# Assessment of temperature and precipitation trends in Kashkadarya, Uzbekistan

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**Abstract.** Climate change is one of the most important environmental issues that occur human-induced with large-scale social, economic, and environmental impacts. Climate models, which have been widely performed in the last decades, allow a study of change in climate variables and their impact on the environment. The present study was conducted to study changes in temperature and precipitation between 2006-2041 in the southern part of Uzbekistan. The results showed that the average temperature decreased from 14.53 °C during 2006-2010 to 14.40 °C during 2011-2015. Monthly average minimum temperature ranges (increases) from east to west in the region during all months of the year for both shared socio-economic pathways in 2021-2040. The minimum and maximum precipitation amount constituted 11.23 mm and 55.91 mm in the region, correspondingly within 2006-2010, whereas these amounts increased during the second period (2011-2015), 11.96 mm and 60.28 mm. Precipitation will not change sharply from SSP2.6 to SSP8.5 from 2021 to 2040.

## 1 Introduction

Climate change is an important issue in the economic sectors of countries. Extreme weather conditions increase the risk of natural disasters and threaten food security. The consequences of climate change are global and unprecedented in scale. Suppose today's decisive action directed to impact climate change studies is not considered. In that case, the subsequent adaptation to climate change will require a lot of effort and expense.

According to an IPCC special report on the impacts of global warming of 1.5 °C, global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Respectively, there is high confidence that risks linked with the climate will be higher than present. The magnitude and rate of warming, geographic location, levels of development and vulnerability, and the choices and implementation of adaptation and mitigation options play a major role in this case (high confidence) [1].

Climate change can affect food security in many ways. One of the direct impacts is the influence on crop yield [2–4]. Also impact of climate change on water availability [5–7]

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and water quality, pests, and diseases [8,9] are considered indirect impacts. Another way of influencing is changing biomass and nutrient quality by shifting the carbon dioxide level in the atmosphere [10].

Many studies applied various methods to analyze the impact of climate change on the main caloric intake crops of the body, wheat, rice, corn, and soybeans. By applying multi-method analysis, different studies have revealed different results. Most of the results from different studies show that temperature harms crop yields on a global scale, which is generally supported by similar effects on a country and site scale [11–14].

According to the results of the analysis of multiple methods, if there is no carbon dioxide fertilization, effective adaptation, and genetic improvement, for every degree Celsius increase in the global average temperature, the global average wheat yield will be reduced by 6.0%, the average rice yield will decrease by 3.2%, and the average maize yield by 7.4% and average soybeans yield by 3.1% [4].

However, the results are quite different between crops and geographic regions. Local scale-based assessments are required to prevent future climate impacts on major world crops and ensure food security for the growing world population.

Conducted assessment by the World Bank shows that Uzbekistan is highly vulnerable to climate change impact, based on the integrated indicators [15]. According to the ranking of Uzbekistan's territory by the degree of vulnerability to climate change, Kashkadarya attributed the medium vulnerable territories to climate change.

In Uzbekistan, the average warming rate is 0.27ºC over ten years. According to the statistical downscaling results (method of downscaling, which is based on the developed statistical relationship between the historically observed climate data and the output of the climate model for the same historical period) of global climate models, the growth of average annual air temperature by regions based on the GHGs emission scenarios will continue. The annual mean temperature may reach 1.3 to 2.1°C by 2030, 1.8 to 3.3°C by 2050, and 2.0 to 5.4°C by 2085.

Analyses of variations in the total annual precipitation over the period 1950-2013 indicate that, in most cases, decreasing in precipitation amount is observed in the southern plains of Uzbekistan (in Bukhara and Kashkadarya). Moreover, stronger trends towards a decrease in the total annual precipitation amounts are possible in the southern part of the region (up to 18-22% by 2071-2090 for extreme GHGs emission scenarios). An increase in precipitation amount in winter and its decrease in the rest of the seasons are expected by all emission scenarios and time intervals (by 2090) for the northern part of Uzbekistan. Retention of the current rates of precipitation amount in winter and their decrease in the rest of the seasons are expected for the southern part of the republic [16].

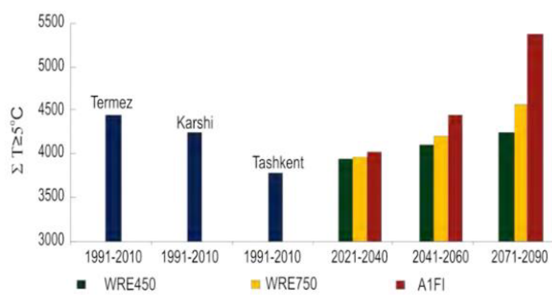


**Fig.1.** Comparison of 20-year average sums of effective air temperature above 5°C for Southern meteorological stations of Uzbekistan (Karshi, Termez) with data scenario assessments for Tashkent meteorological station [16].

Besides, that increasing temperature during the vegetation period causes agriculture by increasing effective air temperature. According to the UZHYDROMET, an increase in sums of effective air temperatures will be 1.5-2 times more in 2030 than now (Fig. 1). These changes require adaptation activities such as revision of current cropping patterns, zoning new crop species and varieties to provide sustainable crop productivity in the area.

All the above-mentioned bio-physical changes in the environment and the climate are often linked with anthropogenic influences' combined effects. To understand and analyze interactions between objects, scientists need useful tool as climate models. They effectively objectively simulate the interactions and feedback and explore their impacts on climate change.

The Coupled Model Intercomparison Project (CMIP), organized under the World Climate Research Programme's (WCRP) Working Group on Coupled Modelling (WGCM), allows access to the output of the variable from several climate models. One of them has been created by the Beijing Climate Center (BCC) with the name of BCC-CSM2-MR for the scientific community to generate climate information and make it available for scientific research [17].

The latest update on expected future climate change is based on a new generation of climate models of CMIP6 constrain in SSP1-2.6, SSP2-4.5, SSP4-6.0, and SSP5-8.5 scenarios. They allow for analyses of future mitigation, adaptation, and impacts that account for climate and societal change in a coherent fashion.

In this study, historical and future climate monthly values of precipitation and monthly average, minimum and maximum temperature have been studied.

The research objective of the paper is to study temporal and spatial change as well as a trend of change of climate variables in Kashkadarya province.

This paper is structured as follows: Section 1 presents the results of analyzing monthly values of temperature and precipitation; section 2 describes the monthly average, minimum, and maximum temperature change during 2021-2040 in Kashkadarya; section 3 includes conclusions.

# 2 Methods and Materials

## 2.1 Study area

The region's territory is mainly located in the Kashkadarya river basin (Fig. 2). The Zarafshan and Gissar ridges surround it in the northeast and southeast. There are hills between mountains and plains. Much of the plain consists of the Karshi Desert, bounded on the west by the Sandikli and Kyzylkum Deserts.

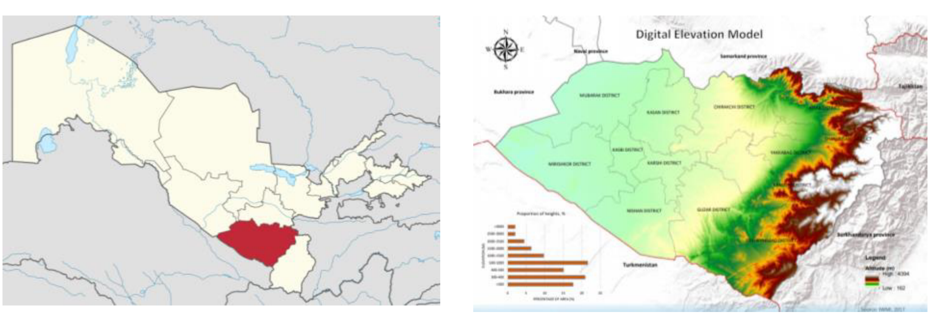


**Fig. 2.** a) boundary map of Kashkadarya b) digital elevation model map of Kashkadarya [18]

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The climate is continental. Summers are long (155-160 days), hot and dry. The average temperature in January is from 0.2°C to 1.9°C, and in July, from 28°C to 29.5°C. The maximum temperature approximately constitutes 45°C. This explains the high degree of evapotranspiration. The lowest temperature is - 20°C. Annual precipitation is 290-300 mm in the plains, 520-550 mm in the hills, and 550-650 mm in the mountains. Rain falls mainly in spring and winter, and *garmsel* blows in summer.

The vegetation period in the plains lasts about 290-300 days. The main river is the Kashkadarya. Rivers are saturated with snow, rain, and glacial water. River water is mainly used for irrigation.

### 2.2 Data collection

The climate data (precipitation and temperature) has been obtained from CRU TSv.4.01 (https://crudata.uea.ac.uk/cru/data/hrg/). This dataset spans from 1901.1-2016.12 and covers the globe; monthly data has a spatial resolution of 0.5° (about 55km). The monthly total precipitation and mean temperature dataset was extracted using a rectangular box including the study area within 2006-2010 and 2011-2015 time scales. Besides, the climate data was spatially downscaled from 55 km to 8 km using Delta downscaling framework [19].

Another historical data for precipitation data is downscaled from CRU-TS-1.03 generation by the Climatic Research Unit, University of East Anglia, using WorldClim 2.1 for bias correction. The variable refers to the total monthly precipitation (mm) for each month for 10 years (2010-2018). The spatial resolution is 2.5 minutes (~21 km2) at the equator.

The future precipitation, minimum and maximum temperature data have been projected in CMIP6. Precipitation data were downscaled and calibrated (bias correction) with WorldClim v2.1 as the baseline climate. Monthly precipitation values were processed for nine global climate models (GCMs): BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MRI-ESM2-0, and for four shared socio-economic pathways (SSPs): 126, 245, 370, and 585. This paper uses only the BCC-CSM2-MR global climate model, and SSP 2.6 and SSP 8.5 Shared Socio-economic Pathways with a spatial resolution of 2.5 minutes during 2021-2040[1].

### 2.3 Delta downscaling

Downscaling gridded data gives the data fine-scale and often involves regression and Delta downscaling methods [20]. Using Delta downscaling method compared to common direct interpolation of low-resolution sources to higher spatial resolution, output data with high-resolution orographic effects not presented in low-resolution input grids can be obtained [21]. The Delta downscaling process of input grid data is presented in [19]. This paper uses the delta downscaling method to make gridded data with 55km spatial resolution of CRU data to 8km resolution.

### 2.4 Mann Kendall trend test

The non-parametric Mann-Kendall method examines the monotonic trend in the climatic factors [22–26]. In this study, the Mann-Kendall trend test at the 95% confidence level is

[1] https://worldclim.org/data/cmip6/cmip6_clim2.5m.html

used to determine the trend of the climatic data (precipitation and temperature) at the 95% confidence level during 2006-2015.

# 3 Results and Discussion

## 3.1 Temporal and spatial change in monthly average temperature and total precipitation

The average monthly temperature decreased from the west to the East of Kashkadarya during both periods (2006-2010 and 2011-2015) (Fig.3). The minimum temperature decreased in the second period from -1.01 °C to -1.05 °C. In contrast, the maximum temperature increased from 17.48 °C to 17.64 °C in the second period (Fig.3). The average monthly average temperature decreased from 14.62 °C from 2006 to 2010 to 14.36 °C from 2011 to 2015 (Table-1). The average monthly total precipitation increased from 253mm during 2006-2010 to 279mm during 2011-2015 (Table 1).

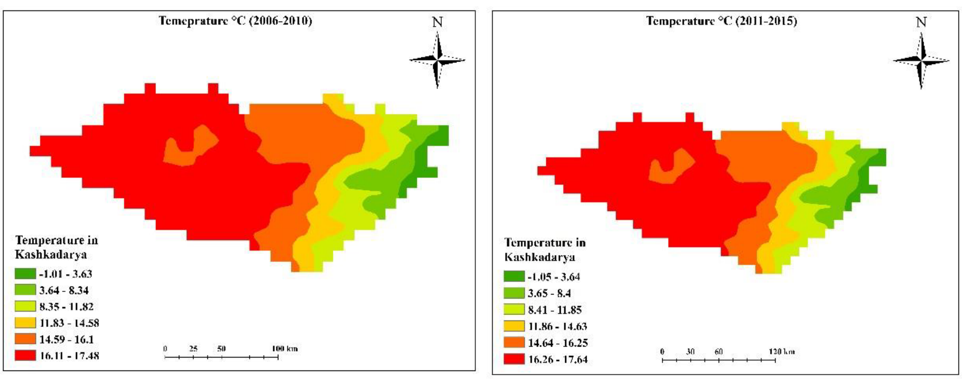


**Fig. 3.** Geographic distribution of average monthly temperature in Kashkadarya during 2006-2010 and 2011-2015

**Table 1.** Changes in precipitation (mm) and temperature (°C) from 2006-2010 to 2011-2015

| Year | Temperature (°C) | Precipitation (mm) |
|---|---|---|
| 2006-2010 | *14.62* | *353* |
| 2011-2015 | *14.36* | *379* |

Average monthly total precipitation ranges (increases) from west to east in Kashkadarya (Fig.4) in the first period (2006-2010). The minimum and maximum precipitation amount constituted 11.23 mm and 55.91 mm in the region, correspondingly within 2006-2010, whereas these amounts increased during the second period (2011-2015), 11.96 mm and 60.28 mm, respectively (Fig.4).

Total annual precipitation amount in the period of 2006-2015 in the region. During this period, 2010 and 2009 can be the year with the least (290 mm) and the most precipitation (477 mm) in Kashkadarya (Fig.5). The highest temperature was observed in 2010 (15.08°C), while the lowest temperature (13.81°C) was in 2014 (Fig.5).

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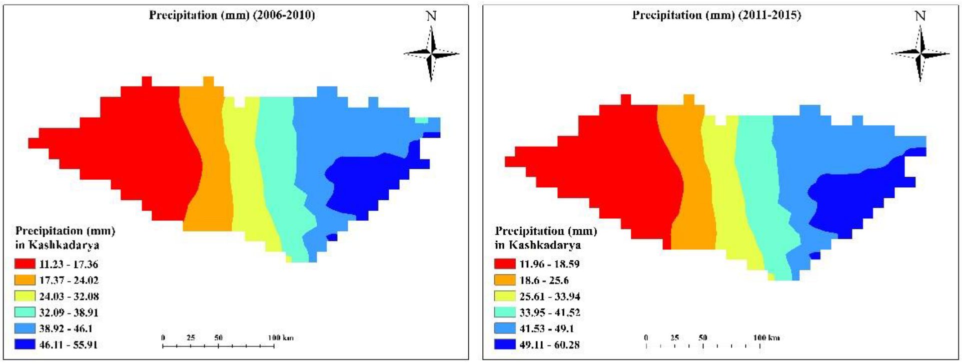


**Fig. 4** Geographic distribution of average of total monthly precipitation (mm) in Kashkadarya during 2006-2010 and 2011-2015

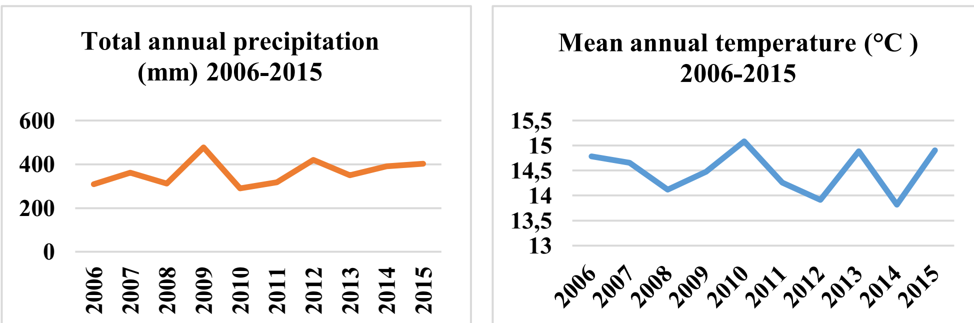


**Fig. 5.** Annual changes of precipitation (mm) and temperature (°C) during 2006-2015

## Trend analysis

The Mann-Kendall trend analysis shows no significant trend in monthly average temperature (Z=0.22) and monthly total precipitation (Z=-0.26) in the period of 2006-2010 (Table 2). The period of 2011-2015 also shows an insignificant trend in monthly average temperature (Z=0.34) and monthly total precipitation (Z=-0.18) (Table 2).

**Table 2.** Mann-Kendall trend results of monthly climate variables

| | MK results during 2006-2010 | | MK results during 2011-2015 | |
|---|---|---|---|---|
| | Precipitation | Temperature | Precipitation | Temperature |
| Z | -0.26 | 0.22 | -0.18 | 0.34 |

## 3.2 Projected climate variables during 2021-2040

### *3.2.1 Projected average monthly maximum temperature during 2021-2040*

Projected monthly average maximum temperature increases in January, March, September, November, and December (Fig.7) while the variable decreases in February, April, May, June, July, August, and October for SSP8.5 case than SSP2.6 in Kashkadarya (Fig.5) and ranges (increases) from east to west (Fig.6).

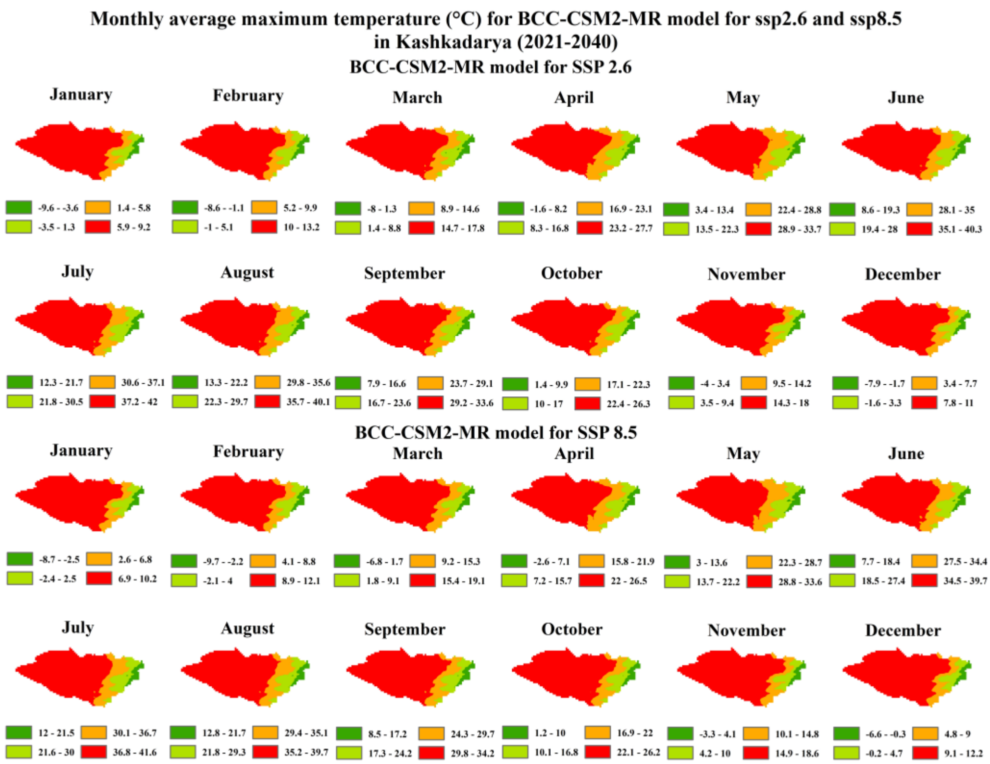


**Fig. 6.** Geographic distribution of the average of monthly maximum temperature (°C) for BCC-CSM2-MR model for SSP2.6 and SSP8.5 in Kashkadarya during 2021 -2040

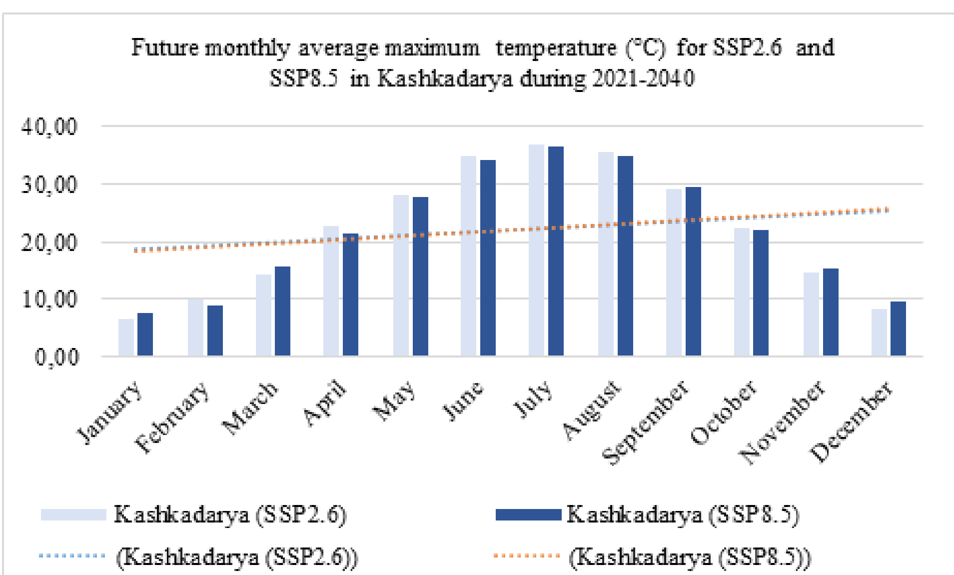


**Fig. 7.** Future projected monthly average maximum temperature (°C) for SSP2.6 and SSP8.5 in Kashkadarya during 2021-2040

### *3.2.2 Projected average monthly minimum temperature during 2021-2040*

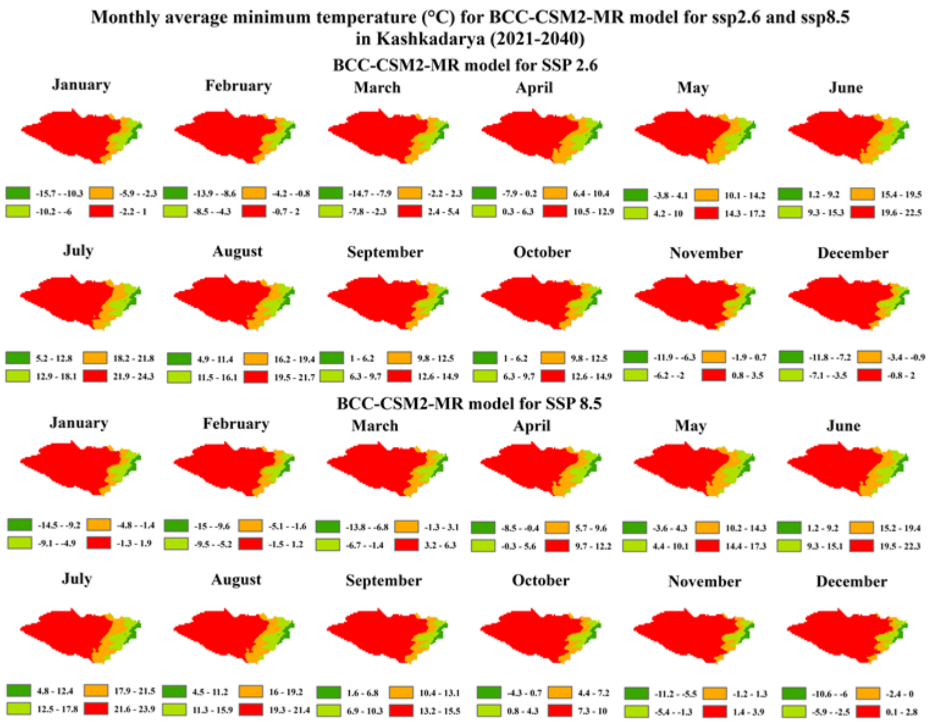


**Fig. 8.** Geographic distribution of the average of monthly average minimum temperature (°C) for BCC-CSM2-MR model for SSP2.6 and SSP8.5 in Kashkadarya during 2021 -2040

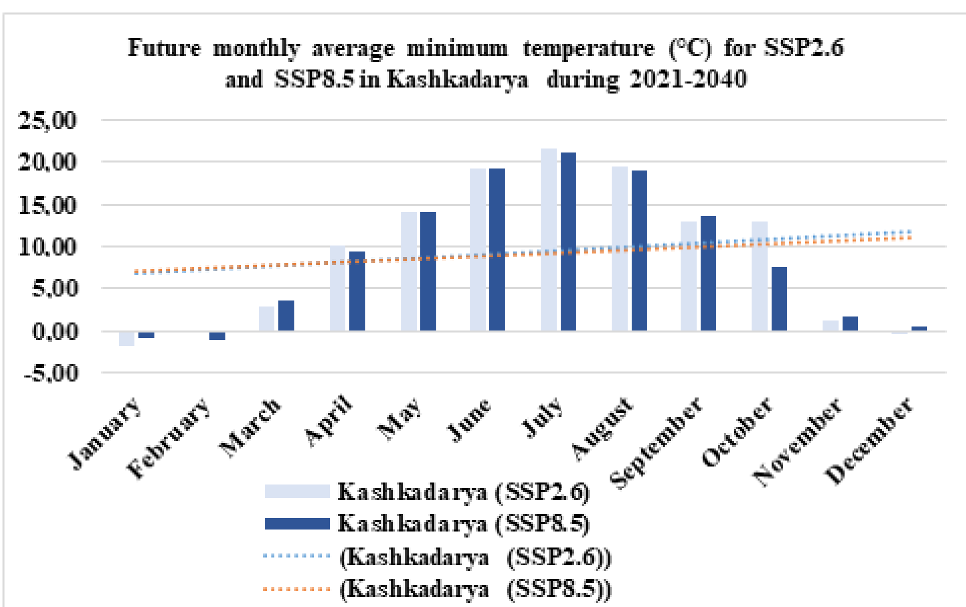


**Fig. 9.** Future projected monthly average minimum temperature (°C) for SSP2.6 and SSP8.5 in Kashkadarya during 2021-2040

The projected monthly average minimum temperature increases during January, March, May, September, November, and December while it decreases during February, April, May, September, November, and December for the SSP8.5 case than SSP2.6 in Kashkadarya during 2021-2040 (Fig.9). Monthly average minimum temperature ranges (increases) from east to west in the region during all months of the year for both shared socio-economic pathways in the period of 2021-2040 (Fig.8).

### *3.2.3 Projected monthly precipitation during 2021-2040*

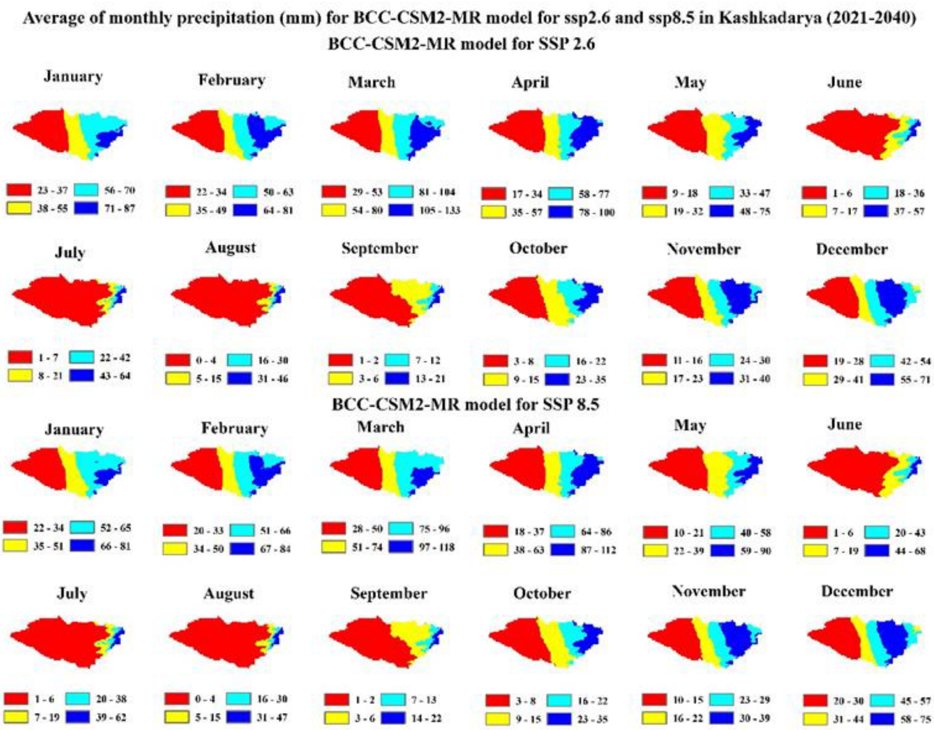


**Fig. 10.** Geographic distribution of average of monthly precipitation (mm) for BCC-CSM2-MR model for SSP2.6 and SSP8.5 in Kashkadarya during 2021 -2040

Precipitation decreases in January, March, and November from SSP2.6 to SSP8.5 in Kashkadarya while increases in February, April, May, June, and December (Table 3, Fig.12). In July, August, September, October, precipitation remains in SSP8.5 as in the SSP2.6 in the area (Fig.12). The increasing trend can be observed from west to east of the region during all months of the years for both socio-economic pathways (Fig.10).

Fig.12 presents the spatial distribution of the average monthly precipitation (mm) in Kashkadarya during 2021-2040 for SSP2.6 and SSP8.5. It can be concluded that based on these figures, precipitation will not change sharply from SSP2.6 to SSP8.5.

Temperature and precipitation are two major factors that affect global climate change. Several studies distinguish, assess, and predict the change in these two variables for the future [16, 27–29].

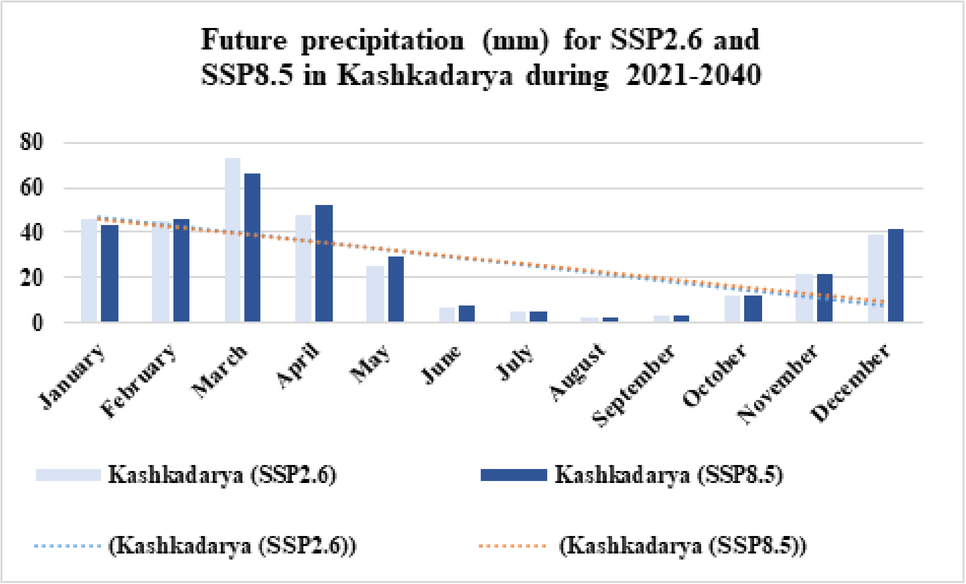


**Fig. 11** Future projected monthly precipitation (mm) for SSP2.6 and SSP8.5 in Kashkadarya during 2021-2040

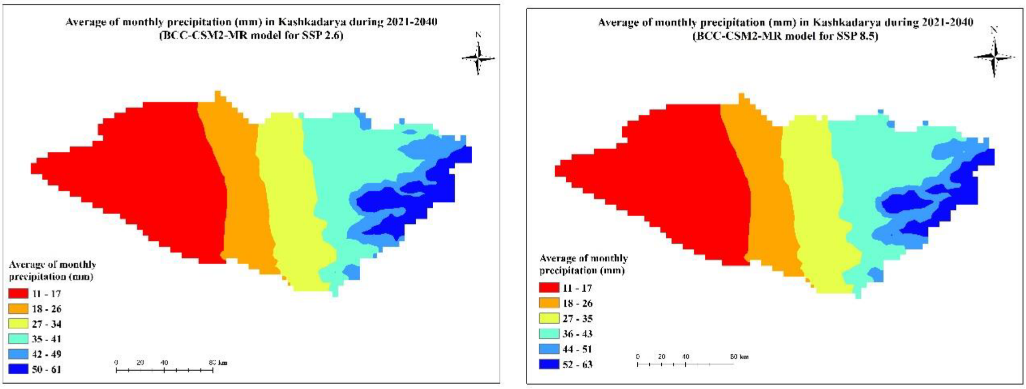


**Fig. 12.** Geographic distribution of the average of monthly precipitation (mm) in Kashkadarya during 2021-2040 (BCC-CSM2-MR model for SSP2.6 and SSP8.5)

According to Erdanaev [27], some scientists believe that changes in temperature and precipitation due to increased carbon dioxide may benefit crops. However, these changes may bring about land degradation in grassland and pasturelands.

According to the results of the survey which were taken in the southern part of Uzbekistan show that most of the local population directly experiences and suffers from the negative effects of climate change, such as increased water shortages and many agricultural pests and diseases, a decrease in income due to the increase in the number of insect pests as well decrease in crop yield and quality.

## 4 Conclusions

This study explored the changes in precipitation, $T_{avg}$, $T_{max}$, and $T_{min}$ region between 2006-2015 and future projected changes between 2021-2040 over the Kashkadarya. The major conclusions can be summarized as follows:

1. The study shows that the average temperature decreased from 14.53 °C to 14.40 °C between 2006-2010 and 2011-2015.
2. Monthly average maximum temperature increases in January, March, September, November, and December from east to west. The variable decreases in February, April, May, June, July, August, and October for SSP8.5 cases than SSP2.6 during 2021-2040.
3. Monthly average minimum temperature increases during January, March, May, September, November, and December while it decreases during February, April, June, July, August, and October for the SSP8.5 case than SSP2.6 during 2021-2040.
4. Monthly average minimum temperature ranges (increases) from east to west in the region during all months of the year for both shared socio-economic pathways in 2021-2040.
5. The minimum and maximum precipitation amount constituted 11.23 mm and 55.91 mm in the region, correspondingly within 2006-2010, whereas these amounts increased during the second period (2011-2015), 11.96 mm and 60.28 mm.
6. Precipitation will not change sharply from SSP2.6 to SSP8.5.

## References

1. IPCC: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) (2018)
2. Faye, Babacar, Heidi Webber, Jesse B. Naab, Dilys S. MacCarthy, Myriam Adam, Frank Ewert, John P.A. Lamers, et al. "Impacts of 1.5 versus 2.0 °c on Cereal Yields in the West African Sudan Savanna." *Environmental Research Letters* 13, no. 3 (March 1, 2018): 034014. https://doi.org/10.1088/1748-9326/aaab40.
3. Zimmermann, Andrea, Heidi Webber, Gang Zhao, Frank Ewert, Johannes Kros, Joost Wolf, Wolfgang Britz, and Wim de Vries. "Climate Change Impacts on Crop Yields, Land Use and Environment in Response to Crop Sowing Dates and Thermal Time Requirements." *Agricultural Systems* 157 (October 1, 2017): 81–92. https://doi.org/10.1016/J.AGSY.2017.07.007.
4. Zhao, Chuang, Bing Liu, Shilong Piao, Xuhui Wang, David B. Lobell, Yao Huang, Mengtian Huang, et al. "Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates." *Proceedings of the National Academy of Sciences of the United States of America* 114, no. 35 (2017): 9326–31. https://doi.org/10.1073/pnas.1701762114.
5. Abbaspour, K. C., E. Rouholahnejad, S. Vaghefi, R. Srinivasan, H. Yang, and B. Kløve. "A Continental-Scale Hydrology and Water Quality Model for Europe: Calibration and Uncertainty of a High-Resolution Large-Scale SWAT Model." *Journal of Hydrology* 524 (May 1, 2015): 733–52. https://doi.org/10.1016/J.JHYDROL.2015.03.027.

6. Hanasaki, N, S Fujimori, T Yamamoto, S Yoshikawa, Y Masaki, Y Hijioka, M Kainuma, et al. "A Global Water Scarcity Assessment under Shared Socio-Economic Pathways-Part 2: Water Availability and Scarcity." *Hydrol. Earth Syst. Sci* 17 (2013): 2393–2413. https://doi.org/10.5194/hess-17-2393-2013.
7. Djumaboev, Kakhramon, Oyture Anarbekov, Bunyod Holmatov, Ahmad Hamidov, Zafar Gafurov, Makhliyo Murzaeva, Janez Sušnik, Shreedhar Maskey, Hamid Mehmood, and Vladimir Smakhtin. "Surface Water Resources." *The Aral Sea Basin: Water for Sustainable Development in Central Asia*, September 17, 2019, 25–38. https://doi.org/10.4324/9780429436475-3.
8. Reyer, Christopher P.O., Ilona M. Otto, Sophie Adams, Torsten Albrecht, Florent Baarsch, Matti Cartsburg, Dim Coumou, et al. "Climate Change Impacts in Central Asia and Their Implications for Development." *Regional Environmental Change* 17, no. 6 (2017): 1639–50. https://doi.org/10.1007/s10113-015-0893-z.
9. Lioubimtseva, E., and G. M. Henebry. "Climate and Environmental Change in Arid Central Asia: Impacts, Vulnerability, and Adaptations." *Journal of Arid Environments*. Academic Press, November 1, 2009. https://doi.org/10.1016/j.jaridenv.2009.04.022.
10. Brouder, Sylvie M., and Jeffrey J. Volenec. "Impact of Climate Change on Crop Nutrient and Water Use Efficiencies." *Physiologia Plantarum* 133, no. 4 (2008): 705–24. https://doi.org/10.1111/j.1399-3054.2008.01136.x.
11. Zhao, Chuang, Shilong Piao, Yao Huang, Xuhui Wang, Philippe Ciais, Mengtian Huang, Zhenzhong Zeng, and Shushi Peng. "Field Warming Experiments Shed Light on the Wheat Yield Response to Temperature in China." *Nature Communications* 7 (2016): 1–8. https://doi.org/10.1038/ncomms13530.
12. Sommer, R., M. Glazirina, T. Yuldashev, A. Otarov, M. Ibraeva, L. Martynova, M. Bekenov, et al. "Impact of Climate Change on Wheat Productivity in Central Asia." *Agriculture, Ecosystems and Environment* 178 (September 15, 2013): 78–99. https://doi.org/10.1016/j.agee.2013.06.011.
13. Shindell, Drew T. "Crop Yield Changes Induced by Emissions of Individual Climate-Altering Pollutants." *Earth's Future* 4, no. 8 (2016): 373–80. https://doi.org/10.1002/2016EF000377.
14. Moore, Frances C., and David B. Lobell. "The Fingerprint of Climate Trends on European Crop Yields." *Proceedings of the National Academy of Sciences of the United States of America* 112, no. 9 (2015): 2970–75. https://doi.org/10.1073/pnas.1409606112.
15. WB. "Adapting to Climate Change in ECA." Vol. 5, 2009. www.worldbank.org/eca.
16. Centre of Hydrometeorological Service Republic of Uzbekistan. "The Third National Communication of the Republic of Uzbekistan under the UN Framework Convention on Climate Change," 2016, 221. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15838-Uzbekistan Country Profile-WEB.pdf.
17. Wu, Tongwen, Yixiong Lu, Yongjie Fang, Xiaoge Xin, Laurent Li, Weiping Li, Weihua Jie, et al. "The Beijing Climate Center Climate System Model (BCC-CSM): The Main Progress from CMIP5 to CMIP6." *Geoscientific Model Development* 12, no. 4 (2019): 1573–1600. https://doi.org/10.5194/gmd-12-1573-2019.
18. Gafurov, Z.; Eltazarov, S.; Akramov, B.; Djumaboev, K.; Anarbekov, O.; Solieva, U. Geodatabase and diagnostic atlas: Kashkadarya Province, Uzbekistan. Colombo, Sri Lanka: International Water Management Institute (IWMI). (2018) 74p. doi: 10.5337/2018.217

19. Peng, Shouzhang, Chengcheng Gang, Yang Cao, and Yunming Chen. "Assessment of Climate Change Trends over the Loess Plateau in China from 1901 to 2100," 2017. https://doi.org/10.1002/joc.5331.
20. Peng, Shouzhang, Yongxia Ding, Zhongming Wen, Yunming Chen, and Yang Cao. "Spatiotemporal Change and Trend Analysis of Potential Evapotranspiration over the Loess Plateau of China during 2011 – 2100." *Agricultural and Forest Meteorology* 233 (2017): 183–94. https://doi.org/10.1016/j.agrformet.2016.11.129.
21. Mosier, Thomas M, F Hill, and Kendra V Sharp. "30-Arcsecond Monthly Climate Surfaces with Global Land Coverage" 2188, no. September 2013 (2014): 2175–88. https://doi.org/10.1002/joc.3829.
22. Atta-ur-Rahman, and Muhammad Dawood. "Spatio - Statistical Analysis of Temperature Fluctuation Using Mann – Kendall and Sen' s Slope Approach." Climate Dynamics, 2016. https://doi.org/10.1007/s00382-016-3110-y.
23. Gocic, Milan, and Slavisa Trajkovic. "Analysis of Changes in Meteorological Variables Using Mann-Kendall and Sen' s Slope Estimator Statistical Tests in Serbia." *Global and Planetary Change* 100 (2013): 172–82. https://doi.org/10.1016/j.gloplacha.2012.10.014.
24. Blain, Gabriel Constantino. "The Mann-Kendall Test: The Need to Consider the Interaction between Serial Correlation and Trend." *Acta Scientiarum. Agronomy* 35, no. 4 (2013): 393–402. https://doi.org/10.4025/actasciagron.v35i4.16006.
25. Tüshaus, Julia, Olena Dubovyk, Asia Khamzina, and Gunter Menz. "Comparison of Medium Spatial Resolution ENVISAT-MERIS and Terra-MODIS Time Series for Vegetation Decline Analysis: A Case Study in Central Asia." *Remote Sensing* 6, no. 6 (2014): 5238–56. https://doi.org/10.3390/rs6065238.
26. Li, Zhi, Fen Li Zheng, and Wen Zhao Liu. "Spatiotemporal Characteristics of Reference Evapotranspiration during 1961-2009 and Its Projected Changes during 2011-2099 on the Loess Plateau of China." *Agricultural and Forest Meteorology* 154–155, no. November 2017 (2012). https://doi.org/10.1016/j.agrformet.2011.10.019.
27. Erdanaev, E., M. Kappas, A. Pulatov, and M. Klinge. "Short Review of Climate and Land Use Change Impact on Land Degradation in Tashkent Province." *International Journal of Geoinformatics*, December 1, 2015. https://doi.org/10.52939/IJG.V11I4.909.
28. Gafforov, Khusen, Anming Bao, Shavkat Rakhimov, Tie Liu, Farkhod Abdullaev, Liangliang Jiang, Khaydar Durdiev, Eldiiar Duulatov, Moldir Rakhimova, and Yerbolat Mukanov. "The Assessment of Climate Change on Rainfall-Runoff Erosivity in the Chirchik–Akhangaran Basin, Uzbekistan," 2021. https://doi.org/10.3390/su12083369.
29. Mukhamedjanov, Shukhrat, Azamat Mukhomedjanov, Rustam Sagdullaev, and Nazokat Khasanova. "Adaptation to Climate Change in Irrigated Agriculture in Uzbekistan*." *Irrigation and Drainage* 70, no. 1 (2021): 169–76. https://doi.org/10.1002/ird.2529.