Spatial distribution of climate factors in average and extreme years

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Abstract. Schematic maps of spatial distribution of seasonal precipitation amounts and average air temperature were obtained for the areas of research in years with normal and extreme values of annual river runoff. To achieve this we used precipitation amount for January-December and average air temperature for June-September during 1961-1990, at 93 meteorological stations located along the intervals: latitude 30.20° - 44.08°N, longitude 67.20° - 82.98°E, and altitude of 122 – 4 169 meters above sea level. According to this information for each point-element (i.e. meteorological station with proper data) were calculated ordinates of integral function of distribution of probabilities by using the sample volume equaled to 30 years and received averages and standard deviations for each year. In characteristic years were revealed significant differences for spatial distribution of climate factors of runoff. It was found out that the spatial distribution of the total amount of glaciers melting is less variable in the years with extreme water yield, if compared to the average years. This peculiarity is very beneficial for hydropower and agriculture because provide additional and natural ability to stabilize water balance of reservoirs. A multi-factor piecewise linear equations were obtained also to calculate the statistical probability of glaciers total melting in low and high flow years as a function of geographical coordinates and the average altitude of firn boundary.
Keywords river runoff; Central Asia; spatial distribution; precipitation; air temperature; extremes

OUTLINING THE PROBLEM OF RESEARCH

Spatial and temporal variability of river runoff and its climate factors like precipitation, air temperature and others play significant role in understanding past, current and future state of environment. It is truth especially in extreme cases like low-water and high-water years, which strongly influence on water management and consumption and needs of population. Everyone may easily understand the essence of the problem after calculating correlation matrix for river runoff in different watersheds within of certain region. Such matrix describes spatial change of correlation independently from distance between of watersheds and other parameters of hydrography. The matrix obtained for some time interval reflects average condition of runoff formation in different river basins. Of course it is interesting but limited characteristic. More important is studying: (a) regional homogeneity of climate fields and (b) spatial variability of climate factors in years of extremal and normal volumes of runoff. These are the main objective of our work. Regular or standard data measurement on precipitation and air temperature at the regional meteorological network will be used for the task (a). Analysis of spatial variability of river runoff, glacier runoff and their climate factors have to be done in the common system of units for them. It will be reached by transforming all studied variables into ordinates of normal distribution of probabilities for corresponding function X, i.e. $P(X) = 1-F(X>x)$.

RESEARCH AREA AND INITIAL DATA

The studied region is located within of the closed basin of the Aral Sea and includes the watersheds of the rivers Syrdarya, Amudarya, Tedjen, and Murgab. It also incorporates a number of smaller rivers draining the western part of Tien Shan. With regard to administrative divisions, the region embraces the entire areas of Uzbekistan, Tadjikistan, Kirghizstan, and parts of northern Afghanistan. The region belongs to the Central Asian territory having total area 1765.9 thousands km^2 and population 41.686 mln. (Data of 1996). The climate in the northern parts of the Aral Sea basin is continental. In the southern parts, it is subtropical. The territory receives considerably more solar energy than any other part of the former USSR. Temperatures during of the remarkably long summer are high (the average temperature in July is 25 to 33 °C). On the plains of the Aral region, the annual amount of precipitation is 90 to 120 millimeters. In the piedmont areas, it is 400 to 500 millimeters, while on the western slopes of Tien-Shan it is more than 2000 millimeters.

Hydrology

The rivers Syrdarya and Amudarya are the principal water sources of the Aral Sea. The area of these rivers basins are equal to 692.3 and 493.0 thousands of km^2 relatively. The surface water resources of the region also include the runoff of the blind drainage rivers Kashka Darya, Zarafshan, Murgab, Tedjen, Chu, Talas, and other smaller rivers flowing in the territory of the former USSR, and of the rivers from the territory of Afghanistan. The average perennial river runoff totals about 116 to 120 km^3 per year. The primary sources of all rivers in the Aral Sea drainage basin are mostly snow/glacier runoff. The runoff formation area amounts about 25% of the Aral Sea basin. At that, 80% of this area located in the Amudarya and Syrdarya river basins. Their runoff formation zones can be approximately estimated as 200 000 km^2 for Amudarya and 160 000 km^2 for Syrdarya. The Amudarya, a product of the confluence of the Piandj and Vakhsh rivers, is 1445 kilometers long. The main part of its water resources (72.8 %) forms on the territory of Tajikistan the other shares enter from the Afghanistan and Iran (14.6 %) and Uzbekistan (8.5%) territories. Low-water periods of the Amudarya occur every four to five years and high-water periods occur every six to ten years. The Syrdarya is the longest river in Central Asia (2790 km). Its average annual runoff is 40.8 km^3.The low-water period is October-March, while the highest water discharge is in June-July. The low-water periods occurs every three to four years and last five to six years. The annual and seasonal runoffs of the basins Amudarya and Syrdarya have perennial variations. For example, the annual runoff in the Amudarya basin in the high-water 1969 year was about 110 km^3. In the low-water 1974 year, it was about 65 km^3. In the Syrdarya basin, in the same high-water year of 1969, the annual runoff was about 70 km^3, and in the low-water year of 1983, it was about 20 km^3. The Aral region has considerable ground water resources. At present, the ground water discharge is 14.7 km^3/yr. Annual water intake in the Aral Sea basin is 117.7 km^3 and irrigation needs more than 90% of this volume.

Hydrometeorological network

National Hydrometeorological Services of Central Asia's states carry out collection of operational information on many characteristics of environment including river runoff and climate. The additional source of hydrological data is observations on the network, subordinated to Ministry of Melioration and Water Economy. The longest range of data exceeds 100 years. Like in many of other countries, the composition of network, number of points, methods and technique of measurements are vary during of 20-th century and later. Distribution of sites on measurement of precipitation and air temperature within of river basins Syrdarya, Amudarya and adjacent territories are shown on Fig. 1.

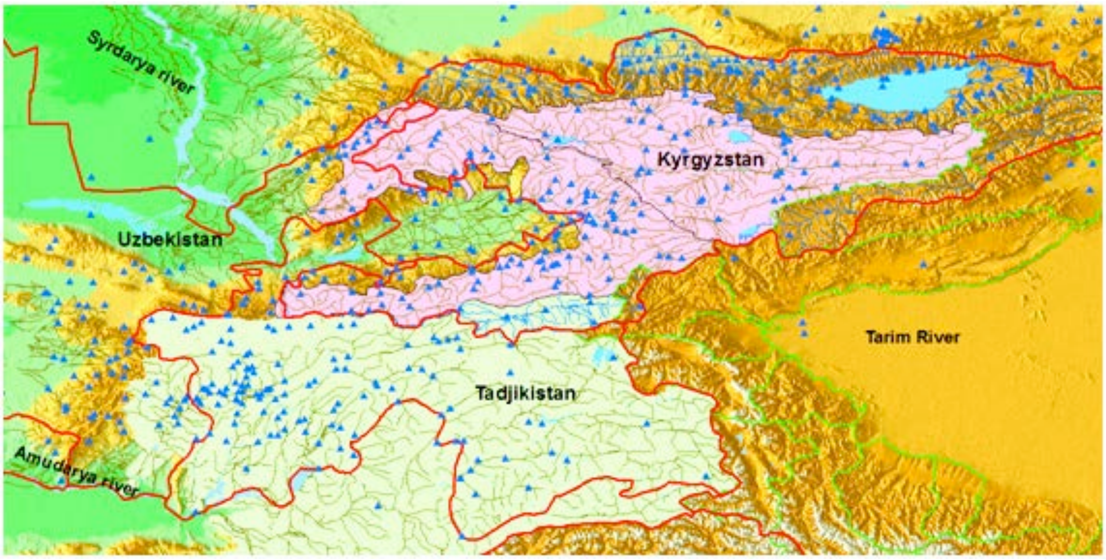


Fig. 1 Points of observation on precipitation and air temperature (blue triangles), red lines – state boundaries. Pink color – Syrdarya basin, light green – Amudarya basin.

Table 1 Hydrometeorological network in Central Asia

Measurement points	Number. percentage and density years				
	1975	1980	1985	1990	1995
(a) runoff	412	505	530	478	366
(b) suspended sediments	181	270	291	245	108
(c) water level	453	540	558	486	397
(a) relative to 1985 in %	77.7	95.3	100.0	90.2	69.1
(b) relative to 1985 in %	62.2	92.8	100.0	84.2	37.1
(c) relative to 1985 in %	81.2	96.8	100.0	87.1	71.1
density (a) per 1000 km^2	1.306	1.310	1.313	1.316	1.320
density (b) per 1000 km^2	0.273	0.334	0.351	0.316	0.242
density (c) per 1000 km^2	0.120	0.179	0.192	0.162	0.071
(d) precipitation	355	365	361	331	282
(e) air temperature	333	341	335	312	273
(f) soil surface temperature	302	312	306	283	248
(g) vapor pressure	303	313	307	284	248
(h) snow cover	348	354	350	324	255
(d) relative to 1985 in %	98.3	101.1	100.0	91.7	78.1
(e) relative to 1985 in %	99.4	101.8	100.0	93.1	81.5
(f) relative to 1985 in %	98.7	102.0	100.0	92.5	81.0
(g) relative to 1985 in %	98.7	102.0	100.0	92.5	80.8
(h) relative to 1985 in %	99.4	101.1	100.0	92.6	72.9
density (d) per 1000 km^2	0.235	0.241	0.239	0.219	0.187
density (e) per 1000 km^2	0.220	0.226	0.222	0.206	0.181
density (f) per 1000 km^2	0.200	0.206	0.202	0.187	0.164
density (g) per 1000 km^2	0.200	0.207	0.203	0.188	0.164
density (h) per 1000 km^2	0.230	0.234	0.231	0.214	0.169

Temporal variability of the number of measurement points inside of Central Asia characterize Table 1 from which we see that the highest quantity of network in the Aral Sea basin was reached by 1985. Since that time began permanent reduction the number of observational sites (Chub, 2000).

Time interval covered 1961-1990 was chosen for our analysis on spatial variability of seasonal (April-September) river runoff, annual precipitation and mean seasonal values (June-September) of air temperature. Main sources for initial data on runoff were (Bodo, 2000) and (Main Hydrological Characteristics …1967-1980). Minimal and maximal parameters of watersheds in the used sample are related to the very different conditions of river runoff formation. Thus, latitude and longitude of hydrological stations are within ranges: 37.20-41.80°N and 66.00-74.00°E, but their elevation vary from 327 m till 3576 m above sea level. Majority of hydrological stations located in sub-mountain and high-mountain areas provide data on runoff, which are not distorted by water management. Area of watersheds varies from 362 km^2 till 113 000 km^2, and their mean weighted altitude from 1.80 km till 4.20 km above sea level. As climate factors for river runoff we used precipitation amount for January-December and average air temperature for June-September during 1961-1990, at 93 meteorological stations located along the intervals: latitude 30.20° - 44.08°N, longitude 67.20° - 82.98°E, and altitude of 122 – 4 169 meters above sea level. Sources of initial data were the following: (Former Soviet Union Monthly Precipitation Archive, 1891-1993; Global Historical Climatological Network Database, GHCN, Version 2; Williams, and Konovalov, 2008).

SPATIAL HOMOGENEITY OF AIR TEMPERATURE AND PRECIPITATION

Well known feature of Central Asian nature – vertical zoning of landscapes and climate characteristics, complicated by the latitudinal differences and local peculiarities (Balashova, et al, 1960; Muminov and Inagamova, 1995; Murzaev, 1958) was used to solve this task. Let us consider as homogeneous such samples of air temperature and precipitation, which present objectively the features mentioned above. Coefficient of determination (R^2) for multifactor equations of linear regression T=T(Long, Lat, Alt) and P=P(Long, Lat, Alt) was adopted as criterion of spatial homogeneity. Further these equations were applied to determine spatial variability of norms of mean monthly air temperature during of January-December and yearly precipitation sum. Time interval 1961-1990 was used as reference period. Here: Long (longitude) and Lat (latitude) – are geographical coordinates of point and Alt – is its altitude above sea level.

Size of samples equaled to 179 meteostations for air temperature and 215 meteostations for precipitation were selected for determination parameters of regression equations. Contribution of each independent variable for describing variances of functions T=T(Long, Lat, Alt) and P=P(Long, Lat, Alt) was calculated by formula (1) from (Alexeev, 1971).

$$\beta_j = \frac{\left|r_{0j}\alpha_{0j}\right|}{\left|r_{01}\alpha_{01}\right| + \left|r_{02}\alpha_{02}\right| + \left|r_{03}\alpha_{03}\right|} \quad (1)$$

$$\beta_1 + \beta_2 + \beta_3 = 1 \quad (2)$$

Here r_{0j} – are coefficients correlation of function with each argument, α_{0j} – are coefficients of normalized multifactor linear regression. Table 2 contents estimations of homogeneity for air temperature in the selected sample of data.

Coefficients of determination in the Table 2 show that linear equation T=T(Long, Lat, Alt) describe in nine cases from 12 more than 80% of spatial variability of mean monthly air temperature in Central Asia region. Moreover the value of R^2 is ≥ 0.93 during of April-August. Obtained characteristics for equation T=T(Long, Lat, Alt) fully correspond to the seasonal conditions of formation of air temperature field within Central Asia (Balashova et al, 1960). The main factor in spring-summer period here is powerful local warming from solar radiation at the local scale and practical absence of latitudinal gradients. Arctic intrusions together with southern cyclones play essential role during October-March that specifies differentiation field of air temperature along latitude. Equation T=T(Long, Lat, Alt) adequately describes these processes. Thus the field of mean monthly air temperature in May-September on all altitudes should be considered as rather homogeneous inside of Central Asia region.

Table 2 Statistical characteristics of equation T=T(Long, Lat, Alt).

	Months											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
R^2	0.7	0.75	0.84	0.93	0.97	0.97	0.95	0.93	0.91	0.88	0.82	0.73
β_1(Long),%	6.5	3.2	1.0	2.7	0.8	0.3	2.4	3.1	2.4	0.6	5.0	7.4
β_2(Lat),%	36.3	41.1	27.3	8.1	2.0	1.9	2.1	4.3	7.4	16.6	23.1	30.9
β_3(Alt),%	57.2	55.7	71.7	89.3	97.2	97.7	95.6	92.6	90.2	82.8	71.9	61.8

Note: R^2 – coefficient of determination (explained part of variance of dependent variable) for the regional equations T=T(Long, Lat, Alt), T – mean monthly air temperature, β_1(Long), β_2(Lat), β_3(Alt) – are consequently determined contributions of Longitude, Latitude, and Altitude in R^2 of multifactor equations T=T(Long, Lat, Alt) for months.

Analogous analysis for general formula of precipitation, i.e. P=P(Long, Lat, Alt) revealed that its coefficient of determination was only 0.23 and contributions of longitude, latitude and altitude were consequently 27.8%, 3.6% and 68.6%. This confirms once more significant spatial variability even yearly norm of precipitation and inefficiency the regional empirical formula in the form of linear function of geographical coordinates and altitude. However searches for a local dependences of precipitation from altitude and geographical coordinates revealed better estimations of homogeneity and representativeness for initial information. Coefficients of determination for equation P=P(Long, Lat, Alt) being calculated separately for river basins Chirchik, Naryn and Zeravshan equaled consequently 0.70, 0.87 and 0.94. Many examples of similar dependences of satisfactory quality for Amudarya and Syrdarya river basins could be found in (Resources …,1969, 1971).

SPATIAL VARIABILITY OF RIVER RUNOFF AND ITS CLIMATE FACTORS

In hydrological computations the empirical probabilities of exceeding $X>x_i$ is determined by rather simply and known procedure (Alexeev, 1971):

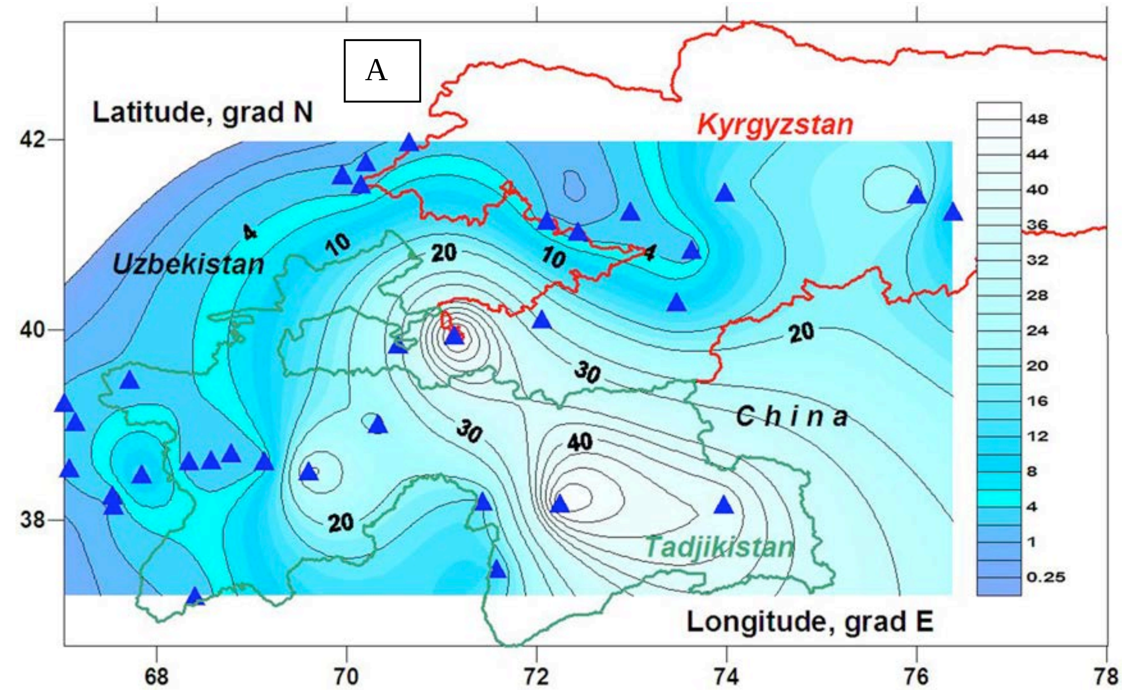
$$p_i(x_i) = \frac{m(x_i) - 0{,}25}{N_i + 0{,}5} * 100, \qquad (3)$$

where $m(x_i) = 1, 2, ..., N_i$ are ordinal numbers of the x_i values after their disposition in the descending order. All temporal ranges of R_{iv-ix} - seasonal runoff for April-September on the selected 33 hydrological stations were processed according to the formula (3). Years when $15\% \geq P(R_{iv-ix}) \geq 85\%$ were related to extreme and when $45\% \leq P(R_{iv-ix}) \leq 55\%$ were considered as normal or average. Here $P(R_{iv-ix})$ is mean probability for 33 values in each year. Table 3 presents results of identification of average and extreme years and their statistical parameters. Fig. 2 a-b illustrate spatial distribution of probability of seasonal river runoff inside of the watersheds Amudarya and Syrdarya in high-water and low-water years.

For the rivers of Aral Sea basin both precipitation and air temperature are used as predictors in order to forecast seasonal and monthly runoff from upper watersheds. Thus revealing their role in formation of extreme values of river runoff we may clarify or improve the methods of hydrological forecasts in the most important situations for water users.

Table 3 Parameters of seasonal river runoff inside of Amudarya and Syrdarya watersheds

Index	Probability of R_{iv-ix} in % in characteristic years and their standard deviation SD		
	1969 – max (high-water)	1974 – min (low-water)	1985 - normal
Mean (%)	11.33	88.19	52.31
Limits (%)	2.46 – 48.36	61.48 – 97.54	12.30 – 84.43
SD	13.95	9.49	17.51



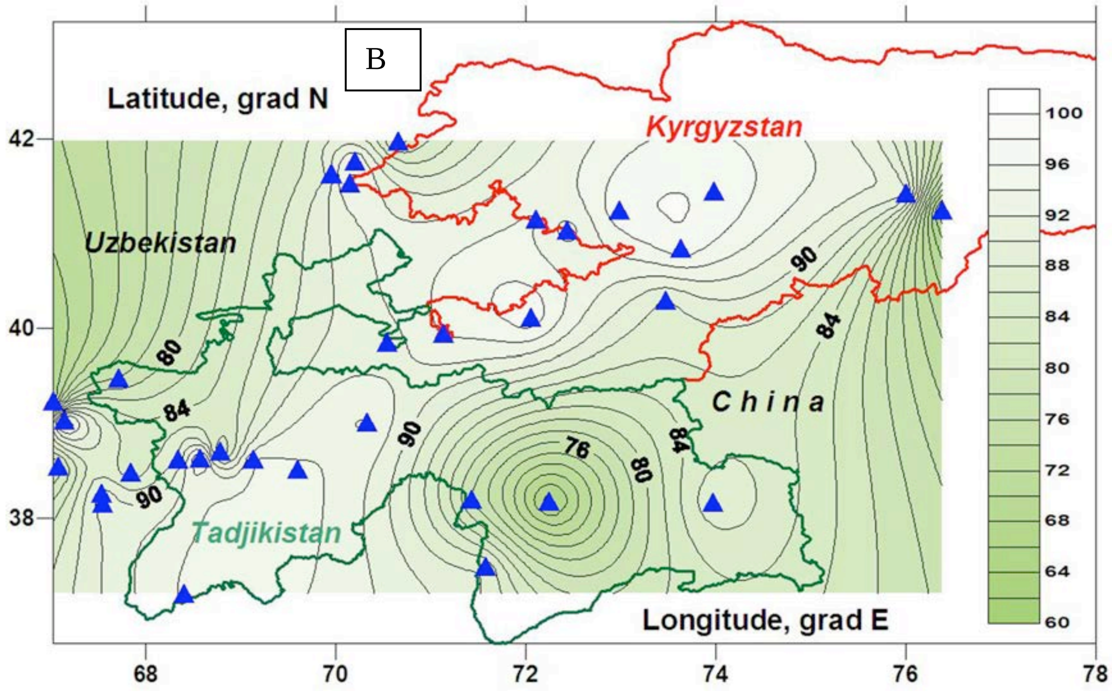


Fig. 2 Spatial distribution of seasonal (April-September) river runoff probability inside of the watersheds Amudarya and Syrdarya in high-water (A) and (B) low-water years. Blue triangles are hydrological stations.

First of all only in 1969 the mean values of probabilities both for runoff – P($R_{iv\text{-}ix}$) and precipitation – P($Pr_{i\text{-}ix}$) could be treated as extremely high, but the same phenomenon is not truth for probability of air temperature – P($T_{vi\text{-}ix}$). Below is the example for regional distribution of extreme precipitation (fig. 3).

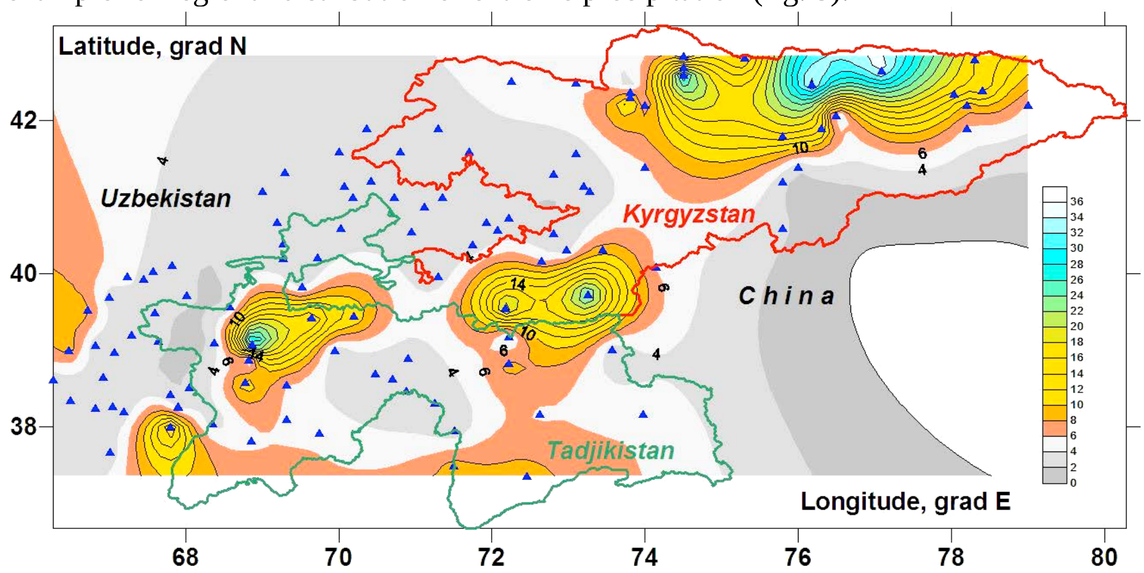


Fig. 3 Spatial distribution of P($Pr_{i\text{-}ix}$) inside of the watersheds Amudarya and Syrdarya in high-water year (1969). Blue triangles are measurement sites.

Tables 4-5 contain the probabilities of annual precipitation and seasonal air temperatures and their standard deviation (SD) related to the years that have been identified previously as low, average and high water basing on $R_{iv\text{-}ix}$ values (see Table 3). Data in the Tables 4-5 are presented as all together (ALL), sorted by Central Asian states (here KYR – Kyrgyzstan, UZB – Uzbekistan, TAD – Tadjikistan) and along altitude Z above sea level. In assessing the probabilities of precipitation and air temperatures in the Table 4-5 as climate factors of to river flow formation we may note the following:

Table 4 Probabilities (%) of yearly precipitation in the characteristic years on runoff

Data	Index	1969	1974	1985	1969	1974	1985	1969	1974	1985
		380 m ≤ Z ≤ 4169 m			Z ≥ 2000 m			Z ≥ 3000 m		
ALL	mean	6.14	67.92	58.37	7.92	58.53	68.03	8.81	58.61	62.30
	Min	2.46	2.46	9.02	2.46	2.46	22.13	2.46	5.74	18.85
	Max	35.25	97.54	97.54	31.97	94.26	97.54	31.97	94.26	94.26
	SD	7.04	26.21	21.94	8.01	28.75	24.28	9.00	31.10	24.61
KYR	mean	9.09	55.00	63.35	8.70	50.86	80.37	9.02	49.59	77.46
	Min	2.46	2.46	9.02	2.46	2.46	48.36	2.46	5.74	61.48
	Max	35.25	97.54	97.54	28.69	90.98	97.54	25.41	87.70	94.26
	SD	9.15	29.24	20.51	8.35	28.90	16.97	8.76	29.16	13.17
UZB	mean	3.20	75.56	62.82	2.46	80.33	51.64	-	-	-
	Min	2.46	18.85	22.13	2.46	71.31	31.97	-	-	-
	Max	18.85	97.54	94.26	2.46	87.70	71.31	-	-	-
	SD	2.82	18.60	19.50	0.00	7.27	16.93	-	-	-
TAD	mean	6.30	75.04	44.40	8.31	63.82	54.22	8.61	67.62	47.13
	Min	2.46	12.30	12.30	2.46	12.30	22.13	2.46	12.30	18.85
	Max	31.97	97.54	90.98	31.97	94.26	97.54	31.97	94.26	90.98
	SD	6.38	24.87	22.12	8.35	29.11	26.08	9.83	32.19	24.47

Table 5 Probabilities (%) of air temperatures for VI-IX in the characteristic years on runoff

Data	Index	1969	1974	1985	1969	1974	1985	1969	1974	1985
		380 m ≤ Z ≤ 4169 m			Z ≥ 2000 m			Z ≥ 3000 m		
ALL	mean	85.74	76.55	34.07	81.64	77.95	31.72	77.66	81.35	33.4
	Min	48.36	9.02	5.74	48.36	9.02	12.3	61.48	12.3	18.85
	Max	97.54	94.26	68.03	97.54	94.26	68.03	90.98	94.26	68.03
	SD	10.18	17.01	13.21	10.72	20.53	10.46	9.46	18.95	12.5
KYR	mean	85.4	70.34	29.13	82.95	73.28	31.48	81.56	84.02	34.84
	Min	48.36	9.02	12.3	48.36	9.02	12.3	74.59	77.87	18.85
	Max	97.54	94.26	68.03	97.54	94.26	68.03	90.98	94.26	68.03
	SD	9.55	19.7	10.52	11.48	21.02	12.33	5.93	5.38	16.39
UZB	mean	93.53	85.88	47.81	90.16	85.25	42.62	-	-	-
	Min	84.43	81.15	22.13	84.43	81.15	38.52	-	-	-
	Max	97.54	90.98	64.75	94.26	87.7	45.08	-	-	-
	SD	3.65	2.31	11.43	4.92	3.14	3.14	-	-	-
TAD	mean	82.3	78.22	32.32	77.87	81.97	29.3	73.77	78.69	31.97
	Min	48.36	12.3	5.74	61.48	12.3	18.85	61.48	12.3	18.85
	Max	97.54	94.26	68.03	94.26	94.26	45.08	90.98	90.98	45.08
	SD	11.04	15.95	12.09	9.5	21.76	7.21	11.05	26.91	7.84

- Probabilities of yearly precipitation completely correspond to the $P(R_{iv\text{-}ix})$ of runoff in high-water, low-water and normal years. This conclusion is correct both for all territory of Amudarya and Syrdarya river basins, its different parts and altitudinal zones. Standard deviation of $P(Pr_{i\text{-}ix})$ is significantly less in high-water year comparing with low-water and normal years. This feature of precipitation is important for obtaining generalized estimation of regional water resources and for improvement hydrological forecasts and computations.
- Probabilities of $P(T_{vi\text{-}ix})$ in the Table 5 demonstrate absence of rather evident relationship with seasonal runoff in characteristic years. We may note only rather cold summer season in high-water 1969 year. Standard deviation of $P(T_{vi\text{-}ix})$ is also significantly less in high-water year comparing with low-water and normal years.

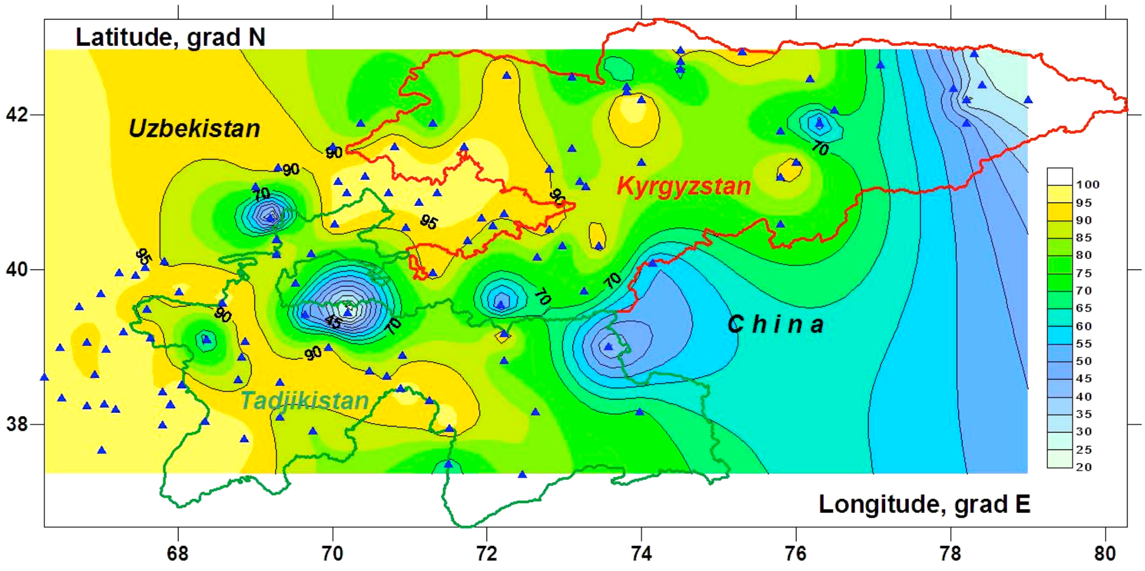


Fig. 4 Spatial distribution of $P(Pr_{i\text{-}ix})$ inside of the watersheds Amudarya and Syrdarya in year (1971) with minimal mean values of precipitation. This year was defined as extreme in the sample of $P(Pr_{i\text{-}ix})$ independently from runoff.

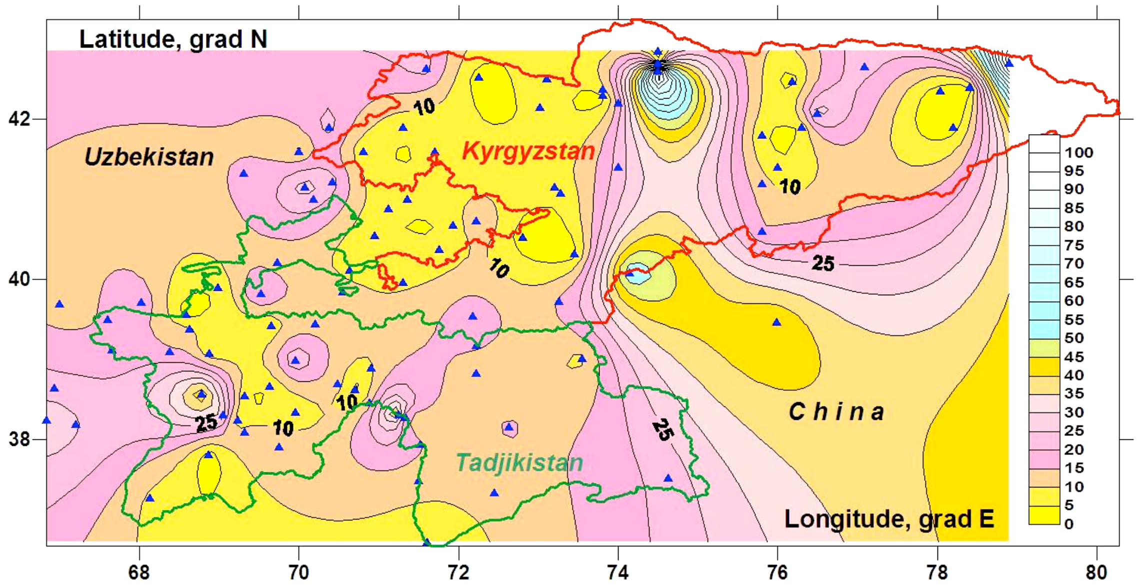


Fig. 5 Spatial distribution of $P(T_{vi\text{-}ix})$ inside of the watersheds Amudarya and Syrdarya in year (1990) with maximal mean value of air temperature. This year was defined as extreme in the sample of $P(T_{vi\text{-}ix})$ independently from runoff.

Thus in high-water year we see rather good synchronism between probabilities of precipitation and runoff, but for low-water condition the extreme value of regional mean $P(Pr_{i\text{-}ix})$ was in 1971 but not in 1974. Asynchronism between extremely and normal years on runoff and air temperature was found out after calculating $P(T_{vi\text{-}ix})$ independently from $P(R_{iv\text{-}ix})$ of runoff in the Table 3. Spatial distribution of $P(T_{vi\text{-}ix})$ in extreme years is shown on Figs. 5-6.

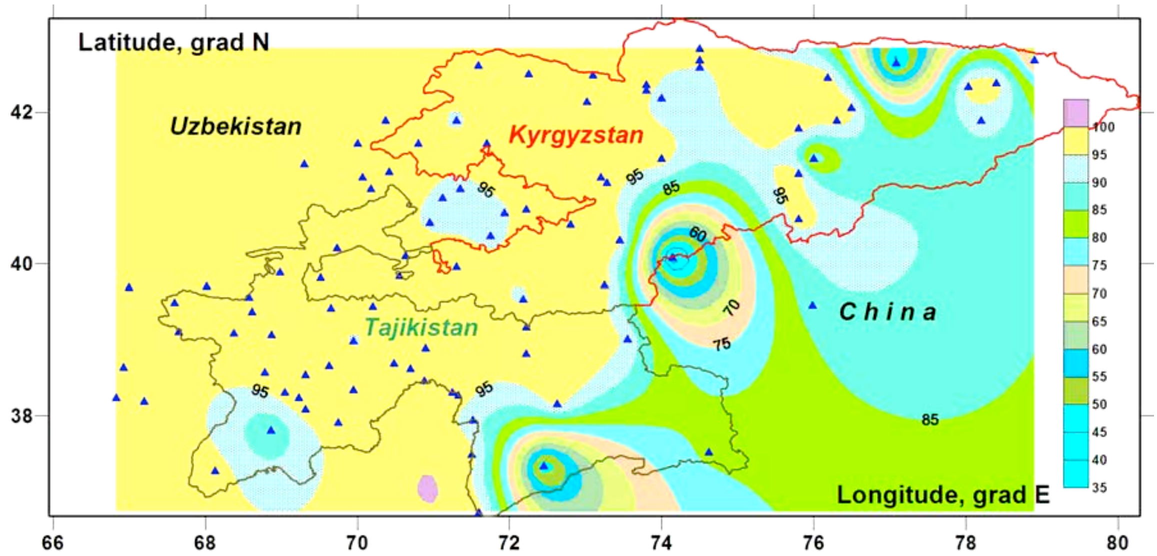


Fig. 6 Spatial distribution of $P(T_{vi\text{-}ix})$ inside of the watersheds Amudarya and Syrdarya in year (1972) with minimal value of air temperature. This year was defined as extreme in the sample of $P(T_{vi\text{-}ix})$ independently from runoff.

TOTAL MELTING OF GLACIERS IN THE UPSTREAM OF AMUDARYA RIVER BASIN

The upstream of Amudarya river basin contains several thousands of glaciers (Inventory..., 1971-1978). These glaciers were regionalized into 138 quasi-homogeneous groups for computing total volume V_M of their melting, where V_M is function of meteorological variables and empirical parameters. Each group is characterized by: geographical coordinates; areas of glaciers and solid moraine; altitudinal distribution of area; altitudes of glacier head, terminus and firn boundary; upper limit of solid moraine cover; depth of solid moraine on the end of glacier; slope and azimuth of glacier surface.

A set of computer programs and data on climate variables were developed in the form of model REGMOD (Konovalov 1985, 2006) for calculating long-term series of hydrological regime of glaciation. The formula realized in the REGMOD for determination of total volume of glacier melting v_m in the moment t, has the form:

$$v_m(t) = M_c(\tilde{z}_{im},t)S_{im} + M(\tilde{z}_i,t)S_i + M(\tilde{z}_f,t)S_f + M(\tilde{z}_{ws},t)S_{ws} + M(\tilde{z}_{ss},t)S_{ss} \tag{4}$$

Here M is intensity of melting for open ice or snow, $M_c = M \cdot f(h_c)$ is intensity of ice melting under cover of solid moraine (im) of depth h_c, i is bare ice, f is old firn, ws is winter snow, ss is summer snow, $f(h_c)$ is function of extinction of ice melting under moraine cover of depth h_c, $\tilde{z}$ is mean weighted altitude for the certain S area. In order to get the total melt volumes V_M from the equation (4) we used:

$$V_M = \sum_{d_{bp}}^{d_{ep}} v_m(t) \tag{5}$$

where d_{bp} and d_{ep}- are dates of the beginning and end of the calculation period. Computations of V_M according to the equations (4-5) are based on using several numerical methods, which were described in detail in (Konovalov, 1985, 2006). The REGMOD model and its main subroutines have been successfully tested (Konovalov, 2007). Total river runoff computed by means of the water balance equation showed very close coincidence with measured data. The REGMOD model was applied for the selected 138 groups of glaciers during of 1935-1994. The set of empirical equations (see below) describing spatial distribution of V_M volumes in high and low water years was obtained in (Konovalov, 2009) as functions of geographical coordinates (longitude and latitude):

V_M(high) = 7E-06·lat^5-0.0028·lat^4+0.4261·lat^3-28.796·lat^2+976·lat,

V_M(low) = -0.0001·lat^4+0.037·lat^3-3.8553·lat^2+186.9·lat,

V_M(high) = -1E-06·long^5+0.0009·long^4-0.1825·long^3+13.899·long^2-115.36·long,

V_M(low) = -1E-06·long^5+0.0005·long^4-0.0801·long^3+5.1975·long^2-32.441·long.

In the upstream of Amudarya river basin the total volume of glaciers melting in high water year equals to 26.888 km^3 and 7.108 km^3 in low water year.

It is known (Konovalov 1985, 2006) that V_M depends from the altitude of firn boundary Z_{fg} on glaciers. Therefore this parameter is necessary to use for additional studying of change V_M. Analysis showed (Schetinnikov, 1998) that decreasing of Z_{fg} along latitude relate to the prevailing (more 76%) concentration of glaciers in the north of the region and inside of interval 3.7 – 4.4 km above sea level, but in the south the largest part of glaciers (62%) located between 4.0 and 5.0 km above sea level. Increasing Z_{fg} along longitude in the same part of Pamiro-Alai mountain region was revealed earlier in (Kotlyakov *et al.*, 1993). Finally, multi-factor piecewise linear equations were obtained to calculate the statistical probability for the volume of the total melting of glaciers in low and high water years as a function of geographical coordinates and average altitude of firn boundary. General form of calculating formula is the following:

$$P(V_m) = a\,Long + b\,Lat + c\,Z_{fg} + Const \quad \% \qquad (6)$$

Empirical parameters of this formula are given in the Table 6.

Table 6. Parameters of piecewise multi-factor linear equation for calculation P(V_m)

	1^{-th} version of formula (6)				2^{-nd} version of formula (6)				*Br*	R^2
	$Const_1$	a_1	b_1	c_1	$Const_2$	a_2	b_2	c_2		
P_1	23.838	-0.196	-0.304	1.084	33.326	0.090	-0.814	0.277	5.085	0.76
P_2	-220.164	1.781	11.804	-70.652	115.416	0.191	-0.933	0.725	91.950	0.88

Note: a_1, b_1, c_1, $Const_1$ and a_2, b_2, c_2, $Const_2$ – are correspondingly parameters for the first and second versions of formula (6), P_1 – high-water year, P_2 – low-water year, *Long, Lat* – are correspondingly longitude and latitude in integer and decimal part of degree, Z_{fg} – firn boundary in km above sea level, R^2 – is explained part of variance of function (coefficient of determination), *Br* – is criteria for selection the version of empirical equation. When $P_1 \leq Br$ computation is performed by the first version of (6) otherwise by the second version, similarly for P_2.

Principally, enhancing of R^2 in the Table 6 is possible by means of using additional independent variables.

CONCLUSIONS

On the presented graphs of spatial variability for river runoff, precipitation and air temperature inside of the basins Syrdarya and Amudarya we see certain subareas where the local data are not consistent with mean value of probability in characteristic year. The reason of such inconsistency is not clear so far. Probably this is combined effect of local relief and pattern of atmosphere circulation. The other interesting and important feature of spatial variability of climate factors of runoff is their even distribution in high-water year. Both effects have to be taken in consideration at water management, hydrological forecasting and computations.

Statistics of climate factors, including integral and differential distributions and spatial correlation functions, provide a much more informative assessment the impact of climate change on the hydrological regime of Asian river basins, compared to the determination of alone average values.

Regional determinations of glacier regimes are necessary for solving the problems of water consumption and forecasts of runoff. Intra-seasonal distribution of total melting in glacier areas is closely connected with the type of water year yield. Glaciers runoff in the upstream of the river Amudarya in maximal and average years concentrated in July-August when winter-spring accumulation of snow has been exhausted outside of glaciers area. It was found out that the spatial distribution of the total amount of glaciers melting is less variable in the years with extreme water yield, if compared to the average years. This peculiarity is very beneficial for hydropower and agriculture because provide additional and natural ability to stabilize water balance of reservoirs. However, the stabilizing role of glacier runoff in the Amudarya basin is becoming less effective due to shrinkage of glacier area on 2324 km^2 during 1961-2000. This is very significant and undoubtedly influences on sustainable availability and utilization of river runoff in the Aral Sea basin, especially in low water seasons.

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