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PROJECT

"Transboundary Water Management Adaptation in the Amu Darya Basin to Climate Change Uncertainties"

Report on positions

3.1.2.2. ***Studying the positive effect of climate change in the basin through shortened period of plant growing***

3.2. ***Developing proposals on water management in the context of climate change***

4.4. ***Presenting results and drafting a plan of dissemination***

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3.1.2.2. Studying the positive effect of climate change in the basin through shortened period of plant growing

In the reporting period, agro-meteorological parameters of crops were analyzed and finalized. The results are summarized in the paper "Accounting of potential positive effect of climate change on plant development processes" by Stulina G.V. and Solodkiy G.F.

Introduction

Central Asia is exposed heavily to climate change threats. The UzHydromet [1] forecasts that climate change would further lead to rising temperatures, changes in precipitation patterns, and more severe and prolonged droughts, with consequent worsening of water availability. The most probable scenarios for Central Asia imply the rise in average annual temperature by more than 4°C by 2080.

Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan share the *basin of the Amu Darya River.* The irrigated area occupies 4.5 Mha in the basin.

It is predicted [2] that the flow may decrease by 10-15% in the Amu Darya Basin. Hence, there is a need for serious efforts to be made for adaptation to climate change and mitigation of risks.

The earlier research results showed that the observed growth of thermal potential made it possible to sow crops earlier and contributed to more rapid accumulation of effective temperatures. This, first, will shorten plant development phases and crop growing season, as a whole, and, consequently, decrease water consumption.

1. Research objectives and implementation:

1. Evolution of bio-climatic potential was analyzed for all planning zones in annual dimension. The year 2000 was taken as a base year.
2. Calculations were made for the sums of effective temperatures > 5 ^{0}C, > 10 ^{0}C, and > 15 ^{0}C.
3. Graphs of the sum of effective temperatures were plotted over 2000-2050.
4. Information on climate change was prepared: transition through temperature threshold > 5 ^{0}C, > 10 ^{0}C, > 15 ^{0}C, which will serve as input for determination of sowing dates for different crops.
5. Graphs showing changes in transition through spring temperature thresholds > 5 ^{0}C, > 10 ^{0}C, > 15 ^{0}C.
6. Information was collected and analyzed on the desired sum of effective temperatures for each crop growth and development phase for crops grown in the basin.
7. The sums of effective temperatures were calculated and analyzed by plant development phase and changes in duration of those phases were studied.
8. The data was prepared for input into the DB to calculate crop water requirements.
9. Crop water requirements were calculated and analyzed.

2. Research methodology

The findings of the past research on climate change adaptation completed together with the McGill University from Canada [3] were used as a working assumption. It was found that a cumulative increase of temperature potential should result in shortening of the growing season of crops. Similar results were published by us together with V.Usmanov [4] earlier. However, those only referred to changes in dates of transition through the threshold values of plant growth and development - 5, 10, and 15°C, respectively for various crops. During further research under the

project "Central Asian Water" (CAWA) financed by the Federal German Foreign Office, it was decided to study an effect the changes in duration of growth phases of various plants and speeded up development of plants would have on crop water requirements, specifically on reduction of desired irrigation period. This work also took into account high temperatures that slow down development of plants until full cessation of cell growth. Such threshold temperature, for example, for cotton is 35 °C. Achieved research results for the Fergana Valley under the CAWA project showed [5,6] that the rise of thermal potential allows accumulating the sum of effective temperatures in a shorter time and sowing crops earlier. Firstly, this will allow shortening the crop development and growth phases and the growing season of a crop in general. Consequently this will decrease water requirements by more than 100 mm for cotton, as the main crop. Distribution of thermal resources should be considered as the basis for crop rotation and water-use plan. Taking into account the positive results achieved earlier, it was decided to use this experience in the analysis of bioclimatic potential and its change in the Amu Darya basin.
The Wurzburg University's REMO model was used for forecasts of climate change. This climatic model is based on the ECHAM 5 model developed at the Max Plank Institute (Germany). That is the model of global atmosphere circulation. It is used for calculation of global and regional models of climate change. The A1B scenario of average warming as a result of greenhouse gas emission was played in the model. Given model allowed constructing the artificial temperature and rainfall series until 2050. The modeling results were calibrated (G.F.Solodkiy).

3. Research results

3.1. Assessment of thermal resources and their forecast

The following thermal zones were singled out in Central Asia [5].

I. Hot zone – the sum of temperatures above 10^{o}C is more than 4000^{o} C (thermal resources are enough for growth and good ripening of cotton)

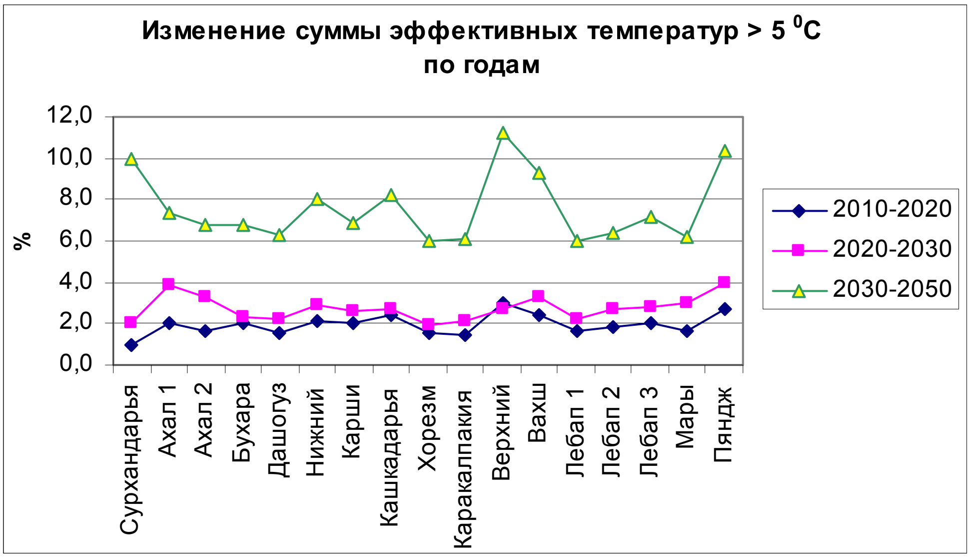
II. Warm zone - the sum of temperatures above 10^{o}C ranges from 2800^{o}C to 4000^{o}C (heat is not enough for good bearing of cotton but is sufficient for grapes, including early varieties).

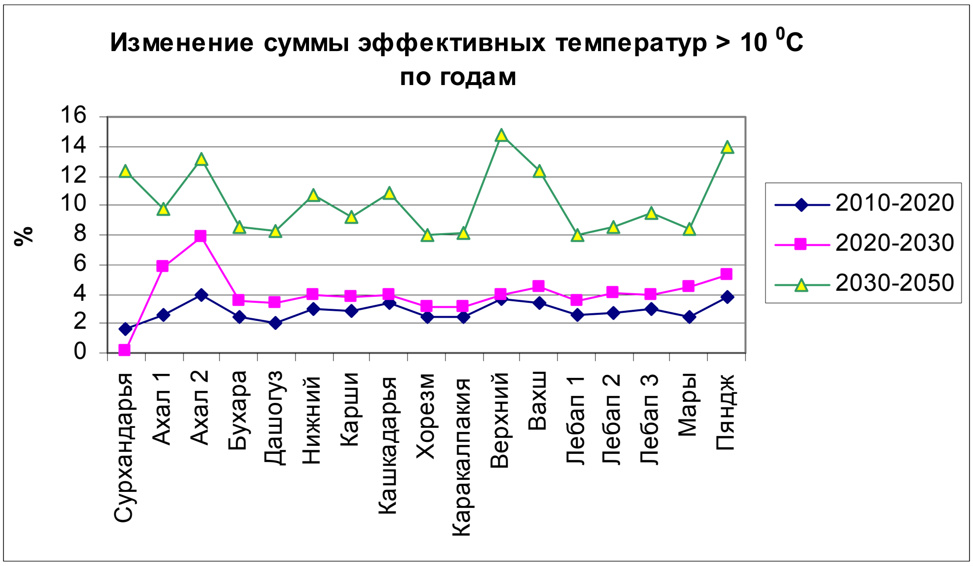
III. Cool zone - the sum of temperatures varies from 1000^{o}C to 2800^{o}C (thermal resources are not enough for ripening of grapes but are sufficient for growth of spiked cereals).

IV. Cold area - the sum of temperatures is less than 1000^{o}C (non-agricultural area).

The rate of crop development is closely linked to the effective temperature. The effective temperature is the difference between the mean daily temperature and the temperature at which development of any crop starts - lower limit of effective temperatures. The sum of the mean daily temperatures that are higher than the lower limit of temperature for one or another period (from sowing to sprouting, from sprouting to formation of 1^{st} leaf, for growing season) is the sum of effective temperatures. The lower limit of temperature varies depending on crop. For example, it is 5^{o}C for cereals and most fruits, 10^{o}C for cotton and 15 ^{o}C for heat-loving plants.
At the same daily air temperature, effective temperatures for crops having different temperature limits for start of their growth will vary.
For the analysis, more significant and universal temperature limits (> 5 ^{0}C, > 10 ^{0}C and > 15 ^{0}C) were chosen to assess bioclimatic potential.

The sum of effective temperatures > 5 ^{0}C varies within 4300-2600 ^{0}C; > 10 ^{0}C within 3100-1600 ^{0}C; and, > 15 ^{0}C within 2000-900 ^{0}C in the Amu Darya basin. According to the classification [7], this territory refers to warm zone and to northern boundary of cotton growing.
Comparison of the sums of effective temperatures in 2010-2020, 2020-2030 and 2030-2050 clearly showed (Fig.1.) an increase in these sums by 2030-2050 in all planning zones. 2000-2010 were considered as base years.





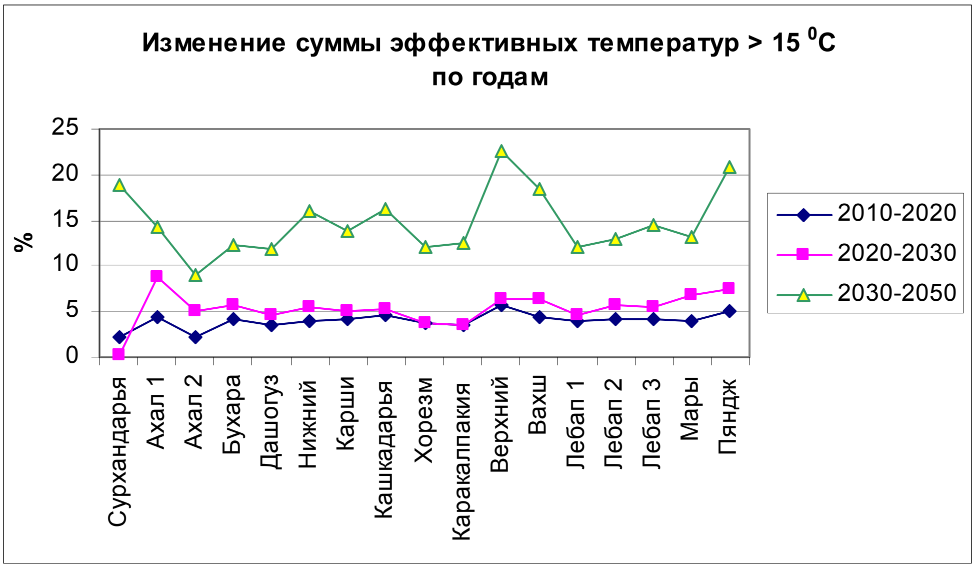


Figure 1. Evolution of thermal potential in the Amu Darya Basin

The use of bioclimatic resource in the future may be more optimal in formation of cropping pattern, selection of crop varieties and change of agronomic practices. Eventually, this should change water use planning.

3.2. Changes in the date of steady temperature transition

The date of steady spring temperature determines the main parameters, such as the beginning of growing season and sowing dates.

In the Amu Darya River basin, the steady transition of air temperature through 0oC, corresponding to the beginning of growth of early fruits (apricot, almond), is observed in the 2nd ten-days of February in Bukhara planning zone. Autumn transition through 0oC is observed in 2nd and 3rd ten-days of December. The duration of the period, when the air temperature is above 0oC is 280-310 days and 365 days in frost-free years.

Renewed growth of alfalfa, cereals and most fruits and spring growth of pasture grasses start when air temperature passes 5 0C. This transition occurs firstly in plain area of the basin in Bukhara planning zone at the end of February, in Akhal planning zone – in the first ten-days of March, in the rest parts of the basin – in March and in the mountainous areas – from the first ten-days of April. The duration of the period, when the air temperature is above 5oC varies for years and planning zones between 200 and 270 days; when the air temperature is above15 0C, it varies between 145 and 180 days.

An active growth of most crops coincides with steady transition of air temperature through 10oC. This time we have favorable conditions for sowing of heat-loving crops, such as cotton and maize.

Spring transition of air temperature through 10 oC is firstly observed in Bukhara and Akhal planning zones in the 3rd ten-days of March, while in the rest parts of the basin – in the first ten-days of April. The duration of the period, when the air temperature is above 10 oC lasts 170-200 days on average and when the air temperature is above 15 0C – 145-180 days.

It is observed that number of dates with the temperatures > 5 ^{0}C, > 10 ^{0}C and > 15 ^{0}C increases (Fig.2).

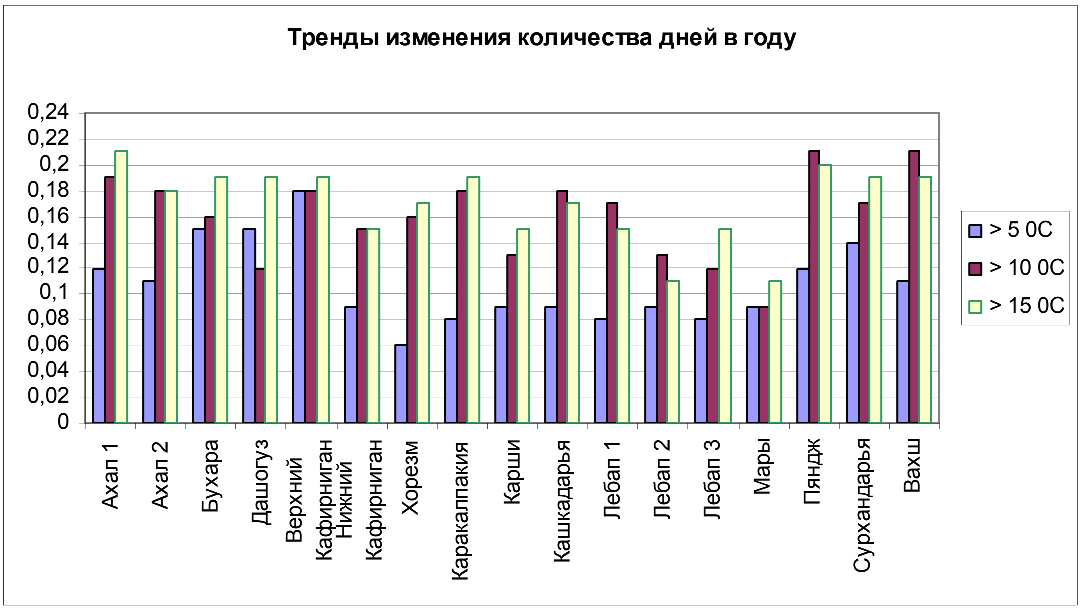


Figure 2. Trends of change in number of days in a year with the temperature > 5 ^{0}C, > 10 ^{0}C, > 15 ^{0}C

Figure 3 shows the changes in steady temperature transition through 5 ^{0}C, 10 ^{0}C and 15 ^{0}C, at which it is recommended to sow many crops, including cotton, maize, rice, many vegetables, etc. (Table 1).

Table 1

Optimal temperatures for sowing crops

№	Crop	t^0 sowing	№	Crop	t^0 sowing	№	Crop	t^0 sowing
1	Peanut	12.00	13	Melon	15.00	25	Early rice	10.00
2	Legumes	12.00	14	Sweet pepper	10.00	26	Late rice	10.00
3	Table grapes	8.00	15	Sorghum	10.00	27	Orchard	5.00
4	Cabbage	5.00	16	Soya	10.00	28	Bush	5.00
5	Potato	10.00	17	Pumpkin	13.00	29	Legumes as double crops	10.00
6	Maize for grain	10.00	18	Tomato	12.00	30	Potato as double crop	10.00
7	Alfalfa	5.00	19	Water melon	15.00	31	Beet as double crop	10.00
8	Small vegetables	9.00	20	Early cotton	10.00	32	Cucurbits as double crops	10.00
9	Carrot	8.00	21	Mead-season	10.00	33	Vegetables as	10.00

				cotton			double crops	
10	Sunflower	8.00	22	Late cotton	10.00	34	Maize for silage as double crop	10.00
11	Winter wheat	5.00	23	Maize for silage	10.00	35	Rice as double crop	10.00
12	Sugar beet	10.00	24	Rice	10.00			

The dates of steady temperature were determined from the actual climatic data of the base period and from the REMO modeling results.
A clear trend of earlier approached date for recommended sowing is observed (Table 1). In the REMO scenarios, the deviations from the base scenario of steady temperature transition through 5^{o}C (sowing dates of wheat, alfalfa, cabbage, etc.) are 1 to 8 days closer to winter in planning zones (Table 2).
By 2030-2050, the steady temperature transition through 15oC would be shifted to 0-6 days in spring season, while transition through 15oC would be shifted to 1-6 days.
For all planning zones, early critical temperature transition is forecasted, but Mary and Pyandj planning zones.

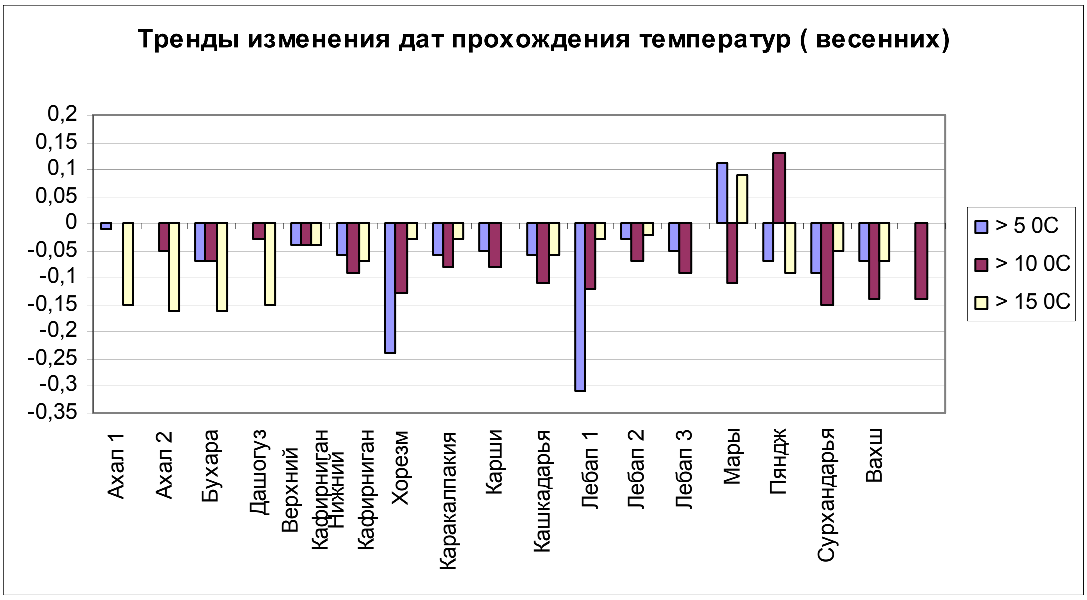


Figure 3. Trends of change in the dates of critical temperatures transition

The use of trends of change in parameters (Fig. 3) in the analysis allows excluding weight of a year in trends and describes temperature dynamics over longer period more reliably. In this case the observed data are smoothed. The trends of change in parameters indicate to the rate of this change.
The predicted earlier air warming will shift the beginning of the growing season closer to winter.

3.3. Length of crop growing season

Thermal resources are to ensure annual ripening of different crop varieties cultivated in the region.
Climate change, temperature rise will lead to changes in the duration of accumulation of the sum of effective temperatures, which is necessary for ripening of crops.

During each plant development phase, starting with sprouting till blossoming, fruit formation and ripening stage, the plant needs enough quantity of effective temperature as the duration of development phase, the growing season in general and the possibility to control water requirements depend on it.

To calculate the duration of development phases, initial data on main crops of the basin was collected for the base period, including critical temperatures and sums of effective temperatures [8-13].

It is well-known that plant development and growth directly depend on temperature data. Crop is sown at certain air (soil) temperature which is steady during 3-4 days; there are several development phases from sowing to ripening of crops. The data analysis shows the change in the sowing dates due to climate change. Based on REMO forecast, the sowing dates will come earlier for all crops in all planning zones (Table 2). Thus, in 2050 sowing dates for cotton will start 1-17 days earlier as compared to those in 2000, for rice – 1-12 days, for legumes – 2-13 days and for vegetables (potato) – 1-17 days earlier. The growing season of winter wheat in spring will start 1-15 days earlier (Table 2).

Ripening of crops occurs at certain sums of effective temperatures, which are higher than critical temperature threshold.

Based on the input data on distribution of the sum of effective temperatures by plant development phase, the length of phases was determined, i.e. the time needed for accumulation of necessary temperature. Climate change will impact the length of temperature accumulation, i.e. it will form the length of the whole growing season and each development phase of a plant.

Based on REMO, the results indicate to shortening of the growing season of almost all crops by 2050 in the basin (Table 3).

The most significant changes in the length of growing season are projected for mead-season cotton – 11-29 days, for early and late cotton – 9-21 and 2-21 days, respectively, for rice – 4-27 days. For other crops the forecast is as follows: for winter wheat – 5-9 days, for maize – 7-11 days, for maize for silage – 3-9 days, for legumes – 2-10 days and for vegetables (potato) – 8-17 days (Table 3, Fig.4-8).

Table 2

Sowing dates by crop

	legumes	potato	maize for grain	alfalfa	winter wheat	sweet melon	early cotton	mead-season cotton	late cotton	maize for silage	rice	orchard	Maize for silage as double crop	rice as double crop
Akhal 1	-3.3	-4.5	-4.5	0.2	-0.5	-9.3	-4.5	-4.5	-4.5	-4.5	-9.3	-0.5	-0.1	-0.1
Akhal 2	-7.5	-2.6	-2.6	0.2	-0.8	-6.7	-2.6	-2.6	-2.6	-2.6	-6.7	-0.8	-0.1	-0.1
Bukhara	-2.0	-0.6	-0.6	-1.4	-1.9	-10.9	-0.6	-0.6	-0.6	-0.6	-10.9	-1.9	-0.1	-0.1
Dashoguz	-6.3	-2.3	-2.3	-1.7	-0.8	-6.0	-2.3	-2.3	-2.3	-2.3	-6.0	-0.8	-0.1	-0.1
Upper Karnifigan	-6.9	-4.1	-4.1	-9.1	-4.9	-3.9	-4.1	-4.1	-4.1	-4.1	-3.9	-4.9	-0.1	-0.1
Lower Karnifigan	-6.1	-7.9	-7.9	-7.0	-1.9	-3.2	-7.9	-7.9	-7.9	-7.9	-3.2	-1.9	-0.1	-0.1
Khorezm	-13.3	-15.0	-15.0	-11.2	-6.3	-12.1	-15.0	-15.0	-15.0	-15.0	-12.1	-6.3	-0.1	-0.1
Karakalpakstan	-0.7	-9.5	-9.5	-9.9	-3.1	-0.2	-9.5	-9.5	-9.5	-9.5	-0.2	-3.1	-0.1	-0.1
Karshi	-2.9	-4.9	-4.9	-6.6	-1.1	-6.1	-4.9	-4.9	-4.9	-4.9	-6.1	-1.1	-0.1	-0.1
Kashkadarya	-6.9	-6.9	-6.9	-5.0	-3.2	-5.5	-6.9	-6.9	-6.9	-6.9	-5.5	-3.2	-0.1	-0.1
Lebap 1	-10.8	-17.4	-17.4	-16.2	-15.1	-0.6	-17.4	-17.4	-17.4	-17.4	-0.6	-15.1	-0.1	-0.1
Lebap 2	-3.6	-6.2	-6.2	-4.1	-0.9	-2.9	-6.2	-6.2	-6.2	-6.2	-2.9	-0.9	-0.1	-0.1
Lebap 3	-6.3	-4.6	-4.6	-6.3	-1.3	-3.4	-4.6	-4.6	-4.6	-4.6	-3.4	-1.3	-0.1	-0.1
Mary	-3.9	-5.0	-5.0	-2.3	-1.0	-1.8	-5.0	-5.0	-5.0	-5.0	-1.8	-1.0	-0.1	-0.1
Pyandj	-7.8	-10.8	-10.8	-7.0	-2.6	-7.5	-10.8	-10.8	-10.8	-10.8	-7.5	-2.6	-0.1	-0.1
Surkhandarya	-5.2	-5.5	-5.5	-8.4	-3.8	-4.6	-5.5	-5.5	-5.5	-5.5	-4.6	-3.8	-0.1	-0.1
Vakhsh	-7.5	-10.5	-10.5	-7.2	-2.5	-5.7	-10.5	-10.5	-10.5	-10.5	-5.7	-2.5	-0.1	-0.1

Table 3

Shortening of the growing season by crop

	legumes	potato	maize for grain	alfalfa	winter wheat	sweet melon	early cotton	mead-season cotton	late cotton	maize for silage	rice	orchard	maize for silage as double crop	rice as double crop
Akhal 1	-5.6	-8.1	-7.2	-10.1	-7.4	-15.4	-9.3	-13.5	-21.3	-4.8	-8.5	9.9	-6.8	6.8
Akhal 2	-3.7	-8.1	-7.2	-9.6	-8.1	-16.0	-9.4	-13.1	-18.5	-4.7	-8.1	9.3	-6.4	6.4
Bukhara	-6.5	-7.6	-7.5	-7.6	-5.6	-8.2	-9.3	-11.3	-15.4	-5.9	-3.9	8.3	-5.4	7.7
Dashoguz	-2.2	-8.4	-7.4	-9.6	-6.9	-13.4	-9.3	-12.0	-20.9	-4.6	-7.5	6.2	-6.0	4.1
Upper Karnifigan	-10.5	-17.8	-15.1	-12.1	-4.9	-30.2	-21.5	-35.4	-18.2	-8.9	-26.7	9.1	-12.7	5.4
Lower Karnifigan	-7.2	-8.9	-7.5	-8.3	-5.8	-21.5	-11.8	-25.4	-7.4	-2.7	-20.5	7.7	-8.7	1.5
Khorezm	-6.7	-8.7	-7.2	-6.0	-5.1	-10.7	-11.1	-25.4	2.8	-3.5	-14.0	8.1	-6.8	3.1
Karakalpakstan	-8.2	-8.1	-6.4	-6.1	-5.3	-11.9	-10.4	-24.7	5.2	-3.1	-19.8	9.1	-6.7	4.2
Karshi	-7.8	-9.5	-8.1	-7.1	-5.5	-14.2	-12.2	-26.4	-2.6	-3.7	-17.4	6.7	-8.1	2.1
Kashkadarya	-7.2	-10.3	-8.6	-9.5	-4.9	-20.2	-12.3	-27.0	-7.6	-3.9	-19.2	9.1	-9.2	3.1
Lebap 1	-6.2	-7.7	-6.1	-6.2	-3.8	-14.1	-10.5	-25.7	2.5	-2.6	-18.1	8.2	-7.3	3.0
Lebap 2	-7.1	-8.5	-7.2	-7.5	-5.2	-13.9	-11.1	-26.3	2.6	-3.0	-18.8	6.2	-7.9	2.6
Lebap 3	-6.7	-10.3	-9.3	-7.4	-5.4	-16.2	-12.6	-27.9	-2.8	-4.5	-20.4	6.3	-8.1	2.0
Mary	-6.8	-9.6	-8.5	-8.7	-4.3	-14.7	-12.7	-28.0	0.6	-3.8	-20.2	5.1	-8.0	2.0
Pyandj	-8.1	-11.2	-9.0	-10.9	-6.9	-25.1	-14.0	-28.8	-12.4	-3.2	-21.9	10.5	-11.4	3.1
Surkhandarya	-9.8	-12.5	-10.9	-9.1	-5.1	-24.9	-15.9	-29.1	-12.3	-5.5	-22.0	8.7	-10.5	2.9
Vakhsh	-7.7	-8.8	-7.2	-9.6	-6.3	-23.5	-12.4	-25.4	-8.6	-1.9	-22.4	10.8	-10.4	2.7

Fig.4. Shortening of the growing season (early cotton)

Fig.5. Shortening of the growing season (mead-season cotton)

Fig.6. Shortening of the growing season (late cotton)

Fig.7. Shortening of the growing season (winter wheat)

Fig.8. Shortening of the growing season (rice)

3.4 *Calculation of crop water requirements and analysis of results*

Calculation of crop water requirements serves as the basis for determination of quantities of water delivery when drawing water use plans in practice.
The REMO climate modeling data were provided by the Wurzburg University for the whole Amu Darya River basin. Water requirements were modeled using the REQWAT model. REQWAT is used for calculation of water requirements for a specific area. A planning zone map, an irrigated area map, the radar survey data, a soil map, a groundwater well location map and the observations on groundwater levels for a series of years were used in those calculations. The results are displayed in form of ten-day or monthly crop water requirements averaged for the studied area or as maps of annual crop water requirements.
The following crops were selected in the project for calculation of water requirements:

1. Cotton
2. Winter wheat
3. Rice
4. Maize for grain
5. Vegetables: potato, tomato, roots, legumes, cucurbits
6. Horticultural crops: orchards and vineyards
7. Forages: maize for silage, alfalfa
8. Other: oil crops, sugar beet
9. Homestead plots
10. Legumes – double crops
11. Vegetables as double crops
12. Maize for silage
13. Rice - double crops
14. Beet - double crops
15. Potato - double crops
16. Cucurbits – double crops

Water requirements were calculated for each crop and then several crops were grouped as vegetables, horticultural crops, other and double crops.

Water requirements are calculated by the following formula:

$$RW = ETc - EfRain - GWC \qquad \textbf{(1)}$$

where:
RW **–** crop water requirements for certain period of time

ETc **–** evaporation from the surface of crop and soil under this crop

EfRain **–** effective rainfall

GWC **–** groundwater contribution

ETc is calculated by formula:

$$ETc = \sum_{i=1:n} ETo_i * Kc_i \qquad \textbf{(2)}$$

where:
$\boldsymbol{ETo_i}$ – reference evapotranspiration for i-day of calculation period

$\boldsymbol{Kc_i}$ – crop coefficient for i-day of calculation period

n – number of days in calculation period

i – sequence number of day in calculation period

ETo is calculated by Penmann-Monteith formula [14] and the Blaney-Criddle method.
Kc – crop coefficient determined for each day of the calculation period. It is derived from tables of the FAO publication 56.

As a result of increased thermal potential, shift in sowing dates of crops closer to beginning of spring and shortening of growing season as a whole as mentioned above, crop water requirements decrease. Besides, according to regional climate scenarios, some periods during the growing season, especially beginning of growing fall to time of increased humidity and intensive rainfall. This also has a certain effect on the decrease of water requirements.
The tendency to decreased water requirements of main crops is observed almost in all provinces (planning zones) in the Amu Darya Basin (Table 4).

Table 4

Evolution of crop water requirements over 2000 - 2050

	Karakalpak stan		**Khorezm**		**Bukhara**		**Karshi**		**Kashkadarya**		**Surkhandarya**	
	Aver	Gro wth	Aver	Gro wth	Aver	Gro wth	Aver	Gro wth	Aver	Growt h	Aver	Growt h
Maize/grain	6898	-313	6854	-279	7099	-323	6763	-305	6723	-555	6681	-638
Winter wheat	1745	-141	1500	-243	2068	184	1809	275	1789	169	1800	202
Cotton	6898	-313	10267	-702	10083	-379	1014	-675	10123	-1013	10002	-1244
Rice												
Vegetables	7743	-161	7681	-220	7843	-343	7595	-251	7585	409	7530	-633
Orchards/ vineyards	6158	131	5939	-479	6506	-281	6069	-120	6055	-204	6038	-232
Forages	6561	-202	6422	-473	6856	-293	6407	-135	6428	-301	6375	-436
Other	5970	36	5915	-27	6273	-286	5870	108	5861	-39	5817	-241
Double crops	5816	-287	5763	-324	5922	-305	5687	-350	5655	-378	5647	-571
Homestead plots	98174	107	9772	28	9849	-571	9685	-171	9662	-437	9580	-740

Substantial lowering of water requirements can be expected in case of cotton (early, mid- and late ripening), maize for grain and forages.
Rice is not considered as a priori it is grown by check flooding. Upland rice is not studied in our farming practices.
Water requirements of winter wheat show both downward and upward trends. Perhaps, the calculation methodology for wheat needs to be updated, first of all, in part of more precise definition of the sum of effective temperatures by plant development phase. Nevertheless, the research proves that consideration of agro-soil parameters in estimating of crop water requirements allows identifying potential changes in the latter. The research results show that climate change has also a positive effect that leads to lowering of crop water requirements.

Figure 9. Crop water requirements, Karakalpakstan

As an example (Fig. 9) we show the results of crop water requirement calculations for main crops grown in Karakalpakstan, the northernmost agricultural zone in the Amu Darya Basin.

References

1 Chub, V.Ye. Climate change and its impact on hydrometeorological and agroclimatic processes and on water resourses in the Republic of Uzbekistan. "Voris-nashriyot", Tashkent, 2007

2 Dukhovny, V.A. (2008) Regional Model of Integrated Water Resources Management in Twinned River Basins – RIVERTWIN. Tashkent, SIC ICWC, 188

3 Stulina, G., Madramootoo, C. (2005) Adaptation Water Resources Management to climate change condition in Aral Sea Basin, Alberta.

4 Stulina, G., Usmanov, A. (2002) What is to expert in agriculture in view of climate change. Dialogue on water and climate: Aral Sea Basin case study, Project N 12.130.021, Tashkent

5 Stulina, G.V., Solodkiy, G.F. (2011) Adaptation of water planning to climatic and hydrogeological changes: the use of water and land resources and environmental problems in the EECCA region in context of climate change, Collection of scientific papers, SIC ICWC, Tashkent, 46-59.

6 Stulina, G. and Solodkiy, G.. “The Effect of Climate Change on Land and Water Use”. Agricultural Sciences, 6, 2015, 834-847. http://dx.doi.org/10.4236/as.2015.68081

7 Babushkin, L.N. (1974) Regarding climatic characteristics of summer atmospheric drought and hot dry winds in the cotton region of Uzbekistan: Hot dry winds, their origin and control. Tashkent, 59-64 (in Russian).

8 Bioclimatology of legumes and grasses: clover, timothy, alfalfa, vetch, lupine, fescue, soya and lathyrus. /Edited by I.G.Gringof, reviewed by the candidate of biological sciences I.G.Gringof (All-Soviet Union Research Institute of Agricultural Meteorology); candidate of agricultural sciences M.S.Rogov (All-Soviet Union Research Institute of Forages named after V.R.Williams). – Leningrad.: Hydrometeoizdat, 1981.- pp.129 (in Russian).

9 Agrometeorology issues /Proceedings of the Central Asian Hydrometeorological Research Institute named after V.A. Bugaev. Issue 88 (169) / Edited by the candidate of geographical sciences V.V.Karnukhova. - M.: Hydrometeoizdat, 1983. – pp.144 (in Russian).

10 Agrometeorology issues/ Proceedings of the Central Asian Hydrometeorological Research Institute named after V.A. Bugaev. Issue 67 (148) / Edited by the candidates of geographical sciences P.A.An and Kh.M.Abdullayev - M.: Hydrometeoizdat, 1979. – pp. 124(in Russian).

11 O.P.Kulkov. Agroclimatic resources of subtropical fruit-growing in Uzbekistan. / Editor-in-chief - doctor of agricultural sciences I.M.Mirzaev. - Tashkent, Publishing house of the Uzbek SSR “Fan”, 1976. – pp.52 (in Russian).

12 The Hydrometeorological Service of the Uzbek SSR. / Handbook on average long-term climatic and agrometeorological data for the Uzbek SSR. – Tashkent, 1945. – pp.41 (in Russian).

13 I.V.Svisyuk, G.G.Vasenina. Weather and vegetable yields. - Leningrad: Hydrometeoizdat, 1989. – pp.112 (in Russian).

14 Crop evapotranspiratuion. Guidelines for computing crop water requirements FAO irrigation and drainage paper, 56. Rome, 1998. - 301 p.

3.2. Developing proposals on water management in the context of climate change

ADAPTATION TO CLIMATE CHANGE

Use of the Positive Effects of Climate Change

Introduction

Climate warming is recognized as an objective reality all over the world. The typical characteristics of this warming include rise in soil and air temperature, more frequent and intensified extreme weather events (droughts, floods, storms) that especially became apparent in the recent decade, and, finally, change in precipitation patterns. In the arid areas, to which the Aral Sea basin, the research object, belongs too, more frequent dry years are accompanied by decreased river water availability and precipitation and an increased aridity of air. Given the average total water resources of 133 km^3 a year in the dry year 2008, their volume decreased to 96 km^3 [1]. This has a negative effect on agriculture in the basin's countries, which is a source of livelihoods for almost half of the population and accounts for 27% of gross regional product. Most researchers studying the climate change effects note that the temperature rise leads to increased evaporation and, hence, to growth of water demands for irrigation of crops. The 4th Assessment Report of the Working group to Intergovernmental Panel on Climate Change [2] warns that although the temperature rose steadily by 1-2 degrees over 100 years, there is no precipitation trend over 1900–1996. According to REMO modeling of climatic scenarios until 2100, evapotranspiration would increase significantly by 4-8 mm/day in summer months.
However, it is demonstrated also that the thermal potential of given area would be changing. We have attempted to verify validity of this suggestion in the studies of the Fergana zone, Uzbekistan and the Amudarya River Basin.
The growth of the thermal potential causes that the sum of effective temperatures is reached in shorter period of time and the crops can be sown earlier. This, first, would reduce the crop development phases and the growing season as a whole, and, consequently, would decrease the total water use. For example, for the mid-season cotton, the growing season would become 30 days shorter and the water use would decrease by 100 mm by 2100 [3]. The thermal patterns should be considered as the basis for crop rotation and, hence, for water planning.

1. Research objective

Demonstrate that accounting of agro-climatic parameters and their changes under an impact of climate change makes it possible to adjust crop water requirements. The latter will serve as a reserve for adaptation to climate change.

2. Methodology

2.1 Use of thermal potential

All plants need a certain sum of effective temperatures for their growing, from sowing till ripening. The duration of each plant development phase also depends on reaching of a certain sum of effective temperatures.
The main tool for determination of duration of growing season of plants is the sum of effective temperatures (SET). Effective temperature is an agro-climatic parameter, which is the difference between the mean daily air temperature and the lower threshold of growing. This lower threshold, which depends on given crop class, is the air temperature, below which growing of

plant slows down sharply. There is also the upper threshold of growing, above which growing also stops because of high temperatures.
Each plant needs certain SET for ripening. This sum is comprised of daily effective temperatures that are above-zero. If the mean daily temperature exceeds the upper threshold of growing, such temperature is not included in the sum and the days with such temperature are not taken into account.
Global warming causes more precipitation as evaporation from the surface of seas and oceans increases. Relative air humidity also goes up. Global warning prolongs the growing season. This fact causes that sowing can be made earlier, i.e. closer to the beginning of spring, and crops can ripen well earlier. Such earlier sowing places the crops into conditions of increased precipitation, higher humidity and appropriate temperatures for growing. This leads to lowering of evapotranspiration. In our work, sowing date was calculated as that of the fifth day with the average air temperature, which was higher or equal to the lower threshold of growing.
Each crop has 4 development phases (according to FAO). These are initial phase, growth, yield formation, and harvesting. SETs were derived for each of crop development phases. The lengths of development phases were taken from the FAO Publication 56. Then, based on retrospective climate, SET was calculated for each development phase. Another way was to derive the sum of effective temperatures from literature sources. The first option is more preferable since the research described in literature sources was carried out in different climatic conditions and in different geographical locations. Additionally, this option allows unifying conditions for re-calculation of SET for all studied crops.

2.2 Calculation of crop water requirements in the context of global warming

Based on calculation of crop water requirements, one determines quantities of water delivery when drawing water use plans in practice.
The Wurzburg University's REMO model was used for forecasts of climate change. This climatic model is based on the ECHAM 5 model developed at the Max Plank Institute (Germany). That is the model of global atmosphere circulation. It is used for calculation of global and regional models of climate change. The A1B scenario of average warming as a result of greenhouse gas emission was played in the model. Given model allowed constructing the artificial temperature and rainfall series until 2050. The modeling results were calibrated (G.F.Solodkiy).
The REMO modeling data were provided for the whole Amudarya River basin. Water requirements will be modeled using the REQWAT model developed on the basis of the CROPWAT model. REQWAT is used for calculation of water requirements for a specific area. A planning zone map, an irrigated area map, the radar survey data, a soil map, a groundwater well location map and the observations on groundwater levels for a series of years were used in those calculations. The results are displayed in form of ten-day or monthly crop water requirements averaged for the studied area or as maps of annual crop water requirements.

Water requirements are calculated by the following formula:

$$RW = ETc - EfRain - GWC \quad \textbf{(1)}$$

where:
RW – crop water requirements for a certain period of time

ETc – evaporation from the surfaces of crop and soil under the crop

EfRain – effective rainfall

GWC – recharge from groundwater

ETc is calculated by formula:

$$ETc = \sum_{i=1:n} ETo_i * Kc_i \qquad \textbf{(2)}$$

where:

ETo$_i$ – reference evapotranspiration in i-day of the calculation period

Kc$_i$ – crop coefficient in i-day of the calculation period

n – quantity of days in the calculation period

i – sequence number of day in the calculation period

ETo is calculated by Penmann-Monteith formula (FAO publication 56) and the Blaney-Criddle method .
Kc is crop coefficient determined for each day of the calculation period. It is derived from tables of the FAO publication 56.

WHAT WHAS DONE?

The conducted research proves validity of expectations.

Below we show the results of assessment of thermal resources and water requirements for cotton grown in the Fergana Valley (Fig. 1, Fig. 2, Fig. 3).

According to REMO forecast, thermal resources will increase by 28 %, 38 % and 56 %, respectively, during the growing season.

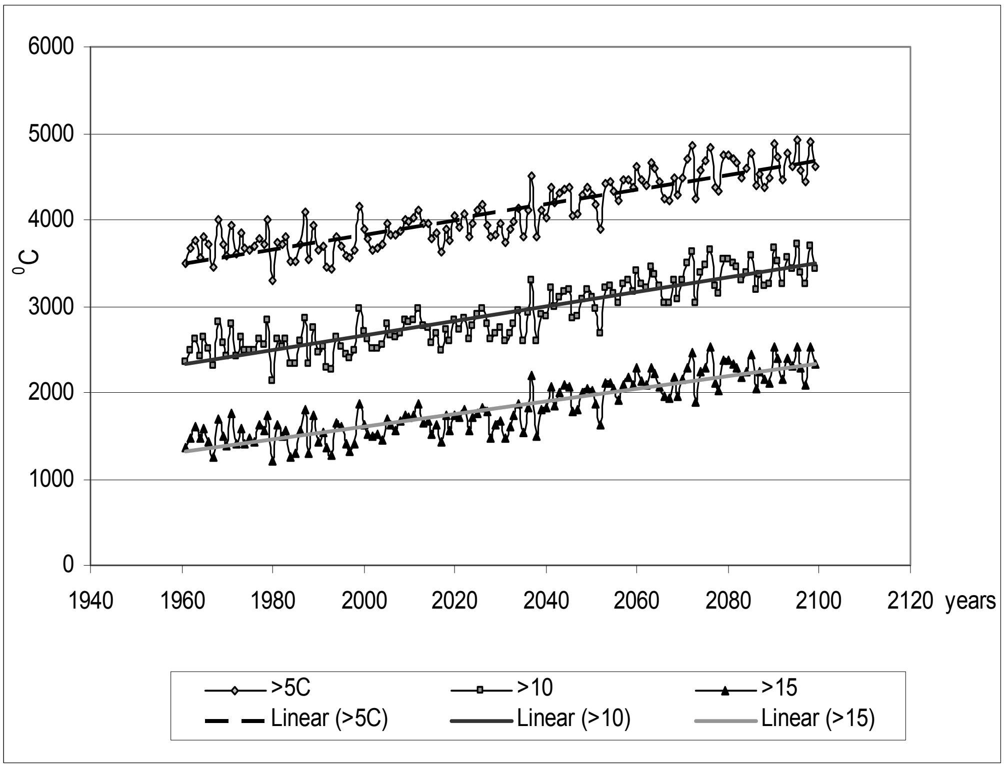


Fig. 1 Sum of effective temperatures during the growing season,
Fergana weather station (Fergana planning zone), REMO forecast.

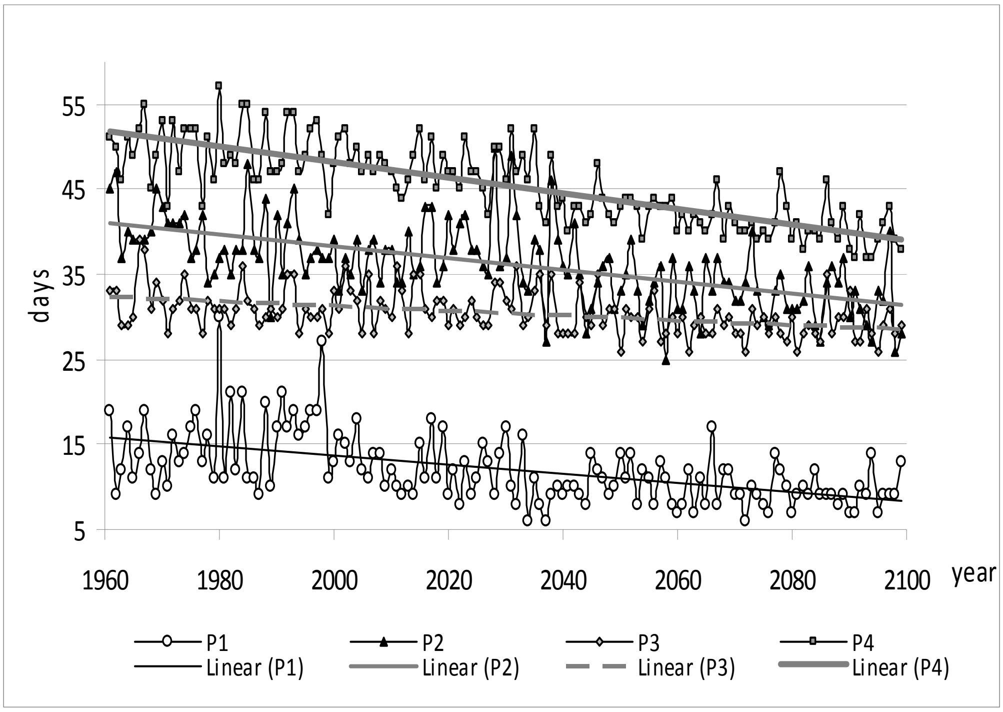


Fig.2 Change in the length of cotton development phases over years

Tab 11 .Change in the length of mid-season cotton development phases over periods of time

		years	P1	P2	P3	P4	Total
Length of phases	base years	1961-1990	15	40	32	50	136
	periods	2000-2030	13	38	32	48	130
		2030-2050	10	36	31	45	122
Changes in length		2000-2030	-2	-2	0	-2	-6
of phases		2030-2050	-5	-3	-1	-5	-14

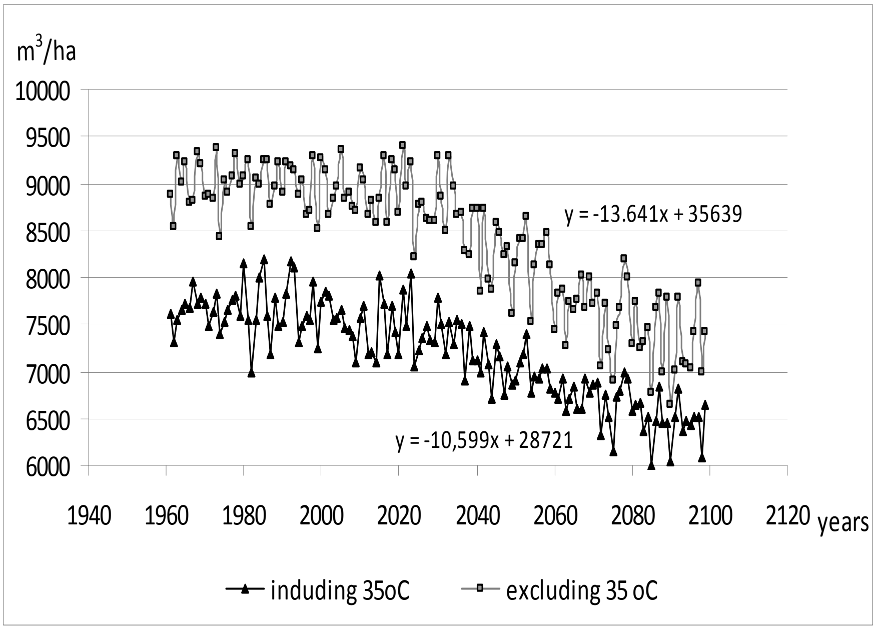


Fig 3 .Scenario of changes in water requirements of mid-season cotton variety under climate change

For cotton, the growing season would become 30 days shorter and the water use would decrease by more than 100 mm by 2100. The thermal patterns should be considered as the basis for crop rotation and, hence, for water planning.

WHAT SHOULD BE DONE?

As the standard set of FAO data on agro-climatic parameters does not contain those for Central Asia, determination or revision of such parameters is an important task for adaptation research.

3. Project tasks

1. Collect available in the region data on agro-climatic parameters of crops.
2. Together with biologists, agronomists, and physiologists, assess agro-climatic parameters on all crops in the region, including effective temperature, sum of effective temperatures, stress temperature, length of development phases, and duration of growing season.
3. For further development and dissemination of the methodology, it is necessary to make SET tables and include them into one of FAO publications.
4. Based on the data collected, assess changes in dates of sowing, lengths of the growing season and development phases, also taking into account climate forecasts by 2030-2080. (As a result of application of SET in our calculations for the Amu Darya basin, the growing season of some crops becomes shorter from 5 to 20 days, depending on year conditions).
5. Adjust crop coefficients for conditions of climate change.
6. Calculate potential and active evapotranspiration and crop water requirements based on climate, agro-climatic, and hydrological data of regional climate scenarios.

References

1 Dukhovny, V.A., Sokolov, V.I. et al. (2012) Dynamics of the present water balance in the Fergana Valley. *Collection of SIC ICWC scientific papers*, Issue 13, 5-27.

2 Parry, M.L., Consiam, O., Palutikof, G.P, Linden, P.J.van der and Hansen, E.C. "Climate change 2007: impacts, adaptation and vulnerability". *Contribution WG2 to the Fourth Assessment report to Intergovernmental panel of climate changes*, Edition Cambridge University press, Cambridge, UK, 469 -506.

3 Stulina, G. and Solodkiy, G. "The Effect of Climate Change on Land and Water Use". Agricultural Sciences, 6, 2015, 834-847. http://dx.doi.org/10.4236/as.2015.68081

4.4. Presenting results and drafting a plan of dissemination

The project results were presented at the following conferences:

1. **International Summit Of The Great Rivers Of The World: "Taking Action For Water And Climate" 23-25 October 2017 Rome, Italy.**
   "Modeling crop water requirements in the context of climate change in the Amu Darya Basin (2000-2050)"

Dr.Galina Stulina, Uzbekistan
Georgy Solodkiy, Uzbekistan

The Amudarya Basin is one of the main water sources in Central Asia. Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan share the basin of the Amu Darya River. The area of the basin is 2687 thousand km2, of which is 4.5 million hectares irrigated. The main crops produced in the basin include cotton, wheat, rice, vegetables, fruits, and cucurbits. The natural deficit of water as a difference between precipitation and evaporation deviates from 600…800 mm in the area of ancient oasis and hillside up to 1400…1600 mm in desert and steppe. As result of such climate, irrigation and water development are the two major foundations of sustainable agriculture and water supply. The objective of given work is analyzing and assessing the positive effects of climate change through changes in bioclimatic potential of the locality and agroclimatic parameters of crops on crop water requirements. This research work was done as part of the PEER Project "Transboundary water management adaptation in the Amu Darya basin to climate change uncertainties" implemented by SIC ICWC with the financial support of USAID. The research results showed that the observed growth of thermal potential made earlier sowing possible and led to accumulation of the sum of effective temperatures in shorter span of time. This, first, would shorten crop development phases and the growing season as a whole and, second, decrease water requirements. The Wurzburg University's REMO model was used for forecasts of climate change. Given model allowed constructing the artificial temperature and rainfall series until 2050. The modeling results were calibrated. The REMO modeling data were provided for the whole Amudarya River basin. Water requirements were modeled using the REQWAT model in ArcView-environment. A planning zone map, an irrigated area map, the RS survey data, a soil map, a groundwater well location map and the observations on groundwater levels for a series of years were used in those calculations. The results are displayed in form of ten-day or monthly crop water requirements averaged for the studied area or as maps of annual water requirements for different crop types.

1. Stulina, G. and Solodkiy, G.. "The Effect of Climate Change on Land and Water Use". Agricultural Sciences, 6, 2015, 834-847. http://dx.doi.org/10.4236/as.2015.68081
2. Stulina G, Eschanov O. "Climate Change Impacts on Hydrology and Environment in the Pre-Aral " ELSEVIER, Quaternary International 10/2013.
3. V.Dukhovny, G.Stulina "Water and Food Security in Central Asia: 'Water and Food Security in Central Asia", Springer, 2011, 1-24.
4. Stulina G.V. Recommendations on hydromodule zoning and crop irrigation rate, SIC ICWC, Tashkent, 2010
5. Galina Stulina, Climate change - good or evil for the water sector? Integrated water resources management: putting good theory into real practice. Central Asia Experience, Tashkent, 2009

2. **Central Asian Conference on Climate Change. January 4-25, 2018, Almaty, Kazakhstan.**
   "Transboundary Water Management Adaptation in the Amu Darya Basin to Climate Change Uncertainties"