QUBAHAN ACADEMIC JOURNAL
VOL. 4, NO. 2, June 2024
https://doi.org/10.48161/qaj.v4n2a253

Algorithm of Development for Stabilization of Socio-Ecological Situation in Karakalpakstan

Alisher Abdullaev [1*]

[1] Department of Methods of Teaching Computer Science, Nukus State Pedagogical Institute named after Ajiniyaz, Republic of Karakalpakstan;

Corresponding author: e-mail: alisherbdulaev8@gmail.com.

ABSTRACT: The relevance of developing a scientific framework for stabilizing the socio-ecological situation of the Republic of Karakalpakstan is determined by the need to address the environmental, social and economic challenges faced by the region. It is designed to improve the population's quality of life, sustainable development and balanced interaction with the environment. The purpose of the research was to establish the relationship between social and environmental factors, to establish a mathematical model based on them, which will enable predicting future development and establishing a set of recommendations to improve the situation in the Republic of Karakalpakstan. The methods of theoretical analysis and mathematical modelling were used. The research outlines modern ideas about modelling the dynamics of socio-ecological processes in the example of the Republic of Karakalpakstan. It is established that the Republic has several problems, the solution of which should be started shortly. Considerable attention is paid to the setting of tasks and using for this purpose methods of system analysis of socio-ecological factors. In this work, the analysis of factors affecting the social and environmental environment of the Republic of Karakalpakstan using regression analysis is considered. The parameters of the developed mathematical model and their adequacy are determined. The developed mathematical model will allow identification of the social and ecological situation of the republic. At the end of the work, ten priority points for the next 5-10 years to improve the socio-ecological situation were presented. The practical value of the results is implemented in promoting the identification of new powerful reserves for further improvement of the management of social processes. This approach allows for increasing the national economic efficiency of the region and ensuring a balance between economic, social and environmental aspects of development, which is an essential step towards a sustainable future.

Keywords: Quality of Life Factor, Population Analysis, Environment, Natural Resources, Pollution.

I. INTRODUCTION

In recent decades, the Aral Sea region of Central Asia has faced a severe socio-ecological crisis due to the drying up of the Aral Sea. This environmental disaster has had far-reaching consequences for the Republic of Karakalpakstan, an autonomous region of Uzbekistan bordering the former Aral Sea. The retreating sea has led to the destruction of the area's once-thriving fishing industry, loss of biodiversity, soil salinization, and severe public health issues among the local population from dust storms carrying pesticides and fertilizers.

Addressing this complex socio-ecological situation requires a comprehensive scientific framework that can model the intricate relationships between environmental, social, and economic factors. Previous studies have explored certain aspects, such as the economic losses from the Aral Sea disaster, ecosystem impacts, and public health effects. However, an integrated approach that combines these different dimensions into a holistic model for stabilizing and improving the situation in Karakalpakstan is still lacking.

The motivation behind this research is to fill this critical gap by developing a robust scientific methodology and mathematical models that can effectively analyze the socio-ecological dynamics in Karakalpakstan. The key challenges involve accurately capturing the complex interactions between variables like population growth, pollution levels, natural resource availability, food production, and economic investment. Establishing these linkages is crucial for predicting future trajectories and identifying targeted interventions to promote sustainable development in the region.

The purpose of this research is to establish scientific and methodological recommendations on using modern monitoring studies in combination with the methods of system dynamics to ensure the stabilization of the socio-ecological situation in the region of the Republic of Karakalpakstan in the conditions of market relations. The research on the region of Karakalpakstan can have many tasks related to demographic, socio-ecological, economic and other aspects of the region's development. Here are the main tasks of the research:

1. Analysis of the demographic and socio-environmental situation in the Karakalpakstan region, including assessment of population dynamics, capital investment levels, environmental pollution and socio-economic characteristics.
2. Exploring problems in food production, waste management, noise pollution levels and food availability, and identifying the causes and effects of these problems on public health and the environment.

Development of recommendations and solutions to the identified problems were designed to optimize natural and other resources, improve infrastructure, reduce pollution, improve the quality of life of the population and stimulate sustainable development of the Karakalpakstan region. The following hypotheses were formulated:

1. Social and environmental factors in Karakalpakstan are deeply interconnected, with changes in one domain significantly impacting the other.
2. A comprehensive mathematical model based on accurate data can effectively predict future socio-environmental dynamics in Karakalpakstan, enabling proactive decision-making.
3. Implementing recommendations derived from the predictive model will lead to significant improvements in quality of life, sustainable development, and balanced human-environment interactions in Karakalpakstan.

II. LITERATURE REVIEW

According to the calculations of specialist S. Baltashov, social and economic losses due to the drying up of the Aral Sea in the region amount to over ten billion UZS per year, including only anthropogenic desertification leading to economic damage of over one billion UZS [1]. These calculations do not consider social losses: low level of working capacity of the population, quality of life, and number of unemployed, which directly affect the normal development of the region. The task of this research is to consider cardinal issues of methodology of development modelling of complex socio-ecological processes development in the region using computational technology, the results of which will allow managing complex socio-ecological systems, strictly guided by scientifically based and statistical data.

Additional information is noted by R. Sigdel et al., who established that bottom sediments are a complex multi-component system and play a key role in the development of the hydrochemical regime of water masses and the functioning of ecosystems of reservoirs and watercourses [2]. An essential issue is the need to establish standards for the quality of bottom sediments as a medium for depositing pollutants and the most dangerous component of the aquatic ecosystem. This issue is widely discussed among specialists and experts. There are various approaches to address this issue, each with its advantages and disadvantages. These limitations may complicate the widespread implementation of appropriate approaches in legislation. Determining the optimal approach to rationing the quality of bottom sediments requires a comprehensive approach, considering the specific features of aquatic ecosystems and the effects of pollution on the environment and human health. Only in this way effective protection of water resources and sustainable ecosystem functioning can be ensured. U. Makhmudova et al. indicate that the interaction of socio-ecological factors determines tension, change and growth [3]. The presence of severe problems in the social, economic and environmental environment is not new. The solution of these problems by classical methods such as migration, economic growth, and technological ways cannot be implemented.

Known tensions in the socio-ecological system are caused by population growth, increasing environmental pollution and social differences in living standards, according to N.K. Komilova [4] and E. Lioubimtseva [5]. These elements are becoming increasingly interconnected. An impact on one element may affect another. For example, population growth is one of the significant tensions that cause sensible fertility planning, food production, pollution dissipation, and land use. Therefore, it is necessary to develop a scientific methodology that helps to understand the links through which the major factors affect each other in the examined object. Ensuring environmental safety is becoming a priority task at the state level. One of the most serious problems that affect cities is the problem of waste [6]. The annual volume of household waste generated in cities is about 700 thousand tones. Therefore, the amount of industrial waste has noticeably increased. It is conditioned, on the one hand, upon the growth of economic activity of enterprises and, on the other hand, by the reduction of industrial emissions due to improved accounting of waste generation, storage and utilization.

In turn, M. Jalolova et al. state that the increase in the production of consumer goods contributes to population growth and environmental pollution [7]. Thus, the activation of each social factor has a positive impact on the development of other factors, contributing to their mutual growth. However, over time, there is a slowdown in the growth of factors, as it is limited by specific limits determined by the available natural resources. Notably, land and natural resources are gradually depleting and the natural self-cleaning capacity of the atmosphere is not infinite. Population growth favors the accelerated use of natural resources, which in turn leads to diminishing stocks and shortages in response to increasing demand. Continued growth in production is accompanied by an increase in pollution levels, adversely affecting natural self-cleaning processes.

This study seeks to fill the gaps by developing an integrated dynamic mathematical model and decision support system specifically tailored to the unique socio-ecological context of Karakalpakstan. Previous studies have explored certain aspects of the Aral Sea disaster, however, an integrated scientific framework that combines these different dimensions into a holistic model for stabilizing the socio-ecological situation in Karakalpakstan is still lacking. Addressing the complex socio-ecological situation in Karakalpakstan requires accurately capturing the intricate interactions between various factors such as population growth, pollution levels, natural resource availability, food production, and economic investment. While some general models and approaches exist, there is a need for a decision support system specifically tailored to the unique socio-ecological context of Karakalpakstan which would integrate different variables and perspectives into a unified analytical framework, enabling forecasting, scenario analysis, and evidence-based policy-making for the region. By integrating different variables and perspectives into a unified analytical framework, this study provides a new tool to forecast potential development trajectories, identify optimal management strategies, and support evidence-based sustainable development policy-making in the region.

III. MATERIAL AND METHOD

1. DATA COLLECTION

This study used a systematic approach to collecting and analyzing data on environmental and social processes in the Republic of Karakalpakstan. Numerous data sources were used to create a comprehensive information base for the study. The main environmental indicators such as air and water pollution levels, soil quality, biodiversity indicators were obtained from the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan [8]. Satellite images and remote sensing data were also used to assess changes in the Aral Sea region over time. Statistics on the prevalence of various diseases, mortality rates and other public health parameters in Karakalpakstan were obtained from the Ministry of Health of Uzbekistan and the regional office of the World Health Organization. Population statistics, including total population, urban-rural breakdown, age distribution, fertility rate and migration processes, were collected from the regional office of the National Statistical Committee of Uzbekistan for Karakalpakstan.

The dataset used in this study is described as follows:

- *Environmental Data*: Main environmental indicators such as air and water pollution levels, soil quality, biodiversity indicators were obtained from the Ministry of Ecology, Environmental Protection and

Climate Change of Uzbekistan. Satellite images and remote sensing data were used to assess changes in the Aral Sea region over time.

- *Public Health Data*: Statistics on disease prevalence, mortality rates, and other public health parameters in Karakalpakstan were obtained from the Ministry of Health of Uzbekistan and the regional office of the World Health Organization.
- *Population Data*: Population statistics, including total population, urban-rural breakdown, age distribution, fertility rates, and migration processes, were collected from the regional statistical office for Karakalpakstan.
- *Economic Data*: Economic indicators such as GDP, employment, sectoral contributions (agriculture, industry, etc.), investment levels, and trade flows were obtained from government databases and publications of international organizations like the World Bank.
- *Literature Review*: An extensive review of previous studies, case studies, and data provided by Uzbek and international researchers on the Aral Sea disaster and its impacts.

Information on economic indicators such as GDP, employment, sectoral contributions (agriculture, industry, etc.), investment levels and trade flows were obtained from government databases and publications of international organizations such as the World Bank. In addition, an extensive literature review was conducted to collect the results of previous studies, case studies and data provided by both Uzbek and international researchers who have studied the Aral Sea disaster and its impact on the environment and communities of Karakalpakstan. The data collected reflect changes in key environmental components such as air, water, and land, as well as corresponding shifts in social factors such as population levels, economic productivity, and health over several decades. Combining these diverse data streams has provided a comprehensive picture of socio-environmental dynamics in the region. Great care was taken to cross-check data from multiple authoritative sources to ensure the accuracy and reliability of the information base used to develop the mathematical models and decision support system in this study. The key points of all the above are as follows:

- Systematic collection of data from multiple authoritative sources (government agencies, international organizations, previous studies);
- Comprehensive information base covering environmental indicators (air, water, soil quality, biodiversity), public health data, population statistics, and economic indicators.
- Mathematical Modeling:
- Developing a dynamic mathematical model to simulate socio-environmental processes;
- Establishing relationships between key variables (population, investment, resources, pollution, food production);
- Regression analysis to identify and quantify relationships between variables;
- Model validation through numerical experiments and real data.

2. RESEARCH DESIGN

The study puts forward three main hypotheses to guide the study and interventions in the Republic of Karakalpakstan. The socio-environmental interdependence hypothesis states that social and environmental factors in the region are deeply interdependent, and changes in one sphere significantly affect the other. This means that, for example, an increase in environmental pollution can directly affect the health of the population and subsequently change socio-economic conditions. Conversely, socio-economic changes such as population growth or investment shifts can affect environmental stability. The mathematical predictive model hypothesis suggests that a well-built mathematical model based on accurate and comprehensive social and environmental data can effectively predict future socio-environmental dynamics. The model is intended to guide decision-making and intervention by providing a tool for predicting and mitigating unfavorable developments. The intervention effectiveness hypothesis suggests that the implementation of targeted recommendations derived from the predictive model will lead to significant improvements in quality of life, sustainable development and balanced interaction with the environment in Karakalpakstan. This hypothesis emphasizes the practical applicability of the study, suggesting that the theoretical findings can translate into tangible benefits for the region.

The study used a range of materials to ensure robust analysis and accurate modelling. Data sources include demographic data from the National Population Statistics, which provide insights into population dynamics and trends. Environmental data from the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan provide critical information on pollution levels, natural resource use and environmental health. Health data provided by the Ministry of Health of the Republic of Uzbekistan and the World Health Organization provide a comprehensive picture of public health problems related to environmental factors. Analytical tools are needed to process and analyze these data. Statistical software allows regression analysis to identify significant relationships between variables. Systems analysis tools help to assess interactions between socio-environmental factors, and mathematical modelling software is used to develop dynamic models that simulate socio-environmental processes in a region. Background research plays an important role in the context of the study. Previous studies and reports by Uzbek and foreign scientists on similar socio-ecological situations serve as a basis for the present study. They provide a detailed analysis of socio-ecological disasters and mitigation strategies, offering valuable ideas and methodologies that can be adapted to the specific conditions of Karakalpakstan.

The methodology combines theoretical analysis, data collection, regression analysis, mathematical modelling, model validation and development of recommendations. The theoretical analysis begins with a thorough review of existing literature on socio-ecological interdependence and disaster mitigation. This review helps to identify key socio-ecological factors that are particularly relevant to Karakalpakstan. Data collection involves gathering demographic, environmental, health and economic data from a variety of sources. The accuracy and relevance of these data are verified by cross-referencing multiple sources to provide a solid basis for analysis. Regression analysis is used to identify and quantify relationships between social and environmental factors. This step is critical in determining the parameters to be used in the mathematical model. Mathematical modelling involves the development of a dynamic model to simulate socio-environmental processes in Karakalpakstan. This model includes system analysis to take into account the interrelationship of various factors. Model validation involves conducting numerical experiments to verify the accuracy of the model and adjusting parameters based on experimental results and real data. Finally, the development of recommendations involves formulating scientific and methodological recommendations based on the results of the predictive model. These recommendations are aimed at optimizing the use of resources, improving infrastructure, reducing environmental pollution and improving the quality of life in the region.

Research Design:

- Hypotheses on socio-environmental interdependence, mathematical predictive modelling, and intervention effectiveness;
- combining demographic data, environmental data, health data, analytical tools (statistical software, systems analysis, mathematical modelling);

Methodology:

- Theoretical analysis, data collection, regression analysis, mathematical modelling, model validation, recommendations.

Recommendations:

- Formulating scientific and methodological recommendations based on predictive model results;
- Identifying 10 main environmental achievements and 10 environmental priorities for the next 7-12 years;
- Recommendations for optimizing resource use, improving infrastructure, reducing pollution, and enhancing quality of life.

Implementation and Adaptation:

- Proposed research design with stages: problem definition, data integration, dynamic modelling, automated systems, outcome evaluation, and dissemination;

Continuous improvement through adaptive management, integrated assessment, innovative technologies, and environmental education.

The proposed research design is based on a structured approach to analyze and improve the socio-environmental situation in Karakalpakstan. Problem definition begins with an initial assessment of demographic, socio-environmental and economic problems in the region. At this stage, key issues such as population dynamics, investment levels, pollution and health problems are identified. Data integration and analysis involve integrating the collected data into the developed mathematical model. This stage allows for a comprehensive analysis of the relationships between demographic trends, environmental conditions and economic factors. Dynamic modelling and simulation are used to conduct simulation models that predict future socio-environmental scenarios. These models assess the impact of different intervention strategies on the socio-environmental stability of a region. Implementing automated systems involves developing automated systems to continuously monitor and update socio-environmental data. This step provides real-time data analysis and decision support, making models more efficient and responsive to change. Outcome evaluation and adaptation involves regularly assessing intervention outcomes against model predictions and adapting strategies based on feedback and new data. This process of continuous improvement ensures that socio-ecological conditions are continually improving. Finally, dissemination and collaboration involve sharing research results with local authorities, stakeholders and the international community. This stage facilitates collaboration with other regions and countries facing similar challenges, refining and improving the models and recommendations developed.

Thus, here are the key steps of our methodology:

1. *Theoretical Analysis:*
   - Conduct a thorough review of existing literature on socio-ecological interdependence and disaster mitigation.
   - Identify key socio-ecological factors particularly relevant to Karakalpakstan.
2. *Data Collection:*
   - Gather demographic, environmental, health, and economic data from various authoritative sources (government agencies, international organizations, previous studies).
   - Verify the accuracy and relevance of data by cross-referencing multiple sources.
3. *Regression Analysis:*
   - Use regression analysis to identify and quantify relationships between social and environmental factors.
   - Determine parameters to be used in the mathematical model.
4. *Mathematical Modelling:*
   - Develop a dynamic model to simulate socio-environmental processes in Karakalpakstan.
   - Incorporate system analysis to account for interrelationships between various factors.
5. *Model Validation:*
   - Conduct numerical experiments to verify the accuracy of the model.
   - Adjust model parameters based on experimental results and real data.
6. *Recommendations Development:*
   - Formulate scientific and methodological recommendations based on predictive model results.
   - Aim recommendations at optimizing resource use, improving infrastructure, reducing pollution, and enhancing quality of life.
7. *Research Design Implementation:*
   - Define the problem by assessing demographic, socio-environmental, and economic issues.
   - Integrate collected data into the mathematical model for comprehensive analysis.
   - Use dynamic modelling and simulation to predict future socio-environmental scenarios and assess intervention strategies.
   - Implement automated systems for continuous monitoring and data updates.
   - Regularly evaluate intervention outcomes against model predictions and adapt strategies based on feedback.
   - Disseminate results and collaborate with local authorities, stakeholders, and the international community.

IV. DATA ANALYSIS

Basic information and data on environmental issues remain largely inaccessible to the general public on the Internet. These data are mainly disseminated through printed publications, which are available mainly to public institutions. As a result, the public is poorly informed about existing environmental information, and their right to request such data and the procedures for obtaining it. Since the beginning of 2021, procedures for the operation of environmental non-profit non-governmental organizations (non-profit NGOs) and control over their activities have been simplified. However, despite the simplification of procedures, obstacles to the operation of environmental non-profit NGOs still exist, including difficulties in obtaining international funding.

The weak involvement of the general public and representatives of non-profit NGOs in environmental decision-making is a problem. Participation in consultation procedures is limited, and invitations are mainly extended to representatives of a narrow circle of non-profit NGOs that already have close ties with government agencies. This lack of public involvement and limited access to information establish obstacles to achieving transparency and active participation of citizens and non-profit NGOs in environmental processes. Notably, digitalization is essential for monitoring the state of the socio-environmental situation, forecasting its future development, and optimizing the work of regulatory services. In addition, the development of public awareness provides an opportunity to continuously collect and analyze information, ensuring the safety of processes. The development of restoration and stabilization measures represents a reliable tool for social management authorities to make alternative calculations in the field of socio-environmental management.

The structure of mutually counterbalancing forces in a social system is explored when factor growth puts excessive stress on the environment. The main results are interpreted based on the behavior of a machine-oriented model. The model incorporates the interrelated social factors and will provide an opportunity to choose the trajectory of the social system. Figure 1 describes one of the possible options for the future development of the social-ecological system of the Republic of Karakalpakstan (formally).

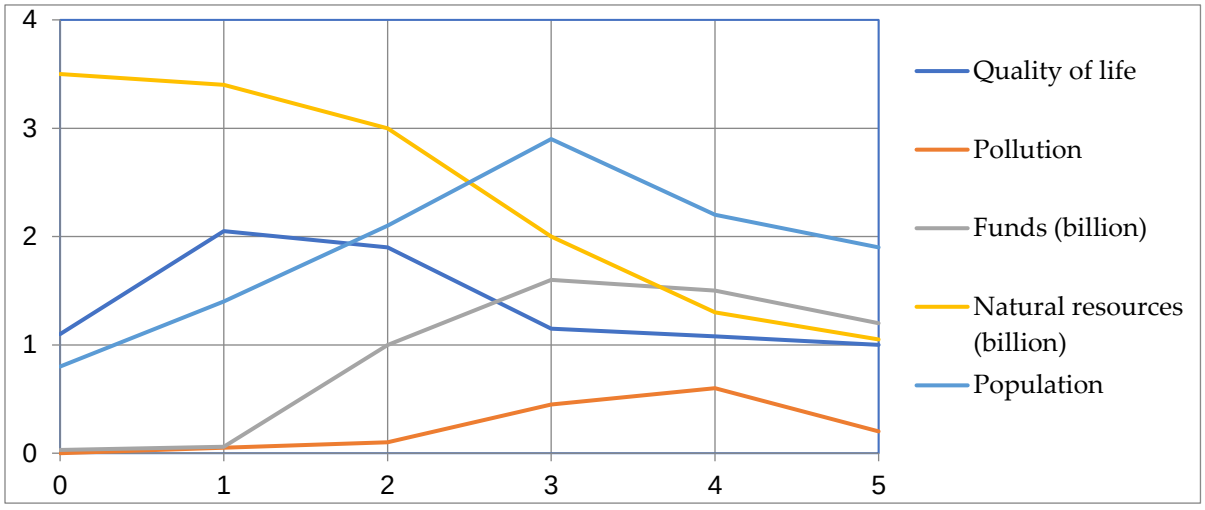

FIGURE 1. One of the possible options for the future development of the socio-ecological system of the Republic of Karakalpakstan

In this context, population and resources grow until the stock of natural resources decreases so much that it begins to limit further growth. As natural resources are further depleted, the population decreases due to reduced investment, and the quality of life deteriorates due to the adverse effects caused by resource depletion. The graph demonstrates that population and capital grow until a crisis arises due to environmental pollution. This pollution, in turn, directly affects population growth by reducing birth rates and increasing death rates, having an adverse effect on food production. Considering the above, a methodology for optimizing living standards by stabilizing social, economic and environmental factors

under conditions of limited natural resources is proposed. The general scheme of functioning of the socio-ecological system (SES) based on information technology is presented in Figure 2.

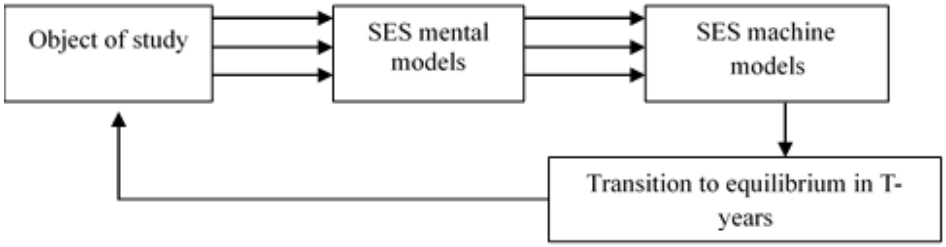

FIGURE 2. General scheme of SES functioning based on information technology

Based on unfavorable forecasts, socio-environmental factors stabilizing the situation in the Republic of Karakalpakstan have been demonstrated through analysis. In this research, it was proved that the adverse impact of socio-environmental factors such as the low level of working capacity of the population, quality of life, and the number of unemployed, directly affects the normal development of the region. These factors are interrelated with population, contributions to the economy, environmental conditions, investment in agriculture, natural resources, degree of pollution, food production, waste management, noise problems, and private market analysis at different levels. In this regard, a mathematical model for analyzing the stabilization of the socio-environmental system of the region was developed to explore the dependence of the above factors. Using the table below, the social growth of the region's population obtained based on the research is presented (Table 1).

Table 1. Dynamics of the quality of life and living conditions of citizens of the republic of Karakalpakstan

Years	X_1	X_2	X_3	X_4	y
1959	891	35640	615160	0.7	0.78
1979	1782	71280	579520	0.3	1.16
1999	3564	142560	508240	0.1	0.87
2019	7128	285120	365680	0.05	0.83
2039	14259	570240	80560	0.006	0.64
2059	28512	1140480	-	-	0.47

Note: y – quality of life of people; x1 – population increase multiplied by twenty years, per thousand people; x2 – suitable land for settlement, ha; x3 – land suitable for agriculture, ha; x4 – land owned by one person for food production, ha.

Using the data in Table 1, the population dynamics will be recorded in the form of a mathematical model:

$$\sum y;\ \sum x_1; \sum x_3;\ \sum x_4; \bar{y};\ \bar{x}_1; \bar{x}_2;\ \bar{x}_3; \bar{x}_4 \sum x_1^2; \sum x_2^2;\ \sum x_3^2; \sum x_4^2;\ \sum y^2; \sum (y-\bar{y});\ \sum (y-\bar{y})^2; \sum (x_i-\bar{x}_i)^2; \sum (x_1-\bar{x}_1)^2;\ \sum (x_2-\bar{x}_2)^2; \sum (x_3-\bar{x}_3)^2; \sum yx_1; \sum yx_2;\ \sum yx_3;\ \sum yx_4; \sum x_1x_2;\ \sum x_1x_3; \sum x_1x_4 2;\ \sum x_2x_3; \sum x_2x_4; \sum x_3x_4. \quad (1)$$

Looking for a mathematical model in the form $y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$of a representation. To find the unknown parameters a_0, a_1, a_2, a_3, a_4 a system of normal equations using the sum calculated above:

$$\begin{cases} 6a_0 + 56536a_1 + 2245320a_2 + 2149160a_3 + 1.156a_4 = 4.75 \\ 56536a_0 + 1083733110a_1 + 4334761330a_2 + 714745164a_3 + 2042.172a_4 = 34305.42 \\ 2245320a_0 + 4334761330a_1 + 1.30069E + 12a_2 + 2?8588E - 11a_3 + 78265?4a_4 = 1372140 \\ 2149160a_0 + 714745164a_1 + 2?8588E - 11a_2 + 2149165a_3 + 674059?4a_4 = 194931 \\ 1.156a_0 + 2042.172a_1 + 78265.4a_2 + 674059.4a_3 + 0.592536a_4 = 1.02634. \end{cases} \quad (2)$$

Solution of a system of equations:

$$a_0 = 6.26092;\ a_1 = -0.00023; a_2 = -7.8E - 06;\ a_3 = 9.47E - 06; a_4 = -19.4256. \quad (3)$$

If put these values into a mathematical model:

$$y = 6.26092 - 0.00023x_1 - (7.8E-06)x_2 + (9.47E-06)x_3 - 19.4256x_4. \quad (4)$$

There is a specific mathematical model to analyze the above socio-environmental factors. Now, using the specified numerical values x_1, x_2, x_3, x_4:

$$\hat{Y}_i = 6.26092 - 0.00023x_1^i - 7.8E-06x_2^i + 9.47E-06x_3^i - 19.4256x_4^i \ (i = \overline{1,6}), \quad (5)$$

calculate adequacy:

$$\hat{Y}_1 = -1.99436;\ \hat{Y}_2 = 4.95545;\ \hat{Y}_3 = 7.199705;\ \hat{Y}_4 = 4.889254;\ \hat{Y}_5 = -0.81948;\ \hat{Y}_6 = 2.98204. \quad (6)$$

Calculate the numerical values of the RMS constraints:

$$\sigma_y = \sqrt{\frac{0.2798}{6}} = 0.2159;\ \sigma_{x_1} = \sqrt{\frac{55855130}{6}} = 3051.09;\ \sigma_{x_2} = \sqrt{\frac{8.93592E+11}{6}} = 385.91;\ \sigma_{x_3} = \sqrt{\frac{214658}{6}} = 189.14;\ \sigma_{x_4} = \sqrt{\frac{0.3327186}{6}} = 0.2354. \quad (7)$$

Numerical values of correlation coefficients:

$$r_{xy} = \frac{n\sum_{i=1}^{n} x_i \cdot y_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right] \cdot \left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right]}}, \quad (8)$$

$$r_{yx_1} = -0.82553;\ r_{yx_2} = 0.82553;\ r_{yx_3} = 0.66053;\ r_{yx_4} = 0.16905;\ r_{x_1x_2} = 1;\ r_{x_1x_3} = -1;\ r_{x_1x_4} = -0.71456;\ r_{x_2x_3} = -1;\ r_{x_2x_4} = -0.71456;\ r_{x_3x_4} = 0.71456 \quad (9)$$

Evaluate the correlation between Y and x_1, x_2, x_3, x_4 using the multiple correlation coefficient:

$$R = R_{x_1x_2y} = \sqrt{\frac{r_{x_1y}^2 + r_{x_2y}^2 - 2 \cdot r_{x_1y} \cdot r_{x_2y} \cdot r_{x_1x_2}}{1 - r_{x_1x_2}^2}}. \quad (10)$$

The correlation analysis reveals the following insights (Table 2).

Table 2. The correlation analysis results

Correlation Coefficient	Value
r_{yx1}	-0.82553
r_{yx2}	0.82553
r_{yx3}	0.66053
r_{yx4}	0.16905
r_{x1x2}	1
r_{x1x3}	-1
r_{x1x4}	-0.71456
r_{x2x3}	-1
r_{x2x4}	-0.71456
r_{x3x4}	0.71456

Now, calculate the elasticity coefficients, which demonstrate by how much % Y (the outcome) will change when the values of variables x_1, x_2, x_3, x_4 change by 1%:

$$E_{x_1} = a_1 \cdot \frac{\bar{x}_1}{\bar{y}} = -0.00023 \cdot \frac{9422,6}{0.7916} = -0.00023 * 11903.2 = \text{-}2.73774; \quad (11)$$

$$E_{x_2} = a_2 \cdot \frac{\bar{x}_2}{\bar{y}} = (-7.8E-06) \cdot \frac{374220}{0.7916} = (-7.8E-06) * 472738 = -3.69E+00; \quad (12)$$

$$E_{x_1} = a_3 \cdot \frac{\bar{x}_3}{\bar{y}} = (9.47E-06) \cdot \frac{358193,3}{0.7916} = (9.47E-06) * 452492.8 = 4.20E+00; \quad (13)$$

$$E_{x_1} = a_4 \cdot \frac{\bar{x}_4}{\bar{y}} = -19.4256 \cdot \frac{0.1926}{0.7916} = -19.4256 * 0.2433 = \text{-}4.7263. \quad (14)$$

To test the adequacy and reliability of the model, several statistical measures were used (Table3).

Table 3. Model adequacy and statistical testing

Statistic	Value
σ_y	0.2159
σ_{x1}	3051.09
σ_{x2}	385.91
σ_{x3}	189.14
σ_{x4}	0.2354
Elasticity Coefficients	
E_{x1}	-2.73774
E_{x2}	-3.69
E_{x3}	4.20
E_{x4}	-4.7263

To test the adequacy of the mathematical model use Fisher's F-criterion and Student's t-criterion of distribution. There are multiple correlation coefficient R=0.7084; number of observations n=6; number of indicators k=5. The value of Fisher's f-criterion:

$$F = \frac{R^2 \cdot (n-k)}{(1-R^2) \cdot (n-1)} = \frac{(0.7084)^2 \cdot (6-5)}{[1-(0.7084)^2] \cdot (6-5)} = \frac{0.5019 \cdot 1}{0.4981 \cdot 1} = \frac{0.5019}{0.4981} = 1.0076. \quad (15)$$

Student's t-value criterion:

$$t = \frac{R \cdot \sqrt{n-k-1}}{1-R^2} = \frac{0.7084 \cdot \sqrt{6-4-1}}{1-(0.7084)^2} = \frac{0.7084 \cdot 1}{0.4981} = 1.4222. \quad (16)$$

When determining autocorrelation in dynamic strings, the Durbin-Watson criterion is used:

$$DW = \frac{\sum(y-\bar{y})^2}{\sum y^2} = \frac{0,2798}{4,04} = 0.0693. \quad (17)$$

The error of the correlation coefficient $S_{xy} = \frac{1-r_{xy}^2}{\sqrt{n-1}}$ is determined by the formula. Then:

$$S_{x_1 y} = \frac{1-r_{x_1 y}^2}{\sqrt{n-1}} = \frac{1-0.6815}{\sqrt{6-1}} = \frac{0.13185}{2.2361} = 0.1424;\ S_{x_2 y} = \frac{1-r_{x_2 y}^2}{\sqrt{n-1}} = \frac{1-0.6815}{\sqrt{6-1}} = \frac{0.3185}{2.2361} = 0.1424. \quad (18)$$

$$S_{x_2 y} = \frac{1-r_{x_2 y}^2}{\sqrt{n-1}} = \frac{1-0.4362}{\sqrt{6-1}} = \frac{0.5638}{2.2361} = 0.2521.\ S_{x_2 y} = \frac{1-r_{x_2 y}^2}{\sqrt{n-1}} = \frac{1-0.0286}{\sqrt{6-1}} = \frac{0.9714}{2.2361} = 0.4344. \quad (19)$$

The analysis of numerical values of the constructed mathematical models demonstrates the following results:

1. There is an inverse correlation between the quality of life of the population (Y) and population reproduction (x_1).
2. There is an appropriate close correlation between the quality of people's lives (Y) and suitable land (x_2) to accommodate the population.
3. There is a proper close correlation between people's quality of life (Y) and land suitable for agriculture (x_3).
4. Reducing the correlation between people's quality of life (Y) and the land (x_4) owned by each person for food production.

Summarizing, there are 10 main environmental results for 2018-2022 in the Republic of Karakalpakstan:

1. Strengthening afforestation efforts for the purpose of mitigating the Aral Sea disaster. It included tree planting and revegetation of dryland areas, which helped to improve the climate and prevent wind erosion.
2. Implementation of engineering measures to restore ecosystems of aquatic and wetland zones in the Amudarya River delta. Ecosystem restoration has contributed to the revival of natural biodiversity and the conservation of unique water resources.
3. Colossal efforts to draw the attention of the international community to the Aral Sea catastrophe. International support has helped raise awareness and led to funding for projects to restore ecosystems and improve water supplies.
4. Reforms in the sphere of household waste management. The introduction of modern methods of waste utilization has reduced environmental pollution and alleviated the litter problem.
5. Investments in the expansion of water supply and sewerage infrastructure, and the introduction of water metering systems through the installation of meters. It helped to improve the quality of drinking water and utilize resources more efficiently.
6. Introduction of mechanisms to incentivize the application of water-saving technologies by farmers. Financial incentives for the introduction of efficient irrigation and water supply methods contributed to the reduction of water consumption in agriculture.
7. Achievement of energy consumption reduction targets at specific enterprises and implementation of measures to improve energy efficiency in residential and public buildings. It has resulted in lower greenhouse gas emissions and reduced climate impact.
8. Investments in electrification of railway infrastructure and renewal of the rolling stock fleet. It contributed to the transition to a more environmentally friendly mode of transport and reduced pollutant emissions.
9. Well-developed environmental education. Training of the population and education of schoolchildren on environmental issues contributed to the development of environmental awareness and a responsible attitude to nature.
10. Compliance with the purposes of sustainable development by setting national priorities and objectives. State support for sustainable development has established favorable conditions for the implementation of environmental programs and projects.

In addition, it is crucial to identify 10 environmental priorities for the next 7-12 years:

1. Guaranteeing wide accessibility of environmental data and information to the public and ensuring active public participation in environmental protection and urban planning. It will help to raise citizens' awareness and involve their active participation in environmental and urban planning decisions.
2. Joining global and regional international programs and agreements to which the country is not yet a party. Joining such agreements will help to obtain additional resources and support to address environmental issues.
3. Improve environmental assessment mechanisms by reforming environmental impact assessment (EIA/SEER) procedures and introducing strategic environmental assessment (SEA). It will help to ensure a more comprehensive and qualitative consideration of the possible environmental impacts of projects.
4. Automation of environmental monitoring and implementation of PM10 and PM2.5 monitoring. It will allow more accurate and efficient control of air pollution levels and timely measures to prevent its deterioration.
5. Expansion of specially protected natural areas (SPNAs) and ensuring ecological connectivity and representativeness of the SPNA network. Protection of unique ecosystems and diversity of fauna and flora will become an urgent priority.
6. Taking additional measures to reduce water losses in agriculture and using more efficient irrigation and water management techniques. It will help to reduce the adverse impact on water resources and improve the efficiency of agricultural production.

7. Introduction of new technologies and methods in the water sector for more efficient use of water resources and prevention of pollution of reservoirs.
8. Development of waste treatment and recycling infrastructure for the purpose of reducing the amount of waste that reaches landfills and pollutes the environment.
9. Promoting the development and implementation of environmentally friendly and energy-efficient technologies in various sectors of industry and production.
10. Establish incentives for businesses and communities to adopt sustainable development practices, such as tax incentives and subsidies for clean technologies, energy efficiency measures and sustainable agricultural practices.

Thus, the method of the study is presented in Figure 3.

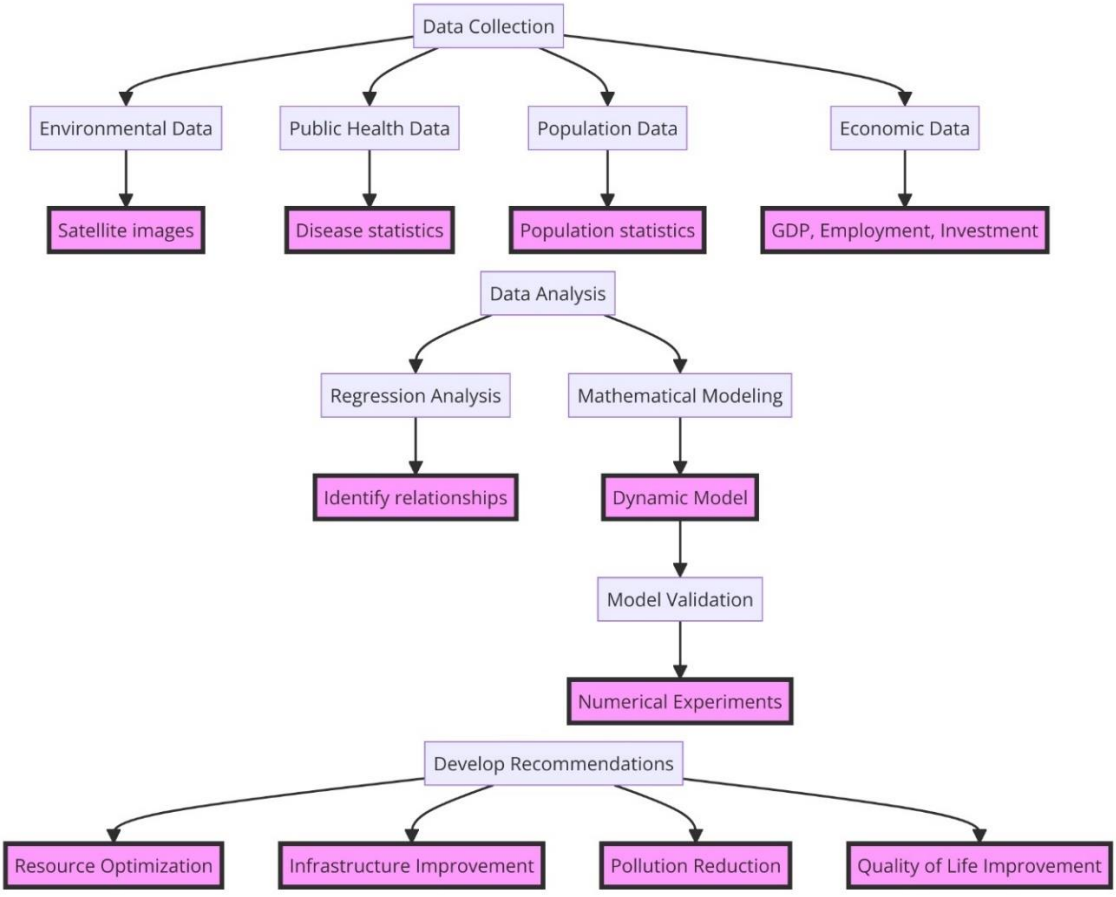

FIGURE 3. A design for the developed method

Socio-environmental work confirms the serious attention and intensified efforts to solve the region's environmental problems. Notably, the improvement of the environmental situation is inextricably linked to sustainable socio-economic development, and the results achieved demonstrate the endeavor to achieve this harmony. The implementation of these priorities will allow the Republic of Karakalpakstan to continue to move forward on the path of sustainable and environmentally responsible development.

V. DISCUSSION

The algorithm for the development of scientific frameworks for stabilization of the socio-ecological situation of the Republic of Karakalpakstan is a complex task and requires a specific attitude. Therefore, it is crucial to analyze the studies of other scientists on this subject and compare the obtained data.

M. Haraldsson et al. indicate that climate change and environmental degradation pose serious challenges to economic growth and employment today, and the risks will increase in the medium and long term [9]. In contrast, climate action and the transition to a green economy can lead to more and better-quality jobs. Both climate change adaptation and measures to reduce greenhouse gas emissions offer opportunities to provide new jobs while preserving existing ones. However, this needs to be carefully managed through policies and transition processes to avoid economic change leading to increased social inequalities, worker frustration, strikes or civil unrest and lower productivity, and reduced competitiveness of businesses and markets in affected sectors. Similar ideas are relevant to the research above.

Equitable transition means greening the economy in a way that is as fair and inclusive as possible for all stakeholders, enabling decent work and leaving no one behind [10]. A fair transition involves maximizing the social and economic opportunities of climate change action while minimizing and carefully addressing any challenges, including through effective social dialogue among all affected groups and respect for fundamental labor principles and rights. The International Labor Organization Guidelines for a Just Transition to Environmentally Sustainable Economies and Societies for All, adopted in 2022 by tripartite consensus, provide detailed recommendations in this regard [11]. In addition, these ideas are relevant to the Republic of Karakalpakstan.

In turn, S. Haghbin and N. Mahjouri note that global greenhouse gas concentrations reached new highs in 2020, with real-time data indicating continued increases [12]. As these concentrations rise, the Earth's temperature rises. In 2022, the average global temperature was about 1.1°C above pre-industrial levels (from 1870 to 1918). The years from 2017 to 2022 were the five warmest years on record. To limit warming to 1.5°C above pre-industrial levels, as specified in the Paris Agreement [13], global greenhouse gas emissions must peak before 2025. They should then be reduced by 43% by 2030 and reduced to zero by 2050. Countries are formulating climate action plans to reduce emissions and adapt to climate impacts through nationally determined contributions. However, current national commitments are insufficient to meet the 1.5°C target. The Republic of Karakalpakstan, as part of Uzbekistan, is a member of the Paris Agreement [13] and the implementation of the identified program is an essential point in stabilizing the socio-environmental situation.

F. Neira et al. state that the implementation of a social-project plan for environmental change requires both justification and credibility in representing the future state and the ability to serve as a foundation for the development of new integrated regulations [14]. These regulations should provide sustainable rules for social behavior and activities. Implementing and adhering to these regulations is an integral part of the successful implementation of a project, which is a process of purposeful transformation of a specific environment [15]. In this context, socio-environmental regulations become essential. They enshrine new socially acceptable standards of human behavior and activities and are key elements in the design of management within a particular natural social system.

Studies by Q. Liu et al. [16] and J.J. Monge et al. [17], demonstrate that society must establish harmonious connections with nature to sustain life processes both within and between generations. If this task fails, society may face destruction. In this context, the regulatory models introduced above can be considered as the foundation for sustainable social patterns. When the interaction between society and nature begins to disrupt (e.g., through overexploitation of natural resources or failure in their effective management), society responds by implementing appropriate patterns of regulation [18-20]. Such second-order regulation is implemented in any society, however, is limited by what is called "regulatory methods". These methods reflect the power dynamics, cultural standards, and conflicts of interest in society and thus shape "social relations" [21]. The same correlations have been effectively demonstrated in one of the possible options for the future development of the socio-ecological system of the Republic of Karakalpakstan.

A. Deslatte et al., conducting similar studies in Poland, note that SES have a hierarchical structure, which finds its foundation in the hierarchy theory [22]. This theory provides a tool for analyzing the components of SES and the links between different levels of their organization. In hierarchical systems, higher levels establish the context or environment in which lower levels function. Notably, SESs have dynamism. While some scientific and planning tasks require a view of equilibrium at specific scales (e.g. in modelling), it is essential to acknowledge that SES dynamics can involve multiple pathways, discontinuities and unexpected changes (known as 'unexpected events' according to [23-25]. In addition, it is essential to consider the ever-changing environmental conditions. Decision makers must consider SES constraints such as productivity

and biomass accumulation. In addition, it is significant that the predictability of SES behavior has its limits. The complex dynamics, hierarchical structure and the presence of multiple optimal operating points in the SES that are far away from equilibrium raise questions about the predictability of ecosystem behavior [26]. The level of predictability varies across spatial and temporal scales. Some events may be predictable while others are not. Sometimes even small fluctuations in system components can lead to significant changes in the functioning of the entire system [27]. All these critical aspects of SES preparation have been considered in the above research.

Studies by R. Nel et al. [28] and L.M. Rouse et al. [29] provide insights that the chosen method of implementing social compensation strategies (including financial support, engagement with local businesses and investment in ecosystem projects) significantly affects the system's response to various external factors (including the presence of negative press coverage). It is demonstrated that the extent to which a wind farm developer engages with the local community, expressed through social compensation, significantly affects the probability of a positive response from various actors in the social system [30-32].

Previous studies performed by L. Berrio-Giraldo et al. [33] and K.J. Dillman et al. [34] indicate that the impact of rewards on project acceptance probably depends on several factors, such as the type of reward, its size, perceived risks in the design, previous experience with similar projects, and whether the compensation is collective for the community or individual. For example, monetary rewards are often associated with the so-called "bribe effect", where stakeholders feel they have been "bought" to solve a problem and research demonstrates its lack of effectiveness in increasing project acceptability [35-37]. Rather, investments in local projects that promote public welfare, and efforts to preserve or restore the environment, appear to be more valuable and have a more positive impact on the local community [38-41]. In addition, it is essential to consider these data when designing the algorithm for developing scientific frameworks for stabilizing the socio-environmental situation in the Republic of Karakalpakstan.

Practical use of the results on the development of scientific bases for stabilization of the socio-ecological situation in the Republic of Karakalpakstan has significant potential for improvement of life of residents and preservation of the unique ecology of the region:

1. Water resources management and ecological rehabilitation of the Aral Sea. Based on scientific studies and models, a comprehensive strategy was developed to restore the water level in the Aral Sea [42]. Measures were implemented to redistribute water resources in the region, artificial canals were established to supply water to the sea, which improved the environmental situation, restored fishing and established new opportunities for tourism development along the coast.
2. Socio-economic development and employment opportunities. The scientific frameworks for stabilization have helped to identify priority sectors for development in the region. As a result, investments have been attracted to establish new businesses in clean technology, agriculture and tourism [43]. It helped to reduce unemployment and improve the living standards of residents.
3. Environmental education and awareness. In addition, the developed scientific frameworks have been used to establish educational programs designed to raise environmental awareness and understanding of the significance of preserving the environment. Schools, universities and public organizations conduct lectures, seminars and workshops, enabling the younger generation to actively participate in the process of stabilizing the socio-environmental situation.
4. Tourism and preservation of natural riches. The successful stabilization of the environmental situation in the region has attracted the attention of tourists interested in the unique nature and culture of the Republic of Karakalpakstan. It has led to the development of ecotourism, the establishment of nature reserves and parks, and the maintenance of traditional crafts and cultural activities, which contributes to the preservation of the region's national identity [44].
5. Co-operation and international partnership. Successful practices in stabilizing the socio-environmental situation in the Republic of Karakalpakstan have attracted the interest of international organizations, scientific institutions and states. It contributes to strengthening international cooperation and exchange of experience and resources and supports sustainable development in the region and on a wider scale [45, 46].

Thus, the successful implementation of the scientific frameworks for stabilizing the socio-ecological situation in the Republic of Karakalpakstan has significantly improved the quality of life of residents,

contributed to the ecological recovery of the region, the development of the economy and tourism, and strengthened international cooperation.

VI. RESEARCH LIMITATIONS AND FUTURE WORK

Although this study provides a comprehensive scientific framework for stabilizing the socio-environmental situation in Karakalpakstan, there are certain limitations that need to be recognized. Despite the use of multiple authoritative data sources, some gaps and inconsistencies were found in the available data, especially for variables that are difficult to measure accurately, such as the level of pollution exposure. More robust environmental monitoring and data collection mechanisms are needed.

Certain assumptions are made in the mathematical models, such as the stationarity of some parameters and the relationship between state and variables. Because the region is changing rapidly, these assumptions may need to be reviewed and models updated accordingly. The models provide regional-level insights, but there may be significant local variation within Karakalpakstan that is not fully accounted for. Data with higher spatial resolution could improve fine-grained analysis.

Future research could address these limitations and further enhance decision-support capabilities:

1. Establishing comprehensive environmental monitoring networks to provide high-quality continuous data streams for all relevant variables. Collaborate with international agencies to share data and standards.
2. Development of adaptive modelling techniques to periodically update model parameters and refine assumptions based on the arrival of new data.
3. Integrating agent-based modelling to better capture local heterogeneities and identify potential pockets of deprivation.
4. Expanding socio-economic analysis to include factors such as governance, policy implementation, public participation, etc.
5. Developing interactive decision support systems to rapidly evaluate different policy scenarios based on integrated models.
6. Facilitate interdisciplinary collaboration among environmental scientists, sociologists, economists, public health specialists and policy-makers to ensure a synergistic approach.
7. Transfer knowledge by developing training programs to build local capacity in socio-environmental analysis, modelling, and sustainable policy development.

By continuously improving data, models and decision support tools, adopting a participatory approach, this research system can gradually improve its effectiveness in guiding the long-term stabilization and sustainable development of Karakalpakstan.

VII. CONCLUSION

This research encompasses a dynamic socio-ecological model that establishes relationships between several key variables: population, investment, geographical topography, natural resources, pollution levels and food production. These key factors and their interactions determine the dynamics of change within the social system. An increasing population stimulates increased production, increased demand for food commodities and an optimal allocation of labor and other resources between different regions.

The above factors will allow interpreting the results obtained in the form of graphs and tables and visualize the examined object based on information technology. Conceptual schemes including macro factors affecting the quality of life of the population of the Republic of Karakalpakstan have been developed. It allows for research of social, economic and ecological factors and scientific substantiation of stabilization of the development of the Republic Karakalpakstan. The developed scientific methodologies allow: the field of applied mathematics to solve problems of stability theory for large dynamic systems such as social, economic, and ecological; to develop user languages and databases; management systems to use computer modelling as a powerful tool for solving crises of large dynamic systems. In addition, significant achievements in the environmental sphere have been identified that contribute to improving the environment and supporting sustainable development of the region. Introduction of incentive mechanisms to encourage farmers to use water-saving technologies had a significant impact on the rational use of water resources in agriculture, helping to reduce the adverse impact on hydro-ecosystems. Implementation of

targets to reduce energy consumption at enterprises and introduction of energy efficiency measures in residential and public buildings have significantly reduced greenhouse gas emissions, contributing to climate protection and reducing the environmental burden. The priority pursuit of the Sustainable Development Objectives, reflected in the adoption of national strategies and targets, has had an important impact on the development of favorable conditions for the successful implementation of large-scale environmental programs and projects.

Nevertheless, it was essential to set priorities for the near future. Active entry into global and regional international programs and agreements that the country has not yet participated in are particularly significant. It will provide additional resources and support to address pressing environmental issues and introduce automated environmental monitoring systems considering PM10 and PM2.5. This approach will ensure more accurate and efficient control of air pollution levels, allowing timely response to air quality deterioration; and establishment of incentives for businesses and population to implement sustainable development practices. It includes tax incentives and subsidies for environmentally friendly technologies, energy efficiency measures and sustainable agricultural practices.

Prospects for further research include the development of adaptive management strategies, integrated assessment of environmental and social factors, introduction of innovative technologies and expansion of environmental education to ensure more effective stabilization of the socio-environmental situation in the Republic of Karakalpakstan.

Funding Statement

This research did not receive funding from any source.

Author Contributions

Alisher Abdullaev is a sole author of the article responsible for conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing - original draft, writing - review & editing, visualization, supervision, project administration.

Conflict of Interests

The author declares no conflict of interest.

REFERENCES

1. Baltashov, S. (2021). Issued and prospects of providing agricultural productions to the population of the Republic of Karakalpakstan. *Bulletin of Science and Practice, 7*(9), 87-95.
2. Sigdel, R., Anand, M., Bauch, C. T. 2019. Convergence of socio-ecological dynamics in disparate ecological systems under strong coupling to human social systems. Theoretical Ecology, 12, 285-296.
3. Makhmudova, U., Khasanov, S., Karimov, A., Abdurakhmonov, S. 2023. Evaluation of perennial reference evapotranspiration (ETo) over a typical dryland using satellite images: A case study from Uzbekistan. *Ecohydrology and Hydrobiology, 23*(3), 484-497.
4. Komilova, N. K. 2021. Territorial analysis of medical geographical conditions of Uzbekistan. *Current Research in Behavioral Sciences, 2*, 100022.
5. Lioubimtseva, E. 2023. The Aral Sea disaster: Revisiting the past to plan a better future. In: *Biological and Environmental Hazards, Risks, and Disasters* (pp. 435-447). Amsterdam: Elsevier.
6. Chobal, I., Chobal, O., Myslo, Yu., Petryshynets, I., Rizak, V. (2023). Elastic-plastic properties of Li2B4O7 determined by nanoindentation. *Scientific Herald of Uzhhorod University. Series "Physics", 53*, 53-63.
7. Jalolova, M., Amirov, L., Askarova, M., Zakhidov, G. 2022. Territorial features of railway transport control mechanisms. *Transportation Research Procedia, 63*, 2645-2652.
8. Permanent population by national and/or ethnic group, urban/rural place of residence. (2023). Retrieved from https://data.egov.uz/eng/data/6117a05996188a0f14ac917b?page=1
9. Haraldsson, M., Raoux, A., Riera, F., Hay, J., Dambacher, J. M., Niquil, N. 2020. How to model social-ecological systems? – A case study on the effects of a future offshore wind farm on the local society and ecosystem, and whether social compensation matters. *Marine Policy, 119*, 104031.
10. Groza, A., & Siddelev, N. (2022). Nonlinear surface polaritons near the interface between a magneto-optical substance and a nonlinear metamaterial with a permittivity close to zero. *Scientific Herald of Uzhhorod University. Series "Physics", 51*, 24-29.
11. Hong, W., Liao, C., Guo, R., An, Q., Li, X., & Ma, T. (2023). Predicting the minimum scale of urban ecological space based on socio-ecological systems analysis. *Science of the Total Environment, 863*, 160912.
12. Haghbin, S., & Mahjouri, N. (2023). Quantifying and improving flood resilience of urban drainage systems based on socio-ecological criteria. *Journal of Environmental Management*, 339, 117799.

13. Paris Agreement. (2015). https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf
14. Neira, F., Ribadeneira, S., Erazo-Mera, E., & Younes, N. (2022). Adaptive co-management of biodiversity in rural socio-ecological systems of Ecuador and Latin America. *Heliyon, 8*(12), e11883.
15. Tyukhtenko, N.A., & Makarenko, S.M. (2016). Economic and mathematic models for staff planning at enterprises of all ownership forms. *Actual Problems of Economics, 175*(1), 435-442.
16. Liu, Q., Yang, J., Gao, L., Dong, Y., Guo, Z., Moallemi, E. A., Eker, S., & Obersteiner, M. (2023). Robust sensitivity analysis to uncertainties in environmental and socio-economic scenarios: A perspective from a global socio-ecological system model. *Journal of Cleaner Production, 410*, 137244.
17. Monge, J. J., McDonald, N., & McDonald, G. W. (2022). A review of graphical methods to map the natural hazard-to-wellbeing risk chain in a socio-ecological system. *Science of the Total Environment, 803*, 149947.
18. Babenko, V., Chukurna, O., Niekrasova, L., Stanislavyk, O., Tyukhtenko, N., Lytvynenko, O., & Davydko, S. (2023). Methodology for Assessing the Risk of Implementing the Strategy of Diversification of Enterprises in the Aspects of Information Technology Management. *Journal of Information Technology Management, 15*(1), 192-207.
19. Andryeyeva, N., Nikishyna, O., Burkynskyi, B., Khumarova, N., Laiko, O., & Tiutiunnyk, H. (2021). Methodology of analysis of the influence of the economic policy of the state on the environment. *Insights Into Regional Development, 3*(2), 198–212.
20. Abudaqa, A., AlMujaini, H., & Faiz bin Hilmi, M. (2019). HRM practices as determinates of the employee intention to stay: the moderating effect of transformational leadership: a case of higher education institutes in uae. *Humanities & Social Sciences Reviews, 7*(5), 1087-1096.
21. Tomashevski, K., & Yaroshenko, O. (2020). Problems of Labour Legislation Codification in Belarus and Ukraine: History, Current Situation and Prospects. *Journal Transition Studies Review, 27*(2), 41-49.
22. Deslatte, A., Szmigiel-Rawska, K., Tavares, A. F., Ślawska, J., Karsznia, I., & Łukomska, J. (2022). Land use institutions and social-ecological systems: A spatial analysis of local landscape changes in Poland. *Land Use Policy, 114*, 105937.
23. James, C., & Bradshaw, K. (2023). Agent-based model development of a complex socio-ecological system: Methods for overcoming data and domain limitations. *Ecological Informatics, 77*, 102224.
24. Babak, V., Kharchenko, V., & Vasylyev, V. (2007). Using generalized stochastic method to evaluate probability of conflict in controlled air traffic. *Aviation, 11*(2), 31–36.
25. Babak, V.P. Babak, S.V., Eremenko, V.S., Kuts, Y.V., Myslovych, M.V.,Scherbak, L.M., Zaporozhets, A.O. (2021). Models of Measuring Signals and Fields. *Studies in Systems, Decision and Control, 360*, 3-59.
26. Fadhillah, A., Glorino Rumambo Pandin, M., & Koesbardiati, T. (2023). Analyzing Forest and Land Fire Disaster Prevention Programs in Riau, Indonesia. *Qubahan Academic Journal, 3*(4), 198-205.
27. Shynkariuk, I.M. (2022). Alternative representation of space and time: Geometric solution of problems of relativity theory. *Scientific Herald of Uzhhorod University. Series "Physics", 51*, 74-82.
28. Nel, R., Mearns, K. F., Jordaan, M., & Goethals, P. (2021). Towards understanding the role of islandness in shaping socio-ecological systems on SIDS: The socio-ecological islandscape concept. *Ecological Informatics, 62*, 101264.
29. Rouse, L. M., Doumani Dupuy, P. N., & Baker Brite, E. (2022). The Agro-pastoralism debate in Central Eurasia: Arguments in favor of a nuanced perspective on socio-economy in archaeological context. *Journal of Anthropological Archaeology, 67*, 101438.
30. Fedoniuk, T., Fedoniuk, R., Klymenko, T., Polishchuk, O., & Pitsil, A. (2021). Bioindication of Aerotechnogenic Pollution of Agricultural Landscapes Caused by the Activities of Industrial Hubs. *Ekológia (Bratislava), 40*(2), 115–123.
31. Fedoniuk, T., & Skydan, V. (2023). Incorporating geographic information technologies into a framework for biological diversity conservation and preventing biological threats to landscapes. *Kosmična Nauka Ì Tehnologìâ, 29*(2), 10–21.
32. Salih Ageed, Z., R. M. Zeebaree, S., Mohammed Sadeeq, M., Fattah Kak, S., Najat Rashid, Z., Abid Salih, A., & M. Abdullah, W. (2021). A Survey of Data Mining Implementation in Smart City Applications. *Qubahan Academic Journal, 1*(2), 91-99.
33. Berrio-Giraldo, L., Villegas-Palacio, C., & Arango-Aramburo, S. (2021). Understating complex interactions in socio-ecological systems using system dynamics: A case in the tropical Andes. *Journal of Environmental Management, 291*, 112675.
34. Dillman, K. J., Heinonen, J., & Davíðsdóttir, B. (2023). A development of intergenerational sustainability indicators and thresholds for mobility system provisioning: A socio-ecological framework in the context of strong sustainability. *Environmental and Sustainability Indicators, 18*, 100240.
35. Kornilova, A. A., Mamedov, S. E. O., Karabayev, G. A., Khorovetskaya, Y. M., & Shlyakhtich, Y. V. (2023). Organization of an Architectural Environment Based on Spatial and Constructive Modules in a Severely Continental Climate. *Civil Engineering and Architecture, 11*(2), 733–740.
36. Almaganbetovna, T. A., Daniyarovna, T. A., Ogly, M. S. E., Papin, H. E., Nikolayevna, K. Y., & Alua, A. (2023). Development of the Architecture of Residential Buildings from the Beginning of XX to XXI Century (By the Example of Astana). *Civil Engineering and Architecture, 11*(3), 1220-1233.
37. Rashid Ismael, H., Mohsin Abdulazeez, A., & A. Hasan, D. (2021). Comparative Study for Classification Algorithms Performance in Crop Yields Prediction Systems. *Qubahan Academic Journal, 1*(2), 119-124.
38. Rybchynskyi, O. (2023). Frontline town centres within the area of the Hirskyi Tikych river. *Architectural Studies, 9*(1), 36-46.
39. Kerimkhulle, S., Koishybayeva, M., Slanbekova, A., Alimova, Z., Baizakov, N., & Azieva, G. (2023a). Created and realization of a demographic population model for a small city. *Proceedings on Engineering Sciences, 5*(3), 383–390.
40. Kerimkhulle, S., Mukhanova, A., Kantureyeva, M., Koishybaeva, M., Azieva, G. (2023b). Applying a housing construction model to improve a small town demographic dynamics. *AIP Conference Proceedings*, *2700*, 040047.
41. Cherkes, B., & Idak, Y. (2022). The phenomenon of the city in the contemporary discourse of urban history. *Architectural Studies, 8*(2), 7-23.

42. Sargsyan, G., Gukasyan, P., Sargsyan, H., & Poveda, R. (2023). Diffusion flames and a semi-empirical method for estimating the distribution of hydrogen molecules in propane flames. S*cientific Herald of Uzhhorod University. Series "Physics"*, *53*, 42-52.
43. Yaroshenko, O. M., Vapnyarchuk, N. M., Burnyagina, Y., Kozachok-Trush, N. V., & Mohilevskyi, L. V. (2020). Professional Development of Employees as the Way to Innovative Country Integration. *Journal of Advanced Research in Law and Economics*, *11*(2), 683.
44. Prokopenko, O., Prokopenko, M., Chechel, A., Marhasova, V., Omelyanenko, V., Orozonova, A. (2023). Ecological and Economic Assessment of the Possibilities of Public-private Partnerships at the National and Local Levels to Reduce Greenhouse Gas Emissions. *Economic Affairs*, *68*(1), 133-142.
45. Chovnyuk, Y.V., Diachenko, L.A., Ivanov, Y.O., Dichek, N.P., Orel, O.V. (2022). Optimisation of dynamic loads of rope systems of lifting mechanisms of bridge cranes during cargo handling. *Scientific Herald of Uzhhorod University. Series "Physics"*, *51*, 59-73
46. Berestetska, O., Iankovets, T., Orozonova, A., Voitovych, S., Parmanasova, A., & Medvedieva, K. (2023). Using Crm Systems for the Development and Implementation of Communication Strategies for Digital Brand Management and Internet Marketing: eu Experience. *International Journal of Professional Business Review*, *8*(4), e01613.