowest-ranked districts of Punjab, Pakistan, according to their contribution to the agricultural GDP of Pakistan’s economy. Outcomes associated with this research would be helpful to build precise and accurate budget allocation policies.

1. Introduction

The agriculture sector is one of the essential production sectors of any nation’s economy. Therefore, this sector provides income for domestic farming and is a major source of foreign exchange earnings for the nation (Rahman and Hossain [1]). Moreover, in Pakistan, agriculture is one of the pillars and the most crucial sector, contributing 19.5% of GDP and employing 43.2% of the labor force (GOP) [2].

Further, Punjab being an agricultural province, has a significant role in the country’s GDP. Still, the districts of Punjab have different types and amounts of agricultural resources such as land, water, machinery, livestock, fertilizer, etc. As a result of this discrepancy, specific sectors in the province have been contributing less to agricultural GDP while, on the other hand, the performance of some districts is appreciable (Khan and Anwar [3]; Iftikhar and Mahmood [4]). Hence, a comparative analysis of crop yield revenue in various regions of Punjab is required to investigate their contribution to Pakistan’s agricultural GDP. There are several methods for comparative analysis of the relative performance of districts in terms of individual crops as well as aggregation of major crops grown in the state. A study conducted by Singh et al. [5] to capture the scenario of agricultural productivity in Rajasthan during 1990–2010 concluded that there is a substantial difference in the productivity of the desert and nondesert districts of Rajasthan.

Jena [6] used principal component analysis to measure the district-wise agricultural development of Odisha by 2010, and the results showed that agricultural development is highest in Kendrapara districts and lowest in Jharsuguda districts of Odisha.
Similarly, Baruah and Borah [7] examined the level of agricultural evolution of twenty-seven districts of the state Assam in 2011–2012. Therefore, the Narain et al. method and Michela et al. method were used for ranking the districts. In another study, Khan and Anwar [3] used multivariate statistical analysis to rank the districts of Punjab, Pakistan, in 1971–2005. Therefore, the empirical results concluded that Lahore, Gujranwala, and Faisalabad are the highest-ranked districts while Dera Ghazi Khan (DGK), Gujrat, and Mianwali are the lowest-ranked districts of Punjab according to their crop production.

In addition, Multi-Criteria Decision Making (MCDM) is a well-known branch of decision making that deals with decision problems under several decision criteria. Moreover, it is a subdiscipline of operations research and is usually concerned with making decisions in the presence of multiple but conflict requirements. MCDM problems are generally classified into two categories: multiobjective decision-making (MODM) and multiattribute decision-making (MADM). Likewise, MADM is further subdivided into multiattribute utility theory (MAUT), analytic hierarchy process (AHP), simple multiattribute rating technique (SMART), technique for order preference by similarity to ideal solution (TOPSIS), simple additive weighting (SAW), data envelopment analysis (DEA), multiplicative exponent weighting (MEW), elimination choice translating reality (ELECTRE), preference ranking organization method for enrichment of evaluations (PROMETHEE), etc (Zare et al. [8], Dotoli et al. [9]).

From the last few decades, various studies have been conducted to compare and rank objects to multiple criteria of choice by using MCDM. Mikael et al. [10] used a MCDM technique, namely, PROMETHEE, to rank the sawability of the dimension properties of the stone. The results of their study showed that PROMETHEE could be reliably used for evaluating the sawability of the dimension stone at any stone factory with different rocks only by testing physical and mechanical properties.

In another study, Zare et al. [8] reviewed and classified academic journal and international conference papers which used MCDM techniques in E-learning evaluation published between 2001 and 2015 and found that AHP integrated approach was used more than any other MCDM integrated techniques. Similarly, Shukla et al. [11] used PROMETHEE to select a competent and suitable Enterprise Resource Planning (ERP) system at a production unit of a leading Asian electronics company. Awasthi et al. [12] investigated application of ideal solution based MCDM techniques namely fuzzy TOPSIS, fuzzy VIKOR (in Serbian: VlSeKriterijumska Optimizacija I Kompromisnos Resenje), and fuzzy GRA ((Grey Relational Analysis) for sustainability evaluation of urban mobility projects and revealed that implementation of a new tramway in the city center of Luxembourg as the best alternative for implementation. Meanwhile, Dotoli et al. [9] performed a comparative analysis among AHP, PROMETHEE, MAUT, and DEA for the management of Public Procurement (PP) Tenders and concluded that AHP and DEA are the most promising methods for application to PP.

However, the classical MCDM methods are often criticized for possible shortcomings, such as the rank reversal paradox. Therefore, a new MCDM approach, namely, the Characteristic Objects Method (COMET) has been developed in response to this challenge. The COMET method helps a decision-maker to organize and solve the problems, carry out analysis, comparisons, and ranking of the alternatives. The presented method is entirely free from the rank reversal paradox. Therefore, if decision-makers add or remove any number of alternatives, then the assessment of alternatives is invariable. This property results from the fact that the COMET method evaluates alternatives using a model identified based on characteristic objects that are independent of the set of assessed decision variants (Faizi et al. [14]; Salabun et al. [15]; Chmielarz and Zborowski [16]). Consequently, Salabun [17] made an experiment to indicate the difference between results from the COMET and TOPSIS methods. For that purpose, they defined the decision problem as a ranking of the electrical resistance of 12 alternatives concerning the potential difference C1 and the electric current C2 (as the two criteria). After comparing the results from Ohm’s law, they concluded that COMET provided a good ranking. Watr´obski et al. [13] identified a decision-making model for the selection of the best scenario of sustainable transport by using the COMET method. Similarly, Chmielarz and Zborowski [16] used COMET to identify the best e-banking websites in Poland in 2017 from the point of view of individual clients.

Similarly, Salabun and Karczmarsczyk [18] used the COMET to identify a decision-making model to select the best model of electric-powered car for sustainable city transport. Again, Salabun et al. [15] used COMET to identify nonlinear decision models. Meanwhile, Salabun et al. [19] presented COMET methods along with its software implementation.

Therefore, in this research, districts of Punjab are ranked according to their contribution to the agricultural GDP of Pakistan’s economy through the application of COMET. But, whenever the crop yield revenue is examined for comparative analysis, much attention is shifted to normalizing the crop yield revenue data to make a fair comparison. In literature (Cheadle et al. [20]; Curtis et al. [21]), normalization of data is merely determined by capturing the difference of values from the arithmetic mean for a specified time period and then dividing by the standard deviation, where the arithmetic means and standard deviation are decided from previous records. However, this modest method is only appropriate for the normally distributed data set. But, crop yield data is usually not normally distributed. Therefore, the basic purpose of this research is to propose a comprehensive framework in which crop yield revenue is normalized under the probabilistic nature and then, establish a comparative analysis of crop yield revenue in various regions of Punjab to investigate which districts contribute more in agricultural GDP and which contributes less, by ranking the districts according to their contribution. This study would not only help to trace
out the most backward or upward districts of Punjab, according to their contribution but also attracts the immediate attention of the planners and policy-makers in formulating appropriate policies for future development and target the planning of services to improve the overall crop yield production. Moreover, it also helps to build precise and accurate budget allocation policies.

The remaining part of this article is organized in the following manners: in the next section, description regarding the proposed framework to normalized crop yield revenue data is given. Moreover, the fundamental notions and concepts of the fuzzy sets that are necessary to understand the COMET method are outlined. Apart from these, a theoretical description of the COMET method along with the proposed algorithm is described. Applications of the proposed framework and the discussion of the results are presented in Section 3. However, Section 4 is devoted to the conclusion of the paper.

2. Materials and Methods

2.1. Parametric Normalization of Crop Yield Revenue Data. Standardization has been used for actuarial calculations since mid of the eighteenth century, a time when neither the pocket calculator nor mechanical calculation types of equipment were accessible. In literature, different methods have been used for this purpose so far (Cheadle et al. [20]; Curtis et al. [21]). Amongst these, the z-score is one of the most commonly used methods. However, the main drawback of this modest method is that this method is only applicable when data follows the normal distribution. In contrast, the crop yield data is usually not normally distributed. Therefore, the essential purpose of this research is to propose a comprehensive technique in which crop yield revenue is normalized under the probabilistic nature. Following are the major steps involved in the calculation procedure of normalized crop yield revenue data.

2.1.1. Proposed Framework.
(1) In the first step, the revenue of crop yield data is computed. For that purpose, each crop yield outcome is multiplied by the average current price (ACP) of the crops.

\[
R_t = Y_t \times ACP,
\]

where \(i\) shows different crops and \(t\) shows the time periods (1992–2019). Various probability distributions, for example, Gamma, Generalized Normal, Logistic, Normal, Laplace, Gumbel distributions are fitted on this revenue data. For the goodness of measure, different tests such as Kolmogorov–Smirnov test (Hassani and Silva [22]) and Anderson–Darling tests (Ghosh et al. [23]) are applied by using the propagate \(R\) package [24]

(2) Then, different methods are used to estimate the parameters of each well-fitted distribution. Table 1 shows different probability distributions corresponding to the estimation method of parameters for each distribution.

(3) The estimated parameters of each well-fitted distribution are used to derive empirical cumulative distribution function (ECDF). After this, the question arises if the value of \(r\) is undefined, e.g., in the case of Gamma distribution, there may be a zero value in the \(R\) sequence, to tackle this challenge, ECDF of each distribution having zero and nonzero values in the \(R\) sequence is estimated by using the following equation.

\[
K(r) = p + (1 - p) F(r),
\]

where \(p\) is the probability of zero crop yield in \(R\) values. If \(h\) is the entire number of zero existing in the \(R\) sequence, then \(p\) is estimated by \(h/T\). Where \(T\) is the entire number of observations in a given series.

(4) ECDF of each probability distribution is then transformed into a standardized normal distribution having mean zero and variance one. The current study employed the approximate transformation method provided by Abramowitz and Stegun (Abramowitz et al. [25]). Here \(Z_{it}\) is expressed as

\[
Z_{it} = -W + \frac{u_0 + u_1 W + u_2 W^2}{1 + v_1 W + v_2 W^2 + v_3 W^3},
\]

Here,

\[
W = \sqrt{\ln \left( \frac{1}{(K(r))^2} \right)}.
\]

When,

\[
0 < K(r) \leq 0.5.
\]

Similarly,

\[
Z_{it} = +W - \frac{u_0 + u_1 W + u_2 W^2}{1 + v_1 W + v_2 W^2 + v_3 W^3},
\]

And

\[
W = \sqrt{\ln \left( \frac{1}{(1 - K(r))^2} \right)}.
\]

| Probability distribution | Method of parameter estimation |
|--------------------------|--------------------------------|
| Generalized normal       | Maximum likelihood method      |
| Gumbel                   | Maximum likelihood method      |
| Normal                   | Method of moments             |
| Gamma (2P)               | Method of moments             |
| Gamma (3P)               | Maximum likelihood method      |
| Laplace                  | Method of moments             |
| Logistic                 | Method of moments             |
| Cauchy                   | Maximum likelihood method      |
| Log-logistic (3P)        | Maximum likelihood method      |

Table 1: Different probability distributions along with their parameter estimation methods.
when
\[ 0.5 < K(r) \leq 1, \]  
where \( u_0 = 2.5155, \ u_1 = 0.8029, \ u_2 = 0.0103, \ u_3 = 1.4328, \ v_1 = 1.4328, \ v_2 = 0.9853, \) and \( v_3 = 0.0013. \)

The average value of standardized revenue of crop yield data is 0 and the standard deviation is 1.

### 2.2. Mathematical Description of Characteristic Object Method (COMET)

This section is devoted to a mathematical description of the COMET method to solve MCDM problems. However, the basic notions and concepts of the fuzzy set theory can be found in (Faizi et al. [14]; Salabun et al. [15]; Chmielarz and Zborowski [16]).

Therefore, the whole procedure of COMET is divided into five colliding steps. The detailed description of each step is as follows:

**Step 1:** definition of the space of the problem.

The expert determines the dimensionality of the problem by selecting \( r \) criteria, \( C_1, C_2, \ldots, C_r \). Then, a set of fuzzy numbers is selected for each criterion \( C_p \), e.g., \( \{C_{i1}, C_{i2}, \ldots, C_{ic_i}\} \):

\[
C_1 = \{C_{i1}, C_{i2}, \ldots, C_{ic_1}\}, \\
C_2 = \{C_{i1}, C_{i2}, \ldots, C_{ic_2}\}, \\
\ldots \\
C_r = \{C_{i1}, C_{i2}, \ldots, C_{ic_r}\},
\]

where \( c_1, c_2, \ldots, c_r \) are the ordinals of the fuzzy numbers for all criteria (Salabun and Karczmarczyk [18]).

**Step 2:** generation of the characteristic objects.

In this step, the characteristic objects CO are obtained with the usage of the Cartesian product of the fuzzy numbers cores of all the criteria (Salabun and Karczmarczyk [18]):

\[
CO = C(C_1) \times C(C_2) \times \cdots \times C(C_r).
\]

As a result, an ordered set of all CO is obtained:

\[
CO_1 = C(C_{i1}), C(C_{i2}), \ldots, C(C_{ir}), \\
CO_2 = C(C_{i1}), C(C_{i2}), \ldots, C(C_{ir}), \\
\ldots \\
CO_t = C(C_{i1}), C(C_{i2}), \ldots, C(C_{ir}),
\]

where \( t \) is the count of CO and is equal to:

\[
t = \prod_{i=1}^{r} c_i.
\]

**Step 3:** evaluation of the characteristic objects

The expert determines the matrix of expert judgment (MEJ) by comparing the COs pairwise. The matrix is presented as follows:

\[
MEJ = \begin{pmatrix}
\alpha_{11} & \alpha_{12} & \ldots & \alpha_{1t} \\
\alpha_{21} & \alpha_{22} & \ldots & \alpha_{2t} \\
\vdots & \vdots & \ddots & \vdots \\
\alpha_{t1} & \alpha_{t2} & \ldots & \alpha_{tt}
\end{pmatrix},
\]

where \( \alpha_{ij} \) is the result of \( CO_i \) and \( CO_j \) comparison by the expert. The function \( f_{\exp} \) designates the mental judgment function of the expert. The expert’s preferences can be presented as

\[
\alpha_{ij} =
\begin{cases}
0.0 & f_{\exp}(CO_i) < f_{\exp}(CO_j) \\
0.5 & f_{\exp}(CO_i) = f_{\exp}(CO_j) \\
1.0 & f_{\exp}(CO_i) > f_{\exp}(CO_j)
\end{cases}
\]

After the MEJ matrix is prepared, a vertical vector of the Summed Judgments (SJ) is obtained as follows:

\[
SJ_i = \sum_{j=1}^{t} \alpha_{ij}.
\]

Eventually, the values of preference are approximated for each characteristic object. As a result, a vertical vector \( P \) is obtained, where the \( i \)-th row contains the approximate value of preference for \( CO_i \) (Salabun and Karczmarczyk [18]).

**Step 4:** the rule base.

In this step, each characteristic object and its value of preference is converted to a fuzzy rule, as follows.

\[
IF C(C_{i1}) \text{ AND } \ldots \text{ AND } C(C_{ir}) \text{ \ THEN } P_i.
\]

After repeating this for all objects, a complete fuzzy rule base is obtained.

**Step 5:** inference and the final ranking.

Each alternative is presented as a set of crisp numbers, e.g.,

\[
A_i = \{a_{i1}, a_{i2}, \ldots, a_{it}\}.
\]

This set corresponds to the criteria \( C_1, C_2, \ldots, C_r \). Mandani’s fuzzy inference method is used to compute the preference of the \( i \)-th alternative. The rule base guarantees that the obtained results are unequivocal (Salabun and Karczmarczyk [18]).

### 2.3. The Proposed Framework: Regionalized Comparative Analysis

In this section, we will discuss the three phases of our proposed framework to make the regionalized comparative analysis of different districts of Punjab and
Islamabad, based on their contribution to agricultural GDP of Pakistan economy.

2.3.1. Phase 1: Parametric Normalization. This section is related to the normalization of crop yield revenue data. In this proposed framework, the first step is the computation of crop yields revenue data. For that purpose, each crop yield outcome is multiplied by the ACP of the crops. After that, various probability distributions are fitted on this revenue data, and then different methods (shown in Table 1) are used to estimate the parameters of each well-fitted distribution. The well-fitted distribution is selected for each station’s time series based on minimum values of Akaike Information Criteria (AIC), and Bayesian Information Criteria (BIC). Next, the estimated parameters of each well-fitted distribution are used to derive ECDF.

Then, ECDF of each well-fitted probability distribution is then transformed into a standardized normal distribution by using the approximate transformation method, which is provided by Abramowitz and Stegun. The detailed description of this proposed algorithm is discussed in Section 2.1.

2.3.2. Phase 2: Classification of Standardized Crop Yield Revenue Data. For our proposed framework, this phase considers the classification of standardized crop yield revenue data into three categories, namely: Above Normal, Normal, and Below Normal by using the classification criteria which are presented in Table 2. Afterward, the values which lie in each of these three categories from 1992–2019 are counted.

2.3.3. Phase 3: Configuration of COMET Algorithm. This phase defines and constitutes the COMET algorithm on district-wise standardized crop yield revenue data of Punjab. The decision problem is defined as a ranking of the 35 districts of Punjab and Islamabad with respect to three criteria, Above Normal, Normal, and Below Normal. The decision regarding the top and low ranked districts is based on the values of the final preferences, which is obtained by Mamdani’s fuzzy inference method. The district which has a higher value of \( P \) is considered top-ranked district, whereas the districts which have a lower value of \( P \) is considered low-ranked district. The detailed description of COMET is presented in Section 2.3. Thus, by incorporating the COMET algorithm, we will be able to decide which stations contribute more in agricultural GDP of Pakistan economy and which contribute less.

3. Application

In this section, in order to validate the efficiency of the proposed framework, the preliminary application of the proposed methodology is applied on Punjab, the most agricultural province of Pakistan, located between 31.1704° N latitude and 72.7097° E longitude. Thus, its contribution in total crop production, particularly in the case of four major crops, is more than 2/3rd of total production in Pakistan; therefore, in this research, it is focused only. The state of Punjab has been stratified into 36 strata, called districts, but one district, namely, Chaniot is not available in the data set because of the circumstance that this is newly established and did not exist at the time of the data collection. Hence, in this research, production data of nine crops, Wheat, Maize, Rice, Barle, Sugarcane, Jowar, Bajra, Tobacco, and Cotton from 35 districts of the Punjab and Islamabad (capital territory) have been used. The production data of crops are time series and taken over the time period 1992–2019. The main source of data is the Pakistan Bureau of Statistics (PBS), Government of Pakistan.

3.1. Empirical Results of Proposed Framework. In this section, the methodology of the proposed framework presented in the previous section is implemented on 35 districts of Punjab and Islamabad. Since the objective of this research is to make a regionalized fair comparative analysis of crop yield revenue of Punjab therefore standardized crop yield revenue data is used to rank the districts according to their contribution in the agricultural GDP of Pakistan’s economy.

3.1.1. Parametric Normalization of Crop Yield Revenue Data

Fitting Distribution. To normalize crop yield revenue data, the second step of the algorithm is fitting of appropriate continuous probability distribution on revenue data by using the propagate \( R \) package and then picking the distribution whose AIC is minimum among all the distributions. In Figure 1, four districts of Punjab are randomly selected, namely, Sargodha, Pakpatan, Bahawalnagar, Narowal to give a graphical representation of appropriately fitted probability distributions on their crop yield revenue. For these districts, the best-fitted probability distributions are Log-logistic (3P) and Cauchy distribution.

| Values Class          | Class       |
|-----------------------|-------------|-------------|
| Less than −0.5        | Below normal|
| Between −0.5 and +0.5 | Normal      |
| Above 0.5             | Above normal|

Parametric Normalization. In this study, normalized crop yield revenue data for different districts of Punjab at different time periods is computed by using Abramowitz and Stegun method (Abramowitz et al. [25]). Graphical representation of four districts (randomly selected), namely Faisalabad, Lahore, Jhelum, and Dera Ghazi Khan (DGK) is illustrated in Figure 2 to visualize the trend in standardized crop yield revenue data of these districts. Although, because of fluctuations no exact increasing or decreasing trend in these districts has been observed, due to the enhancement in technology and other agricultural resources, as time progressed, augmentation in the crop yield revenue has been observed. Similarly, we can visualize the trend in crop yield revenue data for other districts of Punjab.
3.1.2. Regional Crop Yield Revenue Assessment. In this section, the results of the fuzzy rule-based model of MCDM are presented. The proposed methodology of COMET presented in the previous section is implemented on 35 districts of Punjab and Islamabad, to rank them according to their contribution in the agricultural GDP of Pakistan’s...
economy. As the major concern of the COMET is to determine which attributes will be included in the evaluation, followed by an evaluation of a set of alternatives to make the decision. Therefore, in this research, standardized revenue of crop yield data of 35 districts of the Punjab and Islamabad is used for this purpose, whereas districts of Punjab have been included as attributes or alternatives. After that, the standardized crop yield revenue data of Punjab are classified into three categories; namely, Above Normal, Normal, and Below Normal by using the classification criteria which are shown in Table 2. Afterward, the dimensionality of the problem is determined by selecting 3 criteria, above normal ($C_1$), normal ($C_2$), and below normal ($C_3$). Subsequently, the expert’s knowledge is used to divide the domain of each of the criteria into three triangular fuzzy numbers. Thus, the obtained division is expressed by $C_1 = [0, 8, 15]$, $C_2 = [2, 14, 25]$, $C_3 = [0, 10, 20]$. Graphical representation of the TFN for each criterion is shown in Figure 3. In the next step, the characteristic objects $CO$ are obtained with the usage of the Cartesian product of the fuzzy numbers cores of all the criteria:

$$CO = C(C_1) \times C(C_2) \times C(C_3).$$

(18)

On this basis, 27 characteristics objects are obtained, which equally divide the space of the problem. The list of all the COs with their set values is given as follows.

Next, the matrix of MEJ, where, $MEJ = [I_{ij}]_{27 \times 27}$ is obtained. The summary of this step is demonstrated in Tables 3 and 4. After the MEJ matrix is prepared, a vector $S_I$ is obtained by using equation (9).

3.2. Discussion. Agriculture is one of the main sources of economic sustainability across major developed countries in the world, but in developing countries, agriculture productivity is still lagging behind its potential level. Hence, in order to meet the necessities of a rapidly growing populace, comprehensive strategies and actions need to be developed (Timmer [26]; Assam et al. [27]. Moreover, in developing countries like Pakistan agriculture decision problems are most complicated, several factors may be of importance, such as international relations, credit means, the role of the state, price policy, investment of capital, new systems of farming, risk assessment, etc. All these problems are faced on different levels, e.g. national, regional, village, and household (Alphonce [28]. As Punjab is the most agrarian province of Pakistan, therefore, in this research an MCDM method, namely, COMET which is completely free from the rank reversal paradox is used to establish a regionalized comparative analysis of crop yield revenue in various regions of Punjab, Pakistan. The finding of this research would be helpful for policy-makers and planners to improve the overall crop yield production in the region and to construct precise and accurate budget allocation policies. In addition, this paper provides a novel procedure to normalize the crop yield revenue data to make a fair comparison.

In the result section, the fuzzy rule-based ranking for 35 districts of Punjab and Islamabad is obtained. Table 5 depicted an interesting picture of the backward and upward districts of Punjab on the basis of their contribution.
Figure 3: Pictorial representation of the triangular fuzzy numbers (TFNs) for criterion 1 (above normal), 2 (normal), and 3 (below normal), respectively.

| Table 3: Matrix of expert judgments by comparing the COs pairwise (part 1/2). |
|---------------------------------------------------------------|
| CO | CO\textsubscript{2} | CO\textsubscript{3} | CO\textsubscript{4} | CO\textsubscript{5} | CO\textsubscript{6} | CO\textsubscript{7} | CO\textsubscript{8} | CO\textsubscript{9} | CO\textsubscript{10} | CO\textsubscript{11} | CO\textsubscript{12} | CO\textsubscript{13} | CO\textsubscript{14} | CO\textsubscript{15} |
| CO\textsubscript{1} | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| CO\textsubscript{2} | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0.5 | 1 | 0 |
| CO\textsubscript{3} | 0.5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 | 0 | 0 | 0 | 0.5 | 0 |
| CO\textsubscript{4} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{5} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{6} | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{7} | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{8} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{9} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| CO\textsubscript{10} | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{11} | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{12} | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 0 |
| CO\textsubscript{13} | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| CO\textsubscript{14} | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{15} | 0.5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{16} | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{17} | 0.5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{18} | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{19} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{20} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{21} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{22} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{23} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{24} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 |
| CO\textsubscript{25} | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| CO\textsubscript{26} | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| CO\textsubscript{27} | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
Table 4: Matrix of expert judgments by comparing the COs pairwise (part 2/2).

| CO16 | CO17 | CO18 | CO19 | CO20 | CO21 | CO22 | CO23 | CO24 | CO25 | CO26 | CO27 |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0.5  | 0    | 0    |
| 0    | 1    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    |
| 0    | 0.5 | 1    | 0.5  | 0    | 0    | 0    | 0    | 0.5  | 0    | 0.5  | 0    |
| 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    |
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 0.5 | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 1    | 1    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    |
| 1    | 1    | 1    | 0    | 0    | 0    | 0    | 1    | 0    | 0    | 0    | 0    |
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 1    | 0.5 | 1    | 1    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    |
| 1    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 0.5 | 1    | 0.5 | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 0    |
| 1    | 1    | 1    | 0    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    |
| 1    | 1    | 1    | 1    | 0.5  | 1    | 1    | 1    | 0    | 0    | 0    | 0    |
| 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 1    | 0    | 0    |
| 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 1    | 0    |
| 1    | 0.5 | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 1    | 0    |

Table 5: Districtwise ranking of Punjab region with characteristic object method using triangular fuzzy numbers.

| Districts (Alternatives) | Above normal | Normal | Below normal | P    | Rank |
|--------------------------|--------------|--------|--------------|------|------|
| Attock                   | 0            | 25     | 3            | 0.24232 | 26   |
| Bahawalnagar             | 1            | 21     | 6            | 0.25515 | 25   |
| Bahawalpur               | 0            | 25     | 3            | 0.36678 | 12   |
| Bhakhar                  | 2            | 21     | 5            | 0.29457 | 17   |
| Chakwal                  | 3            | 21     | 4            | 0.33400 | 14   |
| DGK                      | 0            | 20     | 8            | 0.20907 | 31   |
| Faisalabad               | 15           | 3      | 10           | 0.73080 | 2    |
| Gujranwala               | 3            | 12     | 13           | 0.27594 | 20   |
| Gujrat                   | 6            | 6      | 16           | 0.35961 | 13   |
| Hafizabad                | 2            | 20     | 6            | 0.28793 | 18   |
| Islamabad               | 0            | 14     | 14           | 0.16920 | 35   |
| Jhelum                   | 4            | 4      | 20           | 0.26923 | 23   |
| Jhang                    | 1            | 20     | 7            | 0.74919 | 1    |
| Kasur                    | 3            | 21     | 4            | 0.33400 | 14   |
| Khanewal                 | 7            | 18     | 3            | 0.47174 | 6    |
| Khushab                  | 5            | 20     | 3            | 0.40620 | 10   |
| Lahore                   | 0            | 24     | 4            | 0.23567 | 28   |
| Layyah                   | 5            | 16     | 7            | 0.37961 | 11   |
| Lodhran                  | 10           | 8      | 10           | 0.54120 | 5    |
| Mandibahudin             | 2            | 23     | 3            | 0.30787 | 16   |
| Muzaffargarh             | 6            | 19     | 3            | 0.43896 | 9    |
| Mianwali                 | 1            | 24     | 3            | 0.27509 | 21   |
| Multan                   | 3            | 9      | 16           | 0.25864 | 24   |
| Nankana sahib            | 1            | 10     | 0            | 0.12020 | 36   |
| Narowal                  | 8            | 10     | 10           | 0.46153 | 7    |
in the agricultural GDP of Pakistan’s economy. It can be observed that Jhang, Faisalabad, and RYK are the top three upward districts of Punjab, whereas Nankana Sahib, Islamabad, and Rawalpindi are the top 3 backward districts of Punjab. The reasons might be behind that most of the areas in Jhang, Faisalabad and RYK are suitable for the cultivation of crops. Moreover, district Jhang is presently famous as “The land of two rivers”, and the quality of water is relatively better in the Jhang than in the surrounding areas. In addition, Jhang is one of the largest wheat-producing districts in the province. The main crops of the districts are sugarcane, rice, barley, tobacco, and cotton. Similarly, in Faisalabad, sugarcane, wheat, rice, and Jowar are the chief crops grown at a larger scale. In RYK, around 50% of the total land is used for agriculture. Therefore, RYK is highly intensive in agriculture and is known for its high production of cotton, sugarcane, rice, and wheat crops. Meanwhile, due to urbanization in Rawalpindi and Islamabad, most of the areas in these districts are not suitable for agricultural production. Moreover, people who live in Rawalpindi and Islamabad have their focus on immigration, they do not have an interest in agricultural credit to improve the productivity or efficiency of crops. Therefore, these two districts contribute less in the agricultural GDP of Pakistan’s economy. Further, in most of the cases Nankana Sahib is shown as not available in data due to the fact that this district is newly formed and did not exist at the time of the data collection. Hence, in this research, it is assumed that Nankana Sahib also contributes less in the agricultural GDP of Pakistan’s economy on the basis of available data.

4. Conclusion

In this research, a comprehensive framework is proposed to normalize the crop yield revenue of Punjab under probabilistic nature. Then a comparative analysis of crop yield revenue in various region of Punjab is established to check which district contributes more in agricultural GDP of Pakistan’s economy and which contributes less, by ranking the district according to their contribution. For that purpose, a MCDM technique, COMET is used. Therefore, it was concluded that the Jhang, Faisalabad, and RYK are highly ranked districts whereas Nankana Sahib, Rawalpindi, Islamabad are low ranked districts of Punjab, according to their contribution to the agricultural GDP of Pakistan’s economy.

Therefore, it can be suggested that to remap the strategic plan to promote the agriculture sector and improve agricultural resources on these high and average ranked districts instead of low ranked districts of Punjab to enhance overall crop yield revenue which is lagging behind its potential level. Drought Monitoring and land use planning should emphasize less water requiring crops. Production of chemical fertilizer should be enhanced and available to farmers at a subsidized rate. Moreover, oil cakes, which are one of the natural organic fertilizers with high nitrogen contents, may also be used as fertilizer to improve agricultural productivity. Further, several scientific means of cultivation should be used to improve production and the farmers should adopt methods like the rotation of crops, use of fertilizers, pesticides. The agricultural sector of Pakistan is mostly dependent on the monsoon; hence, permanent means of irrigation should be developed. Therefore, the government should formulate, adopt and implement area-specific plans and a long-term policy to give a new direction to the state’s agriculture.

This standardized crop yield revenue data can be further utilized in several disciplines such as spatial analysis, time series analysis, classification, modeling, and forecasting purposes. Furthermore, the methodology demonstrated in this research can be further extended at the national and international levels.

However, the limitations of this research are: Due to the limitations of time and resources, this research is limited for the province of Punjab. Moreover, District Chaniot is not included in comparative analysis because of the circumstances that the data for this newly established district was incomplete. [29].

Data Availability

Data will be provided upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.
References

[1] Z. Rahman and M. E. Hossain, "Role of agriculture in economic growth of Bangladesh: a var approach," 2014, https://www.researchgate.net/profile/Md_Hossain29/publication/284030589_Role_of_Agriculture_in_Economic_Growth_of_Bangladesh_A_VAR_Approach/links/564b42f080ae020ae9f7f624.pdf.

[2] Gop, Pakistan Economic Survey (2016-17), Government of Pakistan, Islamabad, Pakistan, 2017.

[3] A. J. Khan and T. Anwar, "Is there any role of technological inputs? A district-wise analysis of output differential in crop sector," Pakistan Development Review, vol. 47, no. 4II, pp. 925–946, 2008.

[4] S. Iftikhar and H. Z. Mahmood, "Spatial distribution of agricultural resources and food security: a case of Punjab Pakistan," Cogent Food & Agriculture, vol. 3, no. 1, Article ID 1357265, 2017.

[5] J. Singh, S. K. Saxena, and D. S. Kulshrestha, Districtwise agricultural development and distance in rajasthan, Vol. 1, University of Rajasthan, Jaipur, India, 2014.

[6] M. D. Jena, "Agricultural development disparities in Odisha: a statistical study," Am Rev Math Stat, vol. 2, no. 1, pp. 45–53, 2014.

[7] S. Baruah and M. Borah, "Inter-district disparity in agricultural development of Assam," International Journal of Mathematical Archive ISSN 2229-5046 [A UGC Approved Journal], vol. 7, no. 4, 2016.

[8] M. Zare, C. Pahl, H. Rahnama et al., "Multi-criteria decision making approach in E-learning: a systematic review and classification," Applied Soft Computing, vol. 45, pp. 108–128, 2016.

[9] M. Dotoli, N. Epicoco, and M. Falagario, "Multi-Criteria Decision Making techniques for the management of public procurement tenders: a case study," Applied Soft Computing, vol. 88, Article ID 106064, 2020.

[10] R. Mikael, M. Abdollahi Kamran, G. Sadegheslam, and M. Atei, "Ranking sawability of dimension stone using promethee method," Journal of Mining and Environment, vol. 6, no. 2, pp. 263–271, 2015.

[11] S. Shukla, P. K. Mishra, R. Jain, and H. C. Yadav, "An integrated decision making approach for erp system selection using swara and promethee method," International Journal of Intelligent Enterprise, vol. 3, no. 2, pp. 120–147, 2016.

[12] A. Awasthi, H. Omrani, and P. Gerber, "Investigating ideal-solution based multicriteria decision making techniques for sustainability evaluation of urban mobility projects," Transportation Research Part A: Policy and Practice, vol. 116, pp. 247–259, 2018.

[13] J. Watr´obski, W. Sa-labun, A. Karczmarczyk, and W. Wolski, "Sustainable decision making using the comet method: an empirical study of the ammonium nitrate transport management," in Proceedings of the 2017 Federated Conference on Computer Science and Information Systems (FedCSIS), pp. 949–958, IEEE, Prague, Czech Republic, September 2017.

[14] S. Faizi, W. Salabun, S. Ullah, T. Rashid, and J. Więckowski, "A new method to support decision-making in an uncertain environment based on normalized interval-valued triangular fuzzy numbers and comet technique," Symmetry, vol. 12, no. 4, p. 516, 2020.

[15] W. Sa-labun, A. Karczmarczyk, J. Watr´obski, and J. Jankowski, "Handling data uncertainty in decision making with comet," in Proceedings of the 2018 IEEE Symposium Series on Computational Intelligence (SSCI), pp. 1478–1484, IEEE, Bangalore, India, November 2018.

[16] W. Chmielarz and M. Zborowski, "On analysis of e-banking websites quality - comet application," Procedia Computer Science, vol. 126, pp. 2137–2152, 2018.

[17] W. Salabun, "The characteristic objects method: a new distance-based approach to multi-criteria decision-making problems," Journal of Multi-Criteria Decision Analysis, vol. 22, no. 1-2, pp. 37–50, 2015.

[18] W. Salabun and A. Karczmarczyk, "Using the comet method in the sustainable city transport problem: an empirical study of the electric powered cars," Procedia Computer Science, vol. 126, pp. 2248–2260, 2018.

[19] W. Sa-labun, A. Piegat, J. Watr´obski, A. Karczmarczyk, and J. Jankowski, "The comet method: the first mcda method completely resistant to rank reversal paradox," European Working Group Multiple Criteria Decision Aiding Series, vol. 3, 2019.

[20] C. Cheadle, M. P. Vawter, W. J. Freed, and K. G. Becker, "Analysis of microarray data using z score transformation," Journal of Molecular Diagnostics, vol. 5, no. 2, pp. 73–81, 2003.

[21] A. Curtis, T. Smith, B. Ziganshin, and J. Elefteriades, "The mystery of the z-score," Aorta, vol. 4, no. 4, pp. 124–130, 2016.

[22] H. Hassan and E. Silva, "A Kolmogorov-smirnov based test for comparing the predictive accuracy of two sets of forecasts," Econometrics, vol. 3, no. 3, pp. 590–609, 2015.

[23] S. Ghosh, M. K. Roy, and S. C. Biswas, "Determination of the best fit probability distribution for monthly rainfall data in Bangladesh," American Journal of Mathematics and Statistics, vol. 6, no. 4, pp. 170–174, 2016.

[24] A.-N. Spiess, "Propagation of uncertainty using higher-order Taylor expansion and Monte Carlo simulation," vol. 11, p. 44, 2018, https://cran.r-project.org/web/packages/propagate/propagate.pdf.

[25] M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, Dover, New York, NY, USA, 2012.

[26] C. P. Timmer, "Chapter 29 Agriculture and economic development," Agriculture and its External Linkages, vol. 2, pp. 1487–1546, 2002.

[27] A. Azam, F. Nazir, M. Rafiq, S. Nazir, S. Nazir, and S. Tasleem, "Role of agriculture in economic development of Pakistan," Int. J. Business, Econ. Manag. Work, vol. 2, no. 2, pp. 9–12, 2015.

[28] C. B. Alphonce, "Application of the analytic hierarchy process in agriculture in developing countries," Agricultural Systems, vol. 53, no. 1, pp. 97–112, 1997.