APPLICATION OF ARTIFICIAL INTELLIGENCE IN CLUSTER ANALYSIS FOR ENHANCING PRODUCTIVITY AND SUSTAINABILITY IN AGRICULTURAL PRODUCTION IN THE REPUBLIC OF SRPSKA

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***Abstract**: This research investigates how cluster analysis and artificial intelligence (AI) can be used to increase agricultural productivity and sustainability in the Republic of Srpska. More accurate strategic planning and effective resource management were made possible by the identification of particular clusters with comparable traits through the analysis of climatic parameters and the classification of regions. While the use of machine learning techniques allows for more precise forecasting of the effect of climatic conditions on yields, the suggested insurance models, which are based on cluster analysis, have the potential to improve farmers' financial protection. This research emphasizes the necessity of creating customized insurance models that account for particular climatic risks and implementing contemporary technology to enhance the claims resolution procedure. Through these approaches, it is possible to significantly increase the resilience of the agricultural sector to climate change and ensure better financial stability and safer production.*

***Key words**: agriculture, climate risks, artificial intelligence, cluster analysis, productivity, sustainability, insurance*

***JEL classification**: Q1, G22, O33*

1. INTRODUCTION

The Republic of Srpska's economy depends heavily on agriculture, although it faces several obstacles, such as changing climate conditions, a variety of soil types, and the requirement for better production methods (Radosavljević, 2016). Artificial intelligence (AI) and cluster analysis are being used more and more in modern agricultural resource management techniques. This allows for more accurate regional classification, which improves resource management and helps create sustainable strategies (FAO, 2023).

Certain regions of the Republic of Srpska are excellent for growing cereals, while others are vulnerable to hazards including drought, erosion, and extreme weather events due to the notable regional variations in agricultural conditions.

However, these particularities are frequently overlooked by current insurance plans and agricultural policies, which leads to inefficient resource allocation and higher financial risks for farmers. Conventional approaches to agricultural zone classification mostly depend on broad economic and meteorological factors, which are frequently too imprecise for risk assessment. (Mihailović, Radosavljević & Popović, 2023).

High-risk and low-risk zones can now be precisely identified because to the development of sophisticated analytical techniques like K-means cluster analysis.

The goal of this research is to improve the Republic of Srpska's agriculture sector's sustainability and productivity by using AI in cluster analysis. Because they make it easier to create customized insurance models and support strategies, the findings should be advantageous to investors, insurance companies, and decision-makers. As a result, farmers face less financial risks and agriculture is more climate change adaptable (Patel et all, 2023).

2. THEORETICAL ASPECTS OF ARTIFICIAL INTELLIGENCE IN ANALYZING SOCIO-ECONOMIC FACTORS

The use of artificial intelligence (AI) in economic, social, and agricultural research is growing, making it a crucial instrument in contemporary analytics. A deeper comprehension of complex systems, the identification of hidden patterns, and the forecasting of future trends are made possible by developed machine learning algorithms and data processing techniques. AI is important in agriculture for managing resources, classifying regions, and evaluating risks and potential.

The goal of artificial intelligence (AI), a multidisciplinary branch of computing, is to create machines that can learn on their own, make judgments, and handle vast amounts of data (Russell & Norvig, 2016). In the field of economics, it simplifies decision-making through algorithmic processing, automates real-time big data processing, and enables predictive analytics that forecasts future patterns based on historical data (James et al., 2013).

AI is used in agriculture for crop monitoring, yield forecasting, risk assessment, and insurance management. (Assimakopoulos et al., 2024, Demirel et al., 2023, Wang et al., 2024, Ghaffarian et al., 2022) AI enables dynamic analysis based on intricate patterns, in contrast to traditional economic analyses that depend on basic statistical techniques. Cluster analysis, one of the main AI methods in economics, finds homogeneous groups of regions based on a number of criteria. Determining agro-ecological zones and making focused strategic choices require the use of this technique. For instance, areas can be grouped using the K-means method according to climatic and agro-ecological factors (Swain et al., 2024), and similarities across regions can be visualized using hierarchical cluster analysis (Rasool et al., 2023).

The Republic of Srpska's regions can be categorized using climatic parameter analyses. These include lowland areas that are ideal for intensive crop production, hilly and mountainous regions that are good for raising livestock and producing fruit, and arid regions that are at high risk of drought and need special irrigation and insurance measures.

Cluster analysis can be used to improve infrastructure planning in the agricultural sector, create specialized agricultural models, and optimize regional subsidy programs. In the Republic of Srpska, artificial intelligence (AI) and cluster analysis are potent instruments that can improve decision-making, forecast climatic hazards, and develop efficient policies to assist farmers.

3. CLIMATIC CONDITIONS OF THE REPUBLIC OF SRPSKA AND THEIR ROLE IN ECONOMIC DEVELOPMENT

A major determinant of economic development, especially in agriculture, is the climate. Geographical diversity in the Republic of Srpska allows for a range of climatic zones and, in turn, a variety of agricultural production types, yields, and economic structures. In order to comprehend how climatic circumstances impact agricultural productivity and sustainability, this research takes into account the region's climatic features, the effects of climatic elements on economic sectors, and soil fertility.

With notable seasonal fluctuations, the Republic of Srpska is located in a temperate-continental climatic zone. From lowland temperate regions to mountainous regions with higher precipitation and extending to the drier climate of Herzegovina, the climate varies according to altitude and proximity to rivers (Republic of Srpska Institute of Statistics, 2023). The average annual temperature in hilly regions is between 7°C and 12°C, while in lowland regions, it is between 11°C and 14°C, according to FAOSTAT data from 2025. The western and central regions receive the most precipitation, which ranges from 600 to 1200 mm annually.

The crops that can be effectively grown are determined by climate, which has a direct impact on agricultural output. The biggest threats to the agriculture industry are droughts, temperature swings, and heavy precipitation. Reduced yields from protracted droughts and harsh heat (FAOSTAT, 2025), higher risks of illnesses and pests from milder winters, and soil erosion from excessive rains are some of the negative effects of climate change (Radosavljević, Mihailović& Popović, 2022).

On the other hand, climate change also brings opportunities, such the creation of new agricultural branches and an extended growing season that can enable longer growth periods for some crops.

Other economic sectors, such as infrastructure, tourism, and energy, are also impacted by climate variables. For example, new strategies are needed to address the growing requirement for hydropower plants to adapt to harsh environments and infrastructure damage brought on by sudden climate change.

Another important element influencing agricultural output is soil fertility. It is dependent on the soil's chemical and physical characteristics, nutritional content, and water-retention capacity. Agricultural land has different pH values and requires agro-technical interventions. It can be categorized as high, medium, or acidic.

Crop rotation, sustainable fertilizing techniques, and methodical soil analysis for the best use of agro-technical measures are all ways to increase soil fertility.

The Republic of Srpska's economy and agricultural development are greatly influenced by the climate. Effective strategy formulation in the domains of infrastructure, insurance, and agriculture is made possible by an understanding of area climate features and an analysis of soil fertility. Artificial intelligence and cluster analysis can improve insurance systems, optimize the distribution of agribusiness subsidies, and enable more precise yield estimates.

4. CLUSTER ANALYSIS OF THE REPUBLIC OF SRPSKA BASED ON CLIMATIC PARAMETERS

One of the key elements affecting the sustainability and productivity of agricultural output is the climate. Significant climatic variations exist among the Republic of Srpska's many regions, which have an immediate impact on the kinds of crops that may be grown there and the dangers posed by severe weather. In order to identify similar climatic-agroecological zones and facilitate more accurate strategic planning and decision-making in the agricultural sector, this component of the research uses cluster analysis.

The methodological approach incorporates machine learning algorithms, statistical analysis of climate data, and region classification according to pertinent factors. Finding distinctive clusters of locations is the aim in order to improve the adaption of insurance models and agricultural methods.

To cluster the regions, it is necessary to define relevant climatic indicators that directly impact agricultural production. Based on data from Republika Srpska Institute of Statistics (2021, 2022, 2023) the following indicators were selected:

- Average Annual Temperature (°C) – A key factor determining the length of the growing season.
- Annual Precipitation (mm) – Directly affects irrigation needs and crop selection.
- Humidity – Important for assessing the risk of insufficient water during critical growth phases.
- Frequency of Extreme Weather Conditions (frost, hail, storms) – A significant parameter for assessing risks in production and insurance.
- Number of Rainy Days.

The field of computer science known as "machine learning" focuses on creating models and algorithms that let computers learn from data and gradually get better at what they do. This allows artificial intelligence to replicate human learning. Without the requirement for programming language expertise, BigML (https://bigml.com) is a cloud-based platform that enables the development of automated and flexible machine learning prediction models. Thanks to its robust features and sophisticated algorithms, it makes modeling tasks like classification, regression, time series forecasting, cluster analysis, anomaly detection, and model visualization simple to complete. It is user-friendly and offers a wide range of services (Wang et al., 2021).

The BigML platform was used in this research's cluster analysis procedure, which grouped cities and municipalities in the Republic of Srpska according to meteorological factors. A three-year average of the values that occurred between 2021 and 2023 was used to calculate each of the observable parameters. 19 municipalities and cities in the RS were covered by the available climate data from the Republic Statistical Office of the Republic of Srpska (Statistical Yearbooks 2021, 2022, and 2023).

One machine learning technique that enables the categorization of regions according to similarities in particular meteorological variables is cluster analysis. In this research, the K-means clustering method (MacQueen, 1967) was applied. The results of the analysis allow for the identification of regions with similar climatic characteristics, which is crucial for optimizing agricultural production, regional planning, and adapting insurance models.

The climatic characteristics of the analyzed municipalities and cities are presented in the following table.

Table 1. *Climatic Characteristics of Municipalities and Cities in the Republic of Srpska (Average 2021-2023)*

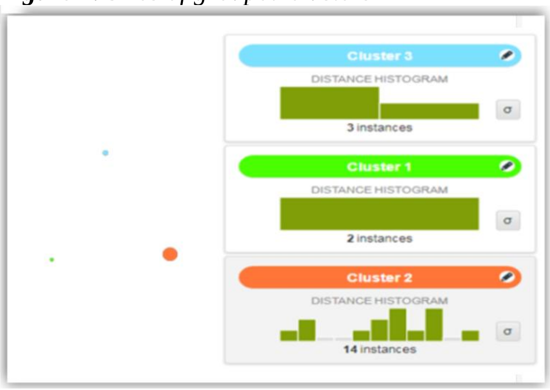
Location	Average Annual Air Temperature (°C)	Humidity (%)	Annual Precipitation (mm)	Frost (Number of Days)	Rain (Number of Days)
Banja_Luka	13.33	72.00	976.33	66.67	145.33
Bijeljina	13.36	76.33	693.20	53.00	140.67
Bileca	13.40	68.33	1613.73	59.33	118.00
Visegrad	12.11	67.33	822.93	67.67	151.00
Gradiska	13.01	77.33	1029.53	64.33	128.33

Location	Average Annual Air Temperature	Humidity (%)	Annual Precipitation (mm)	Frost (Number of Days)	Rain (Number of Days)
Doboj	13.07	73.33	860.67	62.00	146.00
Kalinovik	8.64	70.67	1198.23	117.00	138.00
Mrkonjic_Grad	10.98	73.33	1088.87	80.00	139.67
Novi_Grad	12.63	68.67	1170.27	61.33	133.67
Prijedor	12.83	75.33	1113.17	78.00	123.00
Ribnik	11.60	72.67	1133.40	77.67	156.67
Rudo	11.57	69.33	872.53	77.67	154.00
Sokolac	8.60	71.67	958.73	143.33	149.00
Srbac	12.37	67.67	887.33	63.33	134.67
Srebrenica	10.70	81.00	1014.13	85.67	150.33
Trebinje	15.38	66.33	1627.03	13.33	129.33
Foca	11.45	79.00	1064.07	59.00	138.67
Han_Pijesak	7.83	86.69	1218.00	126.67	177.00
Sipovo	10.63	78.42	966.10	98.00	134.67

Source: Calculated by the author based on data from the Republic Institute of Statistics of RS.

In the clustering analysis, the k-means method was applied, which finds a specified number of clusters by defining the centroids of each cluster, assigning data points to each centroid, and then repeating the centroid determination process until convergence is achieved, meaning the centroids no longer change significantly. To identify favorable, moderately favorable, and less favorable areas for investments in agricultural production that takes place in open fields, the objects were grouped into three clusters (Figure 1).

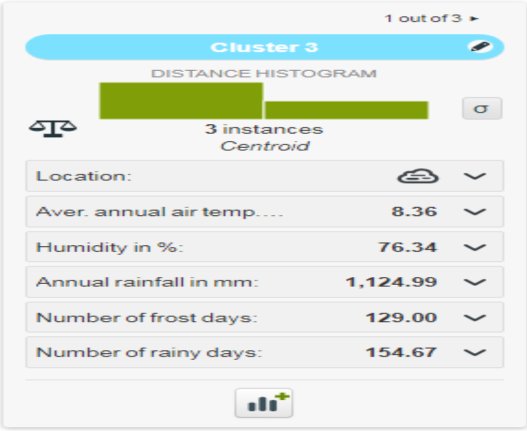
Figure 1. *Sizes of grouped clusters*



Source: Calculated by the authors based on data from the Republic Institute of Statistics of RS.

As shown in Figure 1, the largest number of objects (14 municipalities and cities) is located in Cluster 2, followed by Cluster 3 (3 objects), while the remaining 2 objects are in Cluster 1. Cluster 3 (Kalinovik, Han Pijesak, Sokolac), despite having relatively favorable amounts of precipitation and humidity, has an average of 129 frost days and, compared to the others, the lowest average annual temperature (8.36 °C, Figure 2).

Figure 2. *Average values of observed criteria for Cluster 3*

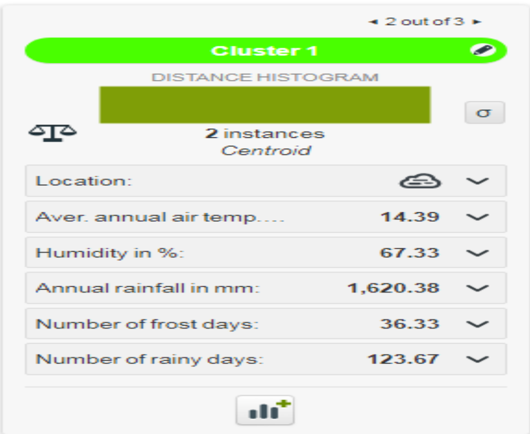


Source: Calculated by the authors based on data from the Republic Institute of Statistics of RS.

Due to the risks of late spring and early autumn frosts, as well as the high number of days with temperatures below optimal for the development of most agricultural species, it can be concluded that the municipalities included in this cluster are less favorable areas for investing in outdoor field production.

Cluster 1 (Trebinje, Bileća) has the lowest average annual humidity (67.33%) alongside the highest average annual temperature of 14.39 °C (Figure 3).

Figure 3. *Average values of observed criteria for Cluster 1*



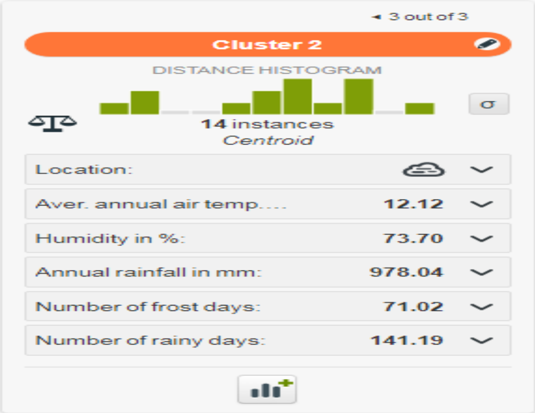
Source: Calculated by the authors based on data from the Republic Institute of Statistics of RS.

High temperatures during the growing season, combined with insufficient humidity, can be a limiting factor for the cultivation of certain vegetable species. This is a key reason why the municipalities and cities classified in this group can be considered moderately favorable for investments of this type.

As mentioned, Cluster 2 is the largest and includes the remaining 14 municipalities and cities in the Republic of Srpska (Banja Luka, Bijeljina,

Višegrad, Gradiška, Doboj, Mrkonjic Grad, Novi Grad, Prijedor, Ribnik, Rudo, Srbac, Srebrenica, Foča, Šipovo).
In comparison to Cluster 3, this cluster is characterized by a significantly lower average number of frost days (71.02). Additionally, regarding the average annual temperature, it has considerably higher values compared to Cluster 3, yet still about 16% lower than those in Cluster 1 (Figure 4).

Figure 4. *Average Values of Observed Criteria for Cluster 2*



Source: Calculated by the authors based on data from the Republic Institute of Statistics of RS

Based on the cluster analysis, the regions of the Republic of Srpska have been grouped into three characteristic clusters:

CLUSTER 1:

- Dry areas at high risk of drought during the summer months (Eastern Herzegovina),
- Limited water supplies o Suitable for Mediterranean crops,
- Considerable irrigation system investment potential.

CLUSTER 2:

- Moderately climatic lowland areas (Semberija, Posavina) with high soil fertility, a long growing season, a high danger of floods, and suitability for industrial crops and cereals,
- Longer growing season but more frequent rainfall in hilly highland areas (Banja Luka),
- Suitable for raising animals and produce,
- Moderate risk of frost.

CLUSTER 3:

- Mountain areas with harsh weather,
- Limited growing season,
- Elevated risk of snowfall and frost,
- Mostly appropriate for vast agriculture and forestry.

The Republic of Srpska's agricultural planning and development might be greatly enhanced by using cluster analysis based on climatic criteria. Better resource management, insurance model optimization, and customized agriculture policy creation are made possible by the clusters that have been found. Long-term productivity and sustainability of the agricultural sector are improved by this method, which gives decision-makers the ability to precisely allocate subsidies, plan infrastructure projects, and establish policies for climate change adaptation.

5. PROPOSED NEW INSURANCE PRODUCTS ALIGNED WITH CLIMATE CONDITIONS

Climate change adds to the many hazards facing agriculture by bringing droughts, floods, and other extreme weather events that have a direct influence on harvests and the viability of farmers' economies. This circumstance emphasizes the necessity of creating contemporary, customized insurance models that can successfully address the unique risks of various geographical areas.
At the moment, the Republic of Srpska's insurance models mostly depend on conventional types of coverage that cover fundamental risks, including livestock insurance or crop insurance against hail and flood damage.
Despite offering basic insurance, these policies do not take into consideration regional specificities and frequently fall short of farmers' needs. According to research, many producers lack sufficient financial protection since the adoption of agriculture insurance is decreased by the absence of accurate risk forecasting models.
Customized insurance models that concentrate on the unique climate hazards of each place can be created by employing cluster analysis of climatic factors. For example, desert locations may use insurance based on soil moisture data, whereas lowland areas with a high risk of flooding may use insurance based on hydrometeorological indicators. It is also necessary to determine risk zones to calculate adequate insurance premiums according to the risk of a certain geographical area. (Mitrašević, et al., 2023)
Artificial intelligence has the potential to improve risk assessment and premium determination even more. It is feasible to examine past climatic data and pinpoint important variables influencing agricultural losses by using machine learning techniques like Random Forest (Breiman, 2001). Moreover, dynamic evaluations of crop conditions and hazards can be made possible by incorporating Big Data analytics, which includes satellite imaging and Internet of Things sensors.
Technologies such as precision agriculture enable the optimization of resource use in farming. AI systems can detect early signs of diseases and pests, allowing for timely interventions. Additionally, forecasting weather conditions and

market trends helps farmers make informed decisions. (Katanić, 2024)

In the Republic of Srpska, modern agricultural insurance solutions necessitate customized strategies that take regional climate variations into account.

Farmers' financial security and the stability of the entire industry can be improved by putting the suggested insurance models based on cluster analysis and artificial intelligence into practice. This would enable quicker claims settlements and more precise risk assessments (Radosavljevic, 2023).

CONCLUSION AND RECOMMENDATIONS

Researches have indicated that cluster analysis and artificial intelligence (AI) are important instruments for raising agricultural productivity and sustainability in the Republic of Srpska. More accurate strategic planning and effective resource management are now possible thanks to the identification of clusters with comparable traits through the analysis of climatic data and the classification of regions. The stability and competitiveness of the agriculture sector can be raised by using this strategy to help decision-makers optimize agricultural policies and modify insurance models.

The development of particular risk management techniques has been made possible by the classification of regions according to their meteorological features using cluster analysis. Utilizing variables like temperature and precipitation, index-based insurance has emerged as a popular concept that enables quicker and more impartial claims settlements.

It is advised to improve subsidy policies to better suit the requirements of various locations and to develop tailored insurance models that take particular climatic hazards into account.

According to these researches, artificial intelligence in agriculture insurance needs to be further integrated. Additionally, the research could be extended to other agriculturally linked fields like energy and water resources.

In conclusion, enhancing agricultural output and insurance can be achieved through the use of artificial intelligence and cluster analysis. It is feasible to greatly increase the sector's resilience to climate change by tailoring investment plans and agricultural policies to particular climatic difficulties. This would guarantee improved financial stability and more secure production in the future.

Acknowledgment

This research was supported by the Ministry of Scientific and Technological Development and Higher Education of the Republika Srpska under the Agreement on Co-financing of the Scientific and Research Project No. 19.032/961-46/24 dated 30.12.2024.

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