REVIEW PAPER: CLIMATE SMART SUSTAINABLE AGRICULTURE IN THE ARAL SEA REGION

Pishenbay Umirbekov, PhD
at the International Westminster
University in Tashkent, Tashkent, Uzbekistan
https://doi.org/10.5281/zenodo.17060880

Keywords: Sustainable agricultural practices, Regional Adaptation Plans (RAP), crop production patterns, crop diversification and smart agriculture.

The agricultural of Karakalpakstan in the future depends on adopting strategic measures to tackle climate challenges, with crop diversification emerging as a pivotal approach for increasing farm income, strengthening farmer resilience, and promoting greater autonomy in agricultural decision-making. Given the mounting pressures of climate change, escalating water scarcity, and progressive soil degradation, traditional, single-crop farming systems have become unsustainable, placing farmers at heightened economic and environmental risk. By incorporating crop diversification as a key component of sustainable agricultural practices (SAP) and climate-smart agriculture (CSA), farmers can reduce their dependence on a narrow selection of climate-sensitive crops, thereby mitigating risks associated with climate variability. This shift towards diversified cropping systems not only stabilizes incomes but also allows farmers to adapt more flexibly to market demands, enhancing their capacity to thrive in a changing agricultural landscape. Diversification gives farmers the power to decide what to grow based on market trends, environmental conditions, and their own goals, rather than being confined to a few staple crops that may no longer be viable under the region's shifting climate conditions. This autonomy enables farmers to pursue higher-value or less resource-intensive crops, opening new income opportunities and fostering greater resilience against market and climate fluctuations. Crop diversification further enhances ecosystem health by improving soil fertility and reducing pest and disease outbreaks, which are often exacerbated by monoculture practices.

However, scaling up SAP and CSA practices, particularly crop diversification, requires a coordinated and robust support framework. Despite the success of techniques such as zero-tillage, drip irrigation, and diversified crop rotations, the adoption of these practices remains limited by gaps in resources, knowledge, and capacity among local farmers. Bridging these gaps demands a collaborative effort among government bodies, international organizations, and the private sector to develop a supportive ecosystem for diversified, sustainable agriculture. This framework should include accessible training programs, financial incentives, and policy reforms that encourage flexible crop selection, market access, and water-saving practices. By supporting sustainable income generation and providing farmers with the tools to make autonomous, informed decisions, a diversified agricultural model in Karakalpakstan holds the potential to secure food security, economic stability, and resilience for rural communities. As the region adapts successfully to climate-smart agriculture and sustainable practices, Karakalpakstan can serve as a model for other areas grappling with similar climate and resource challenges. Its experience highlights the benefits of an integrated, climate-smart agricultural approach that advances both environmental stewardship and economic prosperity in an era of rapid climate change.

1. Introduction. The Republic of Karakalpakstan is located in the northwestern part of Uzbekistan, in the lower reaches of the Amu Darya River, on the southern shore of the Aral Sea. On the southwestern side, the territory of the republic connects with the Karakum Desert. And in the northwest of the region there is the Ustyurt plateau, on the northeast side there is the Kyzylkum desert. Karakalpakstan ranks first in terms of territory among the regions of Uzbekistan with an area of 166.6 thousand square km, which is 37% of the total area of Uzbekistan. It is bordered to the north by Aktobe and Kyzylorda provinces of Kazakhstan and Mangistau province of Kazakhstan to the north-west and with Balkan and Dashoguz provinces of Turkmenistan to the south, Khorezm and Bukhara provinces of Uzbekistan to the south-east, and Navoi province of Uzbekistan to the east. The administrative-territorial composition consists of 16 districts and 1 city. Districts: Amudarya, Beruniy, Bozatau, Nukus, Takhiatash, Kanlykul, Shumanay, Kungrad, Muynak, Kegeyli, Chimbay, Karauziak, Takhtakupyr, Turtkul, Khojeyli, Ellikkala, and the capital of Karakalpakstan the city of Nukus. The population of the region, according to the Statistics

Agency of the Republic of Uzbekistan, is 2 million people (about 5.5% of the country's population). A significant part of the population is rural - 51%. Nukus city, Turtkul, Amudarya and Beruni districts are most densely populated with 17%, 11%, 11% and 10% of the region's population, respectively. In 2023, the number of labor resources made of 1,076 thousand people (54% of the total population). In turn, the number of employed population accounts for 735.5 thousand people, 61.5 thousand of whom are employed in industry, 88.3 thousand - in construction, 173,400 in agriculture and 412,200 in services. The unemployment rate in 2023 in Karakalpakstan amounted to 7.1% (6.8% nationally).

The climate in Karakalpakstan is sharply continental with hot and dry summers and cold winters. The average temperature in January ranges from -5 to -8°C. The minimum temperature in winter is -38°C. The average temperature in June reaches from +26°C to +28°C, and in July and August - +50°C. The average rainfall is 100 mm per year. The region is experiencing severe water shortages due to the arid climate. A temperature increases of 0.29°C per decade since the 1960s has exacerbated the problem. Droughts, which have become more frequent and severe, are negatively affecting agriculture: crop yields are falling, plants are dying, pests are spreading, and water supplies for irrigation and livestock are dwindling, and livestock breeding also pasture degradation is also a consequence of droughts. Along with the negative consequences of decreasing water levels in the Aral Sea and environmental problems, the impacts of climate change now pose a serious threat to the population, biodiversity, and economic activities in Karakalpakstan, with water availability becoming an increasing problem for the region in recent years.

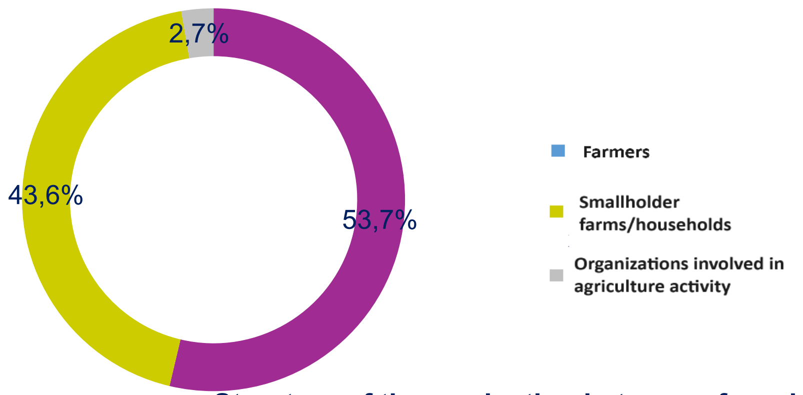
The tragedy of the Aral Sea desiccation has caused an acute shortage of water resources for irrigation and domestic needs, land degradation and desertification, decreased income opportunities, increased poverty, food shortages and deteriorating health of the population in the Aral Sea region. In addition to the increasing level of soil salinization due to the drainage of areas of the Aral Sea bed, which is the main source of salt and mineral sediments, crop cultivation is becoming more of a challenging task. Heat stress, less rainfall, soil salinization and land degradation process have had a negative impact on the agricultural production system in the region. This directly affects the welfare of households and agricultural workers in terms income sources and food security. The cultivation of traditional crops such as **wheat**, **cotton** and **rice** are decreasing in productivity and this type of farming is becoming unattractive. Yields per hectare for several crops are several times lower than the national average. However, there are limited opportunities for permanent income, as the transition to other types of economic activity is not a quick process to achieve in regional economy. At the same time, in Karakalpakstan, water quality is negatively affected by return flow from irrigation fields located in the upper reaches of Amu Darya River containing agricultural chemicals and other harmful substances. It should be noted that, according to expert estimates, by 2050, water resources in the Syr-Darya basin will decrease by 5%

and in the Amu Darya basin by 15% (**ADB, 2024**). If in 2015 the total water deficit in Uzbekistan was more than 3 billion cubic meters, by 2030 it may reach 7 billion cubic meters, and by 2050 - 15 billion cubic meters, at the same time water availability per capita may reduce by about half (**ISRS, 2021**). The frequency and duration of droughts are also expected to increase in the near future.

In addition, according to analyzes of the German Economic Group in partnership with the Center for Economic Research and Reform, the construction of the Kushtepa Canal in Afghanistan will increasingly put the pressure on existing water problems in the region particularly Uzbekistan, as Afghanistan also plans to increase water consumption for agricultural purposes over 500,000 hectares. Therefore, external and internal factors galvanized with progressing climate change in the region pushing to accelerate the transformation of the agriculture sector in the Aral Sea Region into climate resilient and adaptive pathways to secure food and livelihoods in the region.

2. Past and future trends in agriculture sector in Uzbekistan with a focus on Aral Sea Region. The arable land in Karakalpakstan comprises 283,000 hectares, representing 6.5% of Uzbekistan's total arable land. Agricultural output in the region is estimated at 15,349 billion sums, marking a threefold increase since 2017. The region contributes approximately 4% to the country's overall agricultural production annually, with livestock breeding as the dominant sector, accounting for 53.4% of the total agricultural output. According to the 2023 data from the Agency of Statistics, the principal districts in agricultural production were Amudarya (18.8%), Beruni (13.1%), Ellikkala (10.5%), and Turtkul (10.2%).

Figure 1. Author's calculations based on the Statistics Agency



Structure of the production in terms of producers in 2022

In 2023, the livestock population included 1.2 million cattle, of which 91% are owned by dehkan farms (semi-subsistent household farmers), with 356,000 being cows. The numbers of goats and sheep reached 1.2 million, with 83% managed by dehkan farms, and poultry numbers increased to 5.3 million, with dehkan households holding 75%. Large farms account for approximately 60% of crop production, whereas dehkan farms contribute nearly 92% to livestock production. Furthermore, organizations engaged in agricultural activities contribute around 15% of crop production and 2.3% of livestock production.

Since 2010, the proportion of traditional farms has decreased by roughly 11%, partially offset by the expanding role of agricultural organizations. Currently, 283,000 hectares of land are used for agricultural purposes, with large farms utilizing 70%, organizations engaged in agricultural activities occupying 18%, and dehkan farms accounting for 11.15%. As of 2022, land allocation for agricultural crops in Karakalpakstan included 103.5 thousand hectares for cereals (36.5%), 108.7 thousand hectares for cotton (38.4%), 37.1 thousand hectares for horticultural products (13.1%, including fruits, vegetables, melons, and watermelons), and 1.8 thousand hectares for viticulture (0.6%). However, data from 2017 to 2022 indicates a reduction in cotton's share of the overall agricultural output, being increasingly replaced by higher-value crops such as melons, grapes, sesame, and vegetables. Historically, cotton constituted over 70% of agricultural production in the region.

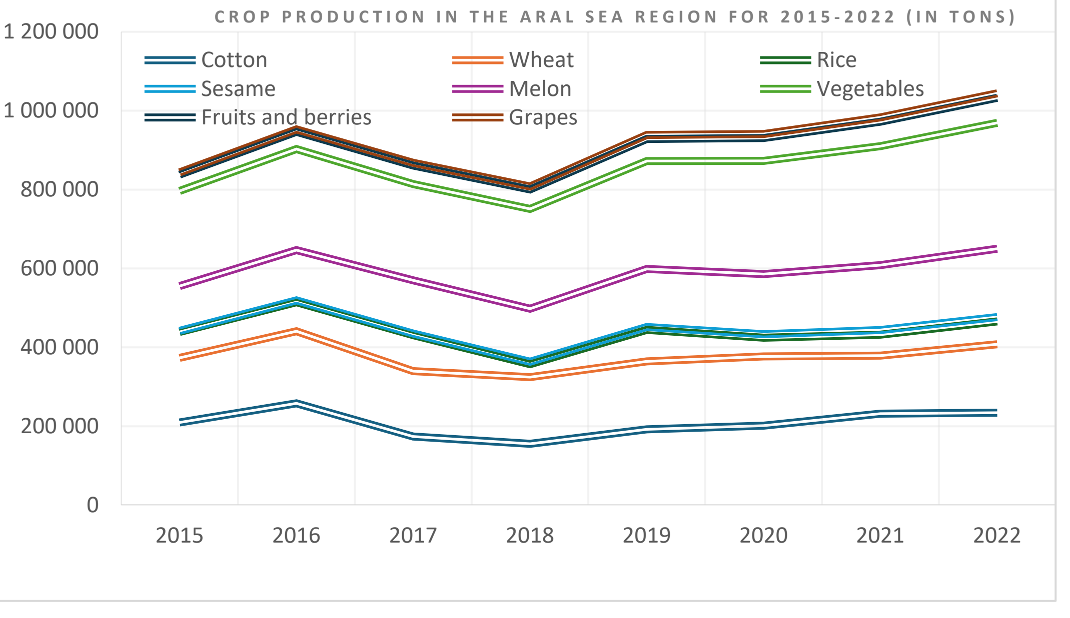


Figure-2. Author's calculations based on the Statistical Data (2022)

Agriculture is the main source of income and employment for many residents of the Republic of Karakalpakstan. The share of agricultural production in the domestic regional product is 30% and the share of employment is 23.6%. The vulnerability of the agricultural sector in Karakalpakstan to climate change has been significantly affected by the tragedy of Aral Sea located in the region.

The agricultural sector in the region is affected by a number of factors, such as soil salinization due to the large amount of salts and mineral deposits carried by the wind and the decreasing water level in the Amu Darya basin. In addition, intense heat in summer, heavy rains and abnormal cold in winter lead to crop failure. Thus, farmers are struggling to produce food and maintain a basic level of income.

In the period from 2013 to 2019, the amount of humus in the soil significantly decreased (Oteuliev J.B., Adilov S, 2022). That is, areas with humus content up to 1% (low yield) increased from 294 thousand ha to 337 thousand ha, areas with humus content of 1-2% (average yield) decreased from 148 thousand ha to 91 thousand ha, and areas with humus content of 2-3% (high yield) decreased from 2.2 thousand ha to 369 ha. To this end, Soil salinity has remained a critical problem in Karakalpakstan for some time. This problem has three aspects: Firstly, the reduction of the Aral Sea has led to the fact that local soil conditions are becoming more saline (**Saukhanov 2021**). Secondly, the drying up of the sea bed of the Aral Sea has led to the emergence of salt dust storms, when salt and dust settle on agricultural lands and soil salinity increases. Thirdly, salt- salt leaching processes have been carried out to remove some of the excess salt from the soil, but such processes are often carried out using saline water. The result is the degradation of the soil itself and the potential reduction in crop yields, land degradation, damage to biodiversity and negative consequences for human health. From the point of view of agriculture, Benley et al. (2016) believe that soil salinization led to a decrease in cotton yields by 33% and winter wheat yields by 25%. As the effects of climate change become more apparent, soil salinization is expected to increase due to a decrease in soil moisture and water availability.

At the same time, the yield of agricultural products for a number of crops per hectare in Karakalpakstan is lower than the national average. For example; the yield of grain crops per hectare in the region is estimated to be 29 centner/ha (national average is 54 c/ha), potatoes - 117.5 c/ha (347 c/ha national average). In addition, viticulture yields are estimated at 89 c/ha (129 c/ha national average). However, in 2023, fruit yields in the region **were** higher than the national average: 103.4 c/ha in the region, in contrast to 90.4 c/ha nationally (Bekbulatova G.A, 2022).

Vegetable yield per hectare of land area in the region is 101 c/ha, which is almost 5 times less than the national average of 486 c/ha. In addition, the level of yield of one crop varies in different districts. For example, grain yield per hectare in Amudarya district is 42.2 c/ha, and in Khojaili and Takhtakupyr districts - 16 c/ha.

Based on the analysis of annual supply and productivity for per hectare of land in all districts of Karakalpakstan, 9 most important agricultural crops were selected: rice, soybean, other cereals and legumes, sunflower, sesame, vegetables and fruits, grapes. According to the Agency of Statistics, among the districts, the highest agricultural production was observed in Amudarya district, providing almost 25% of the total regional production of these selected products, followed by Beruni, Turtkul and Kanlikul districts with 12%, 10% and 9%, respectively.

At that time, Bozatau, Muynak, Takhiatash, Takhtakupyr and Kegeyli districts were the lowest in agricultural productivity at 0.6%, 1%, 1.7%, 1.9% and 2.3%, respectively. Agricultural productivity is also lower in these districts compared to other districts. For example, grain yield in Bozatau district is 17.1 c/ha, 16.3 c/ha in Takhtakupyr district, 16.4 c/ha in Kegeyli district and 16 c/ha in Khojeyli district compared to the regional average of 29 c/ha or 42.2 centners in Amudarya district, which has the highest grain yield.

Currently in agriculture of Karakalpakstan the use of agro-technological measures in many respects do not provide rational need of natural resources, expanded reproduction of soil fertility, ecological balance in agro-biocenosis, which eventually leads to unsustainable farming in this extremely arid region.

For instance, in the region, the system of zero tillage for agricultural crops allows to reduce water consumption for irrigation, reduce material and labor costs, thereby allowing to gain profit by reducing the cost of agricultural products.

For example, due to a significant reduction of mechanized work in growing forage crops using zero tillage, diesel fuel costs are reduced by 71.4%, labor costs - by 33.4% compared to conventional treatment.

3. Sustainable agriculture practices and climate smart agriculture integration in Karakalpakstan. The climatic conditions in Karakalpakstan are arid particularly dry, with an uneven distribution of precipitation from 100 to 200 mm per year, coming mainly in the cold season. This means very little precipitation falls during the critical growing season from June to September, increasing very little precipitation falls during the critical growing season from June to September, increasing dependence on irrigation (Couetil 2020). Average daytime temperatures in July (Couetil 2020) exceed 30 °C, further increasing agriculture's water intensity which further increases the water intensity of agriculture. Meanwhile, the average daily temperature ranges from -5°C to +5°C from November to March, which makes this period certain types of crops can be grown (Couetil 2020).

"Sustainable agriculture" (David Lee 2005,) is a concept that has five major attributes: it is resource conserving (of land, water, plant, and genetic resources), environmentally non-degrading, technically appropriate, and economically and socially acceptable. And (J. Pretty 2008) also provide similar definition to the concept by stating that sustainable agriculture practices: i) do not have adverse effects on the environment, (ii) accessible to and effective to farmers, (iii) leads to both improvements in food productivity and have positive side effects on environmental goods and services. There are several research papers that describe the behavior of farmers who voluntarily adopt sustainable agricultural practices (SAP) and various indicators are designed to capture SAP among farmers and smallholder farms For instance, Setsoafia, Wanglin Ma and Alan Renwick, 2022 research showed that farmers' decisions to adopt

SAPs are influenced by the social demographics of the households (e.g., gender, education, marital status, and household size), plot-level characteristics (e.g., number of crops, soil types, and topography), extension services, and locations. Guang Han at el. 2023 identifies various types of SAP adopter by grouping them into: on-adopters, previous adopters, early adopters, conservative new adopters, and innovative new adopters. Authors claim that communication and benefits to the environment factors were positively associated with early adopters. Moreover, it is vital to identify and construct indicators which best describe the SAP in the farm level to capture behavioral attributes of the farmer and smallholders. In this regard Dan Rigby at el. 2001 proposed an approach from the patterns of the inputs used for agriculture production in horticulture dividing them into 5 subcategories: seed source, pest control, weed control, soil fertility maintenance, and crop management. Oscar Montes de Oca Munguia at el. 2021 suggest that SAP adoption model should include learning process, interaction between decision making and external influences and assessment of performance of new technology among farmers.

While Muhammad Bilal at el. 2022 claim that the awareness-raising process via radio might positively address adoption of crop protection product of multinational brands (CBM) which might result in a responsible farming practice among farmers and smallholders. Further, Muhammad Bilal at el. 2024 identifies main factors hindering adoption of agricultural innovations in Pakistan through the lenses of access to extension services, level of the education of the farmers, access to finance, union membership, market conditions and farm off income level. Further SAP was analyzed from crop diversification perspective in Uzbekistan, Bobojonov at el.2015, outlines opportunities for crop diversification by improving water use efficiency, securing farm income level and environmental benefits. In addition to it, authors claim that dominance of cotton production is a major constraint in promoting crop diversification practices in the Aral Sea Region of Uzbekistan.

Moreover, other researchers N. Djanibekov, A. Tadjiev 2021 argue that farmers' crop diversification options are related to their SAPs adoption decision, SAPs adoption is more likely to occur among risk-averse farmers pointing at the risk-reducing nature of SAPs such as crop rotation, biological pest control methods, and low tillage crop diversification. Given the challenges posed by climate change, these crops will be studied along with their value chains to explore future opportunities for expansion, job creation, income generation and alternative agricultural specialization.

Cotton and wheat have been dominant agricultural crop in Uzbekistan for many decades due to export earnings from cotton and importance of the latter to food security of Uzbekistan. However, the mechanisms for forming state procurement and the pricing system often made wheat cultivation unprofitable for farmers (Petrick and Djanibekov, 2016). In addition to it, the profitability of growing cotton was also somewhat questionable (World Bank 2016). Therefore, Government started to systematically withdraw irrigated land areas from cotton cultivation and allocated for the cultivation of grain crops, primarily wheat, while raw cotton production was reduced from almost 6 to 3.5 million tons. These changes in land use structure were aimed not only at increasing the production of grain, potatoes, and vegetables but also at improving the fertility of irrigated lands through the crop rotation system of "cotton-wheat," which was expected to enhance the efficiency of agricultural sector potential.

In this context, in since 2017 several sustainable agriculture practices were introduced in Karakalpakstan for instance: 19,000 hectares of arable land are equipped with water saving technologies namely: drip-irrigation and water sprinkling systems and 28500 of hectares of arable land are land lasered (total area for agriculture is 414 806 hectares, making sustainable agriculture practices in 11% of total arable land). In addition to it, the Government is rolling out to lay concrete on the so-called irrigation canals that feed the farmers plantations in order to avoid infiltration of the water. Plus, the Government launched performance-based climate smart agriculture loans to farmers residing in the Aral Sea Region, by proving UZS 12mln (around USD 940) for every hectare of land equipped with the water saving technologies. However, the huge capacity gap persists to take up the climate smart and sustainable agriculture practices in the Region. But the important gap is being left behind, that is capacity building of farmers, smallholder farms and households to take up the sustainable agriculture practices. Although the Government is supporting and initiating training programs to the farmers through Council of Farmers, the impact of the trainings are low and inefficient due to lack of institutional knowledge and capacity. Therefore, formal and informal curriculum development on climate smart agriculture and sustainable agriculture development for farmers by attracting international experts, think-tanks, best practices and lessons learnt would be one of the solutions.

4. Climate change and resilience building in the Aral Sea Region. Climate change is affecting the water balances and is also linked to the desertification of the Aral Sea. Shorter and hotter summers, longer and colder winters, and a decrease in precipitation pose further risks to population living in the area. Main causes of environmental pollution are salt dust storms from the dried bottom of the Aral Sea, solid waste, pesticides, and emissions from large enterprises. etween 2020 and 2023, the region's annual average moisture level decreased from 51.4% to 48.5% with an average variation of 2.6 points (Uzhyrdoment data 2023). Cumulatively, between 2020-2022, a decrease in humidity averaging 8.7% occurred by the 4th quarter, and conversely, from 2023 onward, an increase in humidity averaging 5.1% was observed. The same scenario occurred by districts, if the average annual high humidity was observed mainly in 5 districts (Amudarya, Muynak, Takhiatash, Khojaili and Ellikkaliya districts), then in 2023 it occurred in Kegeli, Chimbay, Bozatau, Kanlikul, Kungrad and Shumanai districts.During the same period, the average annual rainfall increased from 5.99 mm to 6.71 mm with an average variation of 1.3 points. While in the period 2020-2022, high rainfall occurred in the first and second quarters (average of 11 mm), in 2023, high rainfall occurred in the second and fourth quarters (average of 9 mm). On a district-by-district basis, the average annual high precipitation has changed over time by district. For example, in the period 2020-2021, high precipitation was observed in Chimbay, Kegeyli and Takhtakupyr districts (average 7.7 mm), then in 2022 it was observed in other 6 districts (Amudarya, Karauzyak, Nukus, Takhiatash, Khojeyli and Nukus city), and in 2023 in other 6 districts (Bozatau, Kegeyli, Kanlykul, Kungrad, Muynak and Shumanai).

Climatic conditions have a great impact on agriculture, and, consequently, most rural residents of Karakalpakstan and their sources of income are vulnerable to climate change. Climate forecasts suggest that the country will be subject to: - an increase in the average annual temperature by 1.9C-2.4C by 2050; the greatest warming will occur in winter and spring periods; - 15-18% increase in the average annual precipitation by 2050 with the greatest increase in the summer season; - a gradual increase in the projected water shortage in the Aral Sea basin as the demand for water increases and the volume of guaranteed water withdrawal from the basins of the Amudarya and Syrdarya rivers decreases; - according to the World Bank experts, the projected water shortage will increase to 11-13 km by 2050; - the conditions of agricultural production will be the most difficult to predict, due to the fact that an increase in temperature will lead to an increase in moisture evaporation (evapotranspiration) of crops, compensating for the predicted increase in precipitation and leading to more arid conditions of agricultural production; - invasions of new agricultural pests and diseases of crops and livestock caused by changes in temperature and precipitation conditions; - an increase in the duration of the growing season, especially in the northern regions, which provides opportunities for sowing crops, increasing productivity and changes in the structure of crops. The projected change in agro-climatic conditions poses a serious threat to agricultural production, water availability and economic growth, contributing to an increase in rural incomes. Non-irrigated lands with already low productivity will be under even greater threat than lands located in areas of relatively high rainfall or irrigated agriculture.

Soil studies have shown that 56.6 thousand hectares of all irrigated land in Karakalpakstan are heavily saline, and the salinity of 171.3 thousand hectares of land (34%) is average. The total salinity level of irrigated lands in the region is 68.8%. It should be noted that in 2000-2017, highly saline lands decreased by more than 2 times and in 2017. they amounted to 22.0 thousand hectares. The salinity of the land is very high in the Karauzyak and Takhtakupyr districts. At the same time, Khojaly (72.9%), Kegeyli (75.5%), Cimbai (78.4%) and Muinak (96.1%) districts have relatively high levels of salinity. As a result, the yield of cotton, wheat, melons grown on high- and medium-saline acreage is reduced. The yield of corn decreased by 3 times, rice – by 2 times, cotton – by 1.6 times, potatoes and vegetable crops – by 1.5-2.5 times. The government of Uzbekistan together with the Green Climate Fund are developing Regional Adaptation Plan (RAP) for Karakalpakstan, the purpose of which is to identify the most vulnerable sectors to climate change and propose measures aimed at adapting them to these changes. One of the selected sectors is agriculture and its transformation to sustainable pathways mid-term and long-term periods. Among the recipients of adaptation measures are agriculture, water management, healthcare, and construction.

The issue of development of the Aral Sea region is defined as a priority of the state policy. On the dried-up part of the Aral Sea, 1.73 million thousand hectares of green areas have been planted. A five-year national program for the restoration of flora and fauna, ecosystem restoration and sustainable socioeconomic development of the Aral Sea region is being developed. Residents of Karakalpakstan depend on the agricultural sector, which is dominated by water-intensive crops irrigated with saline water, in terms of their economic and food security**.** The overall situation in the Aral Sea Region is very far from ideal in terms of adapting agriculture sector into the climate change reality. Although there is strong political will of the Government of Uzbekistan to mitigate the consequences of the Aral Sea Disaster. It is important to note that the dried seabed of the Aral Sea equals to 5.2 million hectares and out of it 2.9 hectares are located in Uzbekistan. In order to tackle the issue, the Government of Uzbekistan in 2018 launched nationwide afforestation campaign in the dried area and to date 1.9 million hectares are covered with saxaul (haloxylon) plants, which are helping to stop sand migration hence mitigating desertification of agriculture land.

The growth of agricultural production in Karakalpakstan is expected to be offset by the expansion of acreage for crops (potatoes by 0.6 thousand hectares for 2017-2021, vegetables by 1.5 thousand hectares, melons by 0.3 thousand hectares, fodder by 5.5 thousand hectares, technical oilseeds by 4.5 thousand hectares, orchards by 0.5 thousand hectares). hectares, vineyards by 0.5 thousand hectares), as well as by increasing crop yields (potatoes by 25.2 c/ha, vegetables by 47.5 c/ha, melons by 14.3 c/ha, fruits by 8.2 c/ha. According to forecast indicators, with an increase in production volumes and crop yields, the volume of their processing will also increase.

Conclusions. The future of agriculture in Karakalpakstan hinges on strategic adaptation to climate challenges through sustainable and climate-smart practices, with crop diversification playing a pivotal role in enhancing farm income and empowering farmer autonomy. Given the anticipated rise in temperatures and increased water scarcity, traditional farming practices are no longer sustainable. Crop diversification not only helps stabilize income by reducing reliance on a few climate-sensitive crops but also provides farmers with greater flexibility in deciding what to cultivate and where to sell. This autonomy allows farmers to respond to market demands, improve profit margins, and mitigate the risks posed by climate volatility. Mplementing SAP and CSA practices alongside diversification efforts is essential to building resilience in the region. While measures like zero-tillage and advanced irrigation techniques have shown promise, widespread adoption depends on comprehensive support, including capacity-building initiatives, improved access to resources, and a policy framework that promotes flexible crop choices. Government and international stakeholders must work collaboratively to build an ecosystem that supports farmers in adopting diversified, sustainable practices, thereby safeguarding their livelihoods and stabilizing the regional economy. Karakalpakstan's successful agricultural transformation could become a model for other regions facing similar climate-driven challenges, showcasing how diversified, climate-smart agriculture fosters both economic resilience and environmental sustainability.

Acronyms and Abbreviations

ISRS -Institute for Strategic and Regional Studies under the President of the

Republic of Uzbekistan

ADB-Asian Development Bank

RAP-Regional Adaptation Plan

SAP-Sustainable Agriculture Practices

CSA-Climate Smart Agriclture

References:

1. Sector assessment: agriculture, natural resources, and rural development. ADB, 2023.

2. Institute for strategic and regional studies under the president of the republic of Uzbekistan. 2021

3. Karakalpak State University named after Berdakh,

Oteuliev J.B., Adilov S. Effect of cotton fertilizer rate on soil

agrochemical properties. Science and Education in Karakalpakstan. 2022 №3/2 ISSN 2181-9203.
4. Economics and Society Bekbulatova G.A, Oteuliev M.O, Allocation and development of agriculture in the Republic of Karakalpakstan. "Экономика и социум" №6(97)-2 2022.
5.Meredith T. Niles. Agricultural Systems. https://doi.org/10.1016/j.agsy.2023.103771.September 2023.
6. A discussion on the outcomes of adopted agricultural technological products and specific sustainable development goals: Evidence from Pakistan. Bilal et al. Cogent Economics & Finance (2022), 10: 2132644. https://doi.org/10.1080/23322039.2022.2132644.
7. Options and Constraints for Crop Diversification: A Case Study in Sustainable Agriculture in Uzbekistan. I. Bobojonov, J. P. A. Lamers, M. Bekchanov, N. Djanibekov, J. Franz-Vasdeki,4 J. Ruzimov, and C. Martius. Agroecology and Sustainable Food Systems, 37:788–811, 2013 DOI: 10.1080/21683565.2013.775539.
8. Barriers to the adoption of multiple agricultural innovations: insights from Bt cotton, wheat seeds, herbicides and no-tillage in Pakistan. Muhammad Bilal and Tinoush Jamali Jaghdani. International Journal of Agricultural Sustainability 2024, Vol. 22, No. 1, 2318934 https://doi.org/10.1080/14735903.2024.2318934.
9. Understanding the Adoption of Innovations in Agriculture: A Review of Selected Conceptual Models. Oscar Montes de Oca Munguia, David J. Pannell 1 and Rick Llewellyn. Review paper, Agronomy. Agronomy 2021, 11, 139. https://doi.org/10.3390/agronomy 11010139.

9. Constructing a farm level indicator of sustainable agricultural practice. Dan Rigby, Phil Woodhouse, Trevor Young, Michael Burton. Ecological Economics 39 (2001) 463–478.

10. The determinants of farmer's decision to adopt sustainable agricultural practices in Uzbekistan. Tadjiev A. A, Djanibekov. International scientific-practical conference on March 25-26, 2021. "Development issues of innovative economy in the agricultural sector".

11. Crop diversification level and its determinants in Ethiopia. Tamrat Gebiso, Mengistu Ketema, Arega Shumetie and Getachew Leggesse (2023), Cogent Food & Agriculture, 9:2, 2278924, DOI: 10.1080/23311932.2023.2278924.

12. Farm and farmer capital foster adoption of improved quality agro-chemical inputs in the cotton-wheat zone of the Punjab, Pakistan. Bilal, M., and Barkmann, J. (2019). Journal of Agriculture and Rural Development in Tropics and Subtropics, 120(2), 229–240. https://doi.org/10. 17170/kobra-20191217881.

13. Sergiy Zorya, Nodir Djanibekov and Martin Petrick, Leibniz Institute of Agricultural Development in Transition Economies (IAMO) Farm Restructuring in Uzbekistan: How Did It Go and What is Next?(2019).)https://documents1.worldbank.org/curated/ar/686761549308557243/pdf/134322-WP-P162303-PUBLIC-Report-Farm-Restructuring-in-Uzbekistan-eng.pdf.

14. World Bank 2016. Assessment of the social impact of cotton harvesting mechanization in Uzbekistan.