THE IMPACT OF CHANGE ON REGIONAL ECONOMIC: PARAMETERS AND DEPENDENCIES

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Abstract

Research on the adaptation of economic growth dynamics to climate change is important for sustainable development on local to global scales. It is important to quantify the balance between two interrelated systems to generate effective knowledge to create a favorable environment in conditions of rapid economic development. The purpose of the work is to develop and test a methodology for assessing the adaptation of regional economic growth to climate change in the regions of the Russian Federation. The author's methodology is based on obtaining the coefficient of adaptation (KA) of economic growth to climate change in the regions of the Russian Federation. The analysis of the autocorrelation KA of the spacecraft within the borders of the federal districts by calculating the global and local Moran's index makes it possible to determine the similarities and differences of the adaptation process in neighboring regions. The following indicators were identified for the study: a) economic sphere: GRP per capita, industrial production index, real monetary incomes of the population, the volume of investments in fixed assets per capita; b) climate: average annual air temperature, the amount of precipitation. Information base: data from the Federal State Statistics Service and the Weather and Climate portal. The object of research is the regions of the Central Federal District, the Southern Federal District and the Siberian Federal District. Study period: 2000, 2003, 2009-2021. Periods of decrease and growth of the coefficient of adaptation, a decrease in the differentiation of regions by the value of the KA empirically have been identified. The calculations performed demonstrate spatial heterogeneity. The indicators of the coefficient of adaptation in the southern regions and parts of the regions of central Russia are significantly higher, which indicates a more coordinated development in these regions. Regions demonstrating a relatively higher level of adaptation to economic growth and climate change have a more differentiated economy and a favorable geographical location. The results obtained can be used to develop and implement climate risk management policies and analyze the economic costs of climate change impacts.

Keywords: Region, Climate, Ecology, GRP, Communication coordination coefficient, Economic development, Air temperature, Precipitation, Moran's index, Autocorrelation

JEL classification: R12

pp. 37-55

1. Introduction

Russia is a unique country not only in the composition of climatic zones and the natural and geographical characteristics of the regions, but also in the location of productive forces in the territorial space. Today, there is a wide differentiation in a number of important indicators in the regions of the Russian Federation: the population range in cities varies from 1 thousand people (Chekalin) to 12330.1 thousand people (Moscow); population density in the regions from 5114.23 people/km^2 (Moscow) to 0.07 people/km^2 (Chukotka Autonomous Okrug); GRP per capita from 5206 thousand rubles (Nenets Autonomous Okrug) to 142 thousand rubles (Republic of Ingushetia); average annual air temperature from -6.7°C (Yakutsk) to 14.9 6.7° C

(Sochi)[1]. The climatic features of the regions of the Russian Federation are one of the important factors determining the migration flows of the able-bodied population, the quality of life and the vector of economic development of the territory. Climate and economic research and adaptation of regional economic growth to climate change are important for sustainable development from local to global scales. It is important to quantify the balance between two interrelated systems to generate effective knowledge to create a favorable environment in conditions of rapid economic development. Most previous studies examining the interaction of economics and the environment have focused on measuring the Kuznets curve of the environment. The purpose of this work is to develop and test a methodology for assessing the adaptation of regional economic growth to climate change in the regions of the Russian Federation.

The research objectives included the following:

– to analyze theoretical provisions on the problems of climate impact on economic development to form a systematic methodological toolkit;

– to present and substantiate the system of indicators and the calculation apparatus of methodological tools;

– to identify trends and the level of inequality in the modern socio-economic development of Russian regions;

– to characterize the climatic features of the Russian Federation;

– to analyze the dynamics of adaptation of economic growth to climate change in the regions of Russia.

The theoretical and methodological basis of the research was scientific publications of domestic and foreign scientists in the field of theory, methodology, assessment and analysis of the relationship between economics and climate, as well as regional economics. The work uses methods that ensure comparability of our estimates with the results obtained in the works of foreign scientists.

2. Literature review of the study

Research on the impact of climate on economic development is popular in modern Russian and foreign literature. In a number of works, the relationship of these systems with the use of composite environmental indexes is studied [Li, 2012; Almeida, 2017], protection of the ecological environment [He, 2017; Liu, 2018], carbon emissions [Zhang, 2019; Wang, 2019]. Approaches to assessing the economic risks of climate change have been developed separately for the United States [Hsiang, 2017], the European Union [Ciscar, 2013], and in general, for the global level [Takakura, 2019].

The influence of urbanization on climate change is of particular interest to foreign researchers. Assessment of the impact of urbanization on the environment has become one of the most relevant topics for management decision-making [Kukkonen, 2014; Monkkonen, 2018; Sun, 2015]. Urbanization reflects the evolution of human socio-economic development, while the ecological environment is a natural environment. Urbanization and the ecological environment are classical complex systems with nonlinear interacting relationships [Fang, 2016]. A number of works claim that urban sprawl reduces ecological resources and ecological space [Grimm, 2008; Wigginton, 2016]. There is increasing empirical evidence that cities have a significant impact on key components of the Earth's system, including the atmosphere, biosphere, and geosphere [Zhu, 2019].

According to Chinese scientists, landscape urbanization, including the expansion and consolidation of cities, acts as a key to linking economic growth with urban climate change. In China, a long-term bidirectional causal relationship has been identified between economic growth and landscape urbanization in the urban and provincial levels [Wu, 2014; Bai, 2012].

Urbanization leads to the widespread occurrence of such phenomena as urban thermal zones of «urban heat islands» UHI, changing the ability of lands to evaporate water and the efficiency of heat convection in the lower atmosphere [Estrada, 2017; Li, 2019]. At the same time, economic growth can help reduce the negative effects of urban thermal zones UHI, as it

[1] Federal State Statistics Service URL: https://rosstat.gov.ru/compendium (date of application 15.02.2025)

provides regions with large financial resources that can be used to green the territory [Gu, 2012].

The CCD model of communication coordination, which is based on communication theory describing the interaction between different systems, has been widely used in assessing the climate and economic development of a territory [Li, 2012; Shen, 2018; Chen, 2019]. The CCD model is able to assign a coordination attribute to each territory during the study period, providing an opportunity for further analysis of spatial and temporal coordination models using geographical approaches (Liu, 2018; Chen, 2019). When evaluating the model of the degree of coordination between the CCD socio-economic status (SAI) and the regional environmental environment (REE) in Beijing, scientists concluded that socio-economic activity showed an upward trend, and the level of the regional environmental environment was stable.

The relationship between REE and SAI in Beijing has improved both spatially and quantitatively in 2018–2020. By May 2020, more than 50% of human activity areas were in a high-level state of coordination, and the average CCD value reached the basic level of coordination [Cai, 2021].

Separately, it is necessary to highlight the direction of scientific research devoted to the analysis of the interaction of economics and ecology, based on the economic curve of Kuznets (ECK). The essence of the ECK is as follows: there is an inverted U-shaped relationship between economic growth and environmental quality: the state of the environment worsens with economic development, and then gradually improves after the economy reaches a certain level. The work of foreign scientists testing the ECK hypothesis has shown an ambiguous result, this curve cannot be applied everywhere [Liu, 2018]. A review of the ECK in the Russian regions showed that the relationship between gross regional product (GRP) and emissions of pollutants into the atmosphere is described only for twenty regions. The factors that reduce the environmental burden are identified: modernization of production facilities, structural changes in the economy [Postnikov, 2014]. The ECC analysis revealed a relationship between income levels and sustainable development [Bobylev, 2007].

In the Russian literature, the scientific direction of assessing the impact of climate change on the economy of individual industries is popular. A.V. Chugunkova and co-authors assessed the impact of global climate change on the forestry and agricultural economies [Chugunkova, 2018]. A team of researchers led by N.M. Svetlov predicts changes in the location of agricultural sectors caused by possible climatic fluctuations, which are simulated by the displacement of natural agricultural zones within the boundaries of the production capabilities of the regions of the Federation[Svetlov, 2019]. D.A. Polzikov presents the results of modeling the influence of the climatic factor on the dynamics and structure of agricultural production, substantiates recommendations for improving agrifood policy, taking into account a set of adaptation measures [Polzikov, 2022].

I.Y. Zhilina identified the most acute economic consequences of climate change: reduced crop yields, the impact of heat stress on labor productivity, water stress problems, and negative effects on public health [Zhilina, 2020]

Based on the results of a comprehensive assessment of current climate change, analysis of various economic scenarios and types of damage from climate change, the threats associated with warming and positive changes have been identified: warming in the Arctic will increase the duration of navigation along the Northern Sea Route and facilitate the development of oil and gas fields on the shelf; the heating season will be shortened by 2-3 days, the northern border of agriculture will shift to the north [Oganesyan, 2019]. There are studies of problems and scientific and methodological approaches to assessing the expected damage to fixed assets from the degradation of permafrost soils used for planning and implementing adaptation measures to climate change and their consequences in the Arctic macro region of Russia. An integral approach to this assessment is proposed ([Porfiriev, 2023]B.G. Ivanovsky's work presents an assessment of damage from natural disasters and climate change [Ivanovsky, 2021]. The main factors determining the composition of the socio-economic consequences of climate change and their corresponding quantitative estimates have been studied [Ksenofontov, 2021].

It is important to note that climate change is accompanied not only by negative, but also by positive consequences in ecological, economic and social systems. I.M. Potravny and V.V. Elsakov, based on the analysis of trends in the development of traditional crafts of indigenous peoples in the context of climate change, concluded that «climatic changes occurring in the

Arctic zone of Russia can positively affect the development of traditional crafts of indigenous peoples, in particular for reindeer husbandry and the extraction of fossil mammoth bones (mammoth fauna)» [Potravny, 2024]. V.V. Zholudeva, conducting a statistical assessment of the impact of climate change on the sociodemographic processes of the Yaroslavl region, empirically proved that «an increase in average air temperature is a positive factor for the agricultural sector of the Yaroslavl region, since crop yields will increase with increasing air temperature.... the effects of climate change on demographic processes and health people are currently insignificant» [Zholudeva, 2019]. Separately, it is necessary to single out scientists involved in climate policy: I.A. Yakovlev (systematization of key issues affecting the country's position in the development of national climate policy) [Yakovlev, 2020]; V.S. Vasiltsov, N.N. Yashalova, E.N. Yakovleva, A.V. Kharlamov (the problem of adaptation of national climate policy) [Vasiltsov, 2021]; N.G. Zhavoronkova, V.B. Agafonov (trends and prospects in the development of Russian climate legislation) [Zhavoronkova, 2022]; Ya.Yu. Blinovskaya, E.A. Mazlova (trends in climate policy in the field of coal mining and processing) [Blinovskaya, 2019].

3. Research methodology

The purpose of the work can be achieved on the basis of the methodological framework presented in earlier studies [Manaeva, 2022], the modification of which for Russian regions at the current stage of globalization development allows us to obtain quantitative estimates of the adaptation of regional economic growth to climate change in the regions of the Russian Federation, as well as to conduct a spatial and temporal analysis of these estimates within the borders of federal districts with using the global and local Moran's index, which can be used to develop and implement climate risk management policies.

Stages of the study:

1. Sample formation.

The study included the regions of the Central Federal District, the Southern Federal District and the Siberian Federal District. These regions of the Russian Federation were chosen because of their location in different climatic zones with a wide range of average annual air temperatures, which will allow for comparative analysis and practical recommendations.

The Republic of Crimea and Sevastopol were excluded from the study due to insufficient statistical data.

2. Analyzed indicators:

a) economic: GRP per capita; industrial production index; real monetary incomes of the population, the volume of investments in fixed assets per capita.

b) climatic: average annual air temperature, amount of precipitation.

Study period: 2000, 2003, 2009–2021.

3. Formation of the calculation apparatus.

Normalization of indicators:

Economic indicators:

$$E_{1,2,3,4} = (X_{ij} - min\{X_j\})/(max\{X_j\} - min\{X_j\}) \quad (1)$$

Climate indicators:

$$U_{1,2} = X_{ij} - \mu_j/\nu_j \quad (2)$$

$$E = E_1 + E_2 + E_3 + E_4 \quad (3)$$

$$U = U_1 + U_2 \quad (4)$$

where E_1 – the normalized value of the indicator «GRP per capita» in the region j in a year i;

E_2 – the normalized value of the index of industrial production in the region j in a year i;

E_3 – the normalized value of the indicator «real monetary incomes of the population» in the region j in a year i;

E_4 – the normalized value of the indicator «volume of investments in fixed assets per capita» in the region j in a year i;

E_{ji} – the final indicator of the economic sphere in the region j in a year i;

U_1 – the normalized value of the indicator «average annual air temperature in the region» in the region j in a year i;

U_2 – the normalized value of the indicator «amount of precipitation in the region» in the region *j* in a year *i*.

U_{ji}– the final climate indicator in the region *j* in a year *i*;

X_{ji} – the initial value of the indicator in the region *j* in a year *i*;

$max\{X_j\}$ – the maximum value of the analyzed indicator in the region during the study period j;

$min\{X_j\}$ – the minimum value of the analyzed indicator in the region during the study period *j*.

μ_j – the average annual rate of the analyzed indicator in the region *j;*

ν_j – the standard deviation for the study period of the analyzed indicator in the region *j.*

$$C = \left\{\frac{E*U}{[E+U]}/2\right\}^{1/2} \quad (5)$$

$$T = \alpha E + \text{в}U \quad (6)$$

$$\text{КА} = (C * T)^{1/2} \quad (7)$$

$$\alpha = U/(E + U) \quad (8)$$

$$\beta = E/(E + U) \quad (9)$$

where *C* – the degree of connection between economic development and urban climate;

KA – the coefficient of adaptation of economic growth to climate change in the region.

T – reflects the overall impact of the performance levels of the two systems on the degree of adaptation (KKS);

α and β describe the contribution of economic growth and climate change in the regions, respectively.

4. Assessment of the adaptation of economic growth to climate change in the regions according to the criteria presented in Table 1.

Table 1 Classification of adaptation of economic growth to climate change in Russian regions (Zhou, 2016)

<table>
<tr><th colspan="2">Level KA</th><th colspan="2">Characteristic</th></tr>
<tr><td rowspan="3">Unadapted</td><td rowspan="3">0<ККС<0,3</td><td>0≤|U-E|≤0,1</td><td>Unadapted</td></tr>
<tr><td>U-E>0,1</td><td>Unadapted, the economy is not changing</td></tr>
<tr><td>E-U>0,1</td><td>Uncoordinated, the climate does not change</td></tr>
<tr><td rowspan="6">The transition period</td><td rowspan="3">0,3<ККС<0,5</td><td>0≤|U-E|≤0,1</td><td>Low level</td></tr>
<tr><td>U-E>0,1</td><td>Low level,
the economy is not changing</td></tr>
<tr><td>E-U>0,1</td><td>Low level, climate does not change</td></tr>
<tr><td rowspan="3">0,5<ККС<0,8</td><td>0≤|U-E|≤0,1</td><td>Basic level</td></tr>
<tr><td>U-E>0,1</td><td>The basic level,
the economy does not change</td></tr>
<tr><td>E-U>0,1</td><td>Baseline,
climate does not change</td></tr>
<tr><td rowspan="3">Adapted</td><td rowspan="3">0,8<ККС<1</td><td>0≤|U-E|≤0,1</td><td>High level of adaptation</td></tr>
<tr><td>U-E>0,1</td><td>The level is high, the economy does not change</td></tr>
<tr><td>E-U>0,1</td><td>The level is high, the climate does not change</td></tr>
</table>

5. Spatial and temporal analysis of the adaptation of the economy and climate within the borders of the federal districts by calculating the global and local Moran's index, which will determine the similarities and differences of the adaptation process in neighboring regions. [Manaeva 2020].

a) calculate the global Moran's index:

$$I_G = \frac{N}{\sum_i \sum_j w_{ij}} * \frac{\sum_i \sum_j wij(x_i - \mu)\ (x_j - \mu)}{\sum_i (x_i - \mu)^2} \quad (10)$$

where I_G – the global Moran's index,
where N – number of regions;
w_{ij} – an element of the spatial weight matrix for regions *i* and *j*;
μ– the average value of the indicator;
x – the analyzed indicator.

b) determines the mathematical expectation of the index:

$$E(I) = \frac{-1}{n-1} \quad (11)$$

where *E(I)* – mathematical expectation of the index,
n – number of analyzed territories.

$I_G \geq E(I)$ – positive spatial autocorrelation (the values of observations for neighboring territories are close to each other);

$I_G \leq E(I)$ – negative spatial autocorrelation (the values of the indicator under consideration differ between territories located close to each other)

$I_G = E(I)$ – there is no spatial autocorrelation.

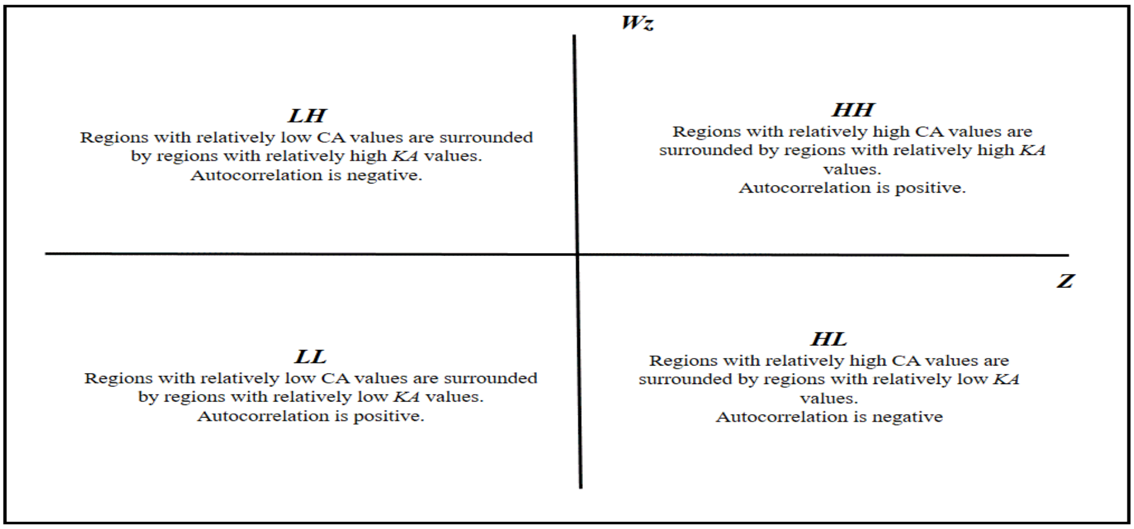
c) to verify the significance of the results obtained using the statistical hypothesis testing method (z-test), by determining the value of the Z-statistics:

$$z - statistics = \frac{I - E(I)}{\sqrt{E(I)^2 - E(I)^2}} \quad (12)$$

The resulting value is determined by the number of standard deviations by which the actual value of the Moran's index is removed from the expected value.

d) construct a spatial Moran's scattering diagram. On the abscissa axis – are the standardized *z*-values of the indicator under study, on the ordinate axis – are the values of the spatial factor *Wz*. The axes of the spatial Moran's scattering diagram are shown in figure 1.

Figure 1 Spatial scattering diagram of the Moran's index



e) calculate the value of the local Moran's index (*LISA – Local Index Spatial Autocorrelation)* and the definition of the closeness of the relationship of a particular region with all the others.

$$I_{L_i} = z_i \sum w_{ij} z_j \quad (13)$$

where I_{Li} – the local Moran's index for the i-th region;
w_{ij} – standardized distance between the *i*-th and *j*-th regions;
zi и zj – standardized values of the studied indicator for the *i*-th and *j*-th region. The values obtained can take values from -1 to 1.

When $I_{Li} < 0$ – negative autocorrelation for region i, i.e. this region differs significantly from neighboring regions by this value (outlier).

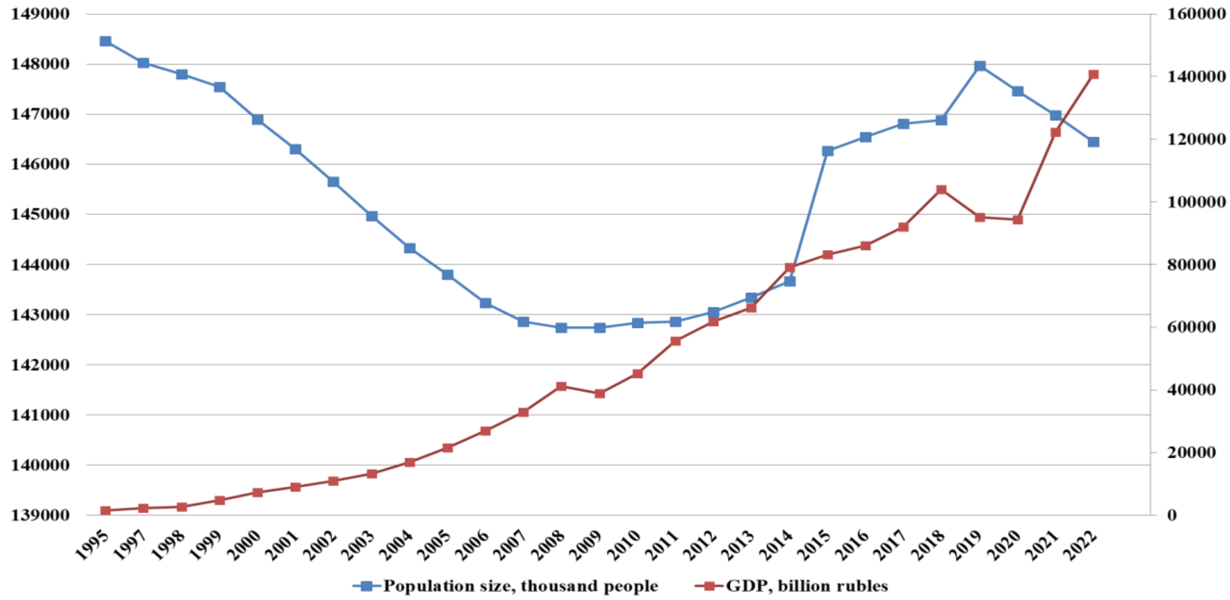
When $I_{Li} > 0$ – the autocorrelation is positive, i.e. this region is similar to neighboring regions (cluster).

When $| I_{Li} | > | I_{Lj} |$ – the similarity/difference of region i with its surrounding neighbors is greater than in the case of region j and its neighbors.

4. Results of the author's study and discussion

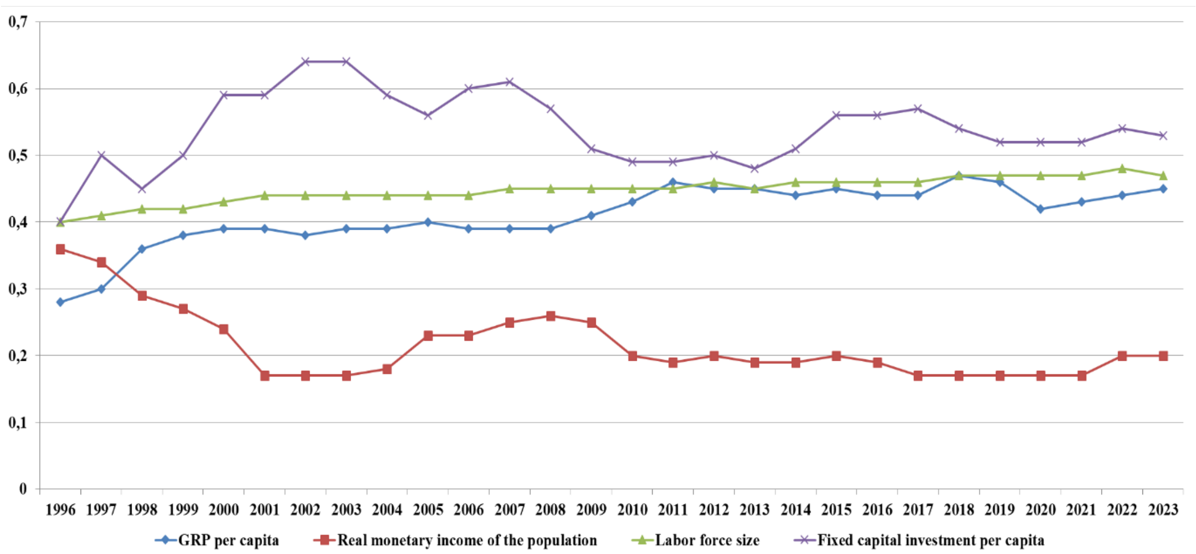
In order to give a general idea of the development of the regions of the Russian Federation, and in part of figure 2, the dynamics of population growth and GDP[2] in the period 1996–2023 are presented, selected in connection with the beginning of reforms and a market economy, using example 3 – as the dynamics of the regions of Russia.

Figure 2 Dynamics of GDP and population in Russia in 1996-2023, thousand people, billion rubles



Calculated by: Unified Interdepartmental Information and Statistical System (EMISS) URL: https://fedstat.ru/ (date of access 14.03.2025)

Figure 3 Dynamics of inequality of regions of Russia in 1996-2023, Gini Index



[2] GDP is calculated taking into account the deflator index.

Calculated by: Unified Interdepartmental Information and Statistical System (EMISS) URL: https://fedstat.ru/ (date of access 14.03.2025)

The data presented in Figure 2 demonstrate the rapid growth of GDP in the Russian Federation. The population during the analyzed period decreased by 2755.4 thousand people. Positive dynamics of the population in the Russian Federation has been observed since 2010, as a result of the implementation of measures to improve the demographic situation. A significant increase in population (2601 thousand people) was noted in 2015. We emphasize that the reason for this dynamic is the annexation of the Republic of Crimea of the Russian Federation and migration from the territory of Ukraine as a result of political conflicts. Since 2020, the process of population decline caused by the Covid-19 pandemic has begun.

Inequality of Russian regions in terms of socio-economic development tends to increase. Thus, the Gini index for fixed capital investment per capita, which was 0.401 (minimum value) in 1996, reached its maximum value in 2007 – 0.61, and in 2020 it was equal to 0.52 (author's calculations). If we analyze this index by the labor force size indicator, we will see that in 1996 it was 0.4 (minimum value), in 2004 – 0.44, in 2009 – 0.45, and reached its maximum in 2018 – 0.47 (author's calculations). The Gini index for GRP (real) per capita in 1996 was 0.28 (minimum value), in 2001 – 0.39, in 2010 – 0.43, in 2016 – 0.44, and reached its maximum in 2018 – 0.47 (author's calculations).

It is important to note the decrease in differentiation of the level of real monetary income of the population, as the Gini index had a maximum value of 1996 – 0,36, in 2001 – 0.17 (minimum value), in 2007 – 0.25, in 2012 – 0.2, since 2017 – 0.17 (author's calculations).

Within the framework of this study, it is appropriate to present a brief description of the climatic features of the Russian Federation. There are four climatic zones on the territory of Russia[3].

The first climate zone: winter temperature -1°C, wind speed up to 4.6 m/s, includes the southern regions of the country.

Second climate zone: winter temperature -9.7°C, wind speed up to 5.6 m/s, western, northwestern regions, Primorsky Krai.

The third climate zone: winter temperature -18°C, wind speed up to 3.6 m/s, Siberia and the Far East.

The fourth climate zone: winter temperature -41°C, wind speed up to 1.3 m/s, the Far North and Yakutia.

Along with them, there is a special zone that includes Chukotka and territories beyond the Arctic Circle.

It is important to emphasize that in recent decades the trend towards warming has intensified; for example, during the period 1990–2000, according to observations from the ground-based hydrometeorological network of Roshydromet, the average annual surface air temperature in Russia increased by 0.4°C, while over the previous century the increase was 1,0°C.

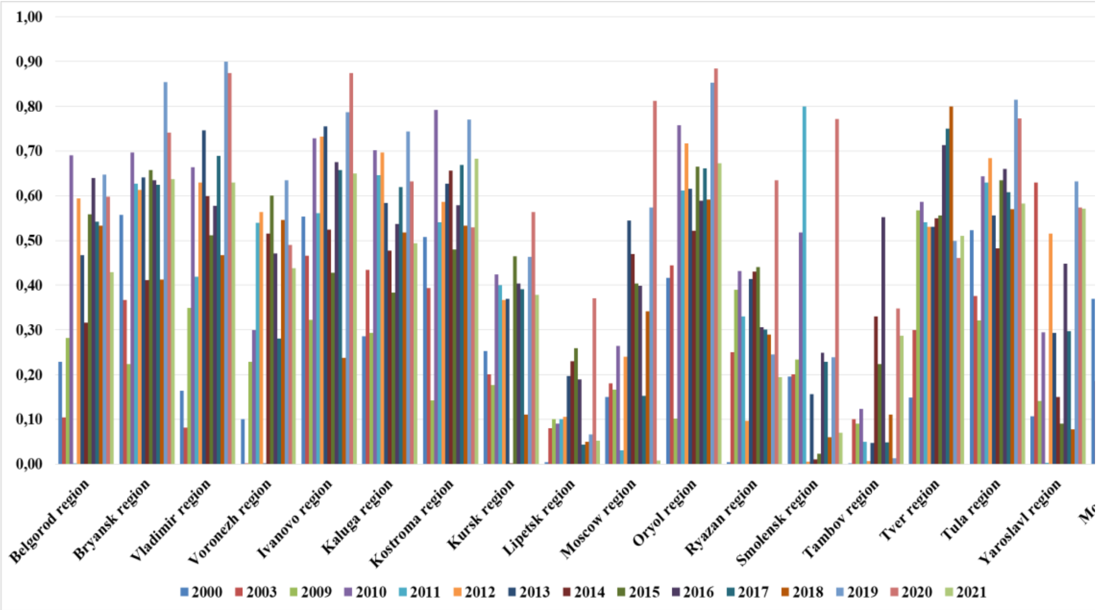
The poles of temperature growth, which reached 5-6 °C, are located in the Altai Territory, the Trans-Baikal Territory, the Irkutsk Region and in the south of Siberia.

In the analyzed sample of regions (regions of the Central, Southern, Siberian Federal Districts), the average annual norm for the indicator "air temperature" varies in the range from -0.7 C° (Tuva Republic) to 12 C° (Krasnodar Krai). The dynamics of the average annual air temperature for the entire analyzed period is ambiguous: both an increase and a decrease in this indicator are observed.

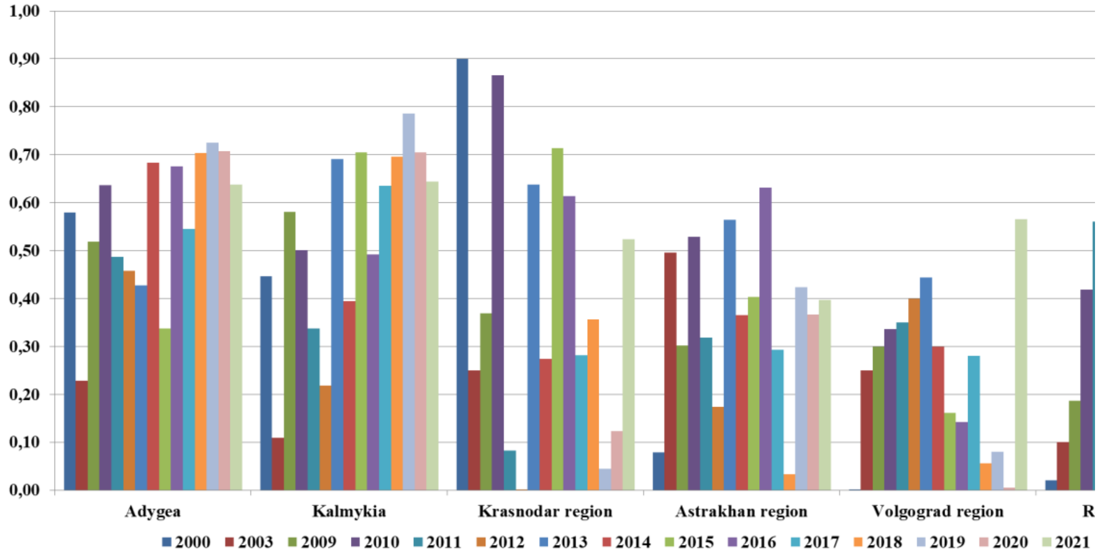
Figures 4-5 present the results of calculations of the dynamics of adaptation of economic growth to climate change in the surveyed regions of Russia.

[3] An area where the same climatic conditions prevail.

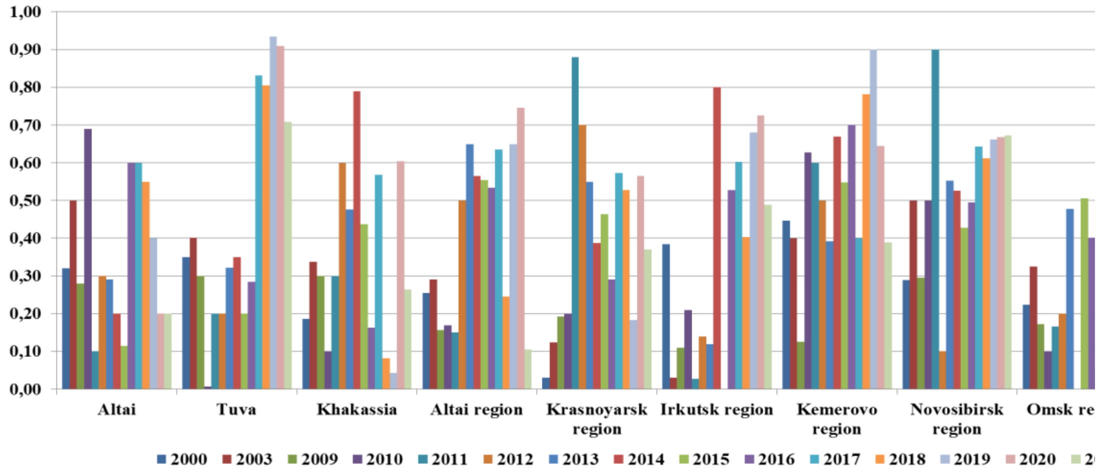
Figure 4 Dynamics of the coefficient of adaptation of economic growth and climate change in the regions of Russia in 2000-2021



A) Central Federal District



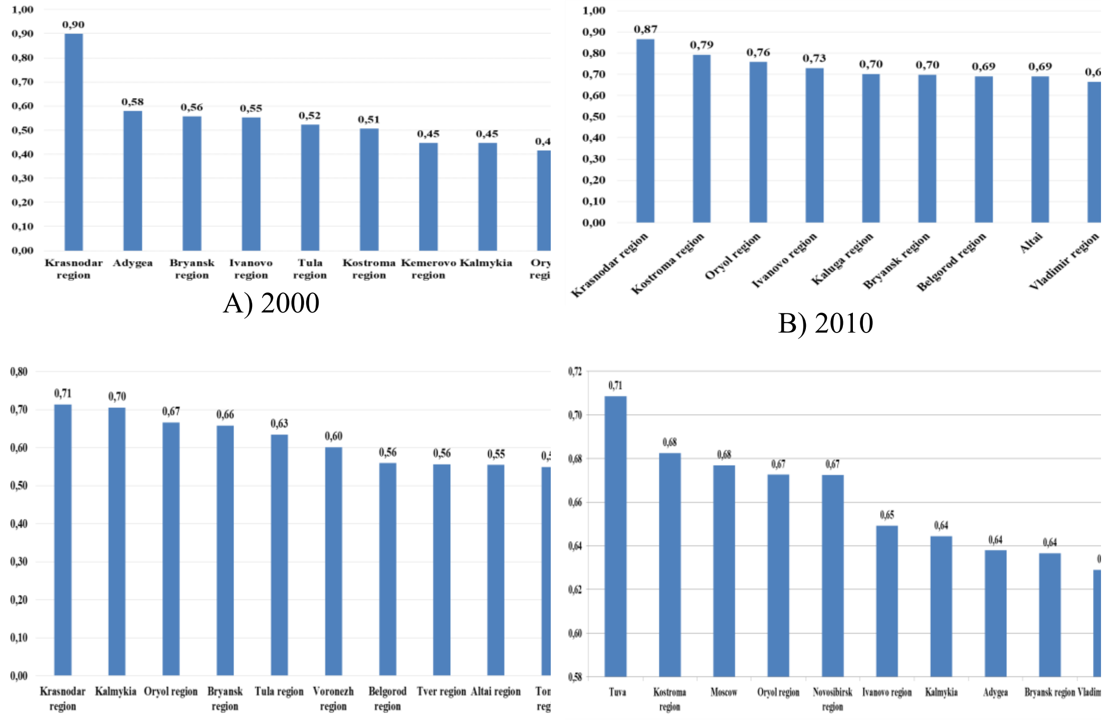
B) Southern Federal District



C) Siberian Federal Distric

Calculated based on data from the Federal State Statistics Service URL: http://www.pogodaiklimat.ru/history.php (date of application 22.02.2025) and the portal «Weather and Climate» URL: http://www.pogodaiklimat.ru (date of application 22.02.2025)

Figure 5 Coordination coefficient of communications in the leading regions of Russia in 2000, 2010, 2015, 2021



Calculated based on data from the Federal State Statistics Service URL: http://www.pogodaiklimat.ru/history.php (date of application 22.02.202 5and the portal «Weather and Climate» URL: http://www.pogodaiklimat.ru (date of application 22.02.2025)

Overall, the calculations demonstrate spatial heterogeneity. The indicators of the coefficient of adaptation of economic growth to climate change in the southern regions and some regions of central Russia are significantly higher, which indicates more coordinated development in these regions. Richer regions in the south of the country benefit from their advantageous geographic location and tourism potential. In the regions of the Siberian Federal District, the adaptation of the economy to climate change is worse, since climate change processes are more intense in this territory, and the structure of the economy is less differentiated.

It is important to note the ambiguous dynamics of the *KA* in all the surveyed regions: there are both periods of decline and growth of the *KA*. Positive dynamics at the end of the analyzed period are clearly visible in Moscow, Kaluga Region, Vladimir Region, Rostov Region, the Republic of Kalmykia, the Republic of Tyva, and Krasnoyarsk Krai.

A significant decrease in the *KA* of Krasnodar Krai is noted, the reason for this dynamics is the relatively rapid pace of economic development with a stable climate. The main reason for the growth of the economy of Krasnodar Krai is the construction of Olympic facilities and the development of the city of Sochi as a mountain climatic resort in preparation for the 2014 Olympics.

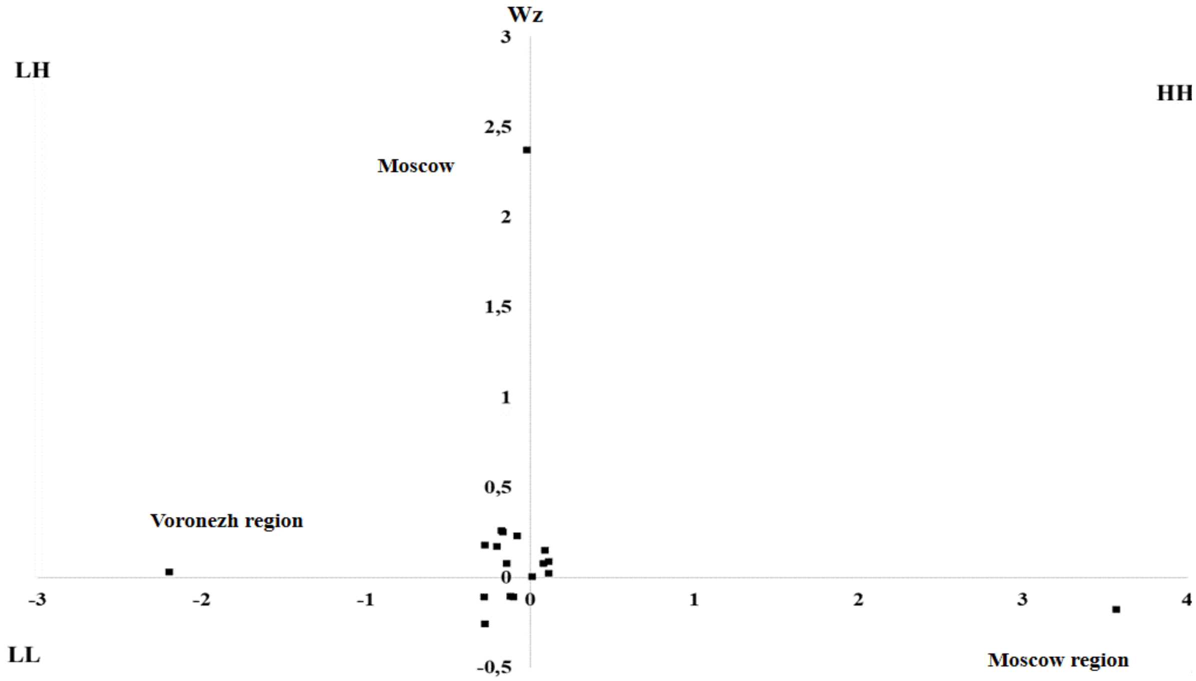
The sample of the leading regions for the analyzed period varies both in terms of the composition of the regions and in terms of the coefficient values obtained. We can conclude that the differentiation of regions by region *KA* has significantly decreased, and this trend is largely a consequence of the adaptation of economic growth to climate change in the outsider regions. In 2000, adaptation was observed in one region (Krasnodar Krai), while the remaining regions were characterized by a low (four regions) and basic (five regions) level of adaptation. In 2010 Krasnodar Region also maintains a high level of adaptation, while the remaining nine have a basic level. In 2015, all regions of the sample have a basic level of adaptation; in 2021, the basic level of adaptation remains in all leading regions. Separately, it is necessary to consider the adaptation of economic growth to climate change in regions with a high level of economic development.

In Moscow, during the period under review, we can assess the dynamics of the *KA* positively, while the *KA* level is in a basic transition period with a stable, unchanging economy (U-E>0.1), in other words, climate changes do not have a significant impact on the economy of the capital region. The current situation can be explained by the volume and differentiated structure of the economy, which makes it possible to reduce not only climate risks, but also various crisis fluctuations. The dynamics *KA* in the Belgorod region is mixed (Fig. 4A), from 2010 the *KA* level has entered a transitional period, but varies in level (low/basic). Since 2015, the economy in this region can be assessed as stable, i.e. adaptive to climate change (U-E>0.1). In the Moscow region, strong jumps *KA* were observed over the analyzed period, from 0.81 in 2020 to 0.01 in 2021, while no significant climate change was observed (E-U>0,1). We believe that these dynamics *KA* in the 2020-2021 period are caused by the impact of the new coronavirus infection on the economic and social spheres, as restrictive measures and control over their implementation in the Moscow region were stricter, and the incidence and mortality rates were higher.

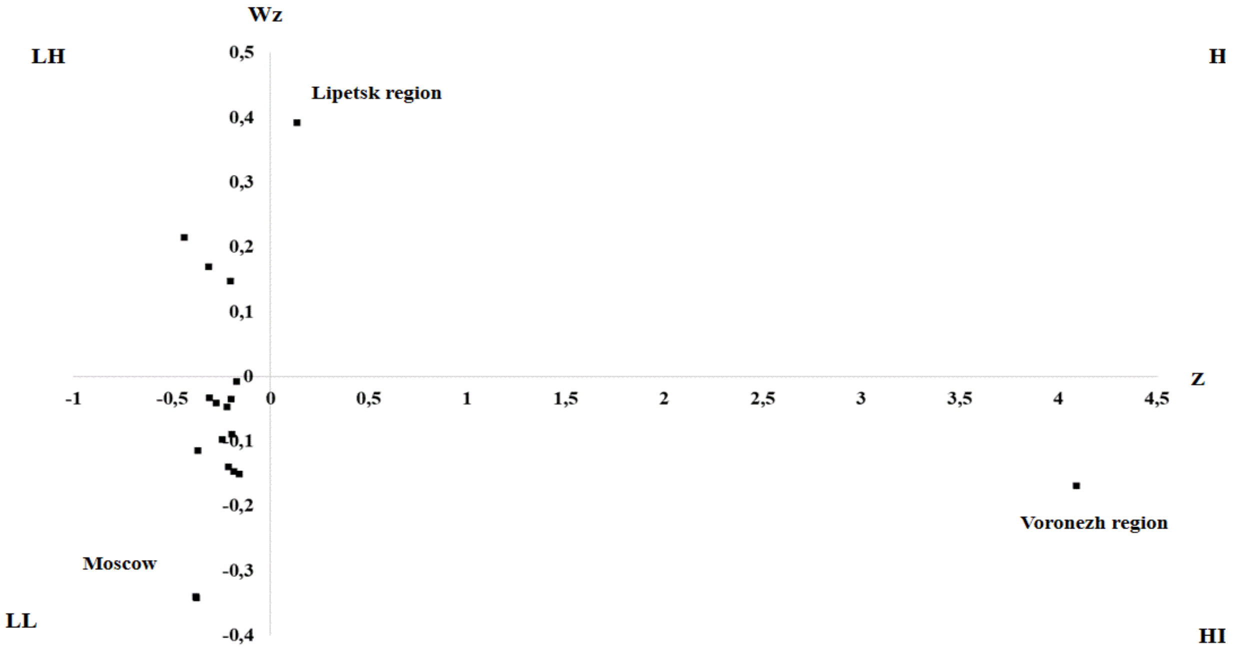
Consequently, this had a significant impact on the socio-economic sphere, which requires a separate detailed analysis.

In Krasnoyarsk Krai, during the analyzed period, there was both an increase and a decrease in the coefficient of adaptation (uncoordinated and transitional periods), while climate changes were observed in a stable economy (U-E>0.1), so are changes in economic growth as a reaction to climate fluctuations. In the Irkutsk Region, the *KA* level has been steadily in transition since 2016 (since 2019, the baseline level), by analogy with Krasnoyarsk Krai, there are both climate changes with a stable economy (U-E>0.1) and changes in economic growth as a reaction to climatic fluctuations. The results of the spatial and temporal analysis of the adaptation of the economy and climate within the borders of the federal districts are presented in figures 6-8.

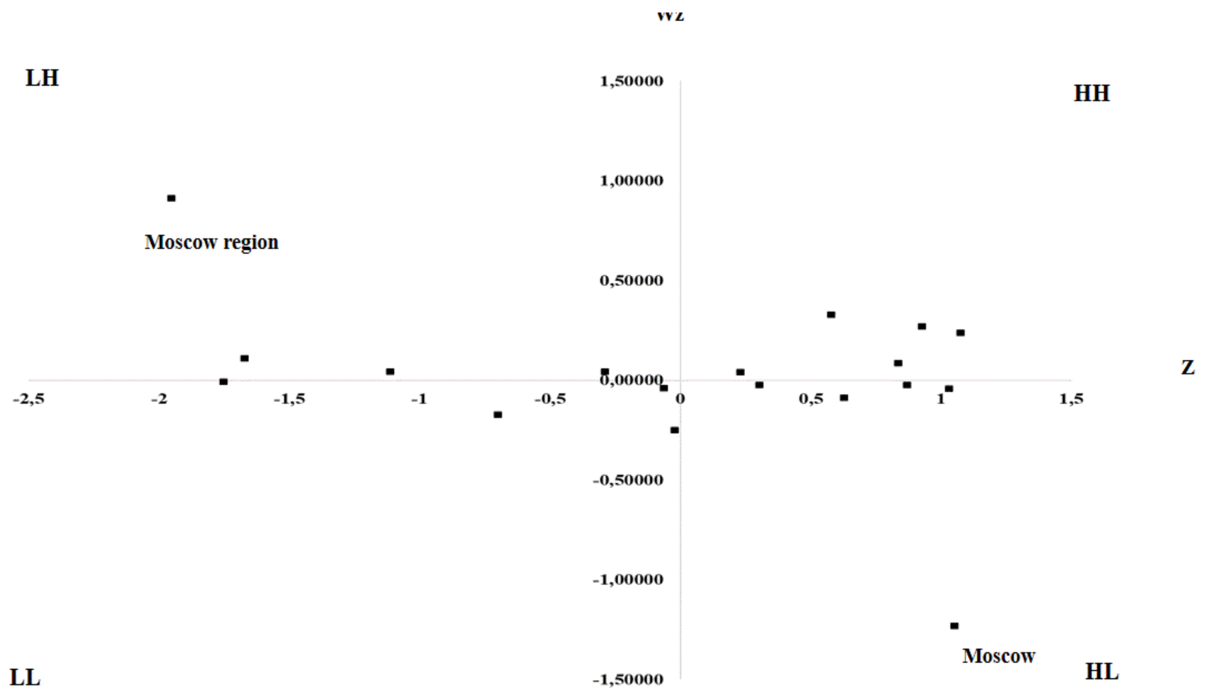
Figure 6 Spatial Moran's scattering diagram for the regions of the Central Federal District in 2000, 2010, 2021



A) 2000



B) 2010



C) 2021 г.

Calculated based on data from the Federal State Statistics Service URL: http://www.pogodaiklimat.ru/history.php (date of application 22.02.2025) and the portal «Weather and Climate» URL: http://www.pogodaiklimat.ru (date of application 22.02.2025)

When determining spatial autocorrelation in the regions of the Central Federal District, the mathematical expectation of the global Moran's index is (-0.06), the global Moran's index was calculated for 2000 data (-0.04); for 2010 data – (-0.02); for 2021 data – (-0.14). The results obtained allow us to conclude that there are global spatial patterns of *KA*, namely, regions with high or low *KA* values, as a rule, are adjacent to other regions with similar values.

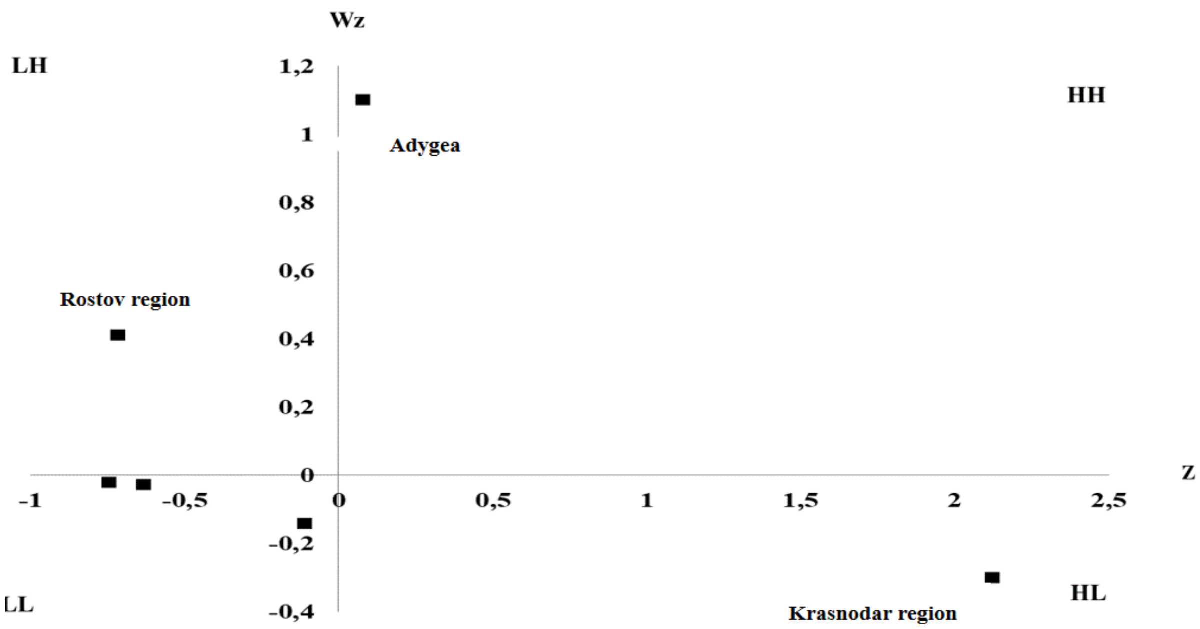
In 2021, there is a feedback loop, i.e. the value *KA* in the surrounding regions is different. It is important to note that the global Moran's index shows a slight downward trend over the analyzed period, which indicates that, in general, neighboring regions tend to have less influence on the regional climate in conditions of rapid economic development.

According to the data shown in figure 6A, the largest share in the sample of cities in the Central Federal District is occupied by regions with a low *KA* value, surrounded by regions with a high *KA* value (group *LH*, autocorrelation is negative), including Moscow and the region with a population of one million – the Voronezh Region.

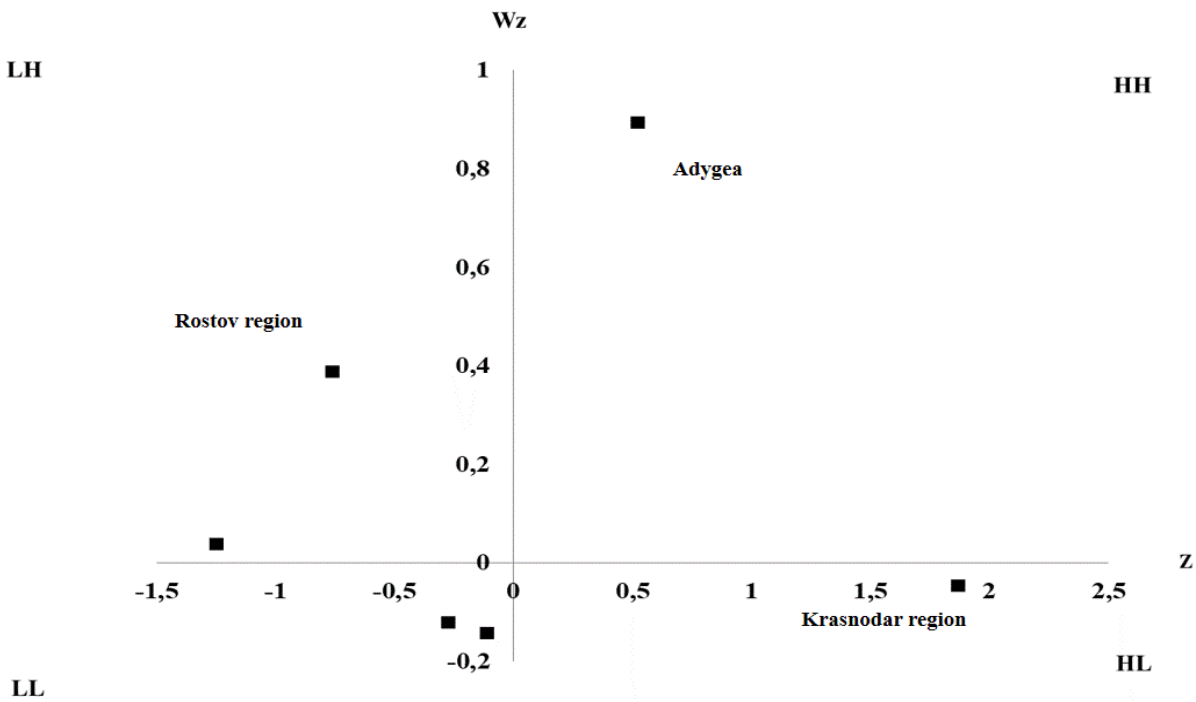
The closest interregional connection is typical for the Lipetsk and Voronezh regions. There are five regions in the *HH* square: Bryansk, Ivanovo, Kostroma, Oryol and Tula regions. In 2010, there has been a significant change in the situation, with the largest concentration of regions in the square *LL*. Relatively high *KA* values (squares *HH* and *HL*) were obtained for the Lipetsk Region, Belgorod Region, Kursk Region, and Tambov Region, i.e. for regions of the Central Chernozem macro-region.

We can conclude that during the analyzed period there have been significant changes in the location of the regions of the Central Federal District in the Moran's diagram, i.e. the relationship between climate and the economy in these regions is in a dynamic state.

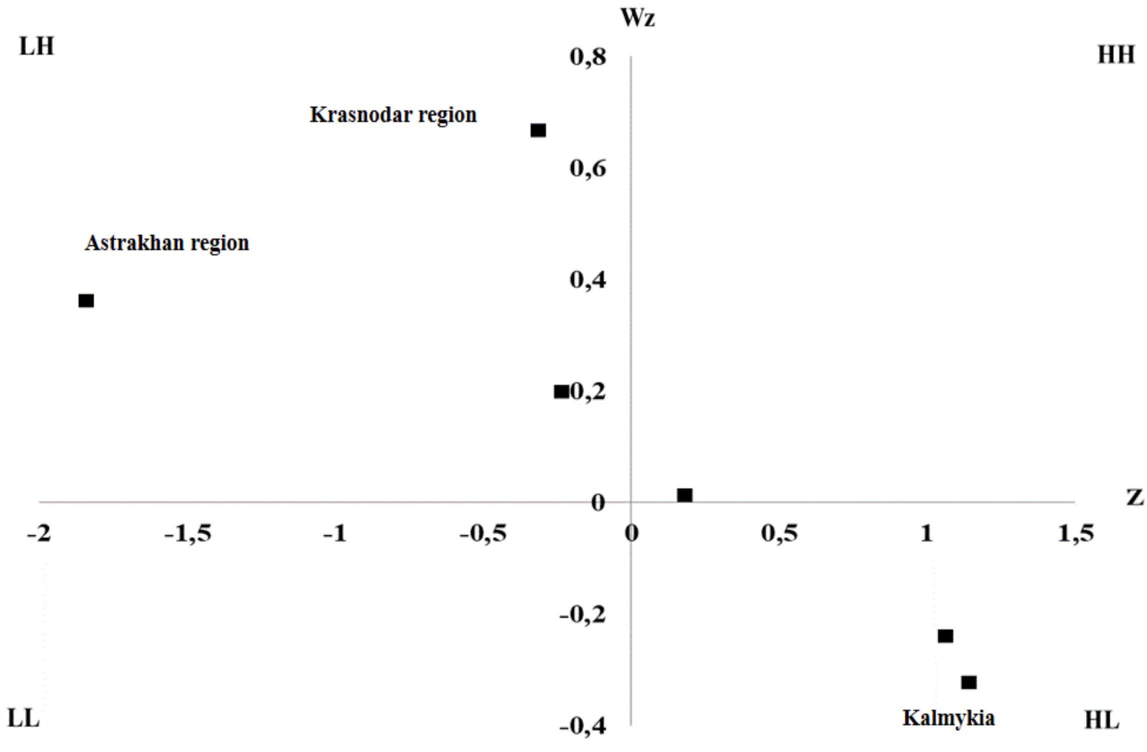
Figure 7 Spatial Moran's scattering diagram for the regions of the Southern Federal District in 2000, 2010, 2021



A) 2000



B) 2010



C) 2021

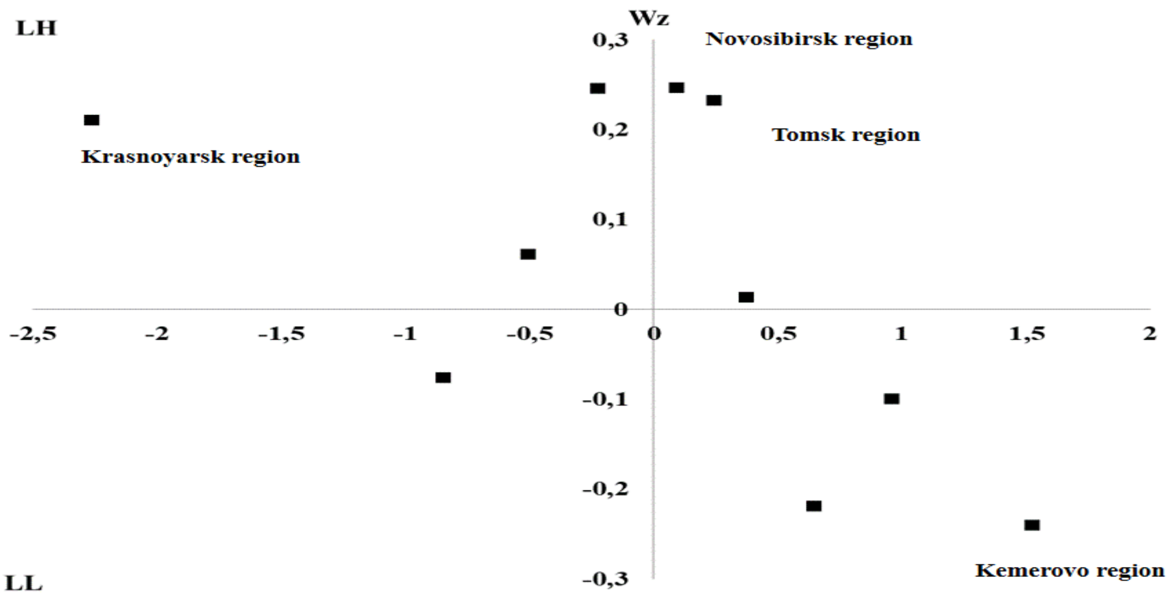
Calculated based on data from the Federal State Statistics Service URL: http://www.pogodaiklimat.ru/history.php (date of application 22.02.2025) and the portal «Weather and Climate» URL: http://www.pogodaiklimat.ru (date of application 22.02.2025)

For the regions of the Southern Federal District, the mathematical expectation of the global Moran's index is (-0.2), the global Moran's index for data from 2000 is (-0,13), 2010 is (0,03), 2021 is (0,13), i.e. there is a direct relationship. Most regions do not show significant local spatial correlation, which indicates a limited spatial relationship between territories.

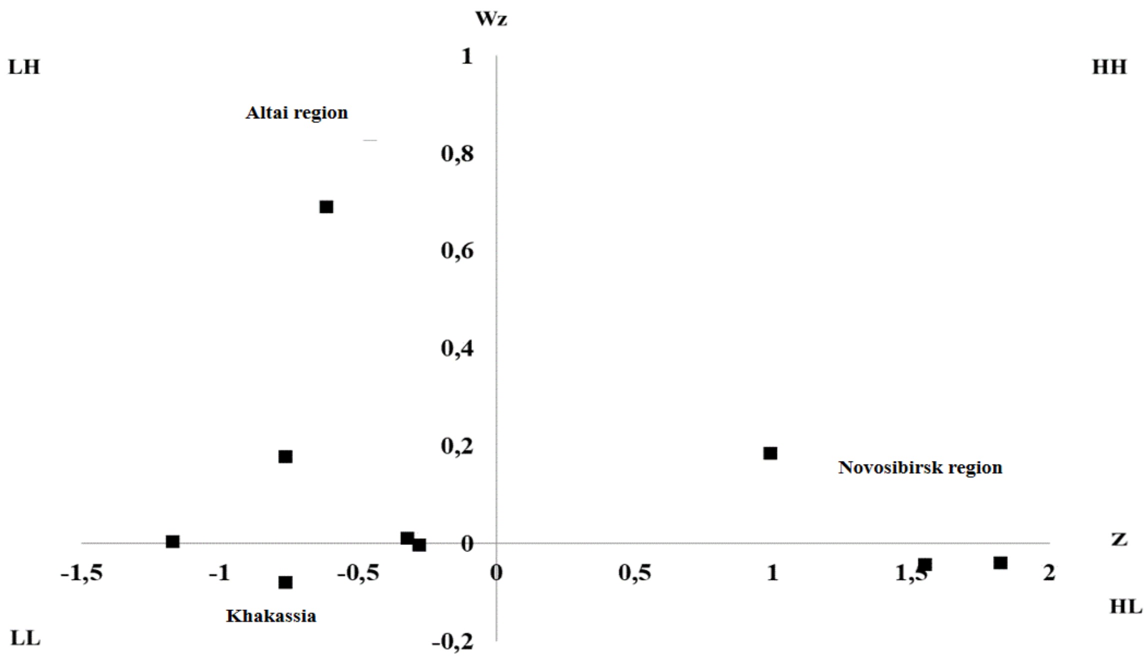
The data presented in figures 7A and 7B demonstrate a stable situation according to the analyzed criterion in the Southern Federal District; Adygea, Krasnodar Territory and Rostov Region are isolated from the rest of the sample.

The strongest direct spatial relationship is observed in the Republic of Adygea and the Krasnodar Territory (2000, *LISA* 0.19; 2010 *LISA* 0.12), Rostov and Astrakhan regions (2021, *LISA* 0.022). These connected regions, which demonstrate a relatively higher level of coordination, tend to be characterized by economic growth and advantageous geographical location.

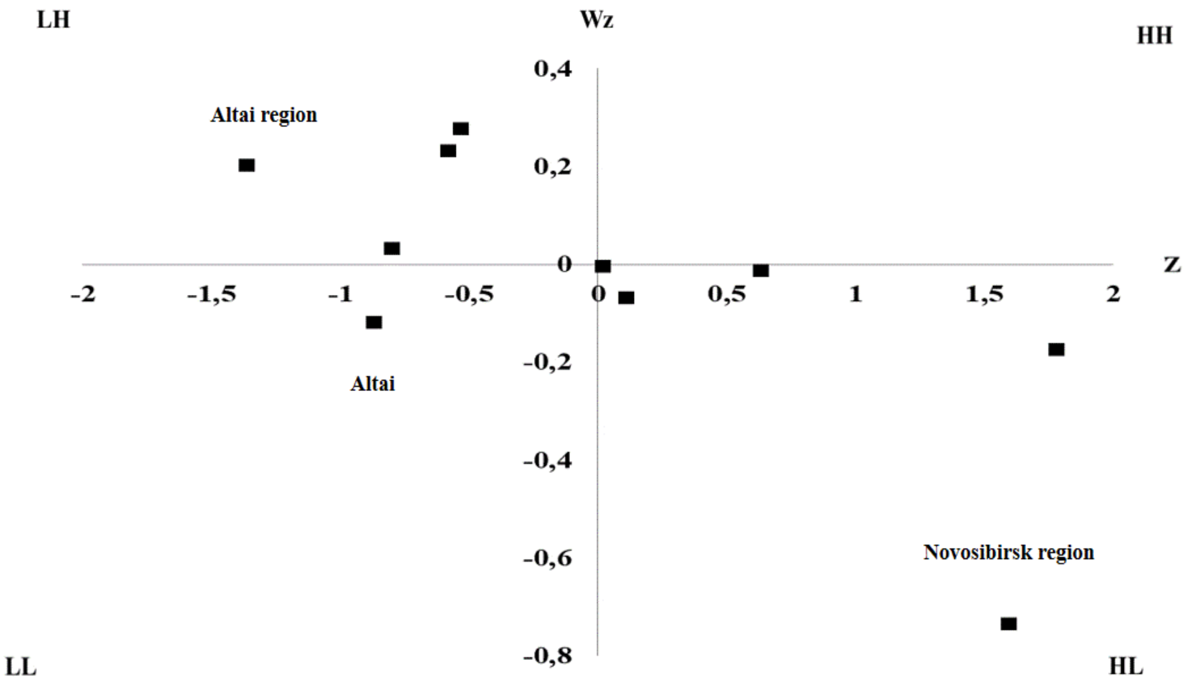
Figure 8 Spatial Moran's scattering diagram for the regions of the Siberian Federal District in 2000, 2010, 2021



A) 2000



B) 2010



C) 2021
Calculated based on data from the Federal State Statistics Service URL: http://www.pogodaiklimat.ru/history.php (date of application 22.02.2025 г.) and the portal «Weather and Climate» URL: http://www.pogodaiklimat.ru (date of application 22.02.2025)

The mathematical expectation of the global Moran's index (-0.1) was calculated for the regions of the Siberian Federal District, in 2000 the global Moran's index was (-0,1), in 2010 – (-0.08), in 2021 – (-0.19). There was direct communication in the regions of the Siberian Federal District in 2000, 2010, and feedback in 2021. According to the data presented in figure 8, we can conclude that during the analyzed period, the regions of the Siberian Federal District have been moving in the Moran's diagram, and dynamic processes are taking place in the adaptation of the economy and climate in the surveyed regions.

In 2000 (figure 8A), the regions were scattered relatively evenly, while the western regions of the federal district, Novosibirsk and Tomsk Regions, were isolated from the rest of the group. In 2010, there was only one region in the *HH* square, the Novosibirsk Region, while the maximum positive *LISA* values were obtained in relation to the Kemerovo Region (0.05) and the Altai Republic (0.04).

In 2021 (figure 8C), there are no regions in the *HH* square, while their greatest concentration is observed in the *HL* square. High positive *LISA* values were obtained for a) Tomsk Region and Altai Territory (0.01); b) Altai Territory and the Altai Republic (0.03); c) Novosibirsk Region and the Republic of Tuva (0,01).

5. Conclusion

The analysis of theoretical provisions on the problems of climate influence on economic development has allowed to establish the absence of a methodological approach for innovative consideration of adaptation of regional economic growth to climate change. According to the results of the assessment of the dynamics of adaptation of economic growth to climate change in the regions of Russia, spatial heterogeneity has been revealed. The indicators of the coefficient of adaptation in the southern regions and parts of the regions of central Russia are significantly higher, which indicates a more coordinated development in these regions. Regions demonstrating a relatively higher level of adaptation to economic growth and climate change have a more differentiated economy and a favorable geographical location.

Climate change processes are more intense in the Siberian Federal District, and the structure of the economy is less differentiated compared to central Russia, therefore, regional authorities should develop more effective measures to mitigate climate change in the context of further economic growth. Most regions of the Southern Federal District do not demonstrate significant local spatial correlation in the «adaptation coefficient» indicator, which indicates a limited spatial dependence of the economic development of these regions. In the regions of the Siberian Federal District, there was a significant movement of regions in the Moran's diagram, which indicates the dynamic processes of adaptation of the economy and climate in the regions of this federal district. On a regional and national scale, a policy framework is needed to mitigate climate risks for the regional economy.

Achieving a synergistic interaction between climate and economic development is crucial for ensuring sustainability at the local and global levels.

The identified spatial and temporal patterns of adaptation of economic growth to climate change indicate the urgent need to fully take into account regional imbalances in the development of national policies.

Mitigation strategies applied for each region should correspond not only to its economic level, but also to specific climatic characteristics.

It is important that pilot projects aimed at mitigating the effects of climate change cover regions with different economic levels in many climatic zones. The results obtained have practical significance and can be used to develop and implement climate risk management policies, including cost-benefit assessment of adaptation and mitigation actions, and analysis of the economic costs of climate change impacts under various strategic scenarios. The presented methodology has the potential for further research, and it is planned to modify it to analyze the links between climate change processes and the economic dynamics of individual industries in the regions of Russia.

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