CLIMATIC CHANGES AND THEIR IMPACT ON WATER RESOURCES OF CHIRCHIK-AHANGARAN HYDROLOGICAL AREA

1. Climatic description

Chirchik-Ahangaran area is located in the northeastern part of the Republic of Uzbekistan between the Syrdarya River and ridges of the western Tien Shan Mountains. In the northwestern part of the area the state border between Uzbekistan and Kazakhstan traverses along the Keles river valley, the Kaarjantau and Ugam mountain ridges; in the east of the area Uzbekistan is adjacent to Kyrgyzstan along the Talas, Pskem and Chatkal mountain ridges. The Kuramin ridge separates Chirchik-Ahangaran Valley from Ferghana Valley.

The relief of Chirchik-Ahangaran physiographic area is rather heterogeneous. Its southwestern part is flat ground, northeastern and eastern parts are mountainous terrain. The relief is gradually declining from northeast to southwest in the direction of the Syrdarya river. Ridges of the western Tien Shan Mountains located in Chirchik-Ahangaran area ramify in a fan-like pattern southwestward. They are separated by river valleys, wide *saiys*[1], and narrow ravines.

In general, the climate - according to Alisov's classification – is attributed to the continental sub-tropical type. Strictly speaking, the area is located at the northern border of sub-tropical and temperate zones.

Climate formation on the territory under discussion is determined to a great extent by atmospheric processes typical for Central Asian region as a whole. As is well known, all this territory is exposed to effects caused by air masses transport from the west with its intrinsic processes of cyclogenesis and anticyclogenesis. Considerable impacts are also induced by cyclones, humid western air masses, and cold northern air masses – thus causing lowering of air temperature and falling of precipitation.

Chirchik-Ahangaran area is exposed to outbreaks of various air masses. Cyclones crossing the territory of Uzbekistan produce sharp weather changes. Atlantic and arctic air masses come to vast plains of Central Asia from the north, northwest and west. Intensive rises in temperatures in winter are caused by intrusion of tropical air masses contained in warm sectors of cyclones; then these occurrences may be quickly replaced by sharp fall of temperature

General nature of atmospheric circulation in the mountains remains similar to relevant processes specific for plains and foothills in Central Asia, but the distribution pattern of climatic elements in conditions of rugged terrain considerably changes. Thus, mount ridges located on the way of humid air masses transportation produce sharpening of fronts and create spaces of intensive moisture on leeward slopes while the parts exposed to the wind remain weakly moistened. Distribution patterns of other climatic elements depend on varieties of terrain elevations and exposure peculiarities of slopes.

Local circulation also produces considerable impacts on formation of climate. This type of circulation is determined by a complex system of mountain-plain winds, fan-draughts and fan-like winds. Temperature inversions are also should be considered, since in some places this phenomenon induces rise in temperature in winter and at night.

Summer in Chirchik-Ahangaran area is hot and long-lasting, especially on the plain part. ***Average air temperature*** in July is +27°C on the plain. Maximum air temperature is +44°C in summer. Winters are not very severe. Average temperature in January is -1°C on the

[1] *Saiy* is a local term for a mountain rivulet

plain, and in the range of -6°C - -8°C in the mountains. Thaws often occur in winter. However, when cold air masses intrude, the air temperature may fall down to -30°C.

Solar radiation regime – Owing to its geographical location, the territory of the Syrdarya river basin receives relatively large amount of solar radiant energy, especially in summer.

Annual amount of short-wave radiation in plain and mountainous parts varies within the range of 137—139 kcal/sm^2. As elevation of terrain rises, accession of solar radiation increases due to decrease in density and dustiness of atmosphere.

Vapor pressure with regard to the steam-content in the atmosphere (as well as the air temperature) measured within a year-span reaches their lowest values in winter and maximum rates in summer – July (Fig. 1).

Monthly average vapor pressure starts rising in January from the southwest on the flat ground where it constitutes 3.5-4.0mb. Values of monthly average vapor pressure in foothills of the Tien Shan western ridges constitute 5-6mb. As elevation of terrain rises in the mountains, vapor pressure values decrease and at the altitude of about 2000m monthly (January) average values are within the range of 2.5-3mb.

Intensive increase in vapor pressure starts in April - the process evolving till July. Vapor pressure reaches its maximum values on the territory of the Tien Shan western ridges, which are rich in vegetation. Decrease in vapor pressure is registered at higher altitudes and deeper in mountain ridges – this induced by fall of temperature. At elevations of about 2000m vapor pressure constitutes on average 6-9mb in July. Beginning from September monthly average vapor pressure starts notably decreasing.

Relative air humidity - representing the degree to which the air is saturated with vapor – changes within a wide range during a year. Of most interest is distribution of relative air humidity at 1 o'clock in the afternoon, when its values are near to minimal levels and evaporation develops most intensively, whereas it is usually high at night during the whole year. In foothills and mountains average relative air humidity at 1 p. m. changes within the range of 70%-50%. Intensive decrease in relative air humidity starts in March.

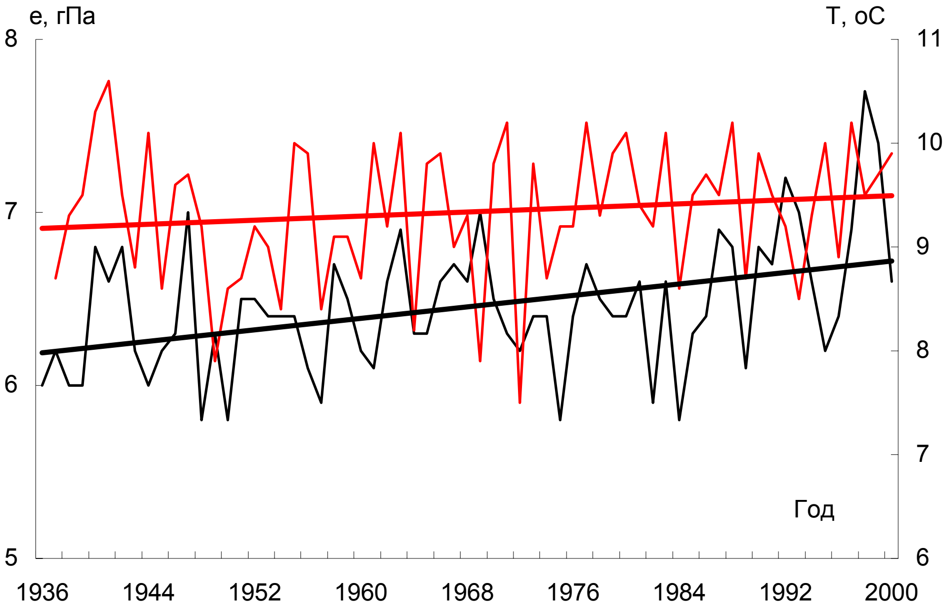

Fig. 1

Changes in average annual air temperature (—) and vapor pressure (—) at the Pskem station.

Amount of precipitation on the territory of Chirchik-Ahangaran area is distributed non-uniformly. Amounts of precipitation increase in the northeast direction (nearer to the mountains). Thus, in southwest of the area (the Syrdarya river valley) 250-300mm of precipitation fall annually, in Tashkent - 367mm, in the northwestern part of the Psken river valley – up to 800mm.

The Ahangaran river basin is located at the periphery of the western Tien Shan; the location is favorable with regard to moisture carrying intrusions from the west and southwest. The size of this basin is near to the critical level in terms of meso-orographic effect that does not show itself yet – therefore, elevation of terrain remains to be the key argument in calculations of the precipitation field. While calculating precipitation fields in the Pskem and Chatkal river basins it is necessary to take into account the inverse longitudinal-circular effect that shows itself in diminution of precipitation as observations advance deeper into mountain river valleys. As to the Chatkal river valley, there is an additional screening effect emanating from the Large Chimgan massif, which augments the previous effect.

Two thirds of annual precipitation in the area fall at winter and spring months. March is the month richest in precipitations; more than 20% of their annual amounts fall at this month. July, August, September are most arid months – there are almost no precipitation during this period. On the whole, the amount of precipitation on the territory of Chirchik-Ahangaran area is less than the rate of evaporation. Average annual amount of precipitation in most parts of the area constitutes 400mm; under local temperature conditions potential rate of evaporation may constitute 1000mm of moisture, i.e. precipitation-evaporation ratio here is 0.4.

Air humidity is an important climate element in arid regions – this applies to Chirchik-Ahangaran area as well. Water vapor content in the atmosphere on the territory of the area changes greatly depending on physiographic conditions, seasons, the state of soil surface, etc.

The amount of precipitation on slopes of the Chatcal ridge is small.

In the mid-elevation zone of the Chirchik and Ahangaran river basins largest monthly precipitation totals are registered in March-April, sometimes in May. Minimum totals fall mainly at August-September. All territory of Chirchik-Ahangaran area occupying the northeastern part of Uzbekistan is characterized by a wide variety of patterns with regard to distribution of precipitation and air humidity; since moister regimes depend on altitudes above see level, landscape topography, and exposure peculiarities of slopes. Moisture content increases significantly on western and southwestern slopes exposed to humid air masses, since mountain slopes promote regulation and intensification of convection processes. Mountain valleys and wide depressions having open outlet to west are also rich in precipitation. The Chirchik river valley exemplifies this observation – the amount of precipitation in the upper part of it constitutes up to 800-900mm; the same goes for the Angren river valley that is rather wide and open to the southwest - the amount of precipitation in the northern part of it (the Kyzylcha river basin) constitutes according to summarized precipitation gage data 1300-1400mm.

Analysis of these observations shows that the largest augmentation of precipitation occurs on western and southwestern slopes of ridges. For instance, laps rates of precipitation at 100m of elevation in the Chirchik valley open to southwest constitute 65-85mm, whereas on the southeastern slope of the Chatkal ridge - 30-35mm.

Rainfalls are possible on the plain of Chirchik-Ahangaran area all the year round. But at altitudes of about 2000m (for example, the Angren plateau) there are absolutely no precipitations in December-January and they are quite rarely (less than 0.5%) observed in November and February.

Number of days with heavy participations, for example, 10mm and more, varies within 1-3 days on the plain and up to 10-20 in foothills. On well moistened western slopes this figure is on average 25-30 days a year. Precipitation of more than 20mm per day are observed very rarely.

Analysis of these observations shows that very fierce droughts (deficit - more than 50% of precipitation) in spring are registered in Chirchik-Ahangaran area rarely (1-3 times for 100 years), whereas droughts with a deficit of seasonal precipitation totals at 20-25% are rather regular phenomenon observed with expectancy of 30%.

Aridity index derived by D.A. Pedya is of greatest interest in terms of climate change, since it incorporates values of temperatures and precipitation in the form of normalized observations, thus permitting to compare objectively trends displayed by various stations during different seasons. Sometimes it is called “Sazonov’s index”:

$$S = \frac{\Delta t_i}{\sigma_t} - \frac{\Delta P_i}{\sigma_p},$$

where Δt and σ_t – anomaly and mean-square deviation of average monthly temperature, ΔP and σ_P - anomaly and mean-square deviation of monthly precipitation totals. Application of normalized values allows exercising this index for comparing purposes in various situations, since it describes a specific meteorological situation regarding some mean level.

Conditions of both – humidity content and heat content – can be characterized through application of the “*S* index”, since in contrast to a hydrothermal coefficient it reflects alternating quantity: - positive values of *S* correspond to dry periods, negative – to humid ones. Another interpretation may be made of it, that is: - positive values of *S* correspond to increased thermal regime during some period, whereas negative ones reflect reversion of cold weather.

Synchronism of aridity index values fluctuations is also observed at stations of Chirchik-Ahangaran area, located in foothill and mountain zones. Changes in seasonal “*S* index” values with regard to “Tashkent” station are represented (Fig.2) in comparison with changes in annual values. More distinct trends are traced as to increment in climate aridity during summer and autumn, while high degree of changeability is retained in terms of time.

Extremely dry years in the area under consideration are actually always registered synchronously.

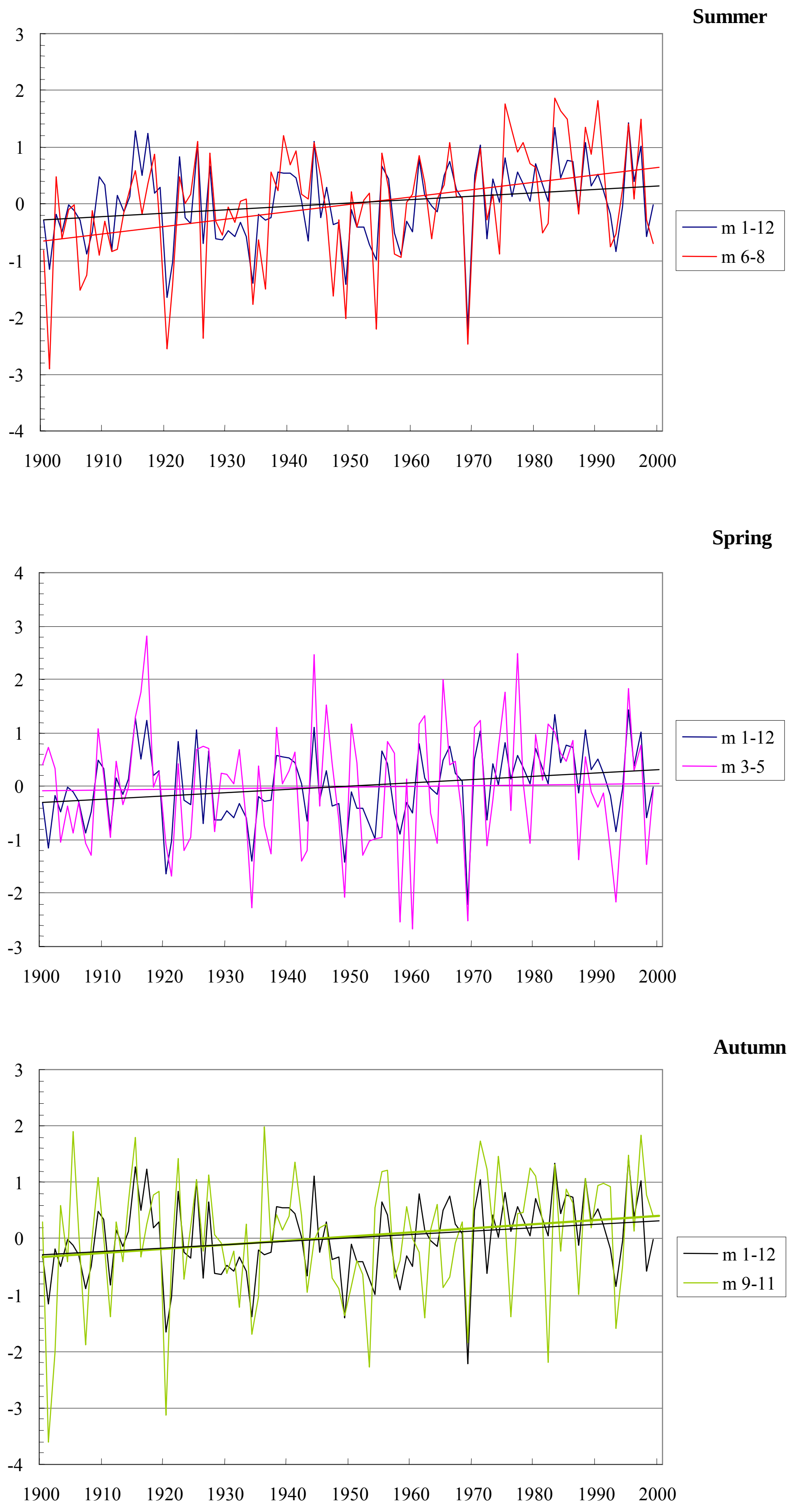

Fig. 2 Changes of seasonal values of aridity index *S* for "Tashkent" station

Evaporation from land. Rate evaporation in mountainous regions decreases as elevation increases. For instance, in the Chatkal and Pskem valleys annual evaporation constitutes 180mm at the altitude of 1200—2000m. Maximum average monthly evaporation constitutes 55—65mm as registered in May. In conditions of plateau, at the same altitude rate of evaporation is higher than in the valleys. Evaporation on the Ahangaran plateau reaches 240mm a year, whereas during some summer months – 70mm.

Wind. Wind regime in the mountains is formed mainly under the influence of general atmospheric circulation in interrelation with air flows within mountainous terrain, where local winds predominate. Mountain-valley winds are typical for local circulation; their dynamics are consistent with the direction of valleys' location; slope winds represent thermal circulation between slopes and valleys or bottom of the valley. Fan-draughts and fan-like winds are widely spread.

In large mountain valleys of the Chatkal and Ahangaran rivers, directed from northeast to southwest, winds of northeast direction predominate all the year round. Their recurrence in winter constitutes 55-65%. Average wind velocities vary within the range of 3-6m/sec.

Snow cover. Snow cover appears in the foothill zone mainly in the second decade of November. At higher altitudes snow cover appears in the mountains earlier. At the altitude of 2000m (the Angren plateau) snow cover appears in the middle of October. Dates when appearance of snow cover is registered deviate notably from year to year.

Formation of sustained snow cover usually takes place in December; at the altitude of about 1000m in the northern part of the area this development is registered in the second decade of December. At higher altitudes sustained snow cover appears in early December or in the end of November. At the altitudes higher than 2000m sustained snow cover is formed as early as by the end of October.

Analysis of observation series with regard to snow cover shows that for the last 10-15 years the tendency towards its diminution has taken shape. At that, synchronous changes are registered as to numbers of days with snow cover and its maximum depth.

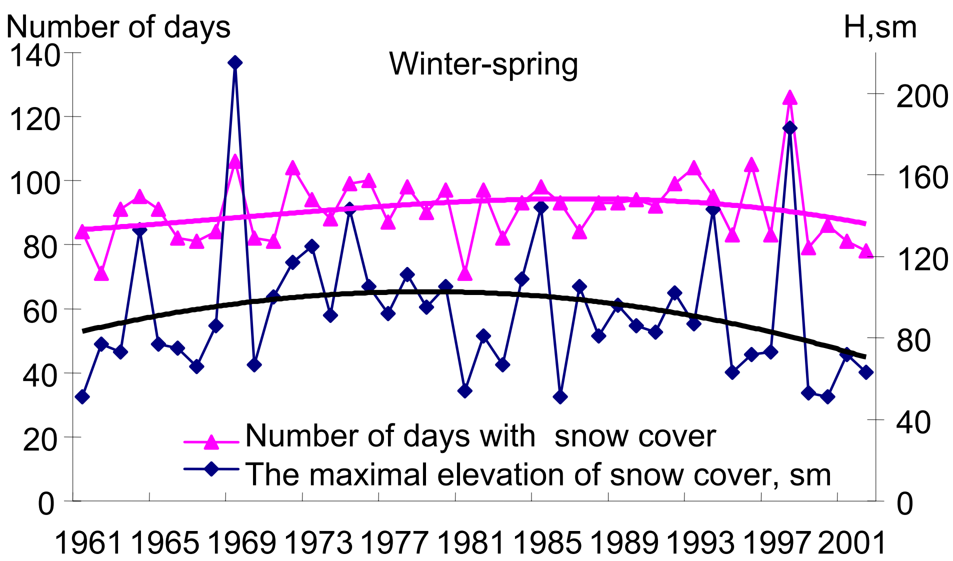

Fig. 3 Changes in numbers of days with snow cover and its maximum depth at "Pskem" station

Flow

Major sources of river flows are melt waters from seasonal snow cover; lesser share is provided by glacier water and rainfalls. The Pskem river is formed by junction of the Maiydantal and Oygaing rivers, the area of its watershed is 2840 km^2. The area of the Chatkal river watershed is 8870 km^2 – both rivers inflow into Charvak water reservoir.

2. Climatic scenarios

Methodical framework

The observed climate change (global warming) has been directly associated with increase in concentration of greenhouse gas in atmosphere. Pace and scope of global warming as well as response to this development in some regions depend on amounts of green gas emission into atmosphere of the Earth in future.

Interstate Expert Group on Climate Change (IEGCC) has proposed a series of greenhouse gas emission scenarios (IS92a,...,IS92f). The IS92a scenario presumes that concentration of CO_2 will be increasing by 1% per year, the world population will grow up to 11.3 billion by the year of 2100, economic growth rates will be 2.3-2.9% per year and there will be no measures undertaken to reduce amounts of green gas emission into atmosphere. This is the so called "non-interference" scenario. The IS92c and IS92d scenarios presume lesser amounts of emissions as compared to the IS92a and IS92b scenarios. As to the IS92e и IS92f scenarios, they give consideration to larger emission amounts – it is explained by differences in assessments of population growth and economic development rates, application of various types of fuel and power sources.

According to the above mentioned scenarios there is the same number of variants describing increase in global air temperature - at that, each variant has its own uncertainty limits. Three-dimensional numerical models of general atmospheric circulation are considered to be the most reliable instrument for simulating physical processes that determine climatic changes. Number of simulations to identify air temperature changes generated by climatic models on a hemisphere and continent scales is larger than that made for separate regions. Besides, quality of assessment with regard to regional climate changes depends on location of the region, its physiographic conditions and peculiarities of employed models. Large degree of area averaging, typical for global models, damps the amplitude of oscillation as it applies to regional climatic characteristics.

In spite of considerable uncertainties, the models are successfully applied for describing global climate in general and climate of separate regions. Outputs calculated in global models of general circulation of atmosphere and the ocean represent most reliable framework for developing regional climate change scenarios and regional assessments of vulnerability. While utilizing outputs of global modeling for assessment of regional climate changes one should take into account appropriate geographic peculiarities of some regions related to relief, local water bodies, nature of underlying surface, etc. For this purpose procedure of "downscaling" is used, which transforms climate characteristics assigned to models into meteorological parameters necessary for further use combined with needed spatial and time resolution.

The given report adduces the results of developing regional climatic scenarios through application of two methodical approaches. ***The first*** approach lies in application of dependences between global temperature and regional climatic characteristics. This empiric-statistical method has been described in a series of papers (see references – 6, 10, 12). Assessments of global climatic characteristic changes adduced in the given variant have been quoted from "Handbook" issued by IEGCC with regard to a high degree of climate response to increase in greenhouse gas concentration in atmosphere to be used in emission scenarios of IEGCC combined "in pairs" (IS92c and IS92d, - IS92a and IS92b, - IS92e and IS92f). ***The second*** approach includes statistical interpretation of models outputs in nodes of regular mesh with application of the "ideal forecast" concept. The given variant represents outputs of modeling for the mean level of climate response to increase in greenhouse gas concentration in atmosphere according to various scenarios.

Scenarios based on dependences between global temperatures and regional climatic characteristics

Studies of climate dynamics in Uzbekistan have shown that thermal regime changes on the territory of the republic are evolving similarly to global changes. Significant statistical dependence has been ascertained between values of average annual air temperature in stations/districts of Uzbekistan, adjacent mountainous terrain and global temperature.

As is known, any impact on climate caused by human activities is superimposed on background "noise" of natural climatic changeability related to both – internal fluctuations and influence of external factors (such as changes in solar activity, orbital parameters of the Earth, volcanic eruptions, etc.). Researches carried out in order to make diagnosis and analysis of current climate changes in Uzbekistan allowed displaying a number of cyclic fluctuations in time series of air temperature. Quasi-22-year cyclic recurrence has been revealed in changes of average annual air temperature, as well average air temperature for cold and warm halves of the year, on the background of current tendency to warming – i.e. cyclic recurrence that is near to the so called "Hail's cycle" of geomagnetic activity. Such cyclic recurrence describes more than 20% of basic data variance. Regard to current natural cyclic recurrences and trends will allow lessening uncertainty of climate change assessments for future.

Scenarios for air temperature changes

Calculations carried out on the basis of the above described approach to making assessment of time dependence in terms of possible temperature changes at some stations were combined into groups according to measurement values.

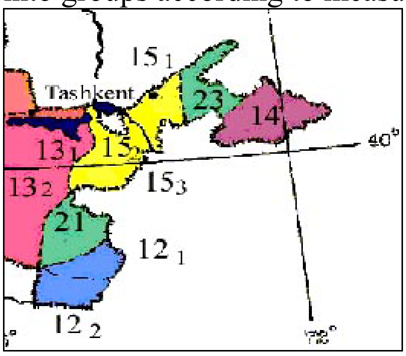

Fig. 4 Location of climatic regions

By way of averaging-out data for each season, sets of values have been derived, which characterize model forecast of temperature changes for the period of 2000-2030, assuming high degree of climate response.

Each set characterizes climatic regions (see Fig 4).

Chirchik-Ahangaran area includes climatic regions 15_1 and 23. Below, assessments of changes are given in the Tables differentially for various elevation zones of the "23" climatic region (indexing them as 23_1 and 23_2).

Regional climatic scenarios for Uzbekistan were developed after the procedure of spatial/time averaging-out. Twenty-year cyclic recurrence is significantly smoothed under averaging-out temperature values. Time dependence of average annual temperatures according to emission scenarios (IS92a and IS92b) for various regions of Uzbekistan is shown in Fig. 5.

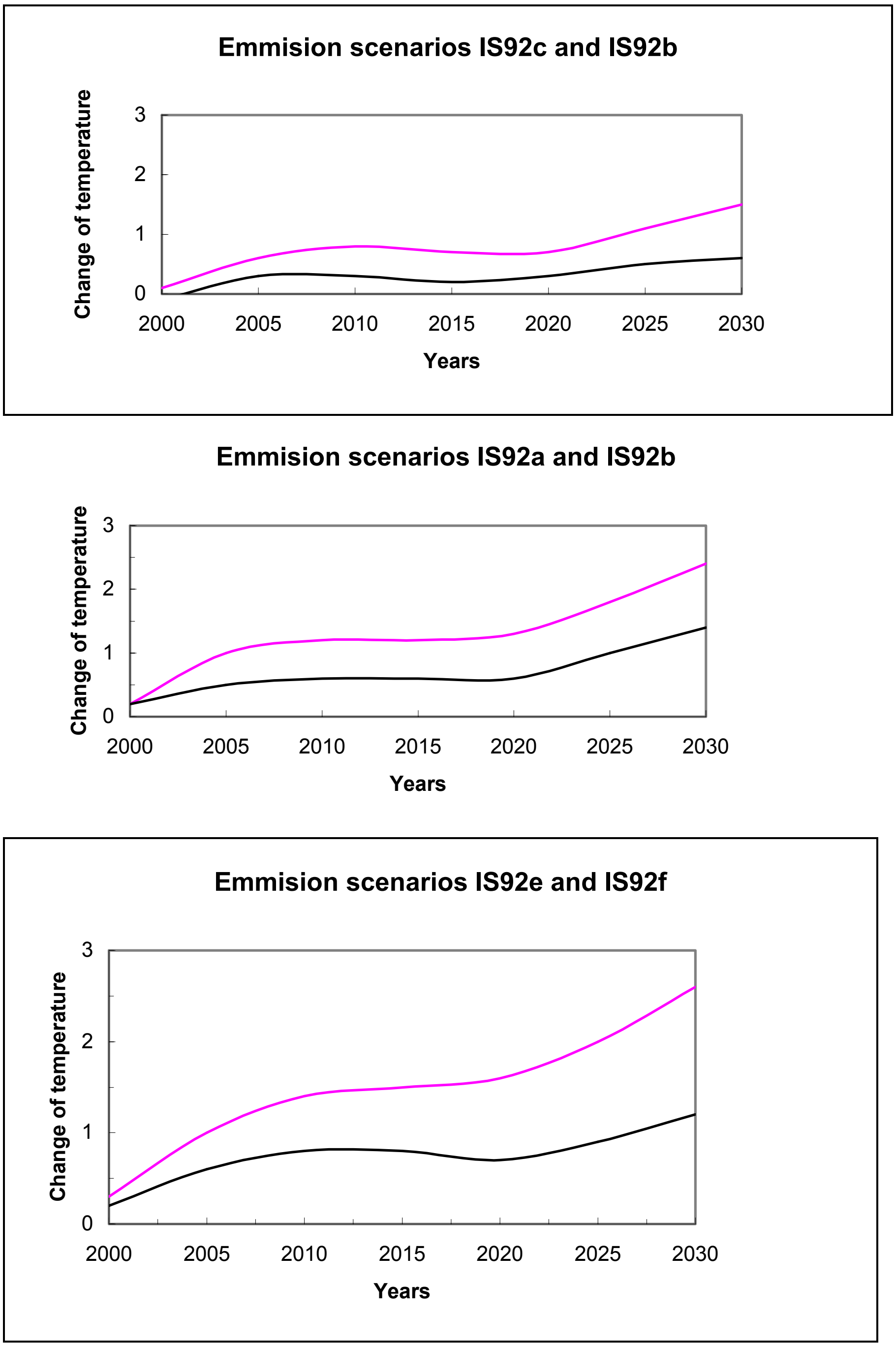

Fig. 5 The range of possible changes with regard to anomalies of average annual air temperature for the 15_1 and 23 climatic regions.

Tables 1 and 2 contain assessments of changes with regard to possible average annual air temperature and average temperatures by seasons, calculated on the basis of the above stated greenhouse gas emission scenarios combined “in pairs”: IS92c and IS92d (they characterize minimal emissions), IS92a and IS92b (mean emissions), IS92e and IS92f (maximum emissions). Hereinafter, combined scenarios will be named as “cd”, “ab” and “ef”.

In the climatic region under consideration the highest warming is expected in the foothill zone as applied to all scenarios. As elevation of terrain rises, the response to global warming in the region is weakening. The range of elevations is graphically shown in Fig 4 and numerically in Tables 1-4.

Scenarios of precipitation changes

Warming of atmosphere leads to rise in its moisture content and induces augmentation of water vapor transport to high latitudes. All models show some rise in mean global precipitation as a result of increase in CO_2 concentration. According to computer-simulation derived assessments amount of precipitation augments in high latitudes during winter; in most cases such augmentation includes middle latitudes too. However, outputs of some models applied to certain regions show even decrease in amount of precipitation.

Development of the scenario reflecting possible precipitation changes in Central Asia proceeds from expert assessments based on numerous computer-simulation derived assessments as well as on current regional climatic trends in precipitation regime with application of the above mentioned empiric-statistical method, which is in accord with response of regional climate changes to the evolving global warming.

For the purpose of developing the precipitation regime scenario for Uzbekistan and the adjacent mountainous terrain: - linear trends have been singled out from the time series of annual precipitation totals collected by reference stations; - assessments of its possible changes have been calculated taking into account the response to global warming within the framework of various scenarios of greenhouse gas emission. Analysis of derived outputs shows that linear trends extrapolated till 2030 are in conformity with calculated values of precipitation for emission scenarios IS92c and IS92d (cd), which assume low level of climate response. Therefore, the values derived through application of these two approaches are accepted in the capacity of minimum assessed values for 2030. Other emission scenarios assume additional increase in precipitation, which is in conformity with global computer-simulation derived assessments. Assessments obtained through computer simulations of possible changes with regard to annual precipitation totals in the studied region within various scenarios greenhouse gas emission are adduced in Fig. 6.

Table 1

Assessment of changes in mean seasonal annual average air temperature by climatic areas (Emission scenarios: ab-*mild*, cd-*slight*, cd-*hard*)

Number and name of climatic region	Climate of base period	Regional climatic scenario by 2030		
		ab	**cd**	**ef**
December-February				
15. Tashkent (15_1)	1.8	2.5	2.0	3.0
23. Western Tien Shan 1000-1500m a.s.l. (23_1)	-2.2	1.5	0.5	2.0
1600-2100m a.s.l. (23_2)	-10.8	1.5	0.5	2.0
March-May				
15. Tashkent (15_1)	14.5	1.0	0.5	1.5
23. Western Tien Shan 1000-1500m a.s.l. (23_1)	9.0	0.0	0.0	0.0
1600-2100m a.s.l. (23_2)	3.3	0.0	0.0	0.0
June-August				

15. Tashkent (15_1)	26.0	2.0	1.5	2.5
23. Western Tien Shan 1000-1500m a.s.l. (23_1)	20.8	0.0	0.0	0.0
1600-2100m a.s.l. (23_2)	15.0	0.0	0.0	0.0
September-November				
15. Tashkent (15_1)	13.6	2.0	0.5	2.0
2100-3000m a.s.l. (21_2)	6.0	1.0	1.0	1.0
23. Western Tien Shan 1000-1500m a.s.l. (23_1)	10.0	1.0	1.0	1.5
1600-2100m a.s.l. (23_2)	3.7	1.0	1.0	1.5
Year				
15. Tashkent (15_1)	14.2	2.0	1.0	1.5
23. Western Tien Shan 1000-1500m a.s.l. (23_1)	9.5	1.0	0.5	1.0
1600-2100m a.s.l. (23_2)	2.8	1.0	0.5	1.0

Table 2

Possible changes of seasonal air temperature (°C) by 2030
(Data from stations)

	Climatic scenarios							
Stations	**Winter**				**Summer**			
	Norm	ab	cd	ef	Norm	ab	cd	ef
Pskem	-2.3	1.3	1.1	1.4	20.8	0.1	0.1	0.1
Charvak W/R	-0.2	1.0	1.0	1.0	23.2	0.1	0.0	0.2
Chatkal	-12.0	2.3	1.8	2.6	16.1	0.7	0.5	0.8

Stations	**Spring**				**Autumn**			
	Norm	IS92ab	IS92cd	IS92ef	Norm	IS92ab	IS92cd	IS92ef
Pskem	9.1	0.0	0.0	0.1	10.0	0.8	0.5	1.0
Charvak W/R	11.5	0.4	-0.3	-0.5	12.1	1.0	0.7	1.3
Chatkal	2.9	0.2	0.0	0.4	4.2	1.1	0.5	1.4

Fig. 6 Changes (%) in annual precipitation totals by 2030 in Uzbekistan and adjacent mountainous terrain as compared to 1961-1990

For emission scenarios cd:
1 - 100-105%; **2** - 105-110%; **3** - 110-115%;
For emission scenarios ab:
1 - 105-110%; **2** - 110-115%; **3** - 115-120%;
For emission scenarios ef:
1 - 110-115%; **2** - 115-120%; **3** - 120-125%.

The present paper introduces clarity into climatic scenarios for stations located in the zones of river flow formation and use. Tables 6-9 adduce possible changes in basic climatic characteristics (air temperature and precipitation) by stations in the "year" and "season" time span.

Table 3

Possible changes in annual average air temperature by 2030 by stations on mountainous territory for various emission scenarios

Station	Norm	Climatic scenarios		
		IS92ab	IS92cd	IS92ef
Pskem	9.4	1.2	0.9	1.5
Charvak W/R	11.6	0.9	0.6	1.1
Chatkal	2.7	1.3	0.9	1.5

Table 4

Possible changes in annual precipitation totals by 2030 (% of norm) by stations on mountainous territory for various emission scenarios

Station	Norm (mm)	Climatic scenarios		
		IS92ab	IS92cd	IS92ef
Pskem	823	109	107	111
Chatkal	437	105	103	108

Assessment of climatic change on the territory of Chirchik-Ahangaran hydrological area through application of existing simulation outputs and the empiric-statistical method indicates that we should expect some increase (from 0 up to 15%) in annual precipitation totals and rise in temperature during all seasons of the year.

Development of regional climate change scenarios based on outputs generated in models of global climate

Previous analysis revealed impracticability of selecting a single general circulation model meant to describe climate on the territory of Uzbekistan and adjacent mountainous terrain in the best way.

Taking into account existing uncertainty of models and necessity to reflect the whole range of possible future changes we have chosen for developing regional climatic scenarios two basic models: 1) HadCM2 (UK, Hadley Centre); 2) ECHAM4 (Germany, Max Planck Institute).

The ECHAM4 climatic model has been developed on the basis of the model created by European Center of Medium-term Weather Forecasts (ECMWF) and parameterization elaborated in Hamburg, enabling to use this model for simulation and forecast of climate. It is a model of transient state. The model incorporates 19 levels in atmosphere and 11 in the ocean. According to the outputs of the model, there will be global warming by +3°C in 2071-2100; global precipitation is expected to rise by 1.97% of 1961-1990 norms. In addition, in the given variant of calculations consideration is given to mitigation produced by sulphate aerosol.

The HadCM2 climatic model is a version of UK Meteorological Office (UKMO). It is a model of transient state. The model incorporates 19 levels in atmosphere and 20 in the ocean. According to the outputs of the model, there will be global warming by +3.1°C in 2071-2100; global precipitation is expected to rise by 5.01% of 1961-1990 norms. In the given variant of calculations consideration is also given to mitigation produced by sulphate aerosol.

To develop regional climatic scenarios with regard to the territory of Chirchik-Ahangaran area the method of statistical interpretation was employed in the present paper; this method is based on the "ideal forecast" concept with application of step-by-step multiple linear regression. Anomalies (obtained from archival materials) of climatic parameters in the "month" time span placed in mesh points are used as predictors in the statistical interpretation method. The predictors are actual data on climatic parameters registered by stations of Chirchik-Ahangaran area and adjacent mountainous terrain.

Table 5

List of reference stations with their numbers as indicated in the unabridged register

Stations in Chirchik-Ahangaran area	
36. Tashkent	42. Pskem
37. Tuyabuguz	43. Dukant
38. Kokaral	44. Oygaing
39. Kaunchy	9. Chatcal (Kyrgyzstan)
40. Dalyverzin	
41. Syrdarya	

Major part of statistical interpretation methods are developed for some specific applications, i.e. with the purpose of utilizing final results for making assessments concerning dependence of agriculture, forestry, water resources, etc. on climate. These methods are applicable only for some specific geographic region and can not be easily used with regard to different physiographic conditions. Regional climatic scenarios, constructed on the basis of statistical interpretation of models, involve retention of statistical dependencies between large-scale and meso-scale climate in future.

This procedure allows obtaining scenarios detailed in terms of territorial peculiarities and take into consideration regional specific features. Average monthly air temperatures by selected models (HadCM2 ECHAM4) are represented in the form of anomalies; as to monthly precipitation totals they are represented in percentage of 1961-1990 norms.

Development of scenarios for the nearest future has been carried out according to the mean emission scenario (IS92a) and medium level of response to increase in greenhouse gas concentration in atmosphere. Calculated values correspond to average values for 30-year period as of 2030, i.e. the range of average-out covers the period of 2011-2040. Statistical interpretation method enabled us to calculate expected by the scenario changes as applied to separate stations in Uzbekistan and Kyrgyzstan (Table 5).

Table 6

Changes in average monthly air temperatures in the ECHAM4 model by 2030 (deviations from reference norm)

Station number	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
36	1.6	1.7	0.6	0.5	1.0	0.7	0.7	1.1	0.9	0.8	0.6	0.7
37	1.7	2.0	0.6	0.5	0.8	0.5	0.6	0.9	0.6	0.7	0.3	0.7
38	1.7	2.0	0.6	0.5	1.1	0.5	0.7	1.0	0.8	0.8	0.5	0.7
39	1.7	1.9	0.6	0.5	0.9	0.7	0.7	0.7	0.8	0.7	0.5	0.9
40	1.7	2.0	0.6	0.5	1.0	0.6	0.6	1.0	0.6	0.5	0.5	0.9
41	1.7	2.0	0.6	0.5	1.0	0.5	0.6	0.8	0.8	0.6	0.4	0.8
42	1.2	1.4	0.7	0.6	0.9	0.9	1.4	1.4	1.4	1.2	0.4	0.7
43	1.1	1.3	0.8	0.6	0.9	1.2	1.3	1.3	1.7	1.4	0.9	0.6
44	0.9	1.3	0.8	0.9	1.4	1.0	1.5	1.4	1.6	0.8	0.4	0.7
9	0.6	0.8	1.0	1.1	0.5	0.7	0.9	1.1	0.9	0.9	0.9	1.0

Table 7

Changes in average monthly air temperatures in the HadCM2 model by 2030 (deviations from reference norm)

Station number	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
36	1.0	1.1	0.4	0.4	0.6	0.5	0.3	0.8	0.7	0.9	0.3	0.6
37	1.0	1.2	0.4	0.4	0.5	0.3	0.3	0.6	0.4	0.9	0.3	0.6
38	1.1	1.2	0.4	0.4	0.8	0.3	0.6	0.9	0.7	0.8	0.3	0.6
39	1.0	1.2	0.4	0.4	0.6	0.5	0.5	0.5	0.7	0.8	0.3	0.8
40	1.1	1.2	0.4	0.4	0.8	0.4	0.4	0.7	0.4	0.7	0.3	0.8
41	1.1	1.2	0.4	0.4	0.7	0.4	0.3	0.6	0.6	0.7	0.3	0.7
42	0.8	0.9	0.4	0.4	0.6	0.6	0.8	1.0	1.1	1.2	0.3	0.7
43	0.7	1.1	0.4	0.5	0.6	0.8	0.7	1.0	1.2	1.5	0.7	0.6
44	0.6	0.9	0.5	0.7	1.0	0.5	0.9	1.1	1.2	0.7	0.3	0.6
9	0.6	0.8	1.0	1.1	0.5	0.7	0.9	1.1	0.9	0.9	0.9	1.0

There was no possibility to construct constraint equations for stations, which actually did not register precipitation during summer months, therefore expected by scenarios values remained unchanged, i.e. they correspond to the reference norm of 1961-1990 (100%).

Table 8

Changes in precipitation in the ECHAM4 model by 2020 (ratio to the reference norm in %)

Station number	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
36	103	106	123	105	92	142	196	192	121	90	117	114
37	103	112	117	106	90	190	166	100	107	91	128	126
38	102	112	115	106	85	94	128	100	111	91	127	130
39	104	110	118	105	93	128	178	100	130	90	121	122
40	102	111	115	106	91	76	153	118	114	94	126	122
41	103	114	121	109	95	88	144	100	102	91	122	125
42	105	107	116	104	93	101	138	134	117	90	109	114
43	103	109	114	107	92	120	138	160	119	90	120	122
44	103	108	117	104	92	99	143	140	108	91	122	117
9	105	105	105	101	95	89	131	124	121	94	108	115

Table 9

Changes in precipitation in the HadCM2 model by 2020 (ratio to the reference norm in %)

Station number	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
36	115	121	107	97	116	183	160	149	107	123	122	115
37	118	121	108	97	116	183	100	134	109	130	131	118
38	119	120	107	92	106	183	100	137	109	130	134	119
39	117	121	106	101	116	183	100	156	108	128	126	117
40	116	121	108	97	88	183	140	145	114	130	127	116
41	120	121	109	104	104	183	100	126	108	129	129	120
42	115	121	108	99	116	158	145	146	102	114	121	115
43	117	121	110	97	116	168	160	149	105	127	129	117
44	117	121	108	97	115	171	150	130	105	130	125	117
9	114	113	106	100	96	149	134	146	111	114	126	114

Regression equations constructed within the framework of this method's implementation enable us to generate only preliminary assessment of changes in humidity under conditions of the climatic scenario. For practical purposes, in order to develop a scenario of relative humidity for the nearest future such values may be used, which are averaged-out for the last ten years as the analog of future warming. Order of enumerating stations corresponds to the list given in Table 5.

Table 10

Average values of relative humidity (%) for the period of 1991-2000
(as analog humidity scenario)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
36	73	68	63	59	58	48	44	44	49	59	69	72
37	81	76	68	60	56	45	44	45	48	57	71	80
38	87	84	76	69	65	56	58	63	65	69	79	86
39	85	80	71	63	59	49	47	50	54	63	76	85
40	80	76	73	65	60	50	51	57	61	69	77	80
41	88	83	76	70	65	58	59	62	64	72	82	88
42	69	68	67	60	62	54	47	39	41	53	65	70
43	57	61	68	62	61	49	43	39	42	50	56	56
44	72	72	75	72	65	61	57	49	49	59	69	71

3. Assessment of changes in water resources of the Chirchik-Ahangaran basin under possible climate change

Assessment of water resources and dependence of their dynamics on climatic factors acquires vital importance in current situation of water scarcity in the republic. The extent of impact caused by possible climate changes on river flow regimes in the region may be assessed through application of sufficiently reliable models of flow formation that generate rather comprehensive and accurate output.

Mountain river flow formation model, which has been developed in SANIGMI enables researches to take into account major mechanisms of run-off formation and assess impacts of climatic changes on river flow, snow cover, glaciers at the level of river basins (see references, 1-2).

The applied set of models incorporates: - a mountain snow cover formation model; - a glacier flow model; and – a model of rainfall, snow and glacier transformation into river run-off. All of them take into account major regional peculiarities of flow formation zone located in high mountains of Tian-Shan and Pamir-Alai.

For practical application of the set of models, automated information system has been developed with the purpose of carrying out hydrological calculations and producing forecasts.

Numerical experiments consist in carrying out a series of calculations in the model specifying a number of meteorological scenarios to assess response of the model to impacts caused by meteorological elements (their values and distribution in time). For assessments of climatic impacts on water resources - flow formation zones of the Pskem, Chatkal and Ahangaran rivers and inflow to Charvak water reservoir have been selected.

As to climatic scenarios it should be noted that documents issued by IEGCC state: *no methods exist for reliable forecast of changes in troposphere temperature and climate as a whole.* All assessments that have been suggested so far are merely variants of climatic system response to increase in greenhouse gas concentration, which habitually are called "climatic scenarios".

Prediction of future climate change on the Earth in general or in some regions is not the objectives of developing climatic scenarios. Climatic scenarios are worked out for assessment of potential vulnerability of regional ecosystems and socio-economic sectors, as well as for developing adaptation strategy. Since high degree of uncertainty is inherent for climatic scenarios, especially regional ones, *it is expedient to apply several climate change scenarios for assessment of vulnerability.* .

Three-dimensional numerical models of general atmospheric circulation (MGC) are considered to be the most reliable instrument for simulation of physical processes determining climatic changes. At present, information is available about at least 20 MGC, which potentially can provide coordinated, physically plausible assessments of global climate change.

Recent development of concurrent climatic "atmosphere-ocean" models enables researchers to use them for assessment of future climate and numerically represent impacts of increase in greenhouse gas concentration in atmosphere. Such models are being developed in leading climate centers and IEGCC recommends to use their results for construction of regional climatic scenarios.

In 1992 IEGCC offered (see references, 11) 6 greenhouse gas emission scenarios (IIS92a,…IS92f) and as a result - the same number of variants for global air temperature rise. The IS92a scenario stipulates for population growth up to 11.3 billion. Economic growth rate is to be 2.3-2.9% per year by 2100 (i.e. twofold increase), and there will be no measures undertaken to limit greenhouse gas emission to atmosphere. This is so called "non-interference" scenario. The IS92b scenario proceeds from similar demographic and economic assumptions, but stipulates for implementation of arrangement to stabilize or reduce emissions in many developed countries. The IS92c and IS92d scenarios stipulate for lesser amounts of emission as compared to the IS92a and IS92b scenarios; as to the IS92e и IS92f scenarios, they stipulate for larger emission amounts – it is explained by differences in assessments of population growth and economic development rates, application of various types of fuel and power sources (see references, 14).

According to the above mentioned scenarios there is the same number of variants describing increase in global air temperature, at that each variant has its own uncertainty limits.

Within every emission scenario sets of values were generated based on specific conditions of Uzbekistan for every season that characterize simulation forecast of temperature changes for the period of 2000-2030. Considering slight differences in terms of impacts on temperature, 'a' and 'b', 'c' and'd', 'e' and 'f' were combined in-pairs. As to possible changes in precipitation by 2030, in various emission scenarios pertinent to stations in mountainous terrain - data were obtained only for annual precipitation totals. The results adduced in Table 11 allow assuming that under considered climatic scenarios there will be no considerable changes in water resources by 2030 in the region; increase in available water resources in the Amudarya river is possible by 2-4%, and in the Syrdarya basin they will remain unchanged or even increase by 3-4%.

Table 11

Norms and possible changes in river flows on the territory of Chirchik-Ahangaran hydrological area by 2030 under various climatic scenarios

River	Q	Q_{norm}	Q in % of norm for various climatic scenarios		
			IS92ab	IS92cd	IS92ef
Ahangaran	$Q_{vegetation}$	33.8	103	102	106
	Q_{year}	20.9	106	103	109
Chatkal	$Q_{vegetation}$	179	103	102	105
	Q_{year}	112	105	103	106
Pskem	$Q_{vegetation}$	118	98	98	95
	Q_{year}	73.5	99	99	98
Inflow to Charvak W/R	$Q_{vegetation}$	297	98	98	93
	Q_{year}	185	100	99	97

At the same time, taking into account high degree of uncertainty of scenarios in defining precipitation parameters (changes in annual precipitation totals are given in scenarios without distribution by seasons and months), it is appropriate to carry out calculations disregarding precipitation changes. The results of this series of calculations are adduced in Table 12; they display a tendency towards retaining the flow at the current level and even some decrease in it.

Table 12

Norms and possible changes in river flow during vegetation in Central Asian region by 2030 under various climatic scenarios

River	Q	Q_{norm}	Q in % of norm for various climatic scenarios		
			IS92ab(t)	IS92cd(t)	IS92ef(t)
Ahangaran	$Q_{vegetation}$	33.8	96	97	94
	Q_{year}	20.9	99	99	98
Chatkal	$Q_{vegetation}$	179	97	98	92
	Q_{year}	112	99	99	97
Pskem	$Q_{vegetation}$	118	98	98	95
	Q_{year}	73.5	99	99	98

Application of climatic scenarios based on models of general atmosphere circulation

Anthropogenic climate changes may be accepted in the form of scenarios developed using equilibrium models of general circulation of atmosphere and the ocean. In this case, outputs of the models in transition state (ECHAM4 and HadCM2 models) are used to construct regional climatic scenarios for the nearest future.

Vegetation flow changes are adduced in Table 13; they were calculated through implementation of transition state scenarios and the regional scenario.

Based on calculations carried out in mathematical models of mountain river flow formation in the course of implementing these climate change scenarios, the assumption can be made that within the analyzed time span for the nearest 20-30 years we should not expect considerable changes in water resources. However, in case of climate warming there will be decrease in average water discharge during vegetation period. Possible flow changes during this period will be within the range of natural changeability: from +3 to –2…7%.

Table 13

Norms and possible changes in river flow during vegetation in Chirchik-Ahangaran hydrological area by 2025 under various climatic scenarios

River	Q	Q_{norm}	Q in % of norm for various climatic scenarios		
			ECHAM4	HadCM2	IS92ab(t)
Chatkal	$Q_{vegetation}$	212	92	97	88
Pskem	$Q_{vegetation}$	126	99	103	105
Inflow to Charvak	$Q_{vegetation}$	338	94	99	94
w/reservoir					

Changes in inflow to Charvak water reservoir are adduced in Fig. 7 as calculated through implementation of transition state scenarios and the regional scenario.

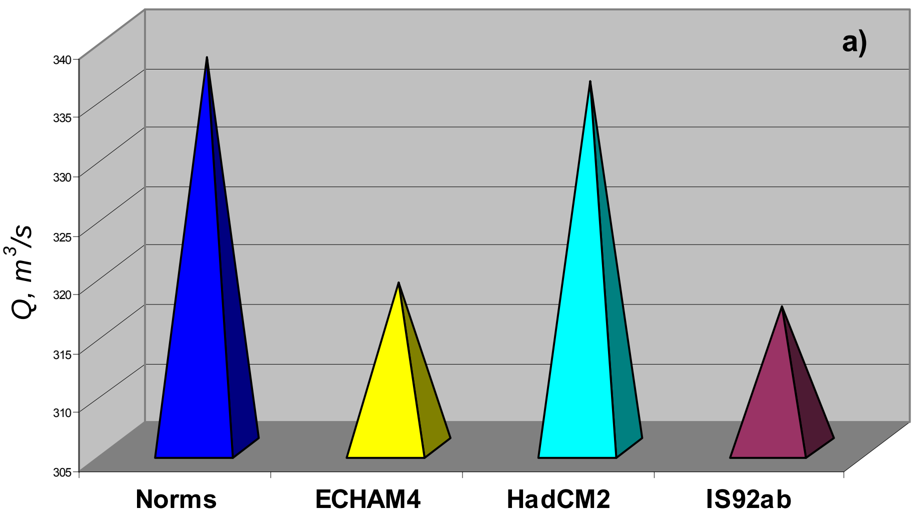

Fig. 7 Changes in river inflow to Charvak reservoir under various climatic scenarios

Calculation results show that there will not be significant decrease in river flow on the territory of Chirchik-Ahangaran hydrological area. Increase in inter-annual fluctuations of flow values may be expected.

Glaciers and climatic changes

Glaciers located in the mountains of Central Asia are the main source and long-term reserve of pure fresh water. However, the ice stock is not stable. At present, glacier contraction is observed everywhere: small glaciers disappear and large ones are breaking to pieces. Glacier shrinking leads to reduction of melt water flow from glaciers.

Observations in various glacier regions have shown that flow from glaciers decreases slower than glacier area. In the process of glaciers degradation, their actual area increases due to expansion of their partitioning process.

Various researchers note inconsistency between increase of melt water from contracted glacier and concurrent decrease of glaciation area. Studying changes in glacier basins under impacts of climatic factors, glaciologists have noted that long-term flow changes linked with glaciers degradation proper are obscured by increased melting in dry years: the less area of glaciers the more flow from them.

The latest assessment of current glaciation situation has been made by glaciologists of NIGMI with regard to a separate mountain basin located on the territory of Uzbekistan – upper reaches of the Pskem river and its left tributary the Oygang river. The digital space image of high spatial resolution (ASTER for 2001) was used as an information basis. The glaciation area of the Oygang river basin constituted - according to calculations of glaciologists - 38.8 km^2. Processing of space images for 1980 revealed that the total area of glaciation on the pertinent territory constituted 46.7 км^2. Glaciation of this region for the last 20 years has declined by 16.8%. According to assessments, glaciers will shrink not less than by 17% more of its initial volume 2020, i.e. by 2020 decrease in mass will constitute 1/3 of the 1960volume.

Calculations of glacier flow carried out within the ECHAM, HadCM2 scenarios show that according to the assumed scenario changes, only slight decrease in glacier flow is expected.

Calculations made on the basis of "transient state" scenarios display that in the nearest future there will be no significant changes in river flow of the region, though some decrease is expected due to rise of global temperature (2-6%). Because of increasing aridity of climate, melted snow water is expected to contribute less to the flow (5-10%), seasonal snow area will shrink; the beginning of seasonal snow melting will shift by 1-4 weeks. Share of rain flow may augment by 7-10% - this causing negative impact on snow reserves.

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