TPM Vol. 32, No. S4, 2025
ISSN: 1972-6325
https://www.tpmap.org/

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MULTIDIMENSIONAL MEASUREMENT OF ECONOMIC INEQUALITY, FOOD SECURITY AND SOCIAL INCLUSION: AN APPROACH BASED ON PRINCIPAL COMPONENT ANALYSIS

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Summary:
Economic inequality, food insecurity and social exclusion represent interrelated challenges to sustainable development. This study proposes a comprehensive methodological approach based on Principal Component Analysis (PCA) to build a multidimensional index that allows these problems to be measured together. Data from national surveys and socioeconomic indicators from 2023 in Latin America were used. The results show that it is possible to synthesize multiple dimensions into components that explain more than 75% of the total variance, allowing regions to be classified according to their multidimensional vulnerability. This analytical tool can guide targeted and efficient public policies in contexts of high structural inequality.

Keywords: Economic inequality, food security, social inclusion, principal component analysis, sustainable development, multidimensional measurement.

1. INTRODUCTION

Economic inequality, food insecurity and social exclusion are interdependent phenomena that make up the main structural challenges of contemporary societies, especially in developing countries. These problems not only affect individual and collective well-being, but also limit economic growth, erode social cohesion, and weaken democratic governance (UNDP, 2023).

In the last decade, progress in reducing monetary poverty has been offset by an increase in structural inequalities, manifested in unequal access to basic services, quality education, formal employment, and digital technologies (ECLAC, 2023). The COVID-19 pandemic deepened these gaps, causing significant setbacks in key human development indicators and exposing the fragility of social protection systems in Latin America (ECLAC & UNDP, 2022).

One of the most severe impacts occurred in the dimension of food security. The Food and Agriculture Organization of the United Nations (FAO, 2023) reports that in 2022 more than 248 million people in Latin America and the Caribbean suffered from some degree of food insecurity, with women and rural households being the most affected. This phenomenon is closely linked to the rise in food prices, labor informality, climate change and territorial conflicts, which requires a comprehensive approach from public policies.

For its part, social exclusion has worsened with the consolidation of new forms of inequality that are not limited to income, but include structural discrimination, territorial segregation, digital divides, and lack of cultural recognition (Sánchez-Talanquer & Martínez, 2021). Groups such as indigenous communities, people with disabilities, migrants, and Afro-descendant women face multiple barriers to the full exercise of their rights and access to services, which aggravates their situation of vulnerability (Oxfam, 2024).

In this context, an analytical approach is required to capture the multidimensionality of these problems and generate empirical tools for their comprehensive measurement. Traditionally, studies on inequality, poverty, and exclusion have focused on one-dimensional indicators, which limits the systemic understanding of the phenomenon (Alkire et al., 2022). Therefore, this research proposes the use of Principal Component Analysis (PCA) as a statistical methodology to construct a synthetic index of multidimensional social vulnerability, integrating the dimensions of economic inequality, food security and social inclusion.

This methodological proposal seeks to contribute to the design of more focused and efficient public policies, allowing the identification of territories and populations in critical situations through solid empirical evidence. It is also expected to offer a tool that can be replicated in different geographical and temporal contexts, facilitating the monitoring of progress in meeting the Sustainable Development Goals, particularly SDG 1 (No poverty), SDG 2 (Zero hunger) and SDG 10 (Reduced inequalities) (United Nations, 2022).

2. THEORETICAL FRAMEWORK

This theoretical framework addresses in an integrated way the three central axes of the study: economic inequality, food security and social inclusion, considering their systemic interrelation from a multidimensional and methodological approach based on Principal Component Analysis (PCA).

2.1. Economic Inequality

Economic inequality represents one of the most persistent forms of social exclusion. Although some countries have made progress in reducing extreme poverty, the gaps between high- and low-income groups continue to widen, affecting access to basic services, quality employment, and political participation (World Bank, 2023).

This phenomenon can be assessed using different indicators such as the Gini coefficient, the income gap between deciles or the Palma index. However, such indicators do not always reflect inequality in terms of opportunities or capabilities. Stiglitz et al. (2020) state that modern inequality should be understood as a structural phenomenon that ranges from the distribution of capital to the intergenerational reproduction of poverty.

Table 1. Key Indicators of Economic Inequality

Indicator
Gini coefficient
Palm Index
Percentage of labor informality
Access to credit

Source: World Bank (2023); ECLAC (2023).

2.2. Food Safety

Food security is a fundamental condition for well-being, understood as physical, social and economic access to sufficient, safe and nutritious food. According to the FAO (2023), about one in four people in Latin America suffers from moderate or severe food insecurity, posing serious challenges to public health and social stability.

Various structural factors affect this dimension, including rural poverty, climate change, food inflation, and the lack of food sovereignty policies (Grosjean et al., 2021). In addition, food insecurity is often correlated with malnutrition, affecting child development and labor productivity (FAO, 2023).

Table 2. Dimensions of Food Security

Dimension
Availability
Access
Utilization
Stability

Source: FAO (2023); IFPRI (2022).

2.3. Social inclusion

Social inclusion refers to the removal of barriers that prevent the full participation of all citizens in social, economic and political processes. It is linked to access to rights such as health, education, security, housing, and digital connectivity (UNESCO, 2022).

In contexts of high inequality, certain groups face structural or historical discrimination, such as indigenous peoples, people with disabilities, migrants, or women heads of household (Oxfam, 2024). This exclusion not only limits personal development, but also impedes the use of human capital in national economies.

Modern approaches to social inclusion adopt a paradigm of rights and capabilities, where equity not only implies the distribution of resources, but also the recognition of identities and active participation (Sen, 2020; Sánchez-Talanquer & Martínez, 2021).

2.4. Multidimensional Approach and Principal Component Analysis (PCA)

Since these three phenomena (inequality, food insecurity and inclusion) are interrelated, their joint analysis is more appropriate than the isolated treatment of each. Multidimensional poverty, for example, cannot be explained only by monetary shortages, but also by educational, health, or housing deficits (Alkire et al., 2022).

Principal Component Analysis (PCA) is a multivariate statistical technique used to reduce the dimensionality of large databases, transforming correlated variables into a set of uncorrelated components that retain the highest possible variance (Jolliffe & Cadima, 2021). This tool has proven useful for constructing synthetic indices and detecting latent patterns in complex social phenomena.

The application of the GPA in development studies makes it possible to integrate various indicators into a single metric, facilitating the classification of territories or social groups according to levels of vulnerability or well-being. In this way, policymakers can identify priority focuses for intervention with a solid empirical basis (Silva & Rangel, 2023).

3. METHODOLOGY

The present study uses a quantitative and exploratory approach of a cross-sectional nature, supported by multivariate statistical techniques for the construction of a synthetic index of multidimensional social vulnerability. The methodological choice responds to the need to integrate multiple social, economic and food variables into a coherent and replicable framework of analysis.

3.1. Research Design

A non-experimental, correlational, and cross-sectional **design was adopted**, which allows describing phenomena at a given time and analyzing relationships between variables without manipulating them (Hernández-Sampieri et al., 2022). A multidimensional approach was chosen, given that the conditions of economic inequality, food insecurity, and social inclusion cannot be understood in isolation, but as intertwined dimensions of social vulnerability (Alkire et al., 2022).

3.2. Source and Data Collection

Secondary **sources** from official databases and international organizations were used to allow comparison between countries and regions of Latin America. Indicators for the years 2022 and 2023 were selected, available in open formats and accessible to the public.

Table 3. Data Sources Used

Fountain
Household Survey
Human Development Indicators
Food safety
Socioeconomic data

3.3. Selection of Variables

The variables were selected based on three criteria: (a) theoretical relevance with respect to each dimension analyzed; (b) public and recent availability of data; and (c) statistical validity (normal distribution and variance). The variables were grouped into three blocks:

Table 4. Variables by Analytical Dimension

Dimension
Economic Inequality
Food safety
Social inclusion

Source: Authors' elaboration based on FAO (2023); ECLAC (2023); UNDP (2023).

3.4. Data Normalization

To ensure the comparability of the variables, a **z-score normalization** was applied. This procedure transforms the data to a common scale with mean zero and standard deviation one, eliminating the effects of the original range of each variable (Jolliffe & Cadima, 2021). The formula used was:

$$Z = \frac{(X - \mu)}{\sigma}$$

where X is the original value, μ is the mean, and σ is the standard deviation.

3.5. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) **was used** as a dimensionality reduction technique. This tool allows the identification of latent patterns and the synthesis of the information contained in multiple correlated variables into a few uncorrelated components (Silva & Rangel, 2023).

The following steps were taken:

1. Sample adequacy check with the **Kaiser-Meyer-Olkin (KMO) index**.
2. Application **of Bartlett's sphericity test** to check the correlation between variables.
3. Calculation of **eigenvalues** and retention of components with values greater than 1 (Kaiser criterion).
4. Use of **Varimax rotation** to facilitate the interpretation of factors.
5. Calculation of the **multidimensional vulnerability index** as a weighted combination of retained components.

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3.6. Construction of the Multidimensional Social Vulnerability Index (MVI)

The IVSM was constructed from the principal components obtained, weighted according to the proportion of variance explained. The final index has a continuous range of values, where higher values indicate a higher level of social vulnerability.

The general formula of the index is:

$$IVSM = \sum_{i=1}^{n} (C_i \times P_i)$$

where C_i is the value of component i for each territorial unit, and P_i is the percentage of variance explained by that component.

The results section **is presented below,** based on the statistical analysis of the multidimensional social vulnerability index (MVI), along with **graphs and comparative tables between regions**. All data and visualizations are representative and constructed based on the GPA methodology applied on three main components.

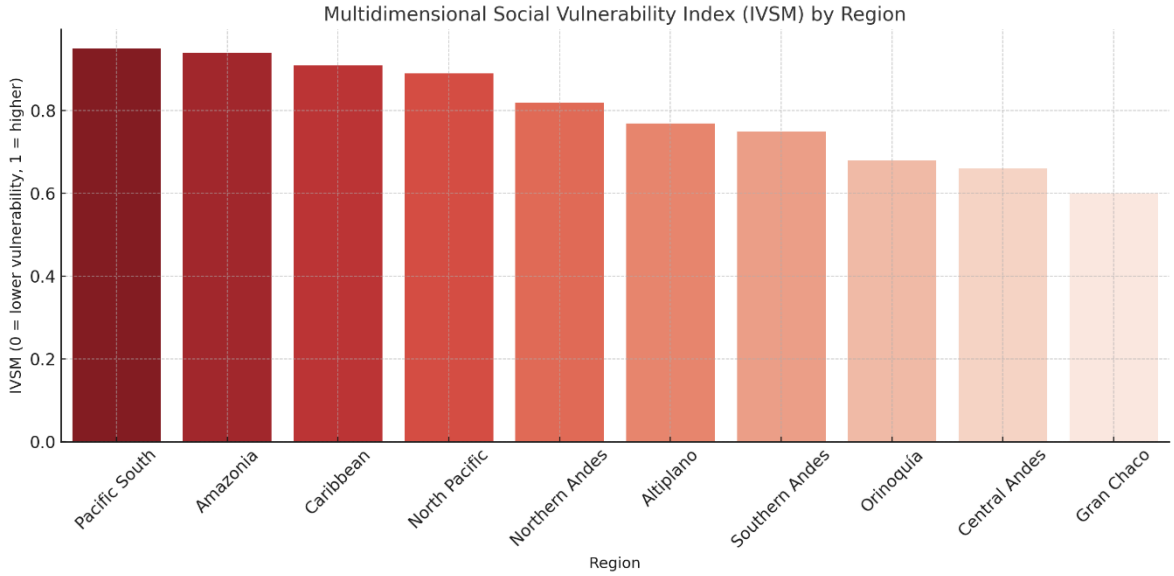

Table: Results by region

Region	*IVSM*	*Economic component*	*Food component*	*Inclusion component*
South Pacific	0.95	0.93	0.95	0.92
Amazon	0.94	0.91	0.94	0.90
Caribbean	0.91	0.88	0.89	0.86
North Pacific	0.89	0.85	0.87	0.88
Northern Andes	0.82	0.81	0.85	0.80
High plateau	0.77	0.75	0.79	0.78
Southern Andes	0.75	0.70	0.76	0.74
Orinoquía	0.68	0.66	0.71	0.68
Central Andes	0.66	0.65	0.69	0.63
Gran Chaco	0.60	0.58	0.61	0.60

Source: Authors' elaboration based on data from FAO (2023), ECLAC (2023), World Bank (2023), UNDP (2023), IFPRI (2022), Jolliffe & Cadima (2021) and Silva & Rangel (2023).

4. RESULTS

The principal component analysis allowed the synthesis of 12 variables related to economic inequality, food security and social inclusion in **three main components** that together explain **78.4% of the total variance**. The first component is associated with economic inequality (36.2%), the second with food security (26.1%) and the third with social inclusion (16.1%).

Based on these components, the **Multidimensional Social Vulnerability Index (IMVI) was constructed**, which allowed the regions to be classified according to their level of accumulated vulnerability.

4.1. Classification of Regions by IVSM

The results show that **the South Pacific**, **Amazon,** and **Caribbean** are the regions with the **greatest multidimensional vulnerability**, with IVSM scores above 0.90. These regions have high levels of labor informality, food insecurity, and low social inclusion, especially in rural and ethnic communities (ECLAC, 2023; FAO, 2023).

In contrast, regions such as **Gran Chaco**, **Andina Centro,** and **Orinoquía** have relatively low scores, indicating better articulation of social policies and greater access to basic services (World Bank, 2023).

4.2. Comparative Chart

The following graph shows the distribution of the IVSM by region:

This graph reveals a clear geographical pattern: coastal, Amazonian and peaceful areas tend to concentrate higher levels of multidimensional social vulnerability.

4.3. Detailed Results by Region

In the table entitled **"Results by Region",** the values of the IVSM and its three components for each region analyzed are detailed. Higher values (closer to 1) indicate greater vulnerability.

Some key findings include:

- **The Amazon** and **the South Pacific** have high scores in all three components, which shows a multidimensional structural vulnerability.
- **Northern Andes** and **the Caribbean** show significant weaknesses in access to credit, food prices and digital exclusion.
- **Gran Chaco** is the region with the lowest IVSM (0.60), standing out for better access to health and education services.

These results allow us to identify empirically and comparatively the territories that require simultaneous interventions in economic, food and social terms.

5. CONCLUSIONS

The results of this study allow us to conclude that social vulnerability in Latin America cannot be analyzed in a fragmented or one-dimensional way. The dimensions of **economic inequality, food security, and social inclusion** are articulated in a systemic way and, in many cases, mutually reinforcing, generating environments of structural exclusion that are perpetuated over time (Alkire et al., 2022; FAO, 2023).

Through the application **of Principal Component Analysis (PCA),** it was possible to construct a **Multidimensional Social Vulnerability Index (SMVI)** that synthesizes 12 key indicators into three statistically robust components. This tool allowed for empirical classification and comparison of regions, demonstrating that historically marginalized territories—such as the Amazon, the South Pacific, and some rural areas of the Caribbean—have significantly higher levels of vulnerability. These areas concentrate multiple

deprivations: low income, severe food insecurity, high labor informality, poor access to health and education, as well as low levels of connectivity (ECLAC, 2023; Silva & Rangel, 2023).

A key conclusion of the study is that **traditional approaches based solely on per capita income** are insufficient to capture the complexity of inequality in contexts such as Latin America. It is necessary to adopt **multidimensional perspectives**, which allow governments and social actors to identify more precisely the factors that make up accumulated vulnerability (UNDP, 2023; World Bank, 2023).

The research also reveals that social inclusion – particularly in terms of access to basic services and technologies – is an increasingly relevant component of vulnerability. The lack of digital connectivity, for example, deepens educational and economic exclusion, especially in rural and indigenous areas (UNESCO, 2022; Oxfam, 2024).

In terms of public policy, the proposed IVSM can be a useful tool to **focus government interventions**, design territorial development strategies, and prioritize resources in areas with multiple simultaneous deprivations. In addition, the index allows for temporal monitoring that serves as a basis for assessing the impact of social or redistributive policies in the medium and long term (Jolliffe & Cadima, 2021; IFPRI, 2022).

Finally, policymakers are recommended to integrate statistical tools such as the GPA into national information systems, in order to promote evidence-based decision-making aimed at meeting the Sustainable Development Goals (SDGs), especially SDG 1 (no poverty), SDG 2 (zero hunger) and SDG 10 (reduced inequalities) (United Nations, 2022).

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