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THE IMPACT OF CLIMATE CHANGE ON FOOD SECURITY IN THE REPUBLIC OF MOLDOVA

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Abstract

Intensified climate change inevitably affects human life and the state of the animal and plant world and becomes a tangible threat to the population's well-being and sustainable development. These factors predetermine the need to consider climate change as one of the key long-term factors of Moldovan food security. In response to this concern, we set out to investigate the impact of climate change on the resilience of food security in the Republic of Moldova. The applied research methodology was based mainly on quantitative methods in the R programming language. Following the analysis, the vulnerability index was constructed for 1997-2023, and the top 5 years with the highest vulnerability were determined. In order to statistically validate the identified critical observations and reduce the complexity in the process of constructing the vulnerability index, the principal components method was applied. The results showed us that 2023 and 1997 are the most vulnerable years. Principal Component Analysis (PCA) reported that climate change explains approximately 80% of the variation, while food security explains 20%. In conclusion, it was found that an increase in vulnerability in recent years indicates that climate pressure is intensifying at a faster pace than the adaptive capacity of the food system of the Republic of Moldova. If the current trend continues, the risk of food insecurity will increase significantly, which justifies the urgency of policies to adapt and strengthen food security resilience.

***Keywords**: Climate Change Index; Food Security Index; Principal Component Analysis (PCA); Vulnerability Index; Food System Resilience.*

Introduction

Rapid climate change, in historical retrospect but at the same time global, is one of the main challenges of the modern world in terms of food security. A combination of climatic, socio-economic, and geographical factors determines countries' vulnerability to the most common climate risks. The leading causes of climate change are the emission of gases from the soil into the atmosphere, which has reached a large scale and continues to grow. The causes of emissions are desiccation, excessive development and intensive use of soils, reduction of areas occupied by vegetation, deforestation, drainage of hydromorphic soils, fires, which have become more frequent in recent years, urbanization, and emissions from "dirty" enterprises [1-3].

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By 2050, total food production will almost double to meet the needs of our planet's augmenting population [4]. The only problem is that the existing agricultural output rates are, firstly, significantly lower and, secondly, subject to increasingly worsening risks. The reasons for the emergence of risks in agriculture are related to several aspects, among which the most important is a relatively strong influence of socio-political and agro-technological circumstances subject to at least some control and uncontrolled environmental factors, such as moisture availability and global temperature [5].

Climate change has a diverse impact on the economy and society. Thus, FAO reports find that extreme climate changes (so-called climate shocks) are one of the reasons for the worsening of food crises [6]. Weather events, especially climate shocks, significantly impact agricultural production and management and can disrupt value chains. Crop failures also cause price increases, which lead to socio-economic tensions in both consuming and producing countries. Real-time processes must be analyzed to respond to climate challenges and develop timely adaptation programs. Furthermore, it is essential to monitor changes in the volume and structure of consumption, to anticipate where changes will occur and what kind of products will be in demand in a given region, and to be prepared for them. Unfortunately, it is currently impossible to accurately determine the consequences of global climate change. However, it is safe to state that for the Republic of Moldova, the role of climatic factors is among the most important conditions influencing the harvest on the territory of the Republic of Moldova. The Republic of Moldova most often faced climatic phenomena, which included heavy and long-lasting torrential rains, hail, ice deposits, and extreme summer temperatures [7].

A high dependence on weather conditions leads to high unpredictability in Moldovan agricultural production and, consequently, a negative impact on food security.

In the specialized literature, the impact of climate change on food security is researched in several ways. Thus, most of it analyzes how climate change affects the decrease in agricultural productivity, food inflation, the disruption of agri-food value chains, and the increase in social inequalities [8-11]. At the same time, it is emphasized that the adverse effects of climate change are felt mainly in developing countries because, in these countries, the resilience of food security to climate shocks is lower, and adaptation resources are limited [12, 13].

As for the assessment of the impact of climate change on food security, the situation is complicated by the process of collecting data related to climate change but also to its impact on food security, which is a multidimensional concept, and also the need to apply more comprehensive models [14]. Some authors have used multiple regressions to examine how climate change affects crop yields [15]. Another study specifies that the fundamental problem is fitting climate anomalies into statistical models [16]. Econometric analyses have been combined with Monte Carlo simulations to elucidate the incidence of climate change (temperature, precipitation, CO_2) on food security [17]. A group of authors focuses on developing projections and scenarios to estimate the effect of climate change on agricultural production and food security at the global level through agricultural yield models (APSIM, DSSAT) and multi-factorial statistical analyses [18, 19].

The literature review highlighted several gaps that need to be addressed.

Problem: Climate change, including the increased intensity and frequency of extreme events, has increased food security risks.

However, the specialized literature lacks a detailed analysis that would examine the imbalances between these two dimensions and simultaneously allow for the elucidation of periods of significant risk.

Developing an approach that integrates relevant indicators and highlights periods of maximum vulnerability will enable public institutions to intervene to strengthen food security resilience**.**

Based on these considerations, this study aims to investigate to what extent climate change influences food security and identify perspectives for integrating and mitigating adverse effects, focusing on the context of the Republic of Moldova.

The purpose of the research will be achieved through the following objectives:

(1). The analysis of the vulnerability of food security of the Republic of Moldova to climate change risks;

(2). Investigation of the common variation between food security and climate change in order to reduce the complexity of the data in an interpretable two-dimensional space;

(3). Identify critical periods for imbalances between climate risks and the Republic of Moldova's food security.

Experimental part

Materials

In the Republic of Moldova, agriculture isn't just about production—it's also deeply connected to our relationship with nature and long-standing traditions.

Agriculture is an important branch that not only makes an essential contribution to food security but also to the development of the national economy of the Republic of Moldova. Thus, the contribution of agriculture to the formation of GDP in 2023 in the Republic of Moldova was 9.3% [20], and the share of exports of agri-food products in total exports was 57% [21]. The analysis of the risks to which the food security of the Republic of Moldova is exposed indicates that climate change hurts the four dimensions of the Republic of Moldova [22].

In the Republic of Moldova, extreme climatic phenomena have been recorded more frequently over the past 30 years. According to statistical data, heavy rains (≥30mm for ≤1 hour and ≥50mm for ≤12 hours), winds with a speed of ≥ 26m/s, and hail are recorded almost annually. On average, long-term rains (≥120mm for ≤3 days), heavy snowfalls (≥20mm for ≤12 hours), and ice deposits with a diameter of ≥20mm are reported once every 2 years. Intense blizzards (with a duration of ≥24 hours) and whirlwinds are possible on average once every 5 years [7]. The maximum air temperature of +40°C and above can occur once every 20 years. Regarding historical trends in climate change, Moldova has experienced changes in average temperature and precipitation. The climate in the country has become warmer, with an average temperature rise of 1.2°C, while the increase in average precipitation volumes was only about 51.3 mm. For the coming decades, a temperature increase of approximately 1.1°C – 1.4°C is estimated across the country. The imbalances between extreme natural phenomena and food security imply the need to analyze the links between climate change and food security [7].

Methods

Analyzing how extreme weather events disrupt food systems resilience is essential to understanding the connection between climate change and food security. To establish the influence of climate change on food security, it is necessary first of all to assess both the food security of the Republic of Moldova and climate change. The problem in evaluating these two concepts lies in their polyvalence. To solve this problem, two composite indices were constructed: the Food Security Index of the Republic of Moldova (Table 1) and the Climate Change Index (Table 2). In both cases, 27 observations were made, covering 1997-2023.

The composite Food Security Index is built from 16 indicators, grouped into four sub-indices, which correspond to the dimensions of food security.

Table 1. Food Security Index

Variables	Source
Availability Subindex	
SSR	FAOSTAT [23, 24]
IDR	FAOSTAT [23, 24]
Cereal yield (kg per hectare)	World Development Indicators [25]
Average dietary energy supply adequacy (percent) (3-year average)	FAOSTAT [26]
Access Subindex	
Food inflation (%)	FAOSTAT [27]
Indicator of Food Price Anomalies (IFPA), by Food CPI	FAOSTAT [28]
Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day)	FAOSTAT [26]
Prevalence of unaffordability (PUA), percent	FAOSTAT [26]
Utilization Subindex	
Food supply, total (kcal/capita/day)	FAOSTAT [29]
Protein supply quantity, total (g/capita/day)	FAOSTAT [29]
Fat supply quantity, total (g/capita/day)	FAOSTAT [29]
Minimum dietary energy requirement (kcal/cap/day)	FAOSTAT [29]
Stability subindex	
Agriculture, forestry, and fishing, value added (% of GDP)	World Development Indicators [30]
Agriculture, forestry, and fishing, value added per worker (constant 2015 US$)	World Development Indicators [30]
Per capita food supply variability (kcal/cap/day)	FAOSTAT [31]
Gross per capita Production Index Number (2014-2016 = 100) (Agriculture)	FAOSTAT [32]

Table 2. Climate Change Index

Variables	Source
Methane (CH_4) emissions (total) excluding LULUCF (% change from 1990)	World Development Indicators [33]
Total greenhouse gas emissions excluding LULUCF per capita (t CO_2e/capita)	World Development Indicators [33]
Carbon dioxide (CO_2) emissions excluding LULUCF per capita (t CO_2e/capita)	World Development Indicators [33]
Nitrous oxide (N_2O) emissions (total) excluding LULUCF (% change from 1990)	World Development Indicators [33]
Temperature change with respect to a baseline climatology, corresponding to the period 1951-1980 in degrees Celsius	FAOSTAT [34]
Annual freshwater withdrawals, total (% of internal resources)	World Development Indicators [35]
Climate Altering Land Cover Index	IMF [36]

The Climate Change Index consists of 7 indicators describing climate change. In both cases, the z-score method was used to normalize the indicators, which corresponds to the following formula [37]:

$$\mathbf{z = (x - \mu) / \sigma} \quad \mathbf{(1)}$$

where: $\mathbf{x}$ - individual observation, $\boldsymbol{\mu}$ - mean, $\boldsymbol{\sigma}$ - standard deviation.

Past assessing the Food Security Index and the Climate Change Index to determine the link between these two composite variables in the first stage, we identified the most susceptible observation to the vulnerability index, calculated for each of the 27 observations.

The vulnerability index is a derivative index that examines the imbalance between two variables in a system [38]:

• Pressure/risk (Climate Change Index)
• Response capacity/adaptation (Food Security Index)

In this sense, two situations can be recorded: unfavorable and favorable.

Climate Change Index > Food Security Index → vulnerability
Food Security Index > Climate Change Index → resilience

In the second stage, Principal Component Analysis (PCA) was applied to investigate the two-dimensional structure of the dataset, investigating whether the variation in vulnerability corresponds to the significant directions of statistical variation between the Food Security Index and the Climate Change Index.

PCA allows us to find those directions in the data where most of their variability is located. These directions are called principal components. The first principal component is the direction along which the spread of the data is the greatest. It contains the maximum information about the differences between the data. The second principal component is perpendicular to the first and includes the second most significant part of the variability. In our case, PCA will identify how the two variables vary, highlighting the main directions of variation and latent patterns.

It is important to note that principal components are not accurate dimensions that are initially present in the data but are artificially created axes that help present the data in a more compact and meaningful way and allow the following: identifying hidden patterns in the standard variation of the data; presenting how observations naturally cluster (e.g., vulnerable vs. resilient years); diminishing the proportion of the data without significant loss of information.

The vulnerability index quantifies each observation's climate change and food security imbalance. PCA was also applied to better understand the latent structure and interdependence between the variables. Combining the vulnerability index with PCA allows both a direct measurement of risk and an integrated visualization of patterns in the data.

Moreover, finally, to outline a systemic risk profile, the years with the most significant vulnerability were determined.

All analysis was performed in the R programming language.

Results and discussion

Establishing the effect of climate change on food security in the Republic of Moldova is a very current issue. Over the past few years, the resilience of Moldovan food security has diminished [22]. In this sense, using the vulnerability index offers multiple advantages from a statistical and an application point of view. Suppose we interpret it from a statistical point of view. In that case, the possibility of estimating the difference between two variables, the Climate Change Index and Food Security Index, which are standardized through z-scores, allows obtaining a neutral scaled value, which eliminates the influence of the units of measurement and allows fair comparisons between the 27 years included in the analysis.

Following the analysis carried out in R, the graph of the evolution over time (1997-2023) of the climate-food vulnerability index was constructed and calculated as the difference between the Climate Change Index (x) and that of the Food Security Index (y) (Fig. 1).

Figure 2 shows that the vulnerability index (x-y) presents a clear pattern. Periods of relative stability (2000-2012) are followed by a clear upward trend, starting in 2013, recording maximum vulnerability values of over 1.5 in 1997 and 2023. This trend is also supported by the increasing linear regression line, which indicates a gradual deterioration of the climate-food balance.

Further, the vulnerability index values identified the most problematic 5 years of the analyzed period.

Following the analysis of the five most vulnerable years, the following was found: 2023 can be considered the most susceptible year, with a very high climate index and a negative food security score; 1997 and 1998 are years in which food security was well below the level of climate risks → the system was highly exposed; 2021 and 2022 have balanced values but remain vulnerable due to increased climate pressure. This graph represents the imbalance between climate risks and food capacity in the years with the most significant negative impact.

To understand how the variables in the model (Climate Change Index (x) and (y) Food Security Index) vary simultaneously, we will next apply PCA to identify which of them explains more of the total variation and how they correlate with each other in a two-dimensional space.

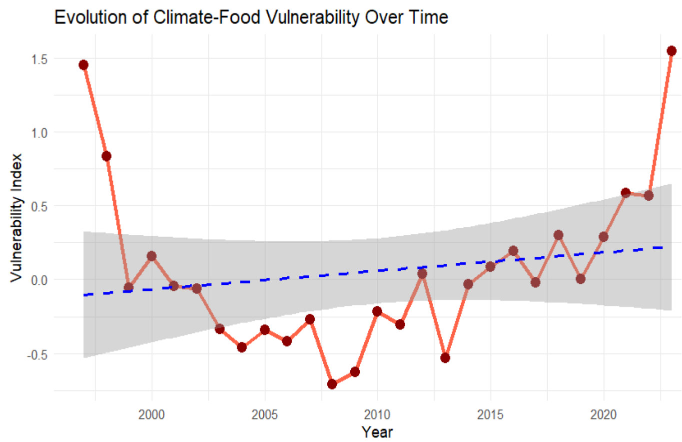

Fig. 1. Evolution of the food climate vulnerability index in the Republic of Moldova

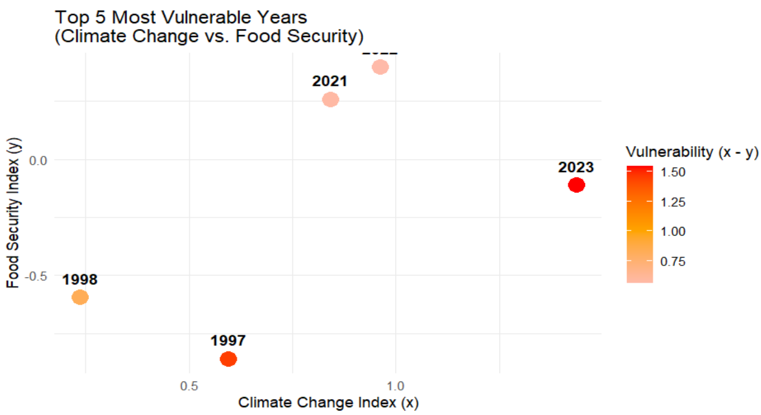

Fig. 2. Top 5 Most Vulnerable Years

Table 3. PCA Analysis

```
Importance of components:
                          PC1    PC2
Standard deviation     0.6239 0.3150
Proportion of Variance 0.7969 0.2031
Cumulative Proportion  0.7969 1.0000
> pca$rotation
         PC1        PC2
y -0.3285721 -0.9444789
x -0.9444789  0.3285721
```

The analysis revealed that PC1 explains approximately 80% of the variation and is dominated by x; PC2, which adds another 20% and is influenced by y. In the context of our research, the PCA results indicate that climate risk is the dominant variable in the imbalance between the Climate Change Index and the Food Security Index.

PC1 = -0.94*x + -0.33*y → *dominated by climate change*

PC2 = +0.33*x + -0.94*y → *separate observations according to food security*

From a statistical point of view, PCA allows the transformation of each year into a point in the PC1–PC2 plane. Accordingly, it is possible to visualize which years are close to each other in terms of climate-food profile and which of them are isolated (Fig. 3).

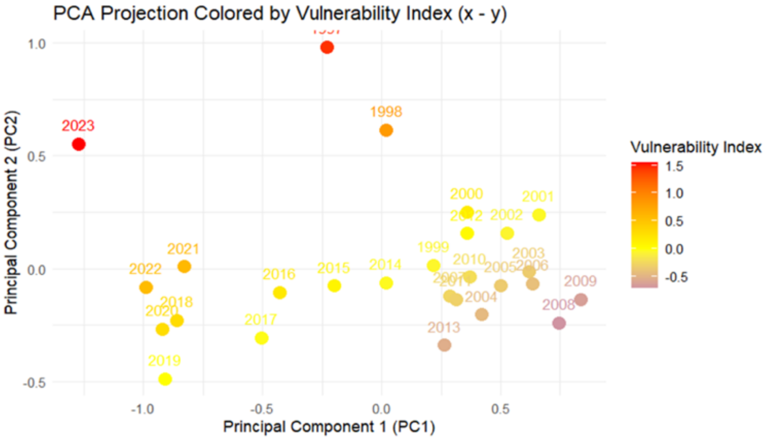

Fig. 3. PCA Projection Colored by Vulnerability Index

Each point on the graph represents a year (1997, 1998) and is positioned in the space defined by the first (PC1) and second (PC2) principal components extracted from the variables x (climate change) and y (food security). The points' coloring reflects the vulnerability index (x-y), and the labels explicitly display the corresponding year.

It can be observed that the years labeled with red values (high vulnerability index) are located in the area where the component x strongly dominated (PC1 is negative), and food security lagged far behind (PC2 can vary depending on y). In contrast, the years in pink shades demonstrate increased resilience – y > x.

The information that emerges from Figure 3 has a dual utility: it provides the structuring of years according to the latent components extracted through PCA, and it highlights the degree of vulnerability for each year. Determining vulnerable points allows us to do this, and the projection in the PCA space makes it possible to understand the structural variation of the overall variation. Thus, PCA does not replace vulnerability analysis but contextualizes it.

The vulnerability index and the principal component analysis (PCA) allow the investigation of the relationship between climate change and food security and provide a valuable tool with multiple practical applications. This vision offers a strong foundation for making strategic decisions in the field of adaptation to climate change and summarizes complex data in an easy-to-interpret framework.

Conclusions

The analysis's results reported that from 1997 to 2023, the food system was subject to significant strong oscillations, with periods of relative stability (2000–2012) followed by a visible increase in turbulence in the last decade.

Identifying years with extreme vulnerability—especially 2023, 1997, and 2021—highlights inflection points in the climate-food balance, which are confirmed by the index values and their positioning in the PCA space. The distribution observable in the PCA graphs shows that the system's variation is dominated by climate pressure, which raises alarm signals regarding the long-term adaptability of food security.

The vulnerability index has become a valuable tool in the comparison process, and the PCA analysis visualizes and statistically confirms the link between climate change and food security. The applied methods complement each other and construct a framework for elucidating systemic risks.

Starting from the fact that there is a trend of increasing vulnerability, which shows that climate change is growing at a faster pace than the adaptation ability of the food system of the Republic of Moldova, public policies must focus on two fundamental directions, namely (1) the development of sustainable agriculture, which involves reducing emissions and climate adaptation, and (2) strengthening the food system resilience of the Republic of Moldova.

Although the results obtained in the analysis can constitute a foundation for the possibility of making decisions, at the same time, we must note that the analysis carried out also has several limitations: first, the period included in the analysis is relatively short, especially for observations related to climate change; second, the composite indices (Climate Change Index and Food Security Index) are obtained by aggregating individual indicators obtained through normalization (z-score), which may influence their interpretation; third, the analysis carried out does not include the impact of agricultural policies and human effects on the phenomena under study.

In the following investigations, we will try to overcome the limitations by expanding the database, modeling the bidirectional relationships between the environment and the food system, including public policies, and conducting regional analyses to identify local disparities in vulnerability and resilience.

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