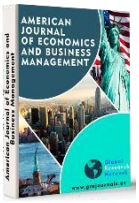

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Article

Econometric Analysis of Factors Affecting Population Well-Being

Xodjaniyazov Shohruh Yuldashevich*[1]

1. "Mamun University" Lecturer, Department of Accounting

* Correspondence: shohruhxodjaniyazov@gmail.com

Abstract: This study was conducted to identify the main factors influencing the well-being of the population of the Khorezm region and to analyze their interrelationships. For the period 2015–2024, 11 indicators specific to the region (literacy, per capita income, unemployment, GDP growth, investment, poverty, Gini coefficient, life expectancy, number of doctors, child mortality, and higher education) were analyzed using Principal Component Analysis (PCA). PCA was applied to simplify multidimensional data and eliminate multicollinearity issues. The results showed that the first principal component (PC1, 67.38% variance) reflected economic and social development (income, investment, education), while the second component (PC2, 14.86%) was related to poverty and GDP growth. During 2015–2024, a significant improvement was observed in PC1, confirming economic development and poverty reduction. However, PC2 indicated that poverty remained high in some years and was negatively associated with health indicators. The study provides an empirical basis for evaluating the effectiveness of economic reforms and strategic planning in the Khorezm region, and emphasizes the need to improve health and social equity.

Keywords: Well-Being, Khorezm Region, Principal Component Analysis, Economic Development, Poverty, Social Indicators

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1. Introduction

The well-being of the population is a key indicator of socio-economic development and is widely studied at both global and regional levels. Well-being encompasses not only material resources but also multidimensional factors such as health, education, equality, and social stability [1]. In developing countries, particularly in the Central Asian region, the impact of economic growth on social outcomes has been uneven, exacerbating pressing issues such as poverty, unemployment, and health-related challenges [2]. In regions such as Khorezm in Uzbekistan, ensuring the well-being of the population remains a priority area of state policy against the backdrop of economic reforms and infrastructure development. At the same time, identifying the factors influencing these processes and analyzing their interrelationships is of crucial importance for the formulation of regional development strategies.

Khorezm region is located in the north-west of Uzbekistan and is characterized by an economic structure based on agriculture, industry, and services. Between 2015 and 2024, the region experienced significant growth in per capita income, investment, and education indicators; however, poverty rates, unemployment, and health sector challenges remain pressing issues [3]. Analyzing the interrelationships between these indicators and

their impact on the population's well-being is important for improving the effectiveness of regional policies. Nevertheless, when multidimensional and highly correlated data are analyzed using traditional statistical methods such as regression analysis, the problem of multicollinearity arises, which reduces the reliability of the results [4].

In this study, Principal Component Analysis (PCA) was employed to identify the main factors affecting the well-being of the Khorezm region's population and to analyze their interrelationships. PCA is widely used as an effective method for simplifying multidimensional data, eliminating multicollinearity issues, and identifying the underlying structure of variables [5]. The study analyzed 11 indicators specific to the region for the period 2015–2024, including literacy rate, per capita income, unemployment rate, gross domestic product (GDP) growth rate, investment, poverty rate, Gini coefficient, life expectancy, number of doctors per 10,000 population, child mortality rate, and the share of the population with higher education. These indicators cover various aspects of economic, social, and health-related well-being, and their interrelationships are important for understanding the dynamics of the region's development.

The main objective of this study is to identify the key factors affecting the well-being of the population in the Khorezm region, analyze their interrelationships, and determine the main directions influencing the region's socio-economic development. To achieve this objective, the following research questions were examined:

(1) Which factors have the greatest impact on the well-being of the population in the Khorezm region?
(2) How are these factors interrelated, and how has their impact changed over time?
(3) How do the principal components identified through PCA provide guidance for the region's development strategies?

The novelty of this study lies in the application of the Principal Component Analysis (PCA) method to conduct an in-depth examination of the socio-economic indicators of the Khorezm region and to identify the interrelationships of well-being factors in the region's specific context. In addition, the research provides an empirical basis for assessing the outcomes of economic reforms implemented in the region during 2015–2024 and for shaping future development strategies.

The findings of this study have practical significance not only for the Khorezm region but also for other regions of Uzbekistan and Central Asian countries, contributing to the development of balanced approaches to socio-economic growth[6], [7], [8], [9] .

Following the introduction, the paper presents the methodology, results, and discussion sections. The methodology section details the dataset, the application of the PCA method, and the analytical process. The results section provides empirical findings, including the principal components, explained variance ratios, and the interrelationships among variables. The discussion section examines the scientific and practical significance of the results, as well as directions for future research.

Literature Review

Population well-being, as a central indicator of socio-economic development, has been the focus of researchers' attention for many years. The concept of well-being encompasses not only material wealth but also multidimensional factors such as health, education, equality, and social stability [10]. In his work Development as Freedom, well-being was defined in terms of people's capabilities and freedoms, with emphasis placed on the idea that economic growth should not only be assessed by its material outcomes but also by its impact on social and human development [2]. Further argued that, in measuring well-being, it is necessary to consider indicators such as health, education, and social equity in addition to traditional economic metrics like gross domestic product (GDP). These approaches require multidimensional data in the analysis of population well-being, which creates challenges in the application of statistical methods.

In developing countries, particularly in the Central Asian region, the impact of economic growth on social outcomes has been uneven, with poverty, unemployment, and health sector issues remaining pressing challenges [5]. According to the United Nations Development Programme, in countries such as Uzbekistan, economic reforms have contributed to a reduction in poverty levels; however, problems of social inequality and health services still require serious attention. In particular, in agriculture-based regions such as Khorezm in Uzbekistan, the social impact of economic development may be limited, as resource distribution and infrastructure development occur unevenly [11].

In analyzing the factors affecting well-being, the necessity of working with multidimensional data plays an important role in the choice of statistical methods. Traditional regression analysis often encounters the problem of multicollinearity among variables, which reduces the reliability of the results [10]. Multicollinearity is particularly pronounced when economic and social indicators—such as income, investment, and education—are highly correlated. To overcome such challenges, Principal Component Analysis (PCA) is widely applied as an effective method [1]. PCA reduces interdependence among variables, identifies the underlying structure of the data, and allows for dimensionality reduction, which is a major advantage in the analysis of complex datasets.

There is a substantial body of research on the application of PCA in socio-economic analysis. For example, the practical aspects of applying PCA to social and economic indicators were discussed, highlighting the method's effectiveness in simplifying multidimensional data (Abdi & Williams). Similarly, PCA was used to analyze economic inequality and well-being indicators, demonstrating the method's reliability in economic measurements [12],[13]. In the Central Asian context, the impact of economic reforms on social outcomes was analyzed, examining the relationship between economic growth, poverty, and inequality, with an emphasis on the importance of statistical methods, particularly PCA [14]. However, PCA-based analyses focused on specific regions such as Khorezm are limited, which underscores the novelty of this study [15].

In research on Uzbekistan, the factors affecting population well-being have generally been examined from the perspective of broad economic indicators (e.g., GDP, investment) and social indicators (e.g., education, health) [11]. The impact of economic reforms on poverty reduction in Uzbekistan was analyzed, with an emphasis placed on the fact that social inequality remains a significant issue [11]. At the same time, in-depth analyses based on region-specific data, such as for Khorezm region, are rare. According to data from the Statistics Agency of the Republic of Uzbekistan (2024), the region has seen growth in per capita income, investment, and education indicators, yet poverty and health-related issues remain pressing. This indicates the necessity of analyzing the interrelationships between well-being factors in Khorezm region.

A review of the existing literature shows that population well-being is multidimensional in nature and requires complex statistical methods for its analysis. While the PCA method is effective for analyzing economic and social indicators, research applying this method to specific regions such as Khorezm remains limited. This study aims to fill this gap by analyzing Khorezm region's socio-economic indicators for the period 2015–2024 using PCA. The research not only seeks to identify the factors of well-being in the region but also to understand their dynamics over time and provide guidance for regional development strategies.

2. Materials and Methods

In this study, the Principal Component Analysis (PCA) method was employed to identify the main factors influencing the well-being of the population in the Khorezm region. The selection of this method is justified by the following considerations:

a. Multidimensional data: The study involves 11 independent variables, most of which are highly correlated with each other.

b. Multicollinearity problem: In traditional regression analysis, strong intercorrelations among variables can lead to biased estimations. PCA addresses this problem effectively.
c. Dimensionality reduction: PCA reduces the number of variables while retaining essential information, thereby simplifying the model.

Step 1. Data Standardization

The initial step in PCA is to standardize the dataset to ensure that all variables are measured on a comparable scale. This prevents variables with larger numerical ranges from dominating the results and ensures that each variable contributes equally to the analysis.

Each variable is standardized as follows:

$$Z_{IJ} = \frac{X_{ij} - \overline{X_J}}{\sigma_j}$$

where:

X_{ij}- is the original value of the variable,

X_j- is the mean of the variable,

σ_j- is the standard deviation of the variable,

Z_{IJ}- the most extreme.

Step 2. Constructing the covariance (or correlation) matrix:

$$C = \frac{1}{n-1} Z^T Z$$

Here,

C - covariance matrix (represents the interrelationships between variables),

Z - standardized data matrix

n - number of observations

Step 3. Determining the eigenvalues and eigenvectors:

$$C * v_i = \lambda_i * v_i$$

Here,

λ_i - the eigenvalue (variance) corresponding to the i-th principal component

v_i - the eigenvector indicating the direction of the i-th component

Step 4. Calculating the principal components:

$$PC_i = Z * v_i$$

Here, PC_i - the values of the i-th principal component.

Step 5. Proportion of variance explained:

Indicates the proportion of the total variance in the data explained by each component

$$Proportion\ of\ variance\ explained = \frac{\lambda_i}{\sum_{j=1}^{p} \lambda_i}$$

Component loadings

The loading represents the weight or contribution of each variable in the principal c omponent

$$L_{ij} = v_{ij} * \sqrt{\lambda_i}$$

Here,

L_{ij} - The loading of the *i-th variable* in the *j-th principal component*,

v_{ij} - the coefficient corresponding to the variable in the eigenvector,

λ_i - the variance of the j-th component (eigenvalue)

3. Results and Discussion

In this study, the Principal Component Analysis (PCA) method was applied to identify the main factors affecting the well-being of the population in the Khorezm region.

The analysis was carried out based on 11 indicators specific to the Khorezm region during the period of 2015–2024, including:

literacy rate, income per capita, unemployment rate, GDP growth rate, investments, poverty rate, Gini coefficient, life expectancy, number of doctors per 10,000 population, infant mortality rate, and share of population with higher education.

The following section presents the main results of the PCA analysis and their interpretation.

The table presents the social and economic indicators of the Khorezm region.

For instance, the income per capita increased from 4,784.4 thousand soums in 2015 to 29,076.6 thousand soums in 2024, while the poverty rate declined from its peak of 19.9% in 2021 to 11.9% in 2024.

These trends indicate that the region has experienced economic growth and social improvements over the analyzed period.

There are no missing values in the dataset, which enhances the reliability of the analysis.

Since the variables are measured in different units (e.g., percentages, thousand soums, billion soums), the data were standardized prior to the analysis. Standardization transformed each variable to have a mean of 0 and a standard deviation of 1, ensuring comparability across indicators.

The standardized results are presented below.

	Year	Literacy_Rate_Total	Income_Per_Capita	Unemployment_Rate	GDP_Growth_Rate	Investments	Poverty_Rate	Gini_Coefficient
1	2015	99.4	4784.4	9.5	6.8	1531.5	14.3	0.274
2	2016	99.5	5570.0	10.8	7.2	1560.5	13.3	0.264
3	2017	99.5	7228.2	11.1	8.1	2175.9	12.9	0.262
4	2018	99.6	9363.5	9.4	5.4	3013.8	12.5	0.262
5	2019	99.6	11117.2	9.1	4.2	5032.0	13.0	0.268
6	2020	99.6	12270.6	10.9	2.8	5391.8	13.0	0.282
7	2021	99.7	15756.4	9.9	8.5	8292.0	19.9	0.279
8	2022	99.7	19541.5	9.0	7.2	8769.7	19.1	0.289
9	2023	99.8	20076.6	6.6	5.8	11666.1	14.1	0.294
10	2024	99.8	29076.6	9.0	6.1	13245.8	11.9	0.292

	Life_Expectancy	Doctors_Per_10K	Infant_Mortality	Higher_Education_Total
1	72.9	26.5	16.8	16.8
2	72.8	26.1	16.2	17.2
3	72.9	26.4	15.9	17.6
4	73.6	27.4	15.4	18.1
5	73.5	27.5	15.6	18.7
6	72.2	27.8	14.6	19.2
7	72.7	27.5	15.9	19.8

8	73.2	28.6	11.3	20.5
9	74.3	28.8	11.2	21.3
10	74.6	29.2	12.2	22.1

3-bosqich: Standartlashtirilgan ma'lumotlar (birinchi bir nechta qator)

	Literacy_Rate_Total	Income_Per_Capita	Unemployment_Rate	GDP_Growth_Rate	Investments	Poverty_Rate	Gini_Coefficient
[1,]	-1.6710200	-1.1329957	-0.02290366	0.3367369	-1.0692111	-0.0359391	-0.2088820
[2,]	-0.9114654	-1.0306181	0.96958807	0.5650331	-1.0623759	-0.3953301	-1.0122741
[3,]	-0.9114654	-0.8145251	1.19862462	1.0786995	-0.9173289	-0.5390865	-1.1729525
[4,]	-0.1519109	-0.5362576	-0.09924917	-0.4622998	-0.7198397	-0.6828429	-1.1729525
[5,]	-0.1519109	-0.3077193	-0.32828573	-1.1471884	-0.2441592	-0.5031474	-0.6909172
[6,]	-0.1519109	-0.1574108	1.04593359	-1.9462250	-0.1593560	-0.5031474	0.4338317

	Life_Expectancy	Doctors_Per_10K	Infant_Mortality	Higher_Education_Total
[1,]	-0.4983545	-1.02478294	1.07886390	-1.30703304
[2,]	-0.6330449	-1.40433218	0.79619214	-1.08264969
[3,]	-0.4983545	-1.11967025	0.65485626	-0.85826633
[4,]	0.4444783	-0.17079716	0.41929645	-0.57778714
[5,]	0.3097879	-0.07590985	0.51352037	-0.24121211
[6,]	-1.4411873	0.20875208	0.04240076	0.03926709

The standardized data reflect the relative variation of each variable.

For instance, the income per capita in 2015 has a standardized value of –1.1329957, indicating that it was below the average level, whereas in 2024, the value is positive, showing that it was above the mean.

Standardization ensures that all variables contribute equally to the PCA results and eliminates potential distortions caused by differences in measurement units.

The Principal Component Analysis (PCA) was then applied to the standardized dataset, and the scores for each year were computed based on the identified principal components.

The results are presented below.

4-bosqich: PCA o'zgartirilgan ma'lumotlar (birinchi bir nechta qator)

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
[1,]	2.7729293	0.1175220	-0.46402344	-0.87824656	-0.5657352	-0.67309198	0.2908105	0.03914911	-0.007941842	-3.663736e-15
[2,]	3.0316940	0.1171285	-0.37234863	0.33906892	-0.2348254	0.14069714	-0.2730671	-0.15126484	-0.099979948	-3.441691e-15
[3,]	2.7849551	0.3010694	-0.63765546	0.87451912	-0.3566139	0.28940480	-0.1494307	0.06909267	0.117799822	-3.552714e-15
[4,]	1.1720564	-1.1293941	-0.59941355	-0.11667568	0.5912359	0.45691582	0.1596882	0.13699957	-0.078126746	-3.497203e-15
[5,]	0.5715393	-1.2955180	0.01824281	-0.41521879	0.7219685	-0.02555943	0.1669937	-0.14160403	0.087988285	-3.469447e-15
[6,]	0.5630795	-1.0199047	2.46965973	0.05853992	-0.1814365	-0.06403544	-0.1454943	0.04692284	-0.004818331	-3.653328e-15

This table illustrates the projection of each year onto the principal components.

For example, the years 2015–2017 have high positive scores on PC1, indicating that their economic and social indicators are well represented by the factors associated with PC1.

In contrast, the year 2020 shows a high score on PC3 (2.46965973), which may reflect the specific variations in certain indicators (such as unemployment rate or GDP growth) during the COVID-19 pandemic period.

In the PCA analysis, the contribution of each principal component to the total variance of the dataset was calculated. The results are presented below.

5-bosqich: Tushuntirilgan dispersiya nisbati

PC1: 0.6738 (0.6738 jami)
PC2: 0.1486 (0.8225 jami)
PC3: 0.0829 (0.9053 jami)
PC4: 0.0491 (0.9545 jami)
PC5: 0.0228 (0.9773 jami)
PC6: 0.0150 (0.9923 jami)
PC7: 0.0066 (0.9989 jami)
PC8: 0.0007 (0.9996 jami)
PC9: 0.0004 (1.0000 jami)
PC10: 0.0000 (1.0000 jami)

PC1 explains 67.38% of the total variance, indicating that this component effectively captures the main variability in the socio-economic indicators of the Khorezm region. PC2

accounts for an additional 14.86% of the variance, meaning that together PC1 and PC2 explain 82.25% of the total variability in the dataset. This suggests that the majority of the information contained in the original variables can be efficiently represented by just two principal components.

The contributions of PC3 and the subsequent components (8.29% and less) are relatively minor, implying that they describe additional but less significant variations within the data.

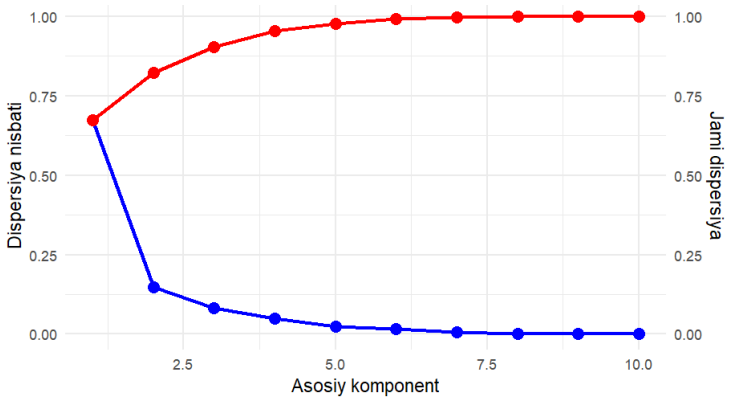

Figure 1. Explained Variance Ratio.

In the scree plot, the explained variance ratio drops sharply after PC1 and PC2, which is interpreted as the "elbow point." This confirms that the first two principal components are sufficient to represent the main structure of the data. The subsequent components (PC3 and beyond) contribute only minimally to the total variance, indicating that their inclusion in the analysis is not essential.

The component loadings show the contribution of each variable to the principal components, illustrating how strongly each indicator is associated with a particular component.

The results are presented below.

7-bosqich: Komponent yuklamalari

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	
Literacy_Rate_Total	-0.34800130	0.045004889	0.03655383	0.161529172	0.46346113	0.21388411	-0.53809715	0.15330122	
Income_Per_Capita	-0.35183191	0.039765480	0.04634534	0.350566119	0.01695138	-0.12557467	0.34163797	-0.20543729	
Unemployment_Rate	0.27253113	0.101454098	0.39310341	0.723102678	-0.12086952	0.13413134	0.17871276	-0.11435645	
GDP_Growth_Rate	0.04386514	0.607435863	-0.58772229	0.298635389	-0.26211603	-0.01710705	-0.13246528	0.31902871	
Investments	-0.35937407	0.072175877	0.03724648	0.155153358	0.09336070	-0.28804414	-0.19062603	-0.24406801	
Poverty_Rate	-0.06549482	0.716739597	0.16658129	-0.351510722	0.31762187	0.11472373	0.33380023	-0.27590241	
Gini_Coefficient	-0.32604598	0.114894393	0.24166124	-0.176548066	-0.54207925	-0.52383620	-0.08635768	0.03594748	
Life_Expectancy	-0.26423934	-0.280348766	-0.60807370	0.086003699	0.08609951	-0.01514021	0.37382393	-0.29416504	
Doctors_Per_10K	-0.35703060	-0.068544272	0.16006244	-0.005093145	0.07478591	0.11760797	0.46916837	0.74131566	
Infant_Mortality	0.33535839	0.005537253	-0.03927778	0.112030426	0.52400356	-0.73122695	0.08302606	0.20661180	
Higher_Education_Total	-0.35973355	0.040888469	0.11006817	0.200439966	0.10279396	-0.03019413	-0.14924652	-0.06069247	

	PC9	PC10
Literacy_Rate_Total	-0.52140390	0.03921093
Income_Per_Capita	-0.13627528	0.34376825
Unemployment_Rate	-0.16914515	-0.12556949
GDP_Growth_Rate	0.06256146	0.02150679
Investments	0.46588027	0.47028522
Poverty_Rate	-0.08353816	-0.09099780
Gini_Coefficient	-0.40856996	-0.17646490
Life_Expectancy	-0.25243982	-0.24963535
Doctors_Per_10K	0.11308474	0.05733542
Infant_Mortality	-0.06085355	-0.09982659

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Higher_Education_Total  0.45373269 -0.72656486
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PC1 (67.38% of variance): This component reflects the overall economic and social development of the Khorezm region. High negative loadings (approximately –0.35) are associated with income per capita, investment, literacy rate, share of population with higher education, and number of doctors per 10,000 people — indicating that higher values of these indicators correspond to higher scores on PC1.

Conversely, the infant mortality rate (0.335) and unemployment rate (0.272) show positive loadings, suggesting that higher values of these variables are linked to lower PC1 scores.

Thus, PC1 can be interpreted as a "component of economic and social well-being," where higher income, investment, and education levels are associated with lower poverty and unemployment rates, reflecting overall improvement in living standards.

PC2 (14.86% of variance): This component is primarily associated with the poverty rate (0.716) and GDP growth rate (0.607). Higher poverty levels and faster GDP growth correspond to higher PC2 scores.

This component may reflect the interaction between economic growth and poverty, suggesting that rapid economic expansion does not necessarily translate into uniform improvements in living standards.

The negative loading of life expectancy (–0.280) indicates that health-related issues may still be correlated with higher poverty levels, despite economic growth.

PC3 and subsequent components: PC3 (8.29%) is mainly related to life expectancy (–0.608) and GDP growth rate (–0.587), reflecting specific relationships between health and economic performance.

The remaining components contribute marginally to the total variance and may capture specific or exceptional conditions, such as the impact of the COVID-19 pandemic in 2020.

The biplot visualizes the distribution of years and variables in the PC1–PC2 plane, illustrating their relative positions and interrelationships.

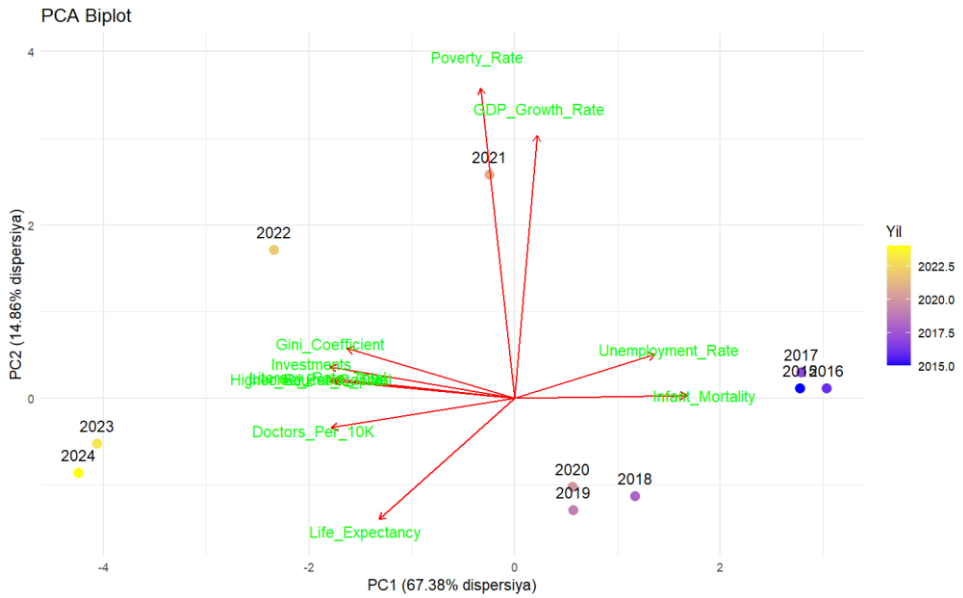

Figure 2. PCA Biplot.

Years (points): In the biplot, the years 2015–2017 are positioned on the right side along PC1, indicating that these years are characterized by lower levels of income, investment, and education, but higher infant mortality and unemployment rates.

Conversely, the years 2023–2024 are located on the left side along PC1, reflecting higher economic and social performance — including higher income, investment, and education levels, combined with lower poverty and unemployment rates.

The years 2021–2022 exhibit high scores along PC2, corresponding to higher poverty levels, such as the peak of 19.9% in 2021.

Variables (vectors): The vectors of income per capita, investment, literacy rate, higher education attainment, and number of doctors are positioned close to each other, indicating a strong positive correlation among these variables. In contrast, the vectors representing infant mortality rate and unemployment rate point in the opposite direction, confirming their negative correlation with the first group of variables. Meanwhile, the poverty rate and GDP growth rate vectors are long and aligned with the PC2 axis, suggesting that these indicators have a strong influence on the second principal component (PC2).

Trends

The shift of the years from right to left along PC1 between 2015 and 2024 indicates a steady improvement in economic and social well-being in the Khorezm region.

The distinct position of 2020 (with a high score on PC3) reflects the economic and health-related disturbances caused by the COVID-19 pandemic.

4. Conclusion

The Principal Component Analysis (PCA) identified the main factors influencing the well-being of the population in the Khorezm region.

Economic and Social Development (PC1): The increase in income per capita, investment, literacy rate, higher education attainment, and number of doctors is associated with a decrease in poverty and infant mortality rates. During 2015–2024, a significant improvement was observed along PC1, indicating the region's economic development and enhancement of key social indicators.

Poverty and Economic Growth (PC2): A high poverty rate coincided with GDP growth in certain years (for instance, 2021–2022), while a negative relationship was observed with health indicators, particularly life expectancy. This suggests that the impact of economic growth on poverty reduction may have been limited, indicating that economic progress did not equally benefit all segments of the population.

Health and Special Factors: PC3 and other minor components capture health-related variables such as life expectancy and infant mortality, as well as specific external factors like the COVID-19 pandemic.

However, their contribution to the total variance is relatively small, indicating that these factors represent specific but less dominant sources of variation in the dataset.

To sustain economic development, greater emphasis should be placed on increasing investment and improving the quality of education.

To reduce poverty, the social inclusiveness of economic growth needs to be improved, as the PC2 results indicate that poverty levels remained relatively high in certain years.

In the health sector, additional measures are required to reduce infant mortality and increase life expectancy, ensuring more equitable access to healthcare services.

These findings serve as an important guideline for strategic planning aimed at enhancing the well-being of the population in the Khorezm region.

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