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Research Article

Evaluating the impact of climate change on the agriculture sector of Pakistan using Multi Criteria Decision Making (MCDM)

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Abstract

In Pakistan, the agriculture sector plays a fundamental role in the economy's growth. However, this sector also faces many problems due to the drastic climatic variation. To handle this problem, we need to investigate the critical atmospheric changes and how they affect the major agricultural crops. Therefore, the purpose of this study is to examine the influence of climatic diversity on agricultural crops of the country using a Multi-Criteria Decision Making (MCDM) approach. The fuzzy VIKOR method has been used to describe the impact of atmospheric factors such as high temperature, heavy rainfall or sleeting, drought, smog, heat waves, poisonous gases, associated humidity, and storms on the agriculture sector of Pakistan. The results indicate that high temperatures and storms are the most critical climate factors which affect agricultural crops. Furthermore, it indicates that tobacco is the most sensitive crop to climate change, whereas sugarcane is the least affected by these climate changes. By analyzing and evaluating the impact of these climate factors, we can efficiently plan to cultivate these crops in areas that are least vulnerable to the adverse effects of these climate changes.

Keywords: Fuzzy VIKOR, Fuzzy number, climate change, atmospheric changes, agriculture, crops, tobacco, sugarcane.

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1. Introduction

Climatic variation remains one of the most challenging problems facing the modern world. These changes are primarily caused by the release of gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) into the atmosphere, which have a significant impact on the global environment. The changes may lead to up and down of sea level, disturb rainfall sequence and increase global temperature. Natural disasters like floods, storms and droughts may also increase due to changing environmental factors. Modern world is responsible for rising the CO_2 level from 280ppm to 380ppm (Stern *et al.*, 2006). This increase is primarily attributed to the widespread use of fossil fuels and deforestation practices. Examining the economic impacts of climate change on the agriculture sector is significant due to the susceptibility of the agricultural industry to climate variations.

The fluctuation in climate patterns has negatively affected the productivity and viability of the agriculture industry, leading to inferior economic and physical outcomes compared to the effects of climate change. Several climate change factors, including rise in temperature, smog, rainfall pattern, drought, heat waves, floods and storms have influenced productivity. These factors not only affect the productivity of agriculture but may also affect the country's economic growth. There have been many investigations into how weather and climate conditions impact food production, specifically focusing on their effect on crop yields.

For instance Lobell *et al.* (2011) conducted a study that showed the global production of maize has decreased by 3.8% and wheat by 5.5% due to changes in climate between 1980 and 2008. Similarly, there is decrease in crop yield recorded by heat waves and associated Russian wheat embargo in 2010/2007 may lead to a low level of cereal stock and increase the food price. The negative effect of temperature was studied by Shakoor *et al.* (2011). According to Field (2014), there has been a decline in the production of wheat, maize and rice in recent decades due to increased temperature. Siddiqui *et al.* (2012) reported that variation in atmospheric conditions is particularly devastating in South Asia and could potentially cause a 50 percent reduction in wheat productivity by the year 2050.

Agriculture sectors play a fundamental act in the recessions of Pakistan. Majority of the population directly or indirectly depend on this sector. It contributes over 21 percent of the country's Gross Domestic Product (GDP), absorbing about 44 percent of labour utilization (Awan & Yaseen, 2017). A major part of the population of the country resides in rural areas and relies on agriculture as their primary source of livelihood. The economy of the country is strongly linked with this sector i.e., it is the primary supplier of new materials to the industries contributing to Pakistan exports while on the other side it is a large market for fertilizer pesticides and other agriculture implements.

Pakistan produces five major crops, such as wheat, rice, cotton, maize, and sugarcane. Due to uncertain change of climate this sector is suffering from secular decline. Climatic factor like smog, wind, sunshine, carbon dioxide level, soil moisture, heat waves, droughts and floods influence agriculture sector and decrease crop production. As observed in (Kreft *et al.*, 2014), Pakistan is considered to be highly susceptible to the adverse impacts of climate change. In Global Climate Risk Index (GCRI) Pakistan was ranked on 21st position for their outrageous climate condition from 1993 to 2012.

Pakistan is ranked at twelfth position effected with environmental change by World Bank (Nomman & Schmitz, 2011). In Smit & Skinner (2002), it is reported that the agriculture sector is confronted with significant challenges due to atmospheric conditions, such as floods, high temperatures, water shortages, droughts, and an increase in the prevalence of diseases and pests. In Khan and Fee (2014) the authors noted that Pakistan's vulnerability to environmental changes is concerning, as it was ranked 29^{th} on the Global Climate Change Vulnerability Index (CCVI) for 2009-2010 and 16^{th} for 2010-2011, indicating that it is one of the most sensitive country to the effects of atmosphere.

The occurrence of severe floods from 2010 to 2014, as well as an extended dry season between 1999 and 2003, are just a few examples of atmospheric events that have affected Pakistan. Anticipated environmental changes are expected to have an adverse effect on Pakistan's economy, as the country has already experienced extreme climate events including changes in precipitation, droughts, and floods (Asif, 2013). Pakistan is especially accessible to changes in the climate due to its heavy reliance on natural assets. Thus, proper adaptations are needed (Abid *et al.*, 2015).

Climate influence crop production in different ways i.e., during the crop growth it gives a positive indicate if rainfall is started while on the other hand if there is no rain and temperature is high, so the crop mostly affects. The production intensity also decreases due to lack of technology in agriculture. After examining current and projected atmospheric conditions, this study aims to analyze the effects of environmental factors such as high temperature, floods, droughts, sunshine, smog, relative humidity, and rainfall on major crops in Pakistan and rank the major crop from most to least effected by climate change using Multi Criteria Decision Model (MCDM). The ranking will help to cultivate the most effected crop in a region where this climatic situation is minimum recorded from the past record and future prediction to reduce economic risk and to increase net return.

The structure of the paper is: Section 2 explains the literature review. Section 3 presents the definitions of fundamental concepts in fuzzy set theory and outlines the proposed methodology in detail. In section 4, the proposed methodology is applied to solve the given problem and explains the results of the study. Finally, section 4 presents conclusion of the study based on the results obtained.

2. Literature review

The mathematical programming model have been widely used in agriculture for planning problems, In Heady (1954) the author apply Linear Programming (LP) model in land allocation. In 1960-1980s LP models have been used in different farm planning problem (Beneke & Winterboer, 1984). Although LP is a powerful optimization technique, it only considers a single objective. However, many farm planning problems involve multiple objectives. To address this issue, Zadeh (1965) introduced fuzzy theories in this field, which take into account multiple objectives and uncertainties. Słowiński (1986) applied Fuzzy Linear Programming (FLP) and solve farm planning models. Pal and Moitra (2003) utilized Fuzzy Goal Programming (FGP) and investigated crop planning models under crisp resource constraints.

In this study, fuzzy VIKOR technique is applied to analyze results. The VIKOR methodology, which stands for Multi-criteria Optimization and Compromise Solution, was originally proposed by Opricovic and Tzeng (2004). This technique is designed to identify and choose the perfect choice from the specific options based on multiple conditions, and to find efficient solution for the problem at hand. The method uses multi-criteria measure to rank the alternatives, which is derived from the l_p-metric used in a compromise programming method developed by Yu (1973). VIKOR technique does not give precise results when there is lack of information i.e., weight to the criteria and values of alternative are not assign properly. Therefore, fuzzy sets were introduced for the first time by Bellman and Zadeh (1970) within MCDM which allow the computation in word instead of number. Here, fuzzy VIKOR technique is utilized where weight to the criteria and rating to the alternatives were assigned in linguistic variables, expressed by fuzzy number.

3.1. Basic concept and definition

A fuzzy set $\widetilde{\boldsymbol{F}}$ defined over a principal set X, and it is characterized by a membership function such as $\mu_{\tilde{f}}(x) \rightarrow [0,1], \forall\, x \in X$. The function value $\mu_{\tilde{f}}(x)$ represents the degree of x in $\widetilde{\boldsymbol{F}}$, and is referred as the class of membership of *x* in $\widetilde{\boldsymbol{F}}$. The closer the value of $\mu_{\tilde{f}}(x)$ is to 1, the higher the degree of membership (Dzitac, 2015).

Fuzzy Numbers (FNs) come in various types, but the most widely used ones are triangular FNs and trapezoidal FNs. A triangular FN is specified by a triplet $\tilde{f}$= (m, n, p). The parameter m, n, p are small positive constants. The membership function for triangular FNs can be expressed as:

$$\mu_{\tilde{f}(x)} = \begin{cases} \frac{x-m}{n-m}, & m \leq x \leq n \\ \frac{p-x}{p-m}, & n \leq x \leq p \\ 0 & \end{cases} \tag{1}$$

And the trapezoidal FNs are expressed in positive parameter $\tilde{f}$=(m,n,p,q). The membership function of trapezoidal FNs can be interpreted as:

$$\mu_{\tilde{f}(x)} = \begin{cases} \frac{(x-m)}{(n-m)} & m < x \leq n \\ 1 & n \leq x \leq p \\ \frac{(p-x)}{(q-p)} & p < x \leq q \\ 0 & otherwise \end{cases} \tag{2}$$

3.2. Distance amid the triangular fuzzy numbers

Here, the vertex method which was proposed by (Chen, 2000) is used to compute the length amid two fuzzy numbers. Let $\tilde{x}_1 = (a_1, b_1, c_1)$ and $\tilde{x}_2 = (a_2, b_2, c_2)$ be two triangular fuzzy numbers then distance between them is:

$$d(\tilde{x}_1, \tilde{x}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \tag{3}$$

The algebraic operation for the fuzzy numbers is discussed in (Kahraman *et al.*, 2002).

3.3. Linguistic variables

Linguistic variable is a type of variable that has values in the form of words or sentences rather than numerical numbers (Zadeh, 1975). Linguistic variables are extremely useful in a model that are complex or vague to be adequately described using traditional quantitative expressions. For instance, “very low”, “low”, “medium”, “high”, and “very high” are not precise values. To address this issue, fuzzy set theory employs a conversion scale to transform linguistic variables into fuzzy numbers. In this study, a rating scale ranging from 0 to 1 is utilized to evaluate the criteria and alternatives. Table-1 presents the correspondence between fuzzy numbers and linguistic variables. It is worth noting that a scale of 1 to 9 can also be used to convert linguistic variables into fuzzy numbers.

Table-1: Conversion list of linguistic variable into fuzzy values

Linguistic variable	Triangular Fuzzy number
Very Low	(0,0,0.25)
Low	(0,0.25,0.5)
Medium	(0.25,0.5,0.75)
High	(0.5,0.75,1)
Very High	(0.75,1,1)

3.4. Fuzzy VIKOR method

To deal with multi-criteria optimization in a complex system the researchers Opricovic and Tzeng (2004) introduced multicriteria optimization and compromise solution or (VIKOR) method. The VIKOR methodology first established a covenant ranking-list, covenant result and determined stable weights intervals for the efficient solution (Opricovic, 1998). To obtain the compromise solution, the VIKOR methodology initially identifies the positive and negative ideal values. The degree of proximity to the ideal solution is subsequently compared to determine the compromise solution. Similar to other MCDM technique the VIKOR technique may also be extended to the fuzzy VIKOR method. The steps wise procedure for this method as follow:

Step 1: First, we have to make a list of the feasible choices under different conditions and constitute a group of decision maker.

Step 2: Assigning linguistic variable

The determine linguistic variable to the criteria according to their importance. Linguistic variable are subjective words that show the view of an expert about the conditions for each choice under supposition. The linguistic terms are converted into fuzzy values as shown in Table-1.

Step 3: Formulate the fuzzy decision matrix.

Consider there are k numbers of decision makers tasked with evaluating m alternatives based on n conditions using fuzzy multi-criteria decision-making, in matrix form the model is shown as:

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} i = 1,2,\ldots,m;\ j = 1,2,\ldots,n$$

Where $\tilde{x}_{ij}$ is the value of alternative A_j $(A_j = A_1, A_2, \ldots, A_m)$ evaluated with respect to criteria C_j $(C_j = C_1, C_2, \ldots, C_n)$, $\tilde{x}_{ij} = (m_{ij}, n_{ij}, p_{ij})$ is a linguistic variable denoted by Triangular fuzzy numbers.

Step 4: Defuzzification

To defuzzify the decision matrx, BNPi (Best Non-fuzzy Performance) values are found from the fuzzy weighted and fuzzy rating using COA defuzzification method (Wu *et al.*, 2016).

$$\mathrm{BNP_i} = \frac{[(\mathrm{p}-\mathrm{m})+(\mathrm{n}-\mathrm{m})]}{3} + \mathrm{m}, \quad \forall\ \mathrm{i}, \tag{4}$$

Step 5: Determine best and worst fuzzy values.

Identify the best fuzzy value $f_i^* = (l_i^*, m_i^*, p_i^*)$ and the fuzzy worst value $f_i' = (l_i', m_i', p_i')$ by using the following expressions.

$$f_j^* = \max \tilde{x}_{ij} \quad j \in B, \qquad f_j^* = \min \tilde{x}_{ij} \qquad j \in C, \tag{5}$$

$$f_j' = \min \tilde{x}_{ij} \quad j \in B, \qquad f_j' = \max \tilde{x}_{ij} \qquad j \in C, \tag{6}$$

where B is benefit, and C is the cost criteria.

Step 6: Compute the separation measure $\tilde{S}_i$ and $\tilde{R}_i$

In this step, the separation value $\tilde{S}_i$ are calculated for the A_i alternatives, from the best fuzzy values f_j^*, and the values of $\tilde{R}_i$ for the A_i are calculated from the worst fuzzy values f_j'.

$$\tilde{S}_i = \sum_{j=1}^{n} \widetilde{w}_j (f_j^* - \tilde{x}_{ij})/(f_j^* - f_j') \tag{7}$$

$$\tilde{R}_i = max\left[\widetilde{w}_j (f_j^* - \tilde{x}_{ij})/(f_j^* - f_j')\right] \tag{8}$$

Where $\tilde{x}_{ij}$ denotes the value of alternative with respect to criteria c_j and w_j represent the importance weight of c_j.

Step 7: Computing value of $\widetilde{Q}_j$

Compute value of $\tilde{Q}_j$ as:

$$\tilde{Q}_j = \mu\left(S_j - S^*\right)/(S' - S^*) + (1-\mu)\left(R_j - R^*\right)/(R' - R^*). \tag{9}$$

Where

$$S^* = \min S_i\,, \qquad S' = maxS_i\,,$$

$$R^* = \min R_i\,, \qquad R' = maxR_i\,,$$

Furthermore, in the strategy of the maximum group utility, a weight parameter μ is introduced, representing the weight given to this strategy. Typically, μ is assumed to be 0.5.

Step 8: Ranking the alternative.

The ranking of the alternatives is based on the values of separation measure S, R and index Q. Sort the values of Q in descending order and the alternative corresponding to the value close to zero is considered to be the best alternative.

4. Data collection, results and discussion

In this section the proposed method is applied to the agriculture sector of Pakistan. The effect of climate factors on the major crops of Pakistan is analyzed and ranked effected wise against different climatic factors. For this purpose, those crops are selected that will contribute more to the economy of the country. The crops like maize, wheat, rice, tobacco, cotton, and sugarcane to be considered as alternatives and the climatic factors including high temperature, heavy rainfall or sleeting, drought, smog, heat waves, poisonous gases, relative humidity and storms are different criteria.

Step 1: The first step towards ranking of crops was pre-processing of data. For data collection a survey form is filled from the farmers and experts to the field from different areas of Pakistan. The survey form is about how different crops are affected by the climatic factor when these factors increase in the climate. For simplification the criteria's high temperature, heavy rainfall or sleeting, drought, smog, heat waves, poisonous gases, relative humidity, storms are represented by (C1, C2, C3, C4, C5, C6, C7, and C8) respectively whereas the alternatives maize, wheat, rice, tobacco, cotton, and sugarcane are represented by (A1, A2, A3, A4, A5, and A6) respectively.

Step 2: Linguistic terms like very high, high, moderate, low, very low are defined to weight the criteria and rate the alternatives. Weighting the criteria mean how these factors are effective i.e. very high is used when a factor is very effective and low or very low is used when a factor is comparatively less effective. Rating of alternative vs the given climatic factor by linguistic variable to check that how these factors affect the corresponding criteria. Data from the experts has been collected in term of linguistic variables. Each expert assign different weight to the criteria and rate to the alternative according to their experience. The linguistic variable with corresponding fuzzy rating is shown in Table-1.

Step 3: The individual choices were combined to obtain the group preferences, and the linguistic variables were transformed into triangular fuzzy numbers using the conversion values provided in Table-1.

Step 4: In this step, the decision matrix constructed in step 3 is defuzzified using Equation (4). The defuzzified decision matrix and the weights of the criteria are presented in Table-2.

Table-2: Defuzzified decision matrix and the weights of the criteria in crisp values.

Alternatives	WEIGHT	A1	A2	A3	A4	A5	A6
Criteria							
C1	0.713235	0.70588	0.632353	0.708333	0.6666667	0.700938	0.740196
C2	0.622549	0.65278	0.617647	0.642157	0.6250000	0.688725	0.718137
C3	0.622549	0.70833	0.669118	0.674020	0.6519608	0.634804	0.705882
C4	0.497549	0.51716	0.441176	0.433824	0.5245098	0.536765	0.546569
C5	0.573529	0.57843	0.600439	0.598039	0.6078431	0.620098	0.669118
C6	0.534314	0.51961	0.536765	0.526961	0.5245098	0.551471	0.607843
C7	0.637255	0.70343	0.669118	0.627451	0.6593137	0.642157	0.693627
C8	0.575982	0.53431	0.509804	0.544118	0.5563725	0.598039	0.605392
C9	0.649521	0.62503	0.674023	0.590686	0.5220588	0.637255	0.673402

Step 5: From Table-2 best crisp values f^* and worst crisp value f' were calculated using equation (5) and (6). The results are given in Table-3.

Table-3: Best and worst crisp values

Criteria	f^*	f'
C1	0.632353	0.740196
C2	0.625000	0.718137
C3	0.622549	0.708333
C4	0.433824	0.546569
C5	0.573529	0.669118
C6	0.519608	0.607843
C7	0.627451	0.703431
C8	0.509804	0.605392
C9	0.522059	0.67402

Step 6: The separation measure value S_i and R_i were calculated in this step using equation (7) and equation (8). Also, the values of Q_i are found by using the formula given in equation (9) for all the alternatives and the results are given in Table-4.

Table-4: Index value of S, R and Q

Alternatives	S_i	R_i	Q_i
A1	2.92	0.64	0.564904
A2	1.59	0.65	0.403226
A3	1.68	0.50	0.173322
A4	1.62	0.40	0.004011
A5	3.04	0.53	0.403528
A6	5.33	0.71	1

From the Figure 1 it is easy to rank the alternative in ascending order using crisp values of the index Q_i. The value closest to zero is considered as the compromise solution. From Figure 1 it is clearly shown that at Q4 the crisp value is very near to zero so the alternative at four (A4) is the compromise solution.

Step 7: Ranking the alternative in ascending order utilizing the crisp values of S, R and Q given in Table-5.

Table-5: Ranking of alternatives

Ranking	1	2	3	4	5	6
S	A2	A4	A3	A1	A5	A6
R	A4	A3	A5	A1	A2	A6
Q	A4	A3	A2	A5	A1	A6

In Table-5, A4 is to be considered as the best alternative. From step one it is noticed that A4 represent tobacco which is our desire solution. From over all procedure, it is found that tobacco is most sensitive crop to be affected by changing climatic factors.

From the analysis the following results are obtained.

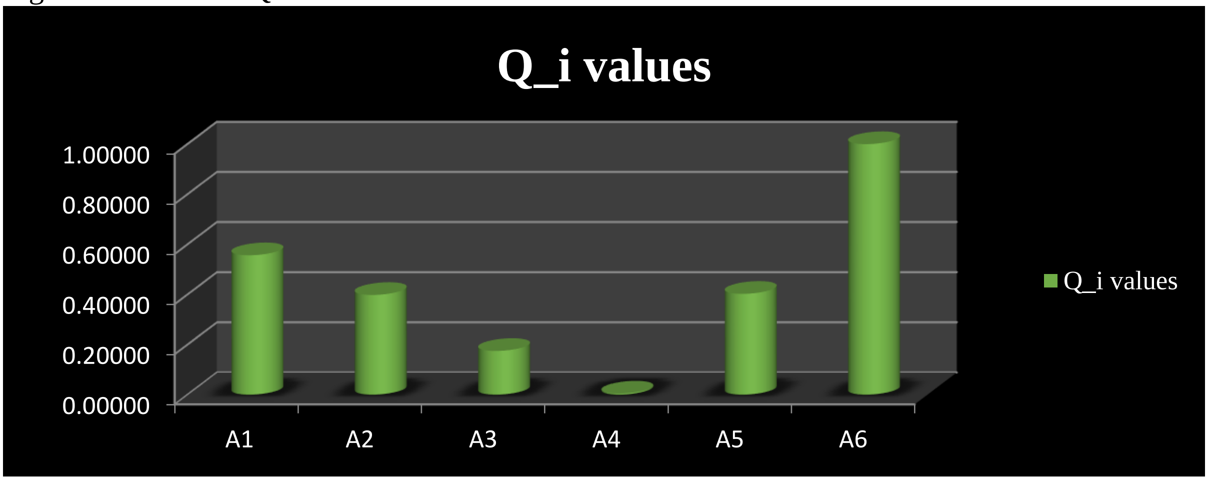
Table-6: Ranking of alternatives according to Q, S and R values

Ranking	1	2	3	4	5	6
S	A2	A4	A3	A1	A5	A6
R	A4	A3	A5	A1	A2	A6
Q	A4	A3	A2	A5	A1	A6

From the obtained results, it is analysed that tobacco is the most sensitive crop to the climatic variations because the crisp value of index Q, S, and R are least. The production of tobacco is decreased in the area where the mention climatic factors are unbalanced. Due to its sensitivity to the climate, it is just produced in some specific area of the country. Tobacco cultivation in Pakistan is limited to only 0.25% of the total irrigated land, but it holds significant importance for the economy of the country. The tobacco industry generates income and employment opportunities at various stages including farming, manufacturing, distribution, and retailing. There are different types of tobacco that were grown here in Pakistan which include Flue-Cured Virginia, Dark Air-Cured, White Patta, and Burley which is cultivated mostly in some district of Punjab and Khyber Pakhtunkhwa (KP), while some other qualities were imported. KP contribute 75% in the production of tobacco generate a total annual income of approximately Rs. 31 billion and contribute Rs. 50 billion to the Government exchequer in the forms taxes (Ali *et al.*, 2015). This contribution to the government exchequer could be increase by increasing the production of different varieties of tobacco.

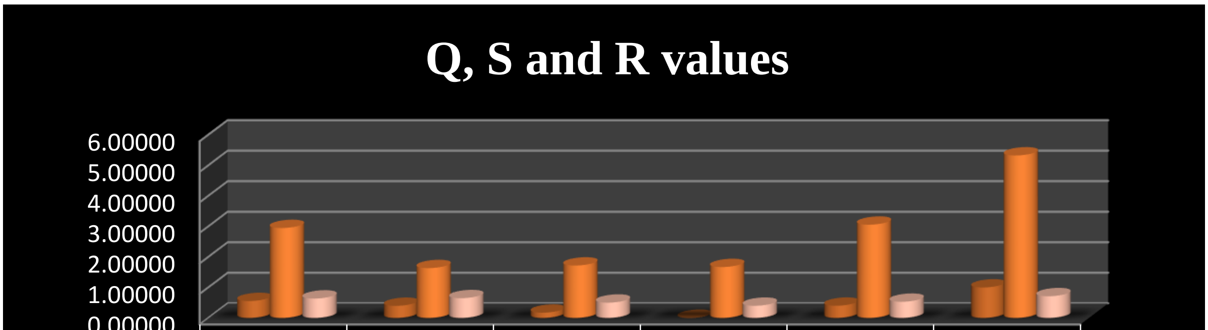
The corresponding values of Q obtained are displayed in the Figure 1.

Figure 1: Values of Q



And the combined value of the measure of separations Q, S and R is shown in Figure 2.

Figure 2: Q, S and R values



	A1	A2	A3	A4	A5	A6
By Q	0.55656	0.39821	0.17486	0.00467	0.40262	1.00000
By S	2.94858	1.63504	1.71955	1.66955	3.05718	5.32646
By R	0.63725	0.64951	0.50251	0.40020	0.53167	0.71324

From this study it is noticed that tobacco is very susceptible to the climate. So, according to the study the production of tobacco will be increased if the government gives serious attention to the tobacco industry. The environment of Sindh and Punjab is very match able to the environment required for tobacco growth. Similarly, the worst alternative is A6 which represent sugarcane which is to be not so much affected by the mention climatic factors. Sugarcane is also a cash crop of Pakistan which contribute 3.4% in agriculture and contribute 0.7% in GDP (Usman, 2016). It is called as worst alternative because the Q, S and R value are high for A6. According to the value of Q given in the table the alternatives are ranked as $A_4 > A_3 > A_2 > A_5 > A_1 > A_6$. Each alternative has their contribution in the economy which can be increased if it is cultivated in the area according to the environmental changes. Pakistan lies between the latitudes of 25° and 36° N, experiencing a continental climate with extreme temperature variations. The weather in the country is predominantly influenced by two factors, namely the Western disturbance and the monsoon, which are responsible for bringing changes in the climatic conditions of the region. It seems to be good to predict weather for a whole season for crops from planting to harvesting to check that which area has a most suitable environment for a specific crop.

5. Conclusion

Pakistan's economy heavily relies on its agricultural sector, but this sector is facing a decline due to its susceptibility to atmospheric conditions. To deal with this problem, in this study some major crops of the country like maize, wheat, rice, tobacco, cotton, and sugarcane are examined and found that how these crops are affected by climatic factors including high temperature, heavy rain falls, drought, smog, poisonous gases, heat waves, flood, humidity and storms. For this purpose, a survey is performed related to the effect of these climatic factors on the mention crops through a questionaries from the experts all over the country. The data is then analyzed using MCDM fuzzy VIKOR technique and ranked the crops in ascending order. From the analysis it is noted that tobacco is most sensitive crop to these atmospheric factors. It is suggested, to predict the weather condition for the year and plant the crops in the ideal area having convenient atmospheric situation.

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