9.3 SIMULATION AND STOCHASTIC FORECASTING OF WATER CYCLE COMPONENTS IN CENTRAL ASIAN ALPINE BASINS

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ABSTRACT: To estimate modern condition of river runoff in Tien Shan alpine basins and to forecast its variability in relation with global and regional climate changes, the mean of the major water cycle characteristics (air temperature, precipitation, evapotranspiration and river runoff) have been simulated using data from 212 hydro-meteorological stations and 304 precipitation gauges. The mean evapotranspiration was calculated using data on air temperature, precipitation, and the topography aspects (including type of vegetation). The findings were simulated over Tien Shan relief using rectangular coordinates of the equivalent cone projection with standard parallels using 1:500 000 scale 100 m grid resolution Digital Elevation Modal that covers 800 000 knotted points. Applicable GIS-based distributed River Runoff Models were implemented in regional conditions and tested in two Tien Shan basins, taking into account glacial melt, forest and irrigated areas. The parameterization between measured and simulated runoff occurred by least square method with discrepancy approximation using linear functions with multiple parameters: annual precipitation, snow and glacial runoff and first-derivative of previous year river runoff. The mean square discrepancy between measured and simulated runoff was in accordance with root-mean-square error of measured runoff ranging from 8% to 12%. The level of calculated evapotranspiration revealed the same order as the river runoff.

Hypothetical climate-change scenarios in Tien Shan modeled as a stepwise progression predict an increase in air temperature of 1.8ºC - 4.4ºC (i.e., on average 3^{o}C) and precipitation at 0.94 to 1.54 times (1.2 times) during the XXI Century, which will lead to a increase of river runoff by 1.047 times. If we assume that precipitation remains constant and air temperature increases by 5^{o}C, river runoff in central Asia can decrease 0.66 due to increased evapotranspiration by 1.24 times.

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1. INTRODUCTION

The water-issue problems that occur during times of persistent drought [*Agrawala et al., 200]* are extremely important for central Asia. With the total population reaching 100,000,000 at the end of the 1990s, water demand is increasing while the supply is potentially decreasing. central Asia is the world's largest closed drainage basin, with area of more than 5,000,000 km^2 receive and retain at least 10% of the western external atmospheric moisture [*Kuznezova, 1984; Aizen and Aizen, 1997*]. Despite the presence of large deserts and prairies with very low precipitation and extremely dry climates, central Asian mountains hold one of the greatest concentrations of perennial snow and ice in the mid-latitudes and constitute a vital source of water for more then seven thousand lakes with a total area of 445,400 km^2 including the Caspian, Aral, Balkhash, Issik Kul and Lobmor lakes [*Aizen, 2003*]. However, in last few decades, the gradual desertification of central Asia has observed [*Vaganov, 1998; Voropayev, 1997, Glantz, 1999*]. There are approximately 30,000 glaciers with a total area of 25,000 km^2 in central Asia [*Haeberli, 1995]* that have been receding since the middle of the

19th century, with 12% that have already disappeared [*Aizen and Aizen, 1997; Aizen et al., 2004a*]. Moreover, during the last 50 years, most the measured increases in precipitation and glacier melt were not associated with a synchronous rise river runoff in low reaches while the central Asian lake levels have dropped, which suggests an increase of water loss to evapotranspiration and possibly as percolation to the ground aquifers that result in progressive droughts and aridization. More than one-third of the lakes with surface areas between 1 and 5 km^2 have disappeared [*Aizen et al., 1997a; Aizen et al., 2003*]. Currently, available general circulation models suggest that the summertime increase in diurnal temperatures in central Asia is likely to be significantly greater than that in other regions [*IPCC, II, 2001*]. Therefore, a further decline in central Asian water resources is expected. It is likely that increased temperatures will cause further deglaciation and loss of snow-covered areas, which could result in increased evaporation and aridization of sub-mountain and plain areas. In several regions of central Asia, threshold conditions exist for irreversible desertification. However, there had not been any precise estimation on the modern state of water cycle components and consequent changes in river runoff.

The main objective of the presented research is simulating, estimating, and predicting the water cycle components in central Asian basins.

2. DATA and METHODS

2.1. Topography: The basis of the Tien Shan topography was Digital Elevation Model (DEM) developed with resolution of 741 m (24") along meridians, 721 m (31") along parallels and 1m along elevation. The piecewise-smooth patch of the surface was used to determine the coefficients of approximation (a_i) (eq.1), angle of slope (U) (eq.2) and exposition (E) (eq.3) of macro-slope for each grid-point:

$$H = a_1 + a_2X + a_3Y + a_4 XY + a_5 X^2 + a_6Y^2, \qquad (1)$$

where H is elevation of a grid point; X and Y are orthogonal coordinates relative the central grid point. There were 9 knotted points at each grid including one central point with the weight of '10', four site points with the weight of '1' and four diagonal points with weight of '0.707'. Index of orientation (P_0) and angle of orientation (O) were computed by equation 4:

$$\cos U = 1/(1 + a_2^2 + a_3^2)^{1/2} \qquad (2)$$

$$tg(E + dE) = a_2/a_3 \qquad (3)$$

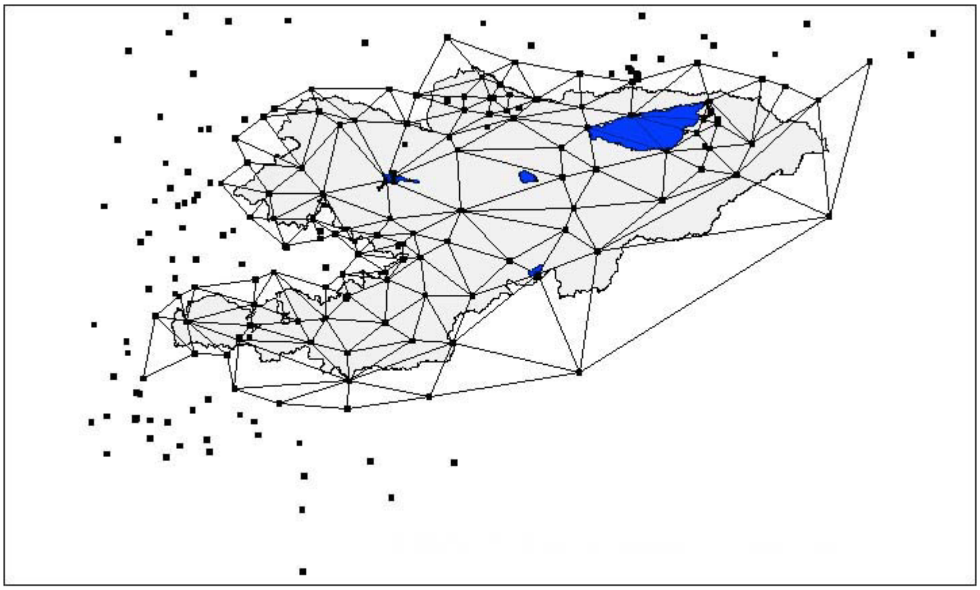
$$Po = \cos O = \cos U \cos(F-\delta_0) + \sin U \{\cos\alpha [tgF\cos(F-\delta_0) - \sin\delta_0 \sec F]\}, \qquad (4)$$

where dE is approach of meridians in the equivalent conical projection, which is the function of latitude; F is latitude of knocked point; δ_0 – declination of sun in local noon of summer solstice (23,°5); α is astronomical azimuth of projection on horizontal surface orthogonal to vector surface.

2.2. Simulation of the long-term mean water cycle characteristics (i.e., air temperature, precipitation, evapotranspiration and river runoff) were based on meteorological, topographic, hydrological and glaciological information [*Glazirin et al., 1993; Applied Reference Book on Climate, 1989; Reference Book on Climate 1966-1969*]. The data are a part of the Central Asian Database (CADB), which is being developed at the University of California Santa Barbara and the University of Idaho, Moscow. The findings were simulated over the Tien Shan relief using orthogonal coordinates of the equivalent cone projection with standard parallels using a 1:500,000 scale with 100-m grid resolution of the Digital Elevation Model that covers 800,000 knotted points. The accuracy in determining the station coordinates was less 0.1-0.5 km.

2.2.1. Digital Model of Mean Air Temperatures (DMMAT) (monthly and annual): Triangulation Irregular Network (TIN) with 176 triangles was developed based on data from 108 meteorological stations. The optimization method of random set triangulation [*Kuzmichonok, 1990*] was implemented using the criteria of minimum angles in pare of contiguous triangles taking into account the

Figure 1. Triangulation Irregular Network and meteorological stations used in simulation of air temperature over the central and western Tien Shan.



topography (Fig. 1). The distribution of stations via latitude, longitude, elevation and periods of air temperature observations is shown at the Fig. 2. Monthly and annual air temperature changes via elevation were computed based on data from 212 stations using the least square method (eq. 5, Fig.3).

$$T = a + bH, \quad (5)$$

where T is air temperature at station located at H, km, elevation; a and b are empirical coefficients (Table 1).

2.2.2. Digital Model of Annual Mean Precipitation (DMAMP): Spatial distribution of precipitation in the Tien Shan basins were studied in numerous investigations [*Getker, 1985; Bakirov 1988; Aizen et al., 1995a,b; 1997b*]. However, significant regional spatial and altitudinal variability of precipitation complicate mathematical simulation of precipitation distribution with high resolution (micro-scale). Furthermore, the main existing meteorological stations are located below 2500 m (Fig. 3). Hence, all

Table 1. Parameters of determining the monthly, seasonal and annual mean air temperatures. *r* is correlation coefficient; m is mean square error of approximation and m_b is mean square error in determining the b coefficient (i.e., altitudinal gradient of air temperature changes).

Months	*r*	A	b	m	m_b
Jan	-.71	-1.07	-4.18	4.0	.29
Feb	-.77	1.98	-4.59	3.7	.26
Mar	-.89	9.11	-5.21	2.5	.18
Apr	-.94	16.98	-5.68	1.9	.14
May	-.95	22.74	-6.03	1.8	.13
Jun	-.96	27.50	-6.53	1.9	.14
Jul	-.94	29.89	-6.30	2.2	.16
Aug	-.92	28.07	-5.75	2.3	.16
Sep	-.90	22.20	-5.12	2.4	.17
Oct	-.89	14.86	-4.70	2.3	.17
Nov	-.82	7.51	-4.57	3.1	.22
Dec	-.75	2.25	-4.44	3.7	.27
Winter	-.74	1.02	-4.40	3.8	.27
Spring	-.94	16.27	-5.64	2.0	.14
Summer	-.94	28.49	-6.19	2.1	.15
Autumn	-.88	14.86	-4.79	2.5	.18
Year	-.90	15.17	-5.26	2.4	.17

available data related to estimations of precipitation were applied including 304 meteorological stations [*Applied Reference Book on Climate, 1989; Reference Book on Climate 1966-1969*]; 23 precipitation gauges (CADB), 103 interpolation points and 328 high altitudinal points where annual precipitation were estimated using in-situ glaciological measurements [*Dikikh and Mikhailova,1976; Aizen 1985; Kotlyakov, 1988; Makarevich, 1985 Glazirin et al., 1993*].

Figure 2. Distribution of meteorological stations in Tien Shan (ms) with air temperature observations.

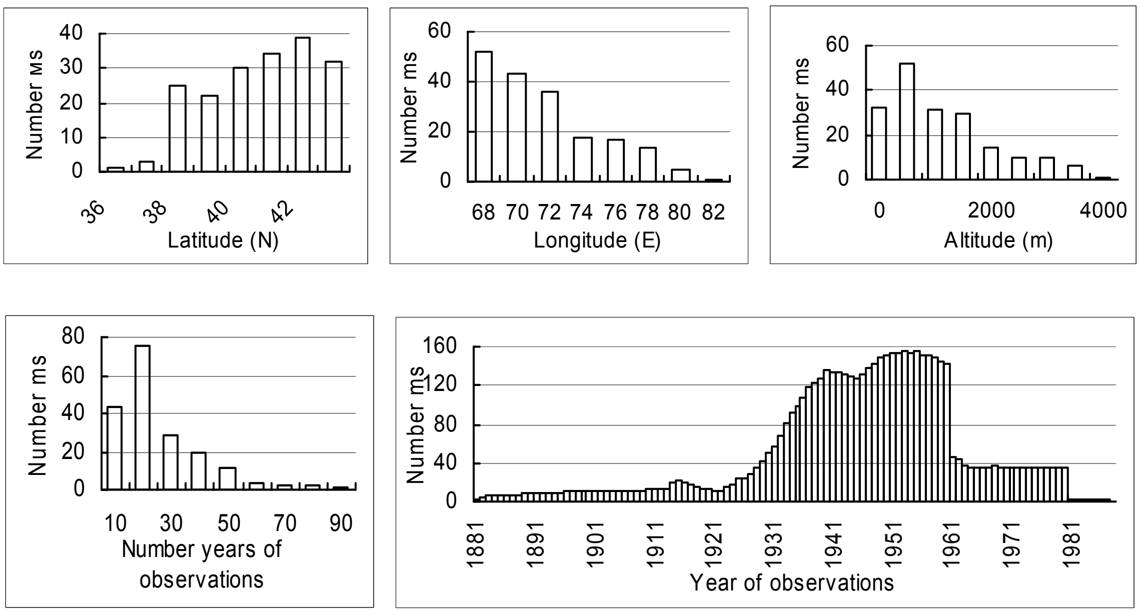


Table 2. An example of long-term mean of summer air temperature ($Ts_{e.l.}$) and annual precipitation (P) at the elevation of glaciers' equilibrium line ($H_{e.l.}$).

Glacier	S, km^2	$H_{e.l.}$, m	$Ts_{el.}$°C	P,mm	Data from
Tuyksu	3.8	3830	2,23	989	*[Kotlyakov, 1988; Makarevich, 1985]*
Golubina	9.4	3840	2,29	954	*[Aizen 1985; Aizen an Aizen, 1997; CADB]*
Kara-Batkak	4.5	3770	3,03	1037	[*Dikikh and Mikhailova,1976*]
Sari-Tor	3.3	4260	-0.,46	728	[*Duyrgerov et al., 1992*]
Inylchek	223.6	4500	-0,72	643	[*Dikikh and Dikikh, 1985 ; Aizen et al., 1997c*]
Abramova	22.8	4260	2,54	1000	*[Glazirin et al., 1993*]

Assuming that annual amount of precipitation (P) is a function of summer average air temperatures ($Ts_{e.l}$) at the elevation of equilibrium line location. To develop the P/$Ts_{e.l}$ relationship (eq.6) data from six Tien Shan and Pamiro- Alai glaciers (Table 2) were used. Mean square error of approximation was 21 mm.

$$P = 99.5\ Ts_{e.l} + 744.1, \quad (6)$$

The annual precipitation has been calculated at the height of equilibrium line of each Tien Shan glacier using data from the USSR and China Glacier Inventory [*Catalogue USSR glaciers, 1970 – 1978; Glacier Inventory of China, 1986 a;b;c; 1987*]. The elevations of equilibrium line for each glacier were further corrected using a method of 'concentric vicinities' [*Kuzmichonok, 1993*]. TIN with 1454 triangles (Fig. 4) was developed based on data from

758 sites where annual mean precipitation data were available.

Figure 3. Distribution of meteorological stations (ms) and gauges (ps) measured precipitation over the Tien Shan.

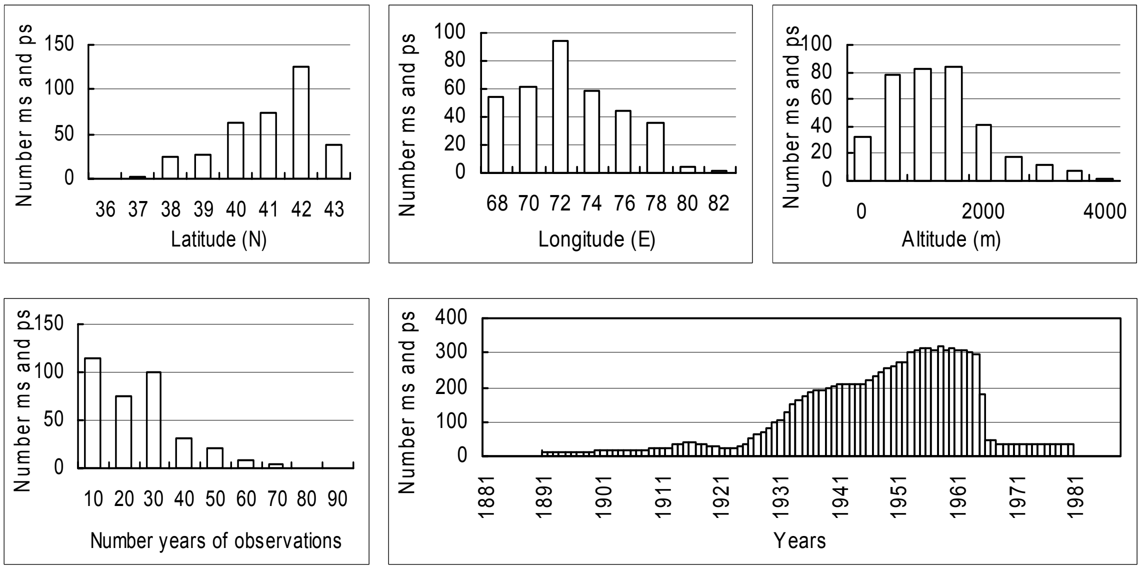
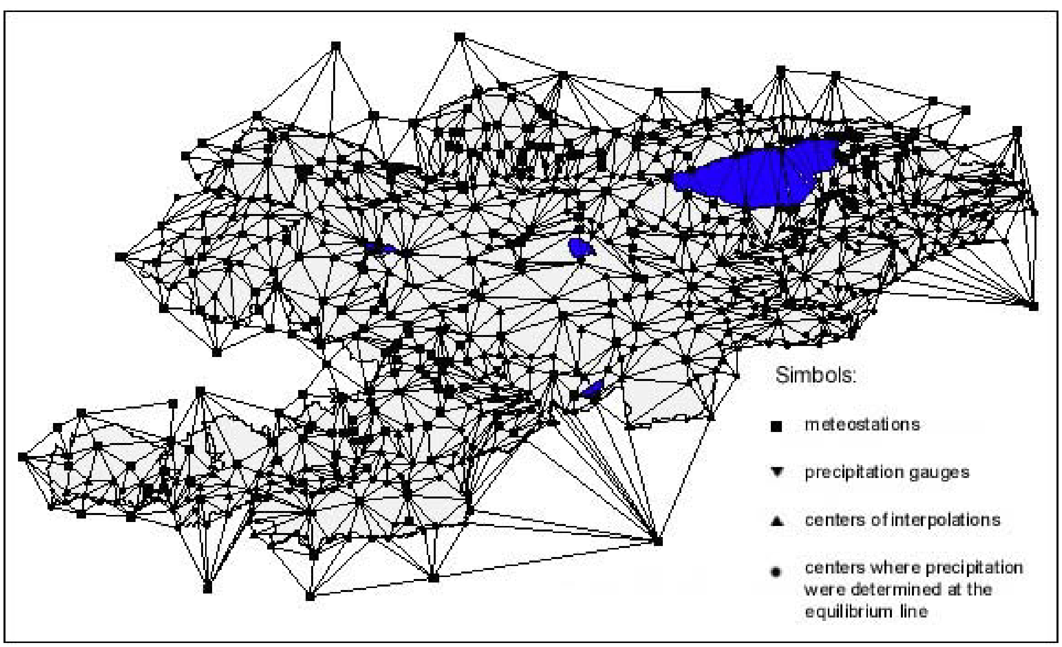


Figure 4. Triangulation Irregular Network and all observational sites used in simulation of annual precipitation over the Tien Shan.



2.2.3. Digital Model of Annual Mean Potential Evaporation (DMAMPE): The amended Ivanov's method [*Ryazanceva, 1965*] was used to estimate the annual potential evaporation (E*,m) using annual mean air temperatures (T C) and annual precipitation (P,m) data instead of relative humidity, and topography (H, km) instead of atmospheric pressure. Data of measurements from [*Ryazanceva, 1965; Sevast'yanov and Smirnova, 1986*] were used to get approximation of potential evaporation (equation 7) using least square method. Mean square error of annual approximation was 97 mm.

$$E^{*}=[0,00005581(27,24 + T)^{3,0889}]\cdot[0,7956 + 0,1155\cdot H\cdot e^{0,3279\cdot H}]\cdot[0,3622+0,00483\cdot P^{-0,9043}] \qquad (7)$$

2.2.4. Digital Model of Annual Mean Evapotranspiration was based on DEM (2.1), DMAMP (2.2.2) and DMAMPE (2.2.3) and Digital mapping of forest and irrigated areas in scale of 1:500 000 with accuracy of 0.25 km [*Forest, 1986*]. Mean annual evaporation (E) for each knocked point was calculated through equation (8):

$$E = (P\vee E^*)[0.625(2.6578\text{-ch}^{1.0625} U) + 0.2264\text{th}C - (0\vee 0.7955)]/\{1 + 0.9016P^{0.9409}/[E^* + 0.0884(P_0 - 0.94)]^{0.5561}\}^{0.7307}, \qquad (8)$$

where C is a mean surface flexion, km^{-1}; Po index of orientation; $\vee$ is logical OR operation; ch is hyperbolic cosine; th is hyperbolic tangent; $P\vee E$ minor; $0\vee 0.7955$ meaningful coefficient if the knocked point is related to forested area.

3. RESULTS

3. 1. The validation of simulations occurred in two Chon Kemin River sub-basins (Table 3). The mean annual runoff was calculated as a difference between annual volume of precipitation and annual volume of evapotranspiration. The hydrological gauges were located in the rocky canyons and therefore we may assume that ground and under-channel water flow are minimal. The annual variability in glacier mass balance and annual water loss for irrigation were taken into account. We also made an assumption that Chon Kemin Basin glaciers' mass balance is equal to mass balance measured on the Tuyksu Glacier (Table 2). The water losses for irrigation were estimated as additional evaporation from the irrigated lands under the long-term annual mean of 300 mm. Simulation of annual river runoff was occurred for the period from 1957 to 1993. Water balance components were calculated for each map knocked points related to the basins. The mean square residual between simulated and measured annual runoff was 0.54 km^3 under mean square variability of 0.054 km^3 for the first basin and respectively 0.148 km^3 and 0.083 km^3 for the second basin.

3.2. Optimization of simulation. To optimize simulated water balance components correlation coefficients between discrepancy in calculated - measured runoff and different parameters were computed (Table 4). The most significant correlation is related to precipitation amount for the current year, because the simulated model based on limited number of precipitation sites, which do not present real distribution of precipitation at the basin. Another important parameter that significantly correlated with calculate-measured runoff discrepancy is the first derivative from annual river runoff for the pervious year. Obviously, in the years with low water, the river runoff is replenished from the ground aquifers but during the years with abundance of water the river runoff replenishes the ground aquifers. The river runoff discrepancy was approximated by different combinations parameters presented in Table 4. The residual accuracies of approximation are presented in Table 5. These assessments revealed the most reasonable approximation is linear function with annual precipitation (Pi), glacier mass balance (Bi), river runoff (R_0) and its first derivative (R_0') for the conducting previous and current years. The applying corrections ($\Delta_{Ch.\ 1,2}$; eqs. 9 and 10) (Fig. 5) have decreased the mean square errors of annual river runoff simulation by 2.5 times (Fig. 6) and, the mean square discrepancy between measured and simulated runoff was in accordance with root-mean-square error of measured runoff ranging from 8% to 12%. Cumulative corrections to the values pointed, that at the beginning of 70th intensive depletion of aquifers has been occurred (Fig. 5b).

$$\Delta_{Ch.\,1} = 0.21417 + 0.96925 \cdot P - 0.06544 \cdot B - 1.31472 \cdot R_0 - 0.68618 \cdot R_0^{'} \quad (9)$$

$$\Delta_{Ch.\,2} = 0.08261 + 1.20798 \cdot P - 0.07770 \cdot B - 0.94741 \cdot R_0 - 0.76925 \cdot R_0^{'} \quad (10)$$

Table 3. Parameters of Chon Kemin River basins with river runoff measurements at the mouse (Ch. 2) and at Karagailibulak R. (Ch. 1)

Parameters	Ch. 1	Ch. 2
Area (km^2)	1037.33	1815.31
Perimeter (km)	193.99	307.97
Mean elevation (m)	3412	3006
Mean slope (grad)	12.6	12.2
Mean curvature of surface($км^{-1}$)	-0,00123	+0,00049
Mean exposition	0.915	0.915
Mean annual air temperature (^oC)	-3.6	-1.9
Mean annual precipitation (mm)	809	729
Mean annual potential evaporation (mm)	719	771
Mean annual evapotranspiration (mm) without melioration loss	379	392
Mean annual river runoff (mm)	430	337
Mean annual volume of runoff ($км^3$)	0.446	0.612
Mean humidification (P/E*)	1.17	1.00
Glacier covered areas (km^2)	134.01	135.67
Lake areas (km^2)	0.48	0.76
Rock areas (km^2)	49.30	69.46
Areas of water-logged ground (km^2)	0.50	0.77
Forest areas (km^2)	13.65	68.90
Bush covered areas (km^2)	0.97	4.77
Garden covered areas (km^2)		0.60
Meliorated areas (km^2)		66.27

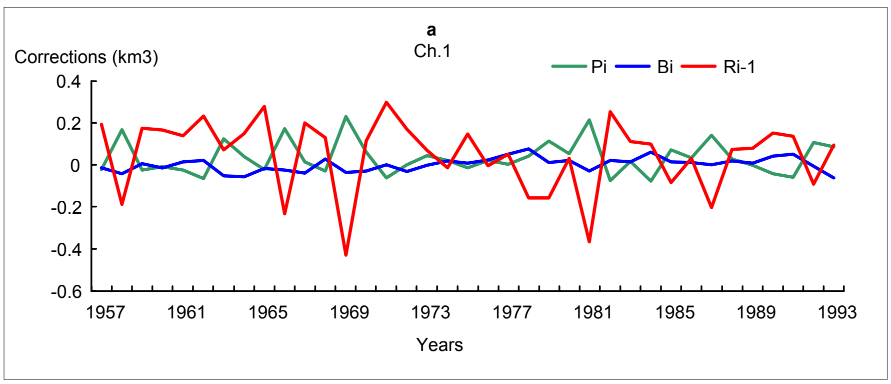
Table 4. Correlation coefficients between calculated –measured discrepancies and different parameters

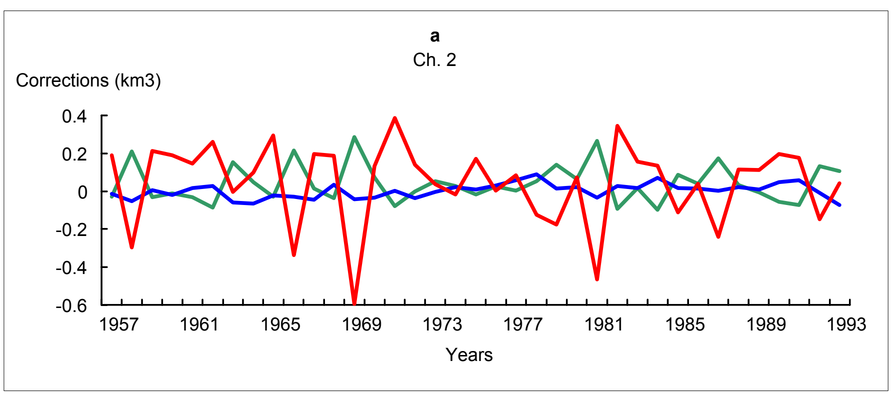
Parameters	Ch. 1	Ch. 2	Ch1+2
T_i	-0.19	-0.25	-0.13
P_i	0.76	0.82	0.50
B_i	0.09	0.29	0.20
R_{i-1}	-0.15	-0.27	-0.21
$R_{i-1}+R_{i-2}$	-0.14	-0.35	-0.23
$R_{i-1}+R_{i-2}+R_{i-3}$	-0.02	-0.25	-0.13
$R_{i-1}+R_{i-2}+R_{i-3}+R_{-i-4}$	-0.08	-0.32	-0.17
$R_{i-1}+R_{i-2}+R_{i-3}+R_{i-4}+R_{i-5}$	-0.05	-0.29	-0.14
R_0 (li)	0.57	0.48	0.40
$R^{'}$ (li)	0.71	0.76	0.74
R_0 (sq)	0.20	0.12	0.12
$R_0^{''}$ (sq)	0.45	0.47	0.46
P_{i-1}			-0.21
P_{i-2}			-0.10
P_{i-3}			-0.03
P_{i-4}			-0.10
P_{i-5}			-0.03
$P_{i-1}+P_{i-2}$			-0.18
$P_{i-1}+P_{i-2}+P_{i-3}$			-0.11
$P_{i-1}+P_{i-2}+P_{i-3}+P_{i-4}$			-0.12
$P_{i-1}+P_{i-2}+P_{i-3}+P_{i-4}+P_{i-5}$			-0.09
P_0 (li)			0.17
$P^{'}$ (li)			0.73
P_0 (kv)			0.01
$P_0^{''}$ (kv)			0.48

Table 5. Residual mean square errors (km^3) of approximating the discrepancy in annual runoff

Parameters	Ch. 1	Ch. 2	Ch. 1+2	Parameters	Ch. 1	Ch. 2	Ch. 1+2
P	0,075	0,085	0,115	P B R_0	0,061	0,080	0,115
B	0,115	0,142	0,130	P B R_0'	0,059	0,073	0,085
R_0	0,095	0,130	0,122	P B R_0''	0,061	0,079	0,105
R_0'	0,082	0,096	0,089	P R_0 R_0'	0,048	0,064	0,060
R_0''	0,104	0,131	0,118	P R_0 R_0''	0,058	0,079	0,092
P B	0,061	0,081	0,115	P R_0' R_0''	0,064	0,067	0,072
P R_0	0,073	0,084	0,115	B R_0 R_0'	0,049	0,063	0,071
P R_0'	0,068	0,074	0,085	B R_0 R_0''	0,059	0,085	0,093
P R_0''	0,072	0,082	0,106	B R_0' R_0''	0,070	0,073	0,072
B R_0	0,095	0,126	0,120	R_0 R_0' R_0''	0,049	0,061	0,066
B R_0'	0,082	0,093	0,088	P B R_0 R_0'	0,046	0,059	0,054
B R_0''	0,103	0,124	0,115	P B R_0 R_0''	0,058	0,079	0,086
R_0 R_0'	0,049	0,064	0,072	P B R_0' R_0''	0,057	0,067	0,072
R_0 R_0''	0,059	0,087	0,095	P R_0 R_0' R_0''	0,048	0,061	0,058
R_0' R_0''	0,070	0,074	0,072	B R_0 R_0' R_0''	0,049	0,060	0,066
				P B R_0 R_0' R_0''	0,046	0,057	0,054

Figure 5 Corrections to the values of annual precipitation (Pi), mass balance (Bi), and river runoff for the previous year (Ri-1; R'i-1) in simulation of river runoff (a), and the cumulative values of corrections of river runoff for the previous year (b) in two Chon Kemin River basin (Ch.1, 2).





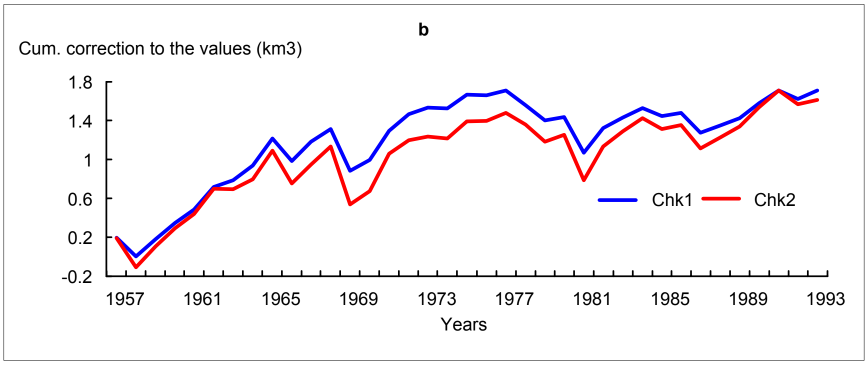
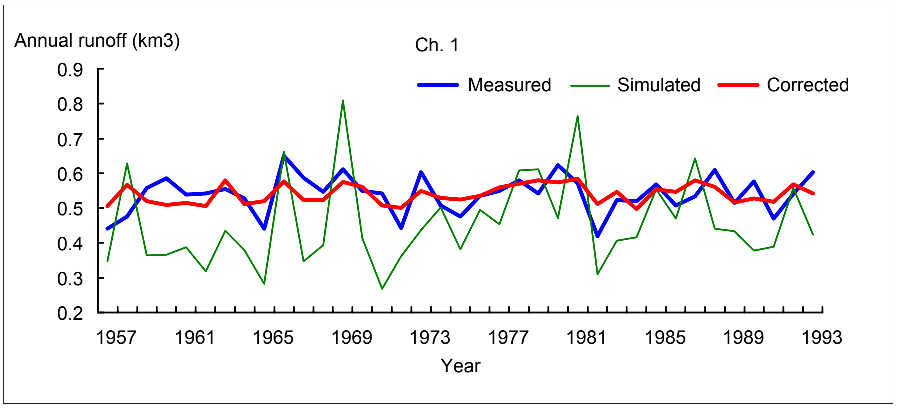
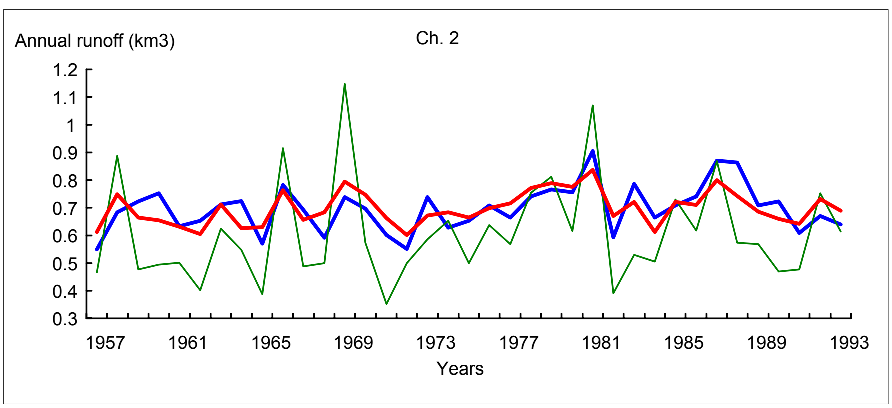


Figure 6. Measured, simulated and corrected annual river runoff in two Chon Kemin River basins.





3.4. Water balance components assessment. Changes in water balance components from 1957 to 1995 shown on the Fig. 7 revealed no significant trend in their variability. Most variable characteristics are precipitation and potential evaporation ranging closed each other that pointed on stability of index of moisture in the basin equaled around 1.0 (i.e., 0.95, Table 8). Abrupt decrease in the annual precipitation from 1100 mm to 600 mm and simultaneous increase of potential evaporation up to 800 mm (Fig. 7) observed at the beginning of 70^{th} caused the observed depletion of aquifer (Fig. 5b). Mean annual evapotranspiration a little higher there than river runoff in basin almost for all period, compounding about half of the basin precipitation (Table 8, Fig.7).

Figure 7 Simulated and corrected water balance components the Chon Kemin R. (Ch.1)

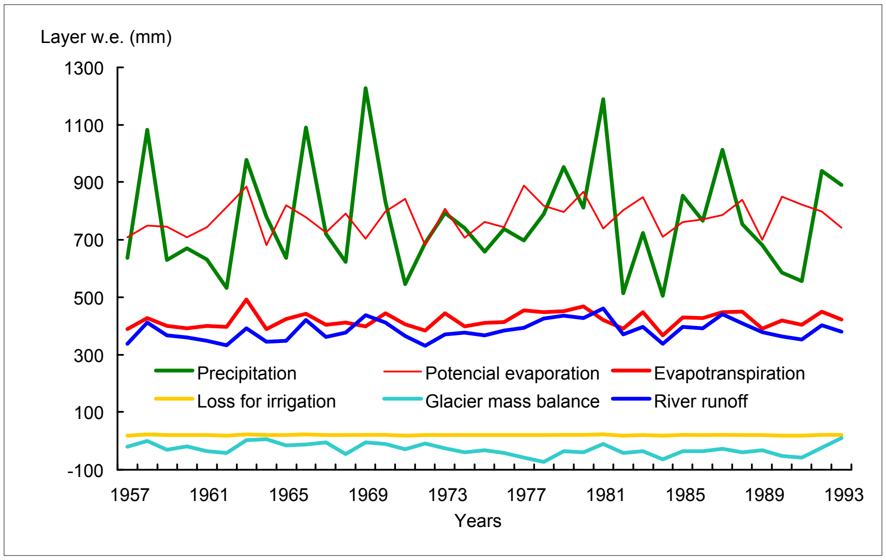
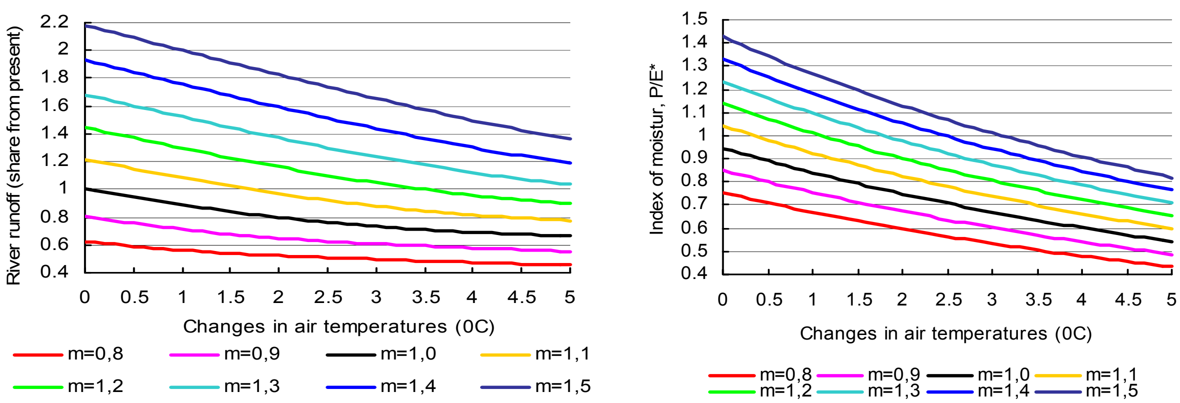


Figure 8. Predicted changes in the current river runoff (R/Rc) (a) and index of moisture conditions (D=P/E*) in the Chon Kemin River basin under the different scenarios of climatic changes ($T = T_c + dT$; $P = mP_c$). R and Rc are predicted and current river runoff; T and Tc are possible and current air temperatures; P and Pc are predicted and current precipitation.



3.5. Prediction of river runoff and index of moisture. Hypothetical climate-change scenarios in Tien Shan modeled as a stepwise progression predict an increase in air temperature of 1.8ºC to 4.4ºC (i.e., on average 3^{o}C) and precipitation at 0.94 to 1.54 times (1.2 times) during the XXI Century, which will lead to a increase of river runoff by 1.047 times. Index of moisture would decrease from 0.95 (present state) to 0.82. River runoff will not drop even under the air temperature rise on 5^{o}C if precipitation will be increasing, e.g., more than 1.25 times of the present (Fig. 8a). Only in case if we assume boundary conditions, e.g., increase in air temperature of 4.4ºC and decrease of precipitation 0.94, than the river runoff in Tien Shan basins may decrease respectively 0.62 times due to increase evapotranspiration by 1.11 times (Table 6). Index of moisture would decrease from 0.95 to 0.54 under the closed to threshold conditions of irreversible desertification.

Table 6. Predicted water balance components under different scenarios of climate change. T is air temperature, T_c is current long-term mean air temperature; P is annual amount of precipitation, P_c is current long-term mean annual amount of precipitation

		$T=T_c$	$T= T_c +1°C$	$T= T_c +2°C$	$T= T_c +3°C$	$T= T_c +4°C$	$T= T_c +5°C$
$P=P_c\cdot0.8$	T, °C	-1.90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	583(1.059)	583(1.059)	583(1.059)	583(1.059)	583(1.059)	583(1.059)
	E^*, mm	773	871	977	1092	1216	1348
	$D=P/E^*$	0.754	0.669	0.597	0.534	0.480	0.432
	E, mm(km^3)	393(0.715)	412(0.749)	424(0.771)	432(0.786)	439(0.798)	446(0.810)
	R, mm(km^3)	189(0.344)	170(0.310)	158(0.288)	150(0.273)	143(0.261)	137(0.249)
	R/Rc	0.625	0.563	0.523	0.496	0.474	0.453
$P= P_c\cdot0.9$	T, °C	-1,90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	656(1.191)	656(1.191)	656(1.191)	656(1.191)	656(1.191)	656(1.191)
	E^*, mm	772	869	975	1090	1213	1345
	$D=P/E^*$	0.850	0.754	0.673	0.602	0.541	0.488
	E, mm(km^3)	413(0.750)	440(0.799)	459(0.834)	472(0.857)	480(0.873)	488(0.887)
	R, mm(km^3)	242(0.441)	216(0.393)	196(0.357)	184(0.334)	175(0.318)	167(0.305)
	R/Rc	0.802	0.713	0.649	0.607	0.579	0.554
$P= P_c\cdot1.0$	T, °C	**-1.90**	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	**729(1.324)**	729(1.324)	729(1.324)	729(1.324)	729(1.324)	729(1.324)
	E^*, mm	**770**	868	973	1088	1211	1343
	$D=P/E^*$	**0.946**	0.840	0.749	0.670	0.602	0.543
	E, mm(km^3)	**426(0.773)**	459(0.835)	487(0.885)	507(0.920)	519(0.943)	528(0.960)
	R, mm(km^3)	**303(0.550)**	269(0.489)	241(0.439)	222(0.403)	209(0.381)	200(0.364)
	R/Rc	**1.000**	0.888	0.798	0.733	0.692	0.662
$P= P_c\cdot1.1$	T, °C	-1.90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	802(1.456)	802(1.456)	802(1.456)	802(1.456)	802(1.456)	802(1.456)
	E^*, mm	769	866	972	1086	1209	1341
	$D=P/E^*$	1.042	0.925	0.825	0.738	0.663	0.598
	E, mm(km^3)	433(0.787)	473(0.859)	508(0.922)	535(0.972)	554(1.007)	566(1.029)
	R, mm(km^3)	368(0.669)	328(0.597)	294(0.534)	266(0.484)	247(0.449)	235(0.427)
	R/Rc	1.216	1.084	0.970	0.879	0.816	0.776
$P= P_c\cdot1.2$	T, °C	-1.90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	875(1.588)	875(1.588)	875(1.588)	875(1.588)	875(1.588)	875(1.588)
	E^*, mm	768	865	971	1085	1207	1339
	$D=P/E^*$	1.139	1.011	0.901	0.806	0.725	0.653
	E, mm(km^3)	437(0.794)	481(0.874)	522(0,949)	557(1.012)	584(1.061)	602(1.093)
	R, mm(km^3)	437(0.795)	393(0.714)	352(0,639)	317(0.576)	290(0.527)	272(0.495)
	R/Rc	1.444	1.297	1.162	1.047	0.958	0.899
$P= P_c\cdot1.3$	T, °C	-1.90	-0,90	0.10	1,10	2.10	3.10
	P, mm(km^3)	948(1.721)	948(1.721)	948(1.721)	948(1.721)	948(1.721)	948(1.721)
	E^*, mm	767	864	970	1083	1206	1338
	$D=P/E^*$	1.235	1.096	0.977	0.875	0.786	0.708
	E, mm(km^3)	438(0.795)	486(0.883)	532(0.967)	574(1.042)	608(1.104)	633(1.150)
	R, mm(km^3)	509(0.926)	461(0.838)	415(0.754)	373(0.679)	339(0.616)	314(0.570)
	R/Rc	1.682	1.523	1.370	1.233	1.120	1.037
$P= P_c\cdot1.4$	T, °C	-1.90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	1020(1.853)	1020(1.853)	1020(1.853)	1020(1.853)	1020(1.853)	1020(1.853)
	E^*, mm	767	864	969	1082	1205	1336
	$D=P/E^*$	1.331	1.182	1.053	0.943	0.847	0.764
	E, mm(km^3)	436(0.792)	487(0.886)	538(0.977)	585(1.063)	626(1.138)	659(1.197)
	R, mm(km^3)	584(1.061)	532(0.967)	482(0.876)	435(0.790)	394(0.715)	361(0.656)
	R/Rc	1.928	1.758	1.592	1.436	1.300	1.191
$P= P_c\cdot1.5$	T, °C	-1.90	-0.90	0.10	1.10	2.10	3.10
	P, mm(km^3)	1093(1.985)	1093(1.985)	1093(1.985)	1093(1.985)	1093(1.985)	1093(1.985)
	E^*, mm	766	863	968	1081	1204	1335
	$D=P/E^*$	1.427	1.267	1.130	1.011	0.908	0.819
	E, mm(km^3)	433(0.787)	487(0.884)	540(0.982)	592(1.076)	640(1.162)	680(1.235)
	R, mm(km^3)	660(1.199)	606(1.101)	552(1.004)	501(0.910)	453(0.824)	413(0.751)
	R/Rc	2.179	2.001	1.824	1.653	1.497	1.364

4. CONCLUSION

The major water cycle characteristics and components (air temperature, precipitation, potential evaporation, evapotranspiration, and river runoff) were digitized through developed simulation over Tien Shan relief using rectangular coordinates of the equivalent cone projection with standard parallels and 1:500,000 scale Digital Elevation Model with 100-m grid resolution of that covers 800,000 knotted points.

Digitized evapotranspiration model took into account air temperature, precipitation, and topography (angle, exposition, curvature of a surface). Applicable GIS-based distributed River Runoff Model was implemented in regional conditions testing in two sub-basins of the Chon Kemin R. basin, using method of transition from large to smaller geographic units (downscale information transfer) taking into account glacier mass balance, forest covered lands and irrigated areas.

Optimization of measured and simulated annual values occurred through approximation of the discrepancy by linear function from multiple parameters (annual precipitation, glacier mass balance, and first-derivative of previous year river runoff) decreased difference by 2.5 times. One of the main predictor in the current year river runoff is river runoff for the previous year that could be less or more replenished by ground water. For example, at the beginning of 70th an observed intensive depletion of aquifers was caused by abrupt decrease of precipitation and rapid increase of potential evaporation.

A distributed river runoff model revealed that the evapotranspiration rate is on average a little higher than surface river runoff and close to half of the total precipitation. Apparently, the central Asian arid and semi-arid areas are delivering moisture from the Aral-Caspian closed drainage basin to the alpine regions that feed central Asia.

A hypothetical climate-change scenario predicted an average air temperature increase of 3ºC and precipitation change at 1.2 times during the 21st Century will even cause insignificant increase of river runoff by 1.047 times. We expect that water cycle of internal central Asian closed drainage basin provides considerable re-evaporated precipitation which suppresses aridization of central Asia under the increasing air temperatures. We propose that central Asia is a self-regulating system, where natural processes maintain this system in a steady state, i.e., increase of air temperature causes increasing internal evapotranspiration with consecutive intensifying of re-evaporated moisture precipitated in mountains that relatively should suppress the increase in air temperature.

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