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The Impact of Climate Change on the Environment in Tajikistan: The Case of the Agricultural Sector (2014–2023)

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Abstract

The study reveals a significant and widespread trend of rising temperatures across all regions from 2014 to 2023, with the most pronounced increases in maximum and mean temperatures occurring in the lowland agricultural areas of Khatlon and Sughd. Additionally, annual precipitation has decreased in most regions, particularly in Khatlon and the Batken, Ayni, and Muminabad Regions (BAMR), raising serious concerns about water scarcity and the likelihood of increased drought events. Despite these climatic challenges, the overall area under agricultural cultivation has remained relatively stable, showing a slight increase. However, this stability conceals important shifts in crop distribution. There has been a decline in the land allocated to cereals and industrial crops, while the area dedicated to higher-value food crops, such as potatoes and vegetables, has significantly expanded. This shift indicates that farmers are adopting new strategies to adapt to the changing climate. The research concludes that climate change is already exerting a measurable and complex influence on Tajikistan's environment and agricultural sector. These observed changes underscore the urgent need for effective adaptive measures, including the adoption of climate-resilient farming practices, enhanced water resource management strategies, and sustained institutional support. Such initiatives are essential for safeguarding the livelihoods of vulnerable rural populations and ensuring the long-term sustainability of agricultural development in Tajikistan.

Keywords

Climate change, Agricultural sector, Temperature rise, Crop distribution, Climate-resilient farming and Crop production.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), the global average temperature of the Earth's surface has increased by about 0.74 °C over the last hundred years (IPCC, 2007a). Recently, an increasing number of studies have provided alarming figures related to climate change. In comparison with the temperature in the pre-industrial period, global warming is expected to rise to 6°C by the end of the 21st century (IPCC, 2007). In this regard, most have estimated that global warming will range between 2.0 °C and 4.8 °C by the end of this century (IPCC, 2013; Güngör, 2018).

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Figure 1. Map of the Republic of Tajikistan

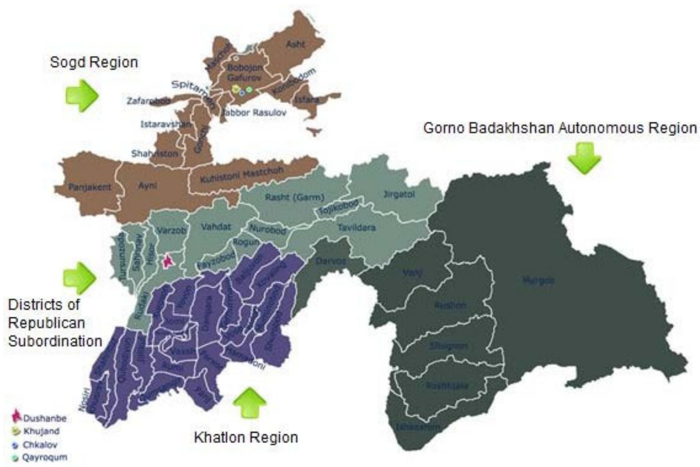

Figure 2. Administrative divisions of the Republic of Tajikistan

The terrain is characterized by oscillating mountain ranges featuring numerous glaciers and snowfields at their peaks, interspersed with mountain depressions and large valleys where agriculture thrives, alongside villages, cities, and industrial centers. The elevations of the nation range from 300 meters to 7495 meters. Due to the unfavorable meteorological and physical-geographical conditions created by the prevalence of rocks, glaciers, and highlands, approximately half of the republic's area is located at an absolute altitude of more than 3000 meters above sea level, making it unsuitable for cultivation.

Land resources are characterized by significant variability across regions. The least agricultural region with an insignificant amount of land suitable for agriculture is GBAO, while the most agricultural region is Sughd, which has more land suitable for cultivation than Khatlon. The RRS accounts for 80% of agricultural pasture resources.

Since the country has a semi-arid climate, the cultivation of agricultural land is highly dependent on irrigation. The development of artificial irrigation systems benefits agriculture in water-rich river valleys. The area of irrigated land increased from 450,000 hectares in 1960 to 720,000 hectares in 2009, accounting for 18% of all agricultural land. Of the total irrigated land, 580,000 hectares (80%) are dedicated to irrigated arable land and 140,000 hectares (20%) are used for irrigated pastures. Thus, about two-thirds of arable land and less than 5% of pasture land in Tajikistan are irrigated (Wolfgramm et al., 2011). The share of irrigated

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agricultural land is only 3% in BAMR, 20-30% in Khatlon and Sughd, and 10% in RRS (Table 1) (Camille, 2011).

Table 1. Structure of different types of land used by region (percentage of agricultural land)

	Agricultural land		Total lands	Arable land		Pasture lands	
	Dry lands	Irrigated lands		Dry lands	Irrigated lands	Dry lands	Irrigated lands
Tajikistan	81.8	18.2	100	6.9	14.7	74.9	3.5
Badakhshon	96.8	3.2	100	0.3	2.0	96.5	1.2
Sughd	71.4	28.6	100	8.5	20.8	62.9	7.8
Khatlon	78.9	21.1	100	7.7	18.6	71.3	2.5
DCC	89.1	10.9	100	7.4	8.9	81.6	2.1

Vegetables are mainly cultivated in irrigated lands, and most of them are grown in greenhouses, making a significant contribution to ensuring the country's food security.

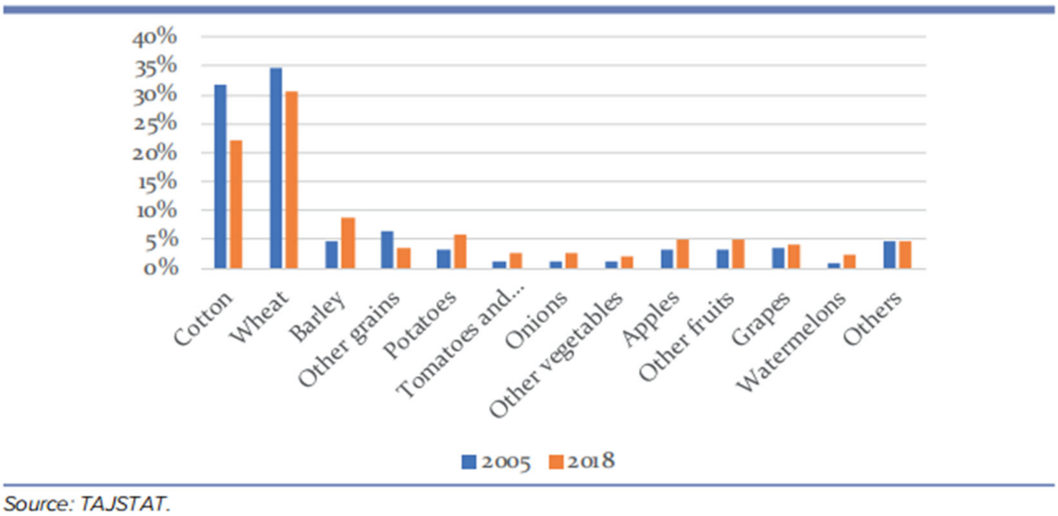

Figure 3. Showed that agricultural land was used for crops from 2005 to 2018 with the percent (%).

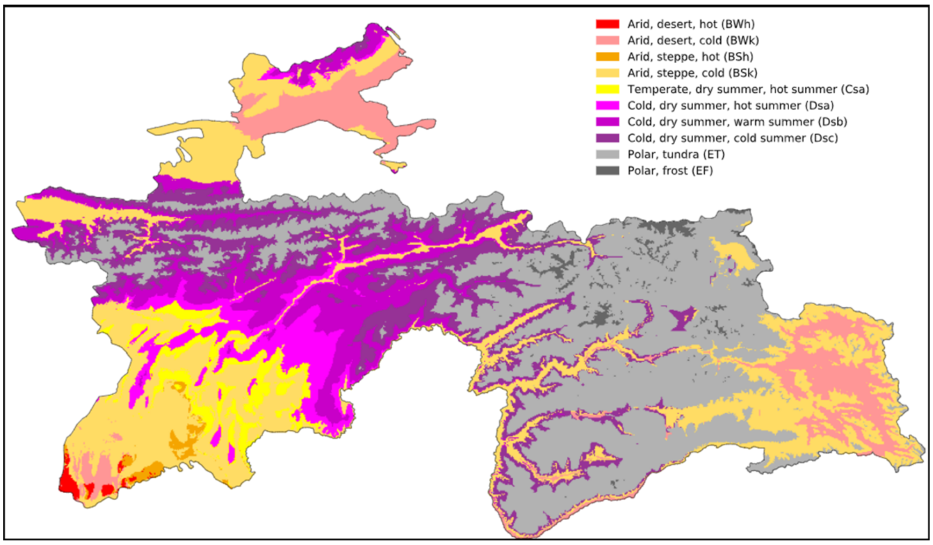

Figure 4. Climate classification map for Tajikistan (1980-2016)

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Despite various adaptation measures and policy interventions, the agricultural sector in Tajikistan continues to experience reduced crop yields, soil degradation, and water shortages, exacerbating rural poverty. One of the major challenges in the agricultural sector is climate change, which has led to numerous problems. For instance, the rapid melting of glaciers and snow-capped mountains—the primary sources of irrigation for the country's agricultural crops—results in water shortages during peak demand periods. Additionally, climate change has contributed to the occurrence of floods that destroy agricultural lands, unseasonal temperature fluctuations such as winter heat and sudden spring frosts that damage trees, soil erosion, and other adverse effects.

The goal of this research is to propose a suitable system and strategy to reduce the negative impact of climate change on the development of Tajikistan's agricultural sector.

2. Literature Review

According to the program for the development of horticulture, viticulture, and citrus growing in the Republic of Tajikistan for 2025-2029, one of the major challenges facing the sector is the annual climate changes. The onset of cold during the flowering season, decreased precipitation, and occasional unpredictable heat across all regions of the republic negatively impact the productivity of fruit trees, particularly apricot plant. Such weather events pose a serious threat to agricultural productivity and the stability of agriculture (Madiev et al., 2025).

Many factors are known to influence fruit development in orchards. Temperature and water are usually considered the most important. Physiological processes in plants range from 0 to 40 °C. However, temperature range for the development of fruits and vegetables is somewhat narrower (Moretti et al., 2010). Temperature is known to affect both photosynthesis and respiration, and their ratio must be high to achieve high yield. At moderate temperatures (15 °C) the ratio is higher than 10 which might explain their better development in temperate regions. Photosynthetic activity is positively correlated with temperature until a certain threshold. Higher temperatures provoke the inactivation of enzymes, and the plant can no longer cope with heat stress. Under extreme conditions in the tropics, fruit may reach 40 °C, while temperatures above 35 °C are 28 Chapter 2 Literature Review considered to stop the ripening process and temperatures above 35 °C suspend ethylene production in climacteric fruit (Moretti & Sargent, 2010).

Climate change poses a direct and indirect threat to crop and livestock yields. Projections show there will be an increased occurrence of extreme heat days and tropical nights, which could intensify drought conditions and heat waves. And although the growing season length may increase, the benefits may be offset by more frequent pests and diseases due to reduced frost days (GIZ, 2020). The findings of a recent study indicate that climate change negatively affects most crop yields but may benefit a few crops, including cotton and potatoes, and show negative impacts from climate change on barley, wheat, maize, and fruit and vegetable yields in Tajikistan, with yield declines of 5 to 10 percent by 2050 (Khakimov et al., 2020).

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3. Research Methodology

All the necessary data were collected before the analysis. The analysis was based on weather and crop data available to the author and seeks to determine the extent to which variations in temperature over recent years have influenced the growth and development of agricultural crops. Following data collection, the dataset was analyzed using SPSS statistical software, with the results concurrently presented in graphical form to enhance clarity and support a comprehensive interpretation of the findings.

The research methodology was based on the analysis of secondary data obtained from the World Bank and the Ministry of Agriculture of the Republic of Tajikistan. The collected data were systematically reviewed and analyzed to assess the impact of climate change on the agricultural sector in Tajikistan. Quantitative analysis techniques were employed using SPSS statistical software to identify trends, correlations, and patterns within the dataset. Graphical representations were also applied to facilitate the interpretation of the findings.

Figure 5. Tajikistan in the world map (study area)

Figure 6. Map of Tajikistan (study area)

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4. Results and Discussions

The dataset, titled "Average Maximum Surface Air Temperature Annual Trends with Significance of Trend per Decade; 2014–2023; Tajikistan", includes annual average maximum temperature as shown in Table 2 and Figure 7. Figure 8 presents the decadal trends of Average Minimum Surface Air Temperature (AMSAT) across Tajikistan, disaggregated by major administrative regions, for the period 2014 to 2023. The data are expressed in degrees Celsius and provide a temporal and spatial perspective on climatic variation in minimum surface air temperatures across different ecological and altitudinal zones of the country.

Sughd province, located in the northwest of the country, presents a moderate climate profile. AMSAT values here range from 1.44°C (2014) to 3.15°C (2023). The temperature trend reflects a consistent increase, especially marked after 2016. The trend's significance is notable given the region's agricultural and industrial significance, and could imply a shift in growing season length, crop viability, and energy demand patterns.

Figure 9 provides a comprehensive overview of the annual mean surface air temperature trends across Tajikistan and its major administrative regions from 2014 to 2023. The dataset, expressed in degrees Celsius (°C), allows for the assessment of temporal trends and regional disparities in warming, serving as an empirical foundation for evaluating climate dynamics and environmental vulnerabilities within the country.

At the national scale, the mean surface air temperature reveals a general upward trend. The temperature increased from 0.03°C in 2014 to 1.58°C in 2023, with year-to-year variations showing clear signs of climate variability. Particularly notable are the peaks in 2016 (1.55°C), 2022 (1.69°C), and 2023 (1.58°C)—years that align with global warming anomalies and possibly reflect the influence of broader atmospheric circulation shifts and El Niño–Southern Oscillation (ENSO) phenomena.

Between 2014 and 2023, the total agricultural crop area in Tajikistan demonstrated moderate variability, reflecting both environmental and socio-economic influences on land use. The total area under cultivation increased slightly from 828,437 hectares in 2014 to 861,471 hectares in 2023, indicating a relatively stable yet gradually expanding agricultural production sector (Figure 10-19).

Table 2. Average Maximum Surface Air Temperature Annual Trends with Significance of Trend per Decade; 2014-2023,

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Tajikistan	5,17	5,63	6,52	5,98	5,69	5,92	5,15	6,11	6,57	6,82
Badakhshan Autonomous Mountainous Region	-3,47	-3,28	-2,31	-2,86	-3,4	-2,97	-3,63	-3,13	-2,25	-2,43
Khatlon Region	20,2	21	22	21,7	21,5	21,6	20,5	22,3	22,3	22,8
Sughd Region	10,5	11,2	11,9	11,2	11,2	11,4	10,4	11,8	11,8	12,6
Cities and districts of the republican subordination	6,36	6,95	7,69	7,11	7,01	7,01	6,46	7,28	7,69	8,2

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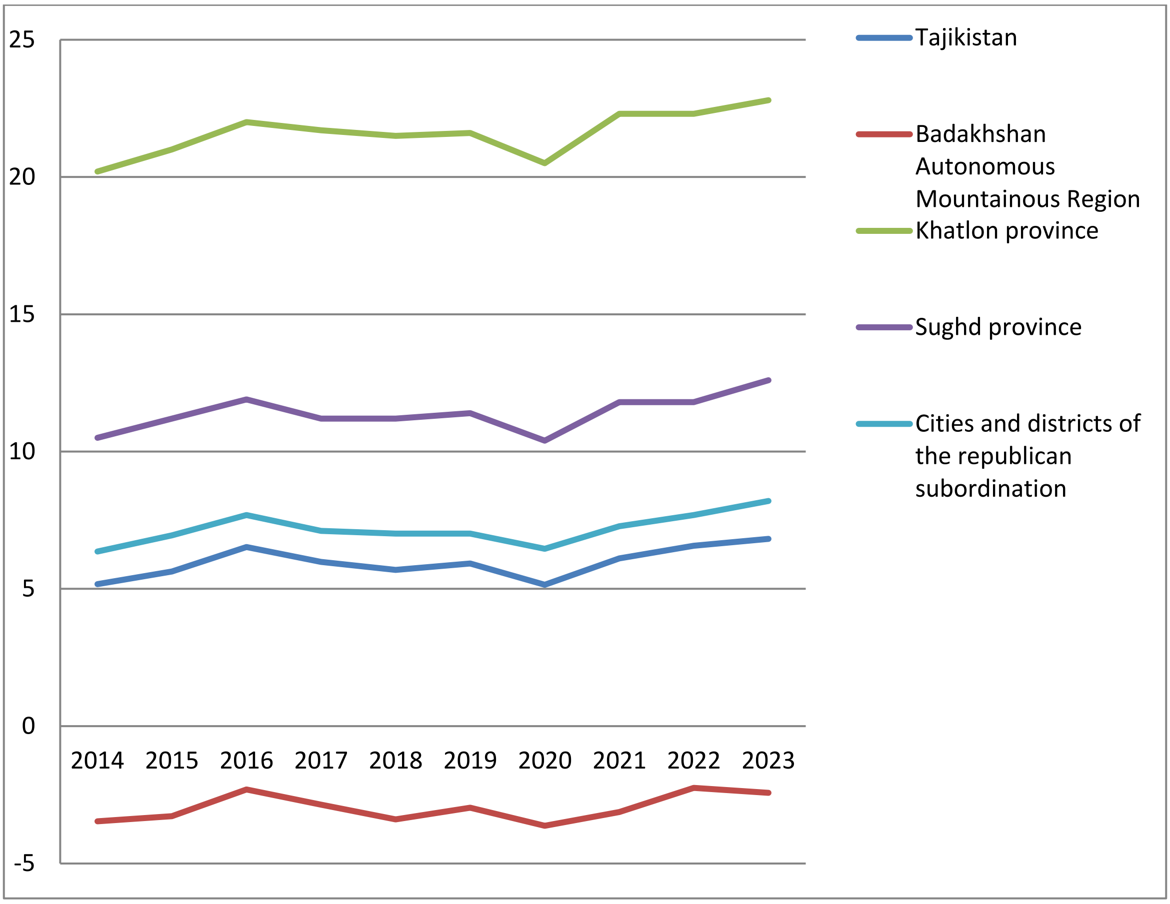

Figure 7. Average Maximum Surface Air Temperature Annual Trends with Significance of Trend per Decade; 2014-2023,

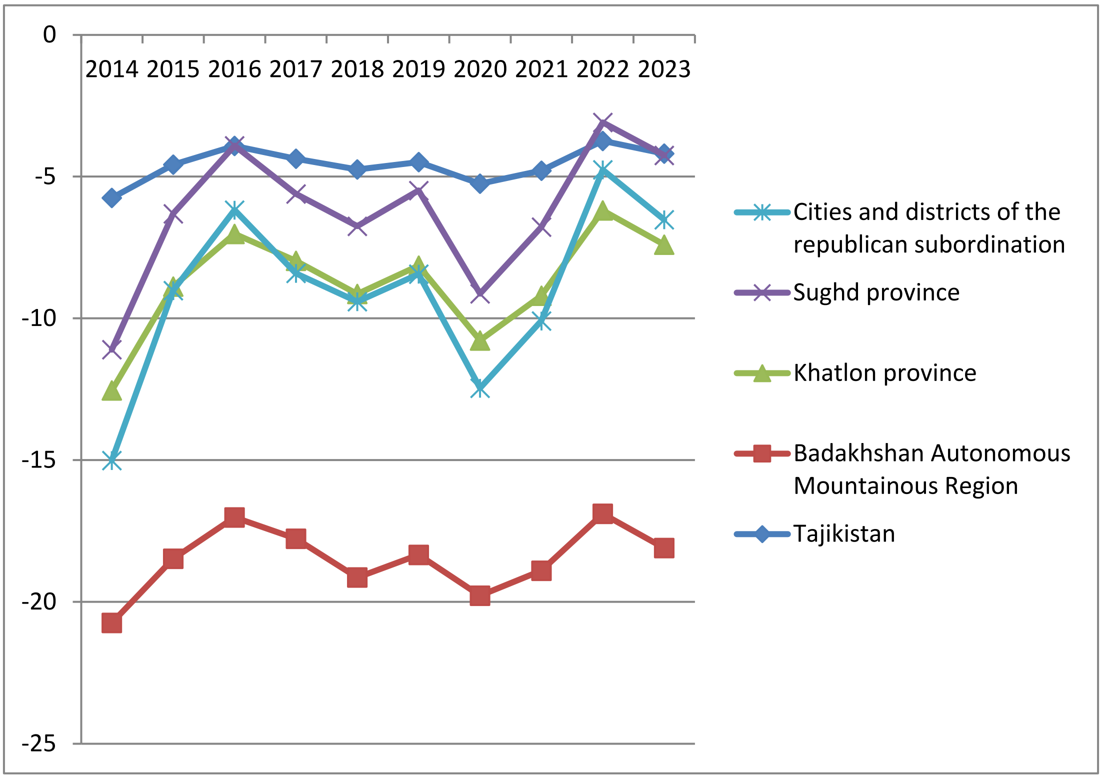

Figure 8. Average Minimum Surface Air Temperature Annual Trends with Significance of Trend per Decade; 2014-2023; Tajikistan

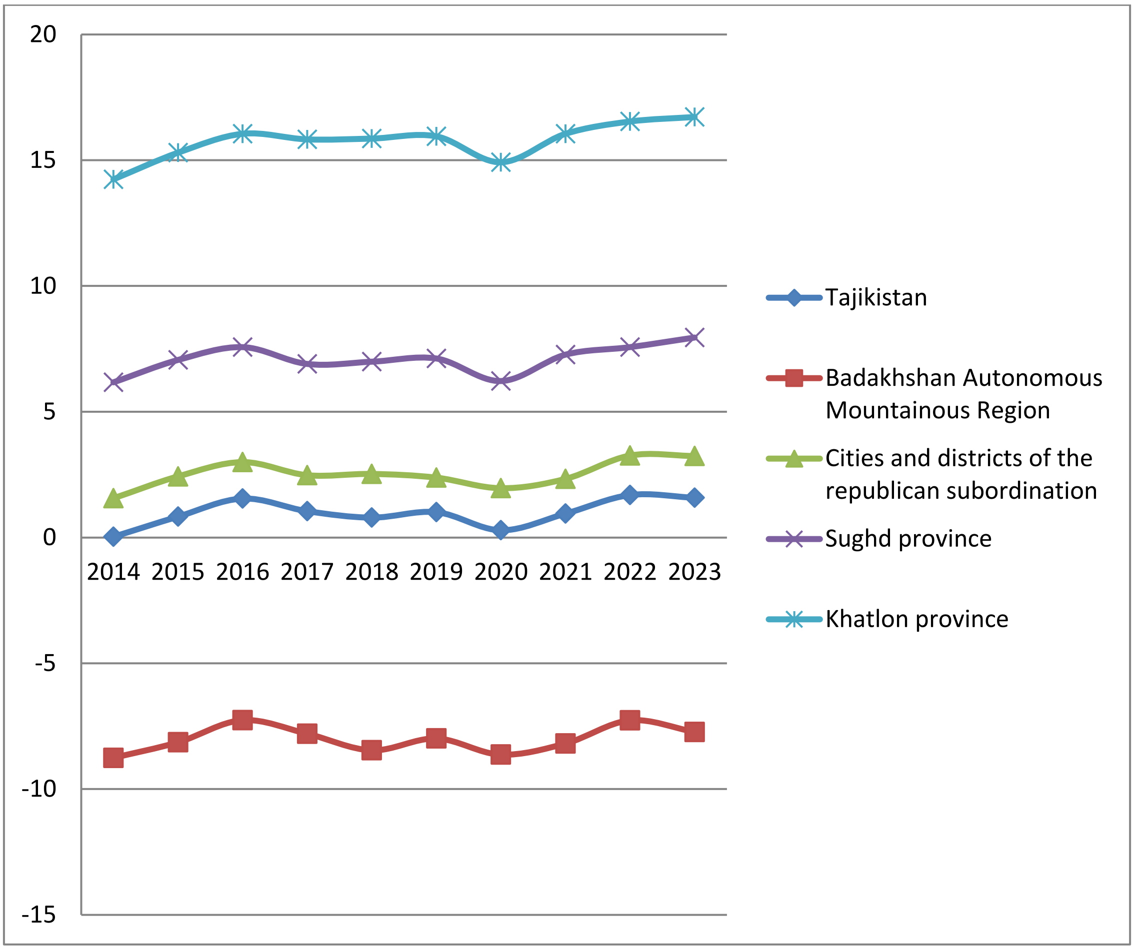

Figure 9. Average Mean Surface Air Temperature Annual Trends with Significance of Trend per Decade; 2014-2023; Tajikistan

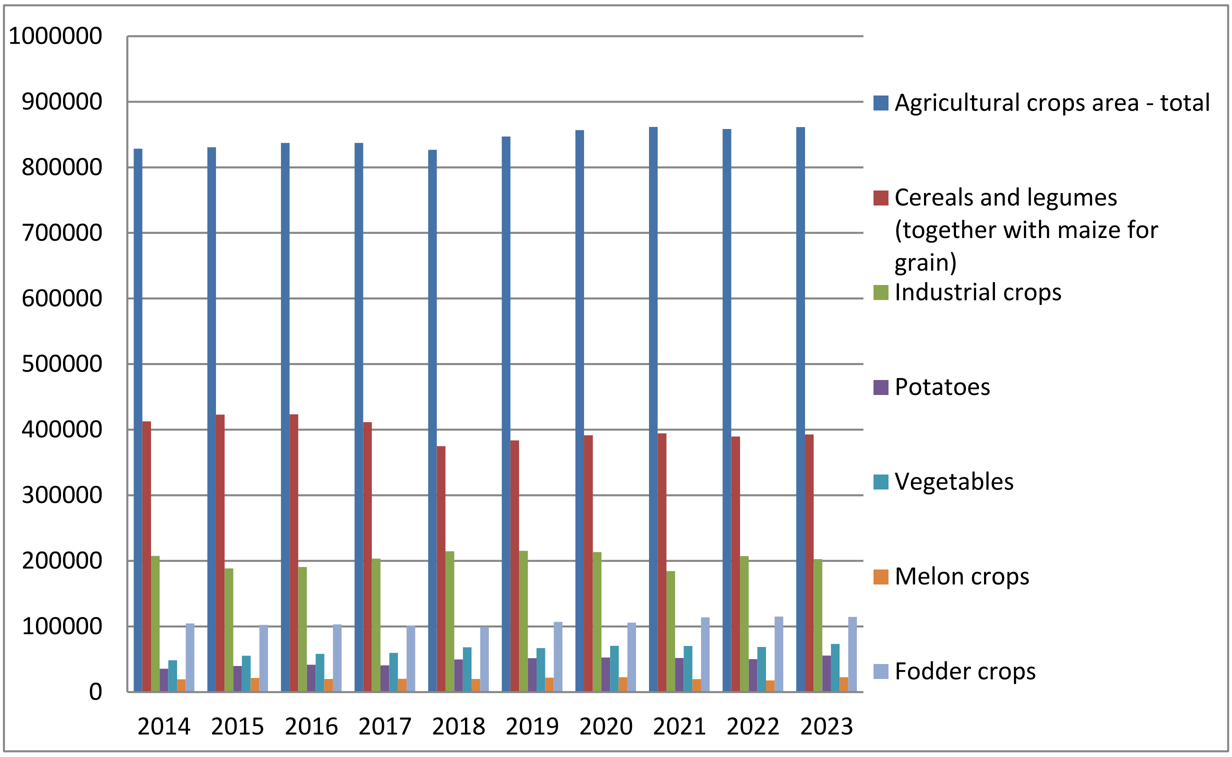

Figure 10. Agricultural crop area (ha) in Tajikistan from 2014-2023

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Cereal and legume cultivation, which includes maize grown for grain, consistently occupied the largest share of agricultural land (Figure 10-11). However, this category experienced a notable decline from a peak of 423,460 hectares in 2016 to 374,994 hectares in 2018, before recovering to 392,668 hectares by 2023. The fluctuation may be attributed to changing government policies, market demand, and climatic conditions affecting cereal productivity and land allocation.

The cultivation of potatoes and vegetables expanded notably during the observed period. Potato cultivation rose from 35,543 hectares in 2014 to 55,527 hectares in 2023, a 56% increase. Similarly, the area allocated to vegetables grew from 48,532 hectares in 2014 to 73,286 hectares in 2023. These trends suggest a growing domestic demand for food crops with higher nutritional value, possibly driven by demographic changes and improvements in household income and food security.

Melon crop - areas displayed modest variability, ranging from approximately 19,399 to 22,593 hectares, with minor year-to-year fluctuations. Meanwhile, fodder crops, essential for livestock production, remained relatively stable but with a gradual upward trend, from 104,620 hectares in 2014 to over 114,703 hectares in 2023 (Table 3). This increase likely reflects efforts to support the livestock sector and ensure feed availability throughout the year. From 2014 to 2023, agricultural land use in Tajikistan exhibited overall stability with a slight upward trend in total cultivated area. While cereals and legumes consistently occupied the largest portion of agricultural land, their share declined moderately over the period, reflecting a gradual diversification in crop structure. In contrast, high-value food crops such as potatoes and vegetables expanded significantly, indicating a shift toward more intensive and market-responsive agricultural practices. Industrial crops and fodder crops showed moderate fluctuations but maintained a relatively steady presence, highlighting their continued importance to both the export sector and livestock production. Overall, the data reflect a transition in Tajikistan's agriculture toward greater crop diversification and responsiveness to both domestic demand and market conditions.

Table 3. Comparison of the years 2014-2023

Category	2014 Area (ha)	2023 Area (ha)	Growth (%)	Trend Type
Total Crops	828,437	861,471	+4.0%	Slight upward
Cereals & Legumes	412,626	392,668	–4.8%	Slight downward
Industrial Crops	207,661	202,614	–2.4%	Fluctuating/slight decline
Potatoes	35,543	55,527	+56.2%	Strong upward
Vegetables	48,532	73,286	+51.0%	Strong upward
Melon Crops	19,399	22,593	+16.5%	Mild upward
Fodder Crops	104,62	114,703	+9.6%	Moderate upward

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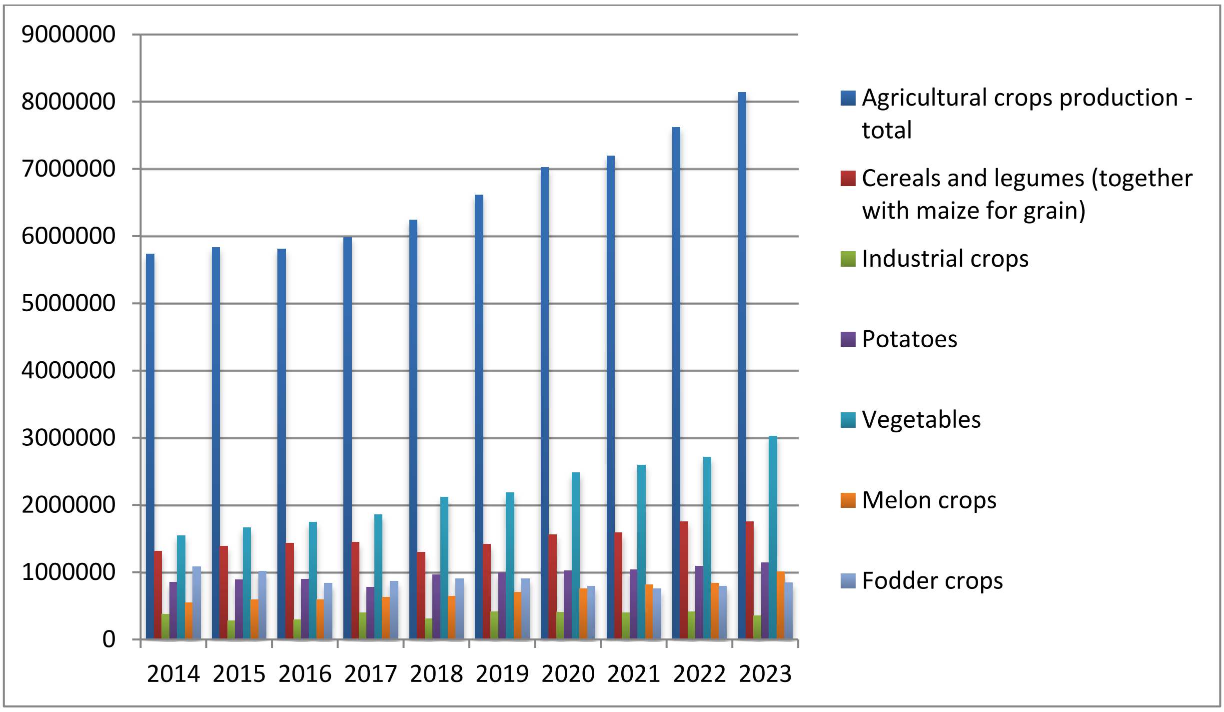

Figure 11. Agricultural crop production in Tajikistan from 2014-2023

Table 4. Comparison of the years 2014-2023

Category	2014 Output	2023 Output	Growth (%)	Trend Type
Total Crops	5.73M	8.14M	42%	Strong upward
Cereals & Legumes	1.32M	1.75M	33%	Moderate upward
Industrial Crops	379K	358K	-5.5%	Fluctuating/decline
Potatoes	854K	1.14M	34%	Moderate upward
Vegetables	1.55M	3.02M	95%	Strong upward
Melons	546K	1.01M	85%	Strong upward
Fodder Crops	1.08M	849K	-22%	Downward

Among all crop categories, vegetables and melon crops demonstrated the most dynamic growth, nearly doubling in output during the study period (Table 4). This rapid expansion indicates both growing domestic demand for fresh produce and possible opportunities for regional exports. It also reflects a positive shift toward crop diversification, which can contribute to improved dietary nutrition and enhanced economic resilience for farmers. Potato production also experienced stable and healthy growth (+34%), suggesting increasing importance in household diets and its role as a food security buffer. Meanwhile, cereal and legume production, including maize for grain, grew at a slower pace (+33%). Although positive, this moderate growth signals the need for enhanced productivity measures in staple grain farming, such as improved seed varieties, efficient irrigation, and better soil management.

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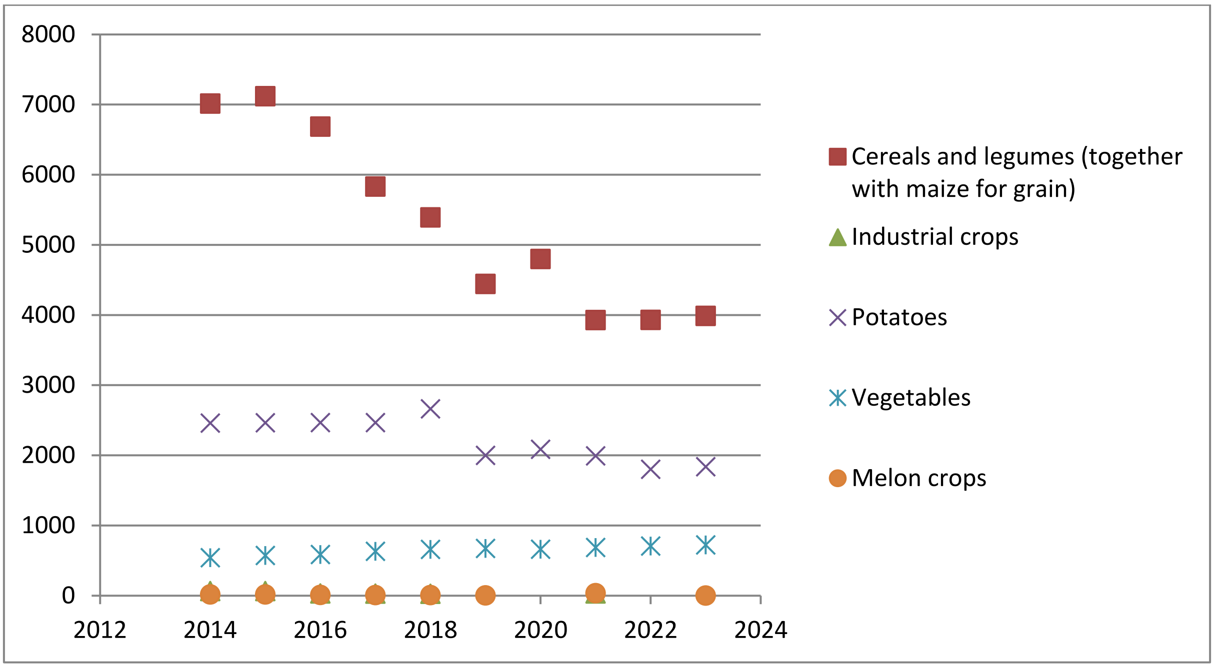

Figure 12. Agricultural crop area 2014-2023;

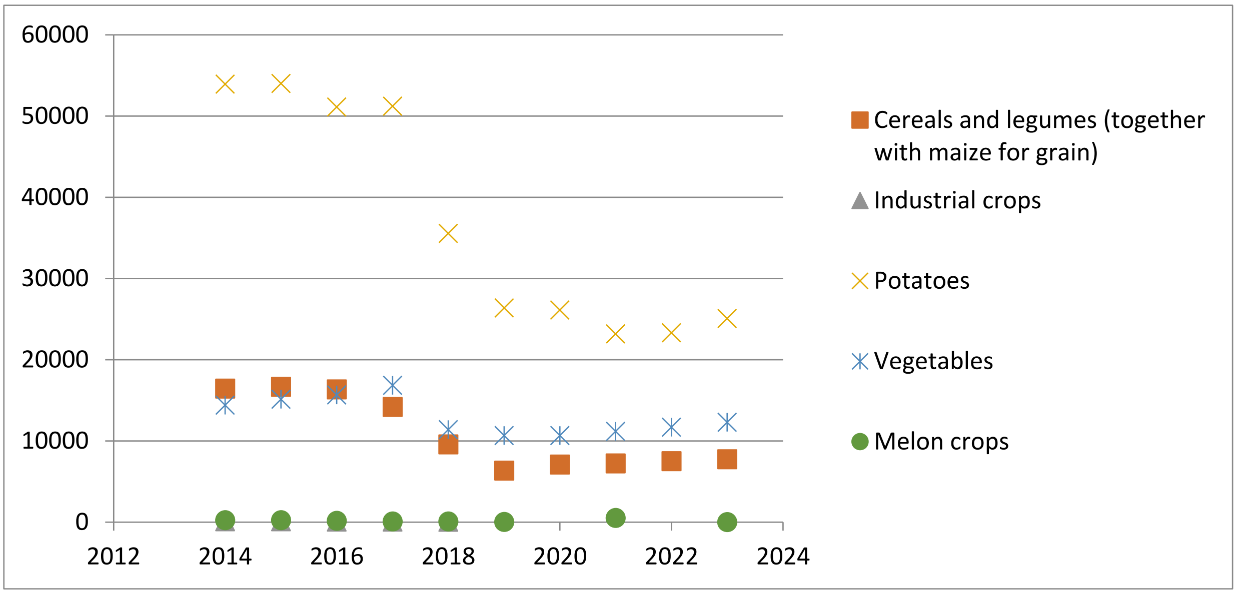

Figure 13. Agricultural crop Production 2014-2023;

The cultivated area dedicated to cereals and legumes dropped sharply, from 7,014 hectares in 2014 to 3,987 hectares in 2023, a 43.2% decline (Figure 12-13). Simultaneously, production fell from 16,455 tonnes to 7,755 tonnes. This dual reduction is a strong indication that cereal crops are losing priority in favor of other, more profitable or less intense resource crops. The trend is concerning from a food security standpoint, as cereals are staple foods in the national diet.

Industrial crops experienced a notable contraction, with cultivated areas decreasing by over 60% and production falling from 94 tonnes to 37 tonnes between 2014 and 2018.

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5. Vegetables

Vegetables show a divergent trend: the area under cultivation increased from 539 hectares in 2014 to 722 hectares in 2023, a gain of nearly 34%. However, production declined by 14.7% in the same period. This unusual pattern could indicate reduced yield per hectare, potentially due to environmental stress, input constraints (e.g., fertilizers), or quality of land expansion. Over the past decade, Sughd Province has exhibited notable changes in both the area dedicated to various crops and their respective production levels (Figure 14). This period of observation—from 2014 to 2023—demonstrates important regional shifts in agricultural practices, reflecting both market-driven choices and improvements in agronomic techniques. The data indicate that the area under cultivation for cereals and legumes (including maize for grain) has remained relatively stable in Sughd Province (Table 5). In 2014, the area was recorded at 123,700 hectares, and by 2023 it had slightly increased to 127,351 hectares (a modest 2.9% rise). This stability suggests that despite national pressures to shift land use, Sughd maintains a consistent focus on staple grains.

Table 5. Synthesis Table: Agricultural Crop Area and Production Trends (2014–2023)

Crop Type	Area in 2014 (ha)	Area in 2023 (ha)	% Change in Area	Production in 2014 (t)	Production in 2023 (t)	% Change in Production	General Trend
Cereals & Legumes	7,014	3,987	-43.2%	16,455	7,755	-52.9%	📉 Decline
Industrial Crops	63	25	-60.3%	94	37	-60.6%	📉 Sharp Decline
Potatoes	2,46	1,837	-25.3%	53,945	25,076	-53.5%	📉 Moderate Decline
Vegetables	539	722	+33.9%	14,408	12,295	-14.7%	🔄 Mixed (↑ area, ↓ production)
Melon Crops	17	1	-94.1%	237	13	-94.5%	📉 Severe Decline

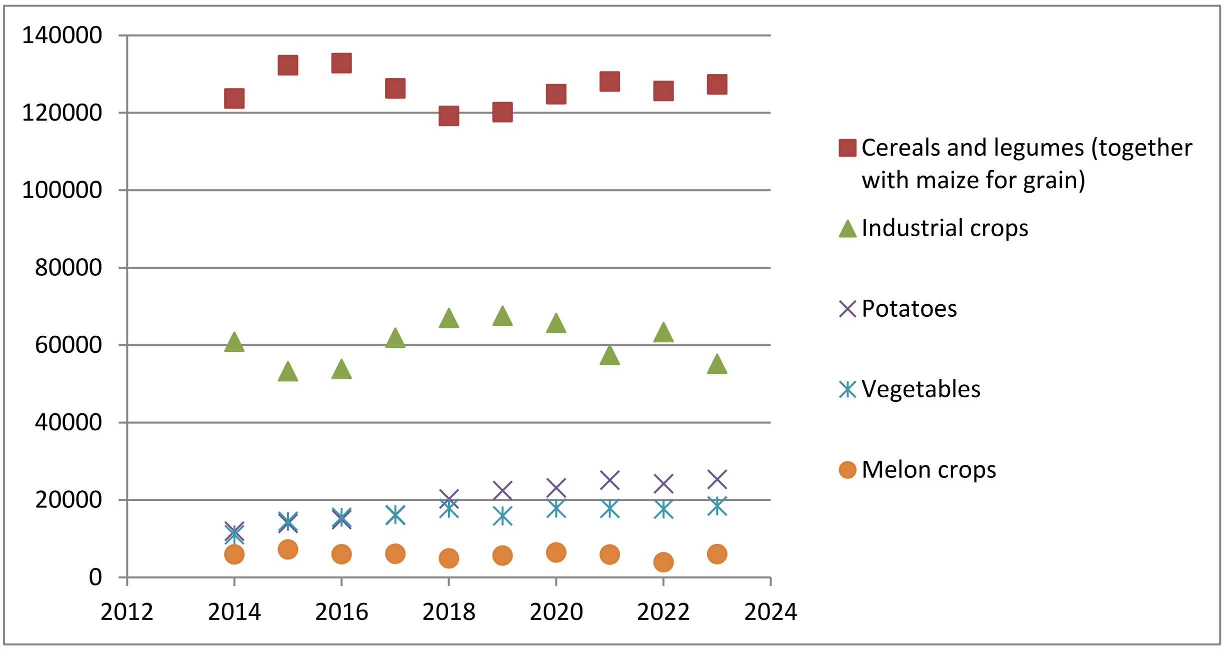

Figure 14. Agricultural crop area 2014-2023;

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Table 6. Agricultural Crop Area in Sughd (2014–2023)

	Area in 2014 (ha)	Area in 2023 (ha)	% Change in Area	General Trend
Cereals & Legumes	123,7	127,351	+2.9%	Slight Increase
Industrial Crops	60,877	55,167	-9.4%	Decrease
Potatoes	11,944	25,337	112%	Significant Increase
Vegetables	11,013	18,456	+67.6%	Strong Growth
Melon Crops	5,979	6,065	+1.4%	Relatively Stable

Similarly, vegetable cultivation expanded strongly, with the area increasing from 11,013 hectares to 18,456 hectares (a 67.6% increase) (Table 6). This trend implies that vegetable farming is receiving greater attention, possibly due to rising consumer demand and improved agronomic practices. On the other hand, melon crops saw only a marginal increase in area (from 5,979 hectares to 6,065 hectares, or about 1.4%), suggesting that while the land devoted to these crops has remained stable, other factors may be influencing their production levels. The production data (Figure 15) in Sughd Province underscore some complementary and contrasting trends related to crop areas. For cereals and legumes, production has increased markedly. In 2014, the output was 232,804 tonnes, while in 2023 it climbed to 409,762 tonnes—an increase of approximately 76%. This substantial production growth, despite only a slight rise in acreage, suggests significant improvements in yield, perhaps through better inputs and modern farming techniques.

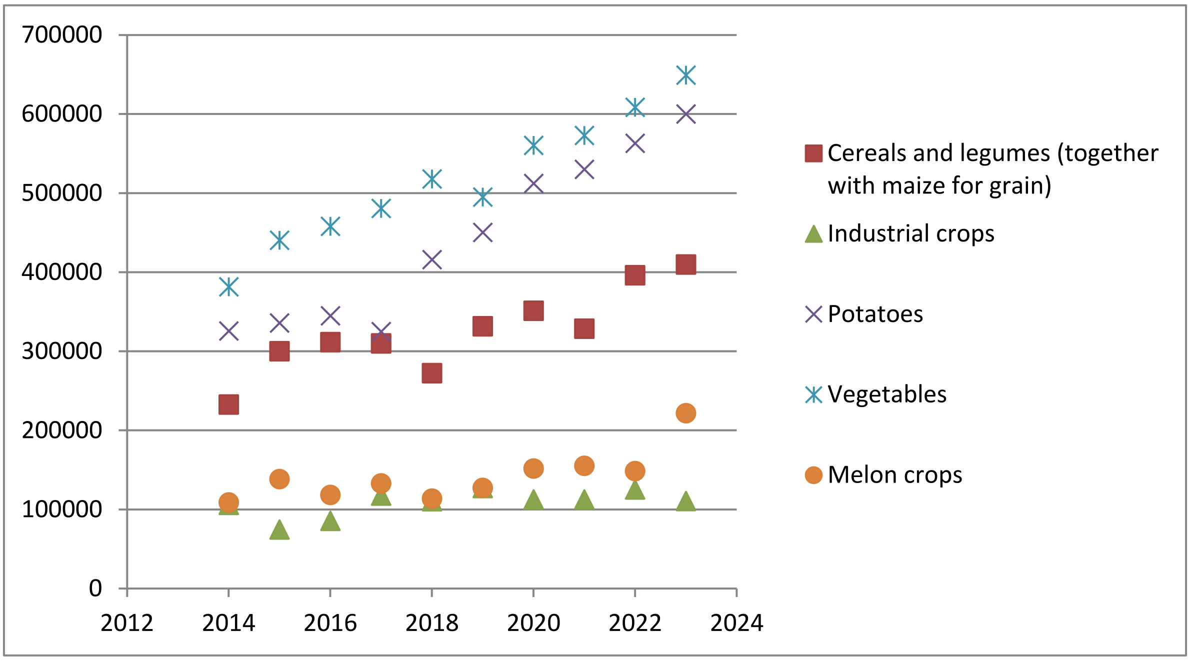

Figure 15. Agricultural crop Production 2014-2023; Sughd

Industrial crops show a modest production increase from 105,852 tonnes in 2014 to 110,762 tonnes in 2023 (a rise of about 4.6%) (Table 7). This slight change, in conjunction with the decline in land area, may indicate that while the crop mix is shifting, efforts to maintain production levels through efficiency improvements are yielding some positive results. Similarly, vegetable production increased from 381,517 tonnes to 649,080 tonnes (a 70.1% increase).

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The near-parallel rise in both area and output illustrates a successful scaling-up of vegetable farming activities, which likely benefits from increased market demand and investments in technology and infrastructure. Melon crops, while grown on a relatively limited area, experienced a notable jump in production, from 109,019 tonnes in 2014 to 221,799 tonnes in 2023 (a 103.4% increase). This significant enhancement in output, despite the stable cultivation area, points to increased efficiency in production practices or improved post-harvest processing.

Table 7. Difference from 2014 to 2023 in production

	Production in 2014 (t)	Production in 2023 (t)	% Change in Production	General Trend
Cereals & Legumes	232,804	409,762	76%	Strong Growth
Industrial Crops	105,852	110,762	+4.6%	Slight Growth
Potatoes	325,569	600,063	+84.3%	Strong Growth
Vegetables	381,517	649,08	+70.1%	Strong Growth
Melon Crops	109,019	221,799	+103.4%	Very Strong Growth

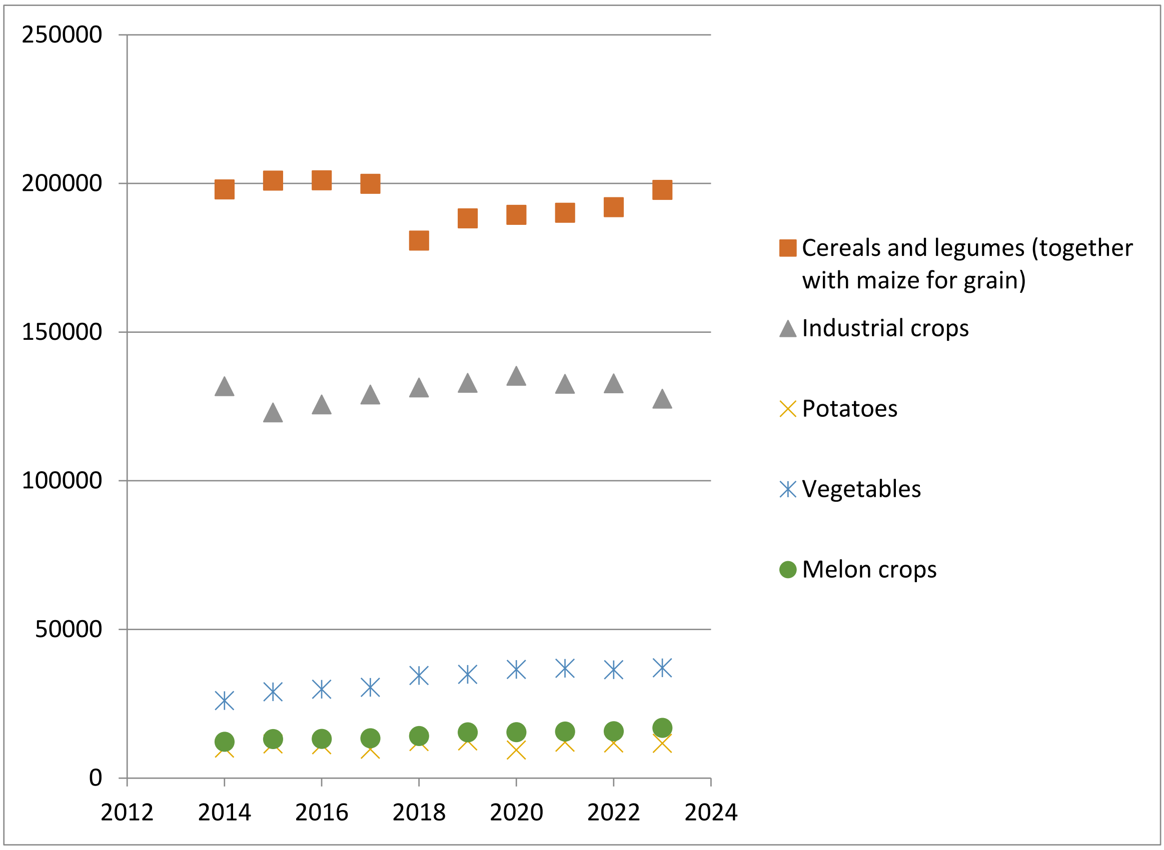

Figure 16. Agricultural crop area 2014-2023; Khatlon

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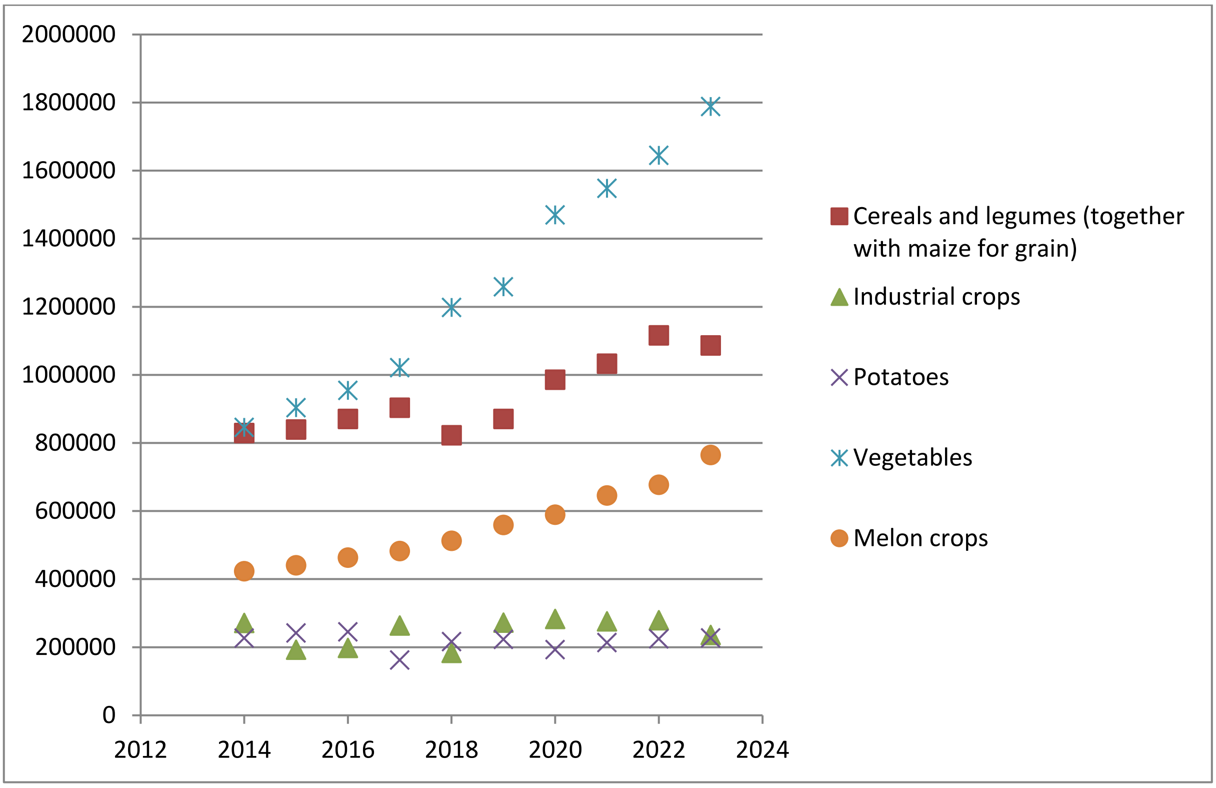

Figure 17. Agricultural crop Production 2014-2023; Khatlon

Cultivated Area: The area under cereals and legumes in Khatlon remained relatively stable, increasing slightly from 198,034 hectares in 2014 to 197,872 hectares in 2023 (Figure 16). While this reflects a minor decrease in certain years (e.g., 2018), the overall trend suggests continued prioritization of grain cultivation.

Production: Output in this category rose substantially from 828,709 tonnes in 2014 to 1,086,171 tonnes in 2023, a 31% increase (Figure 17). This indicates notable improvements in productivity per hectare, likely supported by better seed quality, farming techniques, and possibly expanded irrigation.

6. Vegetables

Cultivated Area: The area under vegetable cultivation expanded considerably from 26,052 hectares in 2014 to 37,053 hectares in 2023, representing a 42.2% increase. This trend highlights the growing importance of vegetables in meeting dietary and economic needs.

Production: Vegetable production rose impressively from 846,051 tonnes in 2014 to 1,788,155 tonnes in 2023, more than doubling (a 111% increase) (Table 8). This surge reflects not only increased acreage but also improved yields, varietal selection, and market-oriented production. The agricultural sector in the Cities and Districts of Republican Subordination (CDRS) (Figure 18, 19 and Table 9) has undergone notable changes over the period from 2014 to 2023, reflecting both structural shifts and productivity improvements across major crop categories.

Vegetable crops recorded strong growth both in area and production. The cultivated area increased by 57.7% over the period, from 10,928 to 17,233 hectares, while production surged from 307,506 tonnes to 576,693 tonnes, an 87.5% rise. This reflects a deliberate policy or market-driven shift toward high-value horticulture, underpinned by advancements in irrigation, crop varieties, and cultivation technologies.

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Table 8. Synthesis of Agricultural Crop Trends in Khatlon Province (2014–2023)

Crop Category	Area Trend (2014–2023)	Production Trend (2014–2023)	Key Insights
Cereals and legumes	Relatively stable (-0.08%)	Significant growth (+31%)	Improved yields despite stable area; priority crop for food security
Industrial crops	Slight decline (-3.2%)	Fluctuating; mild decline (-13%)	Volatile output; possibly impacted by market or policy changes
Potatoes	Moderate increase (+15.7%)	Very slight growth (+0.1%)	Area increased but yields stagnated; potential issue in productivity
Vegetables	Strong increase (+42.2%)	Very strong growth (+111%)	High-value crop; driven by both area and productivity improvements
Melon crops	Significant increase (+38.6%)	Strong growth (+81%)	Popular cash crop; increased demand and better cultivation practices

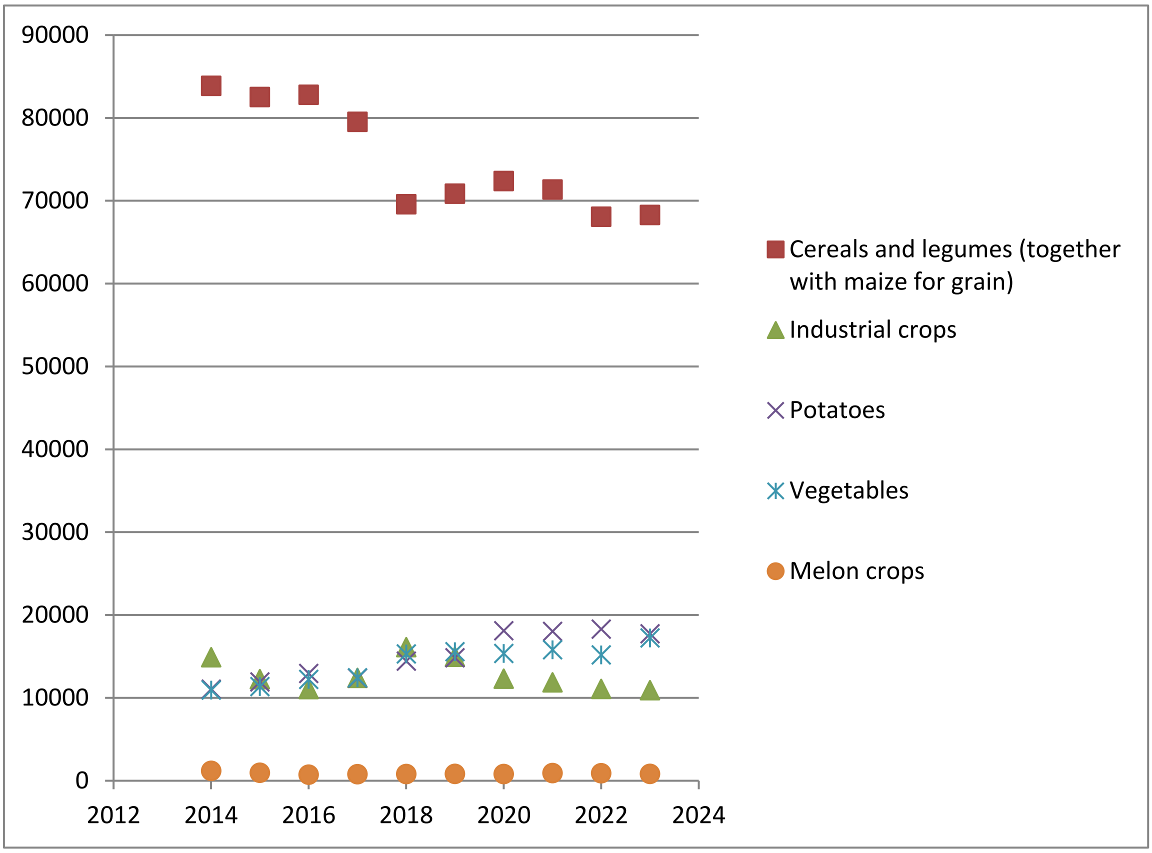

Figure 18. Agricultural crop area from 2014-2023; CDRS

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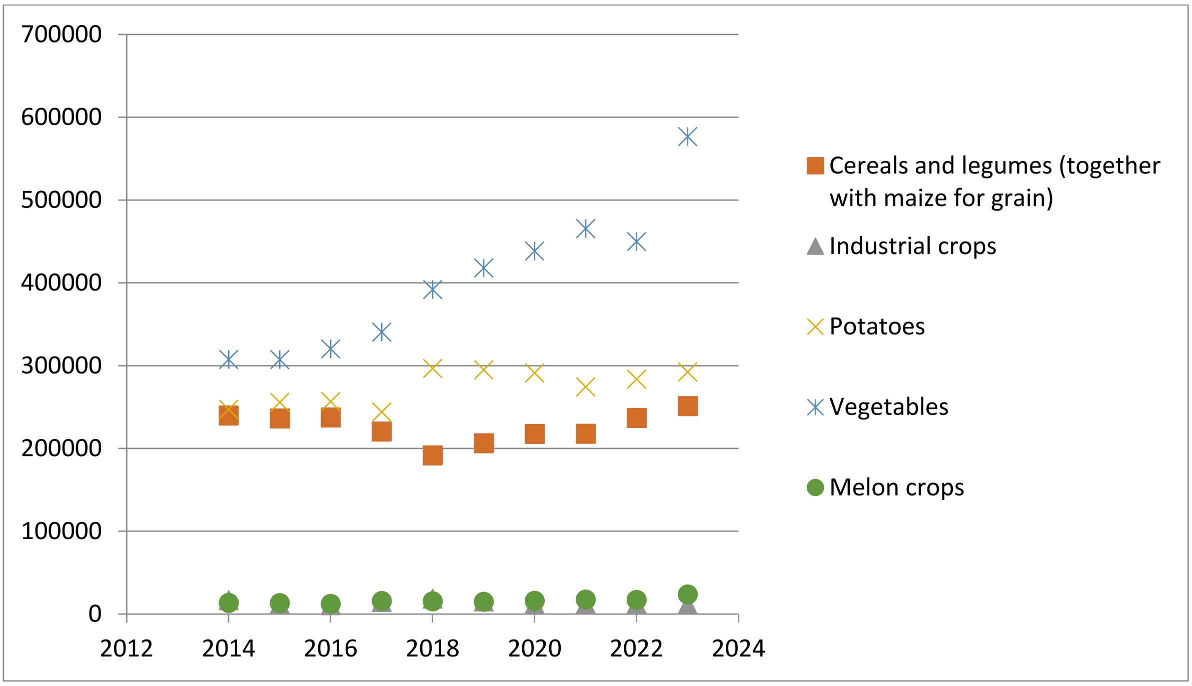

Figure 19. Agricultural crop production from 2014-2023; CDRS

Table 9. Synthesis of Agricultural Crop Trends in Cities and Districts of Republican Subordination (CDRS)

Crop Category	Area Trend (2014–2023)	Production Trend (2014–2023)	Key Insights
Cereals and legumes	Decreased (−18.6%)	Increased (+4.7%)	Area decreased, but yield improved—indicates better efficiency
Industrial crops	Decreased (−26.6%)	Decreased (−31.6%)	Notable decline in both area and output—the sector needs support or restructuring
Potatoes	Increased (+60.4%)	Increased (+18.3%)	Significant area expansion; moderate production growth; possible yield drop
Vegetables	Increased (+57.7%)	Increased (+87.5%)	Strong dual growth in area and productivity—high-value and strategic crop
Melon crops	Decreased (−31.2%)	Increased (+76.4%)	Smaller area but much higher productivity—shift to intensive farming methods

This section presents a detailed analysis of the interrelationships between key climatic variables (maximum temperature, minimum temperature, and precipitation) and various agricultural indicators (crop area and production for cereals, industrial crops, potatoes, vegetables, and melons) in Tajikistan. The relationships are quantified using Pearson correlation coefficients and visualized through a correlation heatmap, as depicted in Figure 20. The correlation heatmap (Figure 20) visually represents the Pearson correlation coefficient (r)

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for every pair of variables in the dataset. The Pearson correlation coefficient is a measure of the linear relationship between two continuous variables, ranging from -1 to +1.

Strong Positive Correlation with MaxTemp and MinTemp: A striking observation is the pervasive and strong positive correlation (mostly above r>0.90) between both MaxTemp and MinTemp and the Crops_Area and Production of Cereals, Industrial, Vegetables, and Melons. For instance, MaxTemp exhibits correlations of r=0.99 with Crops_Area_Cereals and r=0.98 with Crops_Area_Vegetables, alongside similar high correlations with their respective production outputs. MinTemp also mirrors these strong positive relationships.

Implication: This distinct pattern highlights that potatoes in Tajikistan might have different climatic requirements or cultivation practices compared to cereals, industrial crops, vegetables, and melons. Their relatively stronger positive correlation with precipitation suggests a greater reliance on rainfall, or that they are cultivated in areas where precipitation plays a more significant role in water supply, potentially in non-irrigated or rain-fed agricultural systems. This difference warrants further investigation into the specific agronomical practices and regional variations for potato cultivation.

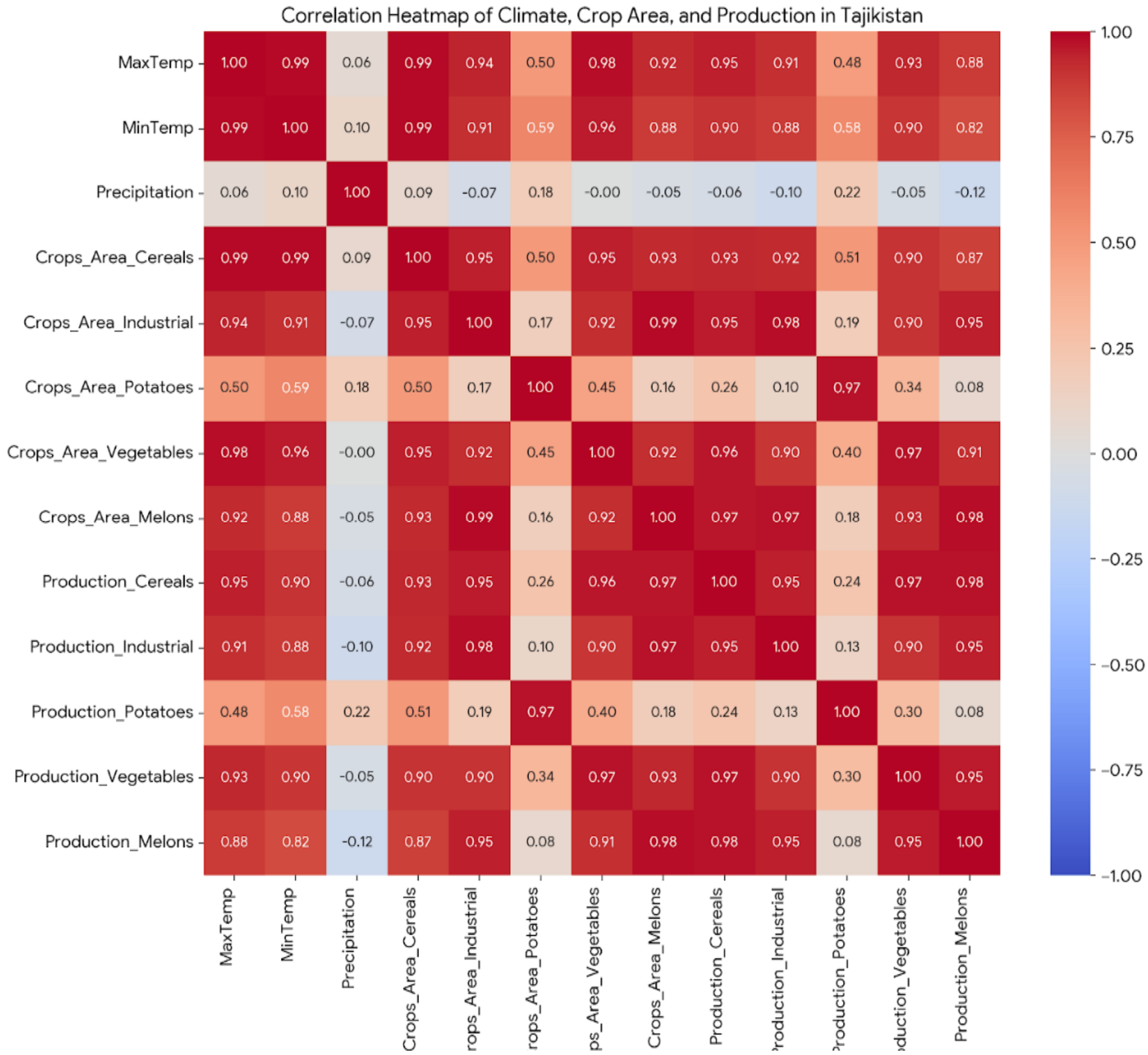

Figure 20. Correlation heatmap of climate, crop area and production in Tajikistan

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Table 10. Correlation Coefficient Between Weather Variables and Crop Production Indicators in Tajikistan

Weather Variables	Cultivated Area	Total Crop Production	Interpretation
Maximum Temperature	0.9907** (p < 0.001)	0.9469** (p < 0.001)	Very strong positive correlation
Minimum Temperature	0.9877** (p < 0.001)	0.9033** (p < 0.001)	Very strong positive correlation
Precipitation	0.0852 (ns)	−0.0582 (ns)	Weak and insignificant correlation

Correlation coefficients marked with double asterisks (**) are significant at p < 0.01., ns = not significant. Cultivated area and production values are aggregated across cereals, legumes, potatoes, vegetables, and melons for five regions of Tajikistan (n = 5).

Table 11. Visual summary by region

Visual Summary by Region				
Region	**Climate**	**Crop Area**	**Crop Production**	**Notes**
Tajikistan (avg)	National avg	Highest	Highest	Summed-up stats of all regions.
Khatlon	Warm & moderate rain	High	Highest	Best region for most crops.
Sughd	Warm & dry	High	High	Strong cereal and melon production.
CDRS	Moderate	Medium	Medium	Balanced conditions.
Badakhshan	Cold & dry	Very low	Very low	Cold weather limits crops.

Table 10 presents the correlation coefficients between key weather variables and agricultural performance indicators across five regions of Tajikistan. The analysis reveals a strong and statistically significant positive relationship between temperature and both the area under cultivation and total crop production. Maximum temperature demonstrates a particularly high correlation with cultivated area (r = 0.9907) and crop production (r = 0.9469), indicating that regions with higher temperatures, such as Khatlon and Sughd, tend to have greater agricultural output. Similarly, minimum temperature also shows strong positive correlations (r = 0.9877 with area and r = 0.9033 with production), reinforcing the importance of thermal conditions in supporting crop growth. In contrast, precipitation displays a weak and statistically insignificant correlation with both variables (r = 0.0852 and r = -0.0582, respectively), suggesting that rainfall does not play a major role in determining agricultural performance. This pattern implies that irrigation infrastructure likely compensates for limited or inconsistent rainfall and that temperature is a more reliable predictor of agricultural productivity in Tajikistan. These findings emphasize the need for climate-responsive agricultural planning and investments in water management systems, particularly in regions with less favorable thermal conditions. Table 11 provides a high-level overview of climatic conditions, crop area, and crop production

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across Tajikistan's main administrative regions. The table visually summarizes how varying regional climates directly influence agricultural activity and output across Tajikistan, highlighting the strong agricultural potential of warmer regions like Khatlon and Sughd versus the limitations in colder, drier areas like Badakhshan.

7. Conclusion

Despite these formidable climatic challenges, the total area under agricultural cultivation has remained relatively stable, even showing slight overall increases. However, this stability masks significant shifts in the types of crops cultivated. Fluctuations in cereal and industrial crop areas, alongside notable increases in land allocated to potatoes and vegetables, suggest that farmers are already implementing emergent adaptation strategies in response to changing climatic conditions and evolving market demands. This indicates a proactive, albeit potentially reactive, move towards crop diversification and enhanced food self-sufficiency at the local level, aiming to optimize yields under altered climatic regimes.

In conclusion, the period from 2014 to 2023 provides clear and compelling evidence of climate change in Tajikistan, characterized by pervasive rising temperatures, concerning declines in precipitation, and consequential shifts in agricultural patterns. These changes collectively pose significant risks to both environmental stability and the agricultural sector, which remains an indispensable cornerstone of the national economy and rural livelihoods. The findings underscore the urgent and imperative need for the implementation of robust adaptive strategies. These must include, but are not limited to, the development of enhanced water resource management systems, the promotion and cultivation of climate-resilient crop varieties, and comprehensive institutional support for farmers to ensure the long-term sustainability and resilience of Tajikistan's agricultural sector in the face of ongoing climate change. Future research should delve deeper into the specific socio-economic impacts of these climatic shifts on farming communities, assess the effectiveness of current adaptive measures, and explore the potential for innovative agricultural technologies and practices to further bolster climate resilience. Proactive policy interventions, informed by detailed scientific data, are essential to safeguard the country's ecological integrity, ensure sustainable food security, and protect the well-being of its population in a warming world.

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