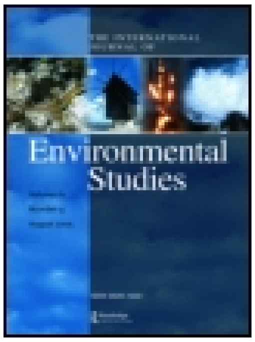

International Journal of Environmental Studies

ISSN: 0020-7233 (Print) 1029-0400 (Online) Journal homepage: http://www.tandfonline.com/loi/genv20

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To cite this article: J. Sagin, D. Adenova, A. Tolepbayeva & V. Poryadin (2017): Underground water resources in Kazakhstan, International Journal of Environmental Studies, DOI: 10.1080/00207233.2017.1288059

To link to this article: http://dx.doi.org/10.1080/00207233.2017.1288059

INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES, 2017
http://dx.doi.org/10.1080/00207233.2017.1288059

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Underground water resources in Kazakhstan

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ABSTRACT

The assessment of natural resources and the ecological demand for underground water in Kazakhstan is based on a water-balance equation which considers underground lateral flow, hydrogeoecological regions and river basins. We propose a methodology to estimate the underground water resource for this region. The flow of water in all the rivers of Kazakhstan is estimated at 102.3 km^3/year, of which 57.6 km^3/year originates in the territory of the country, and 44.7 km^3/year in the adjacent countries. With potential increase of the underground water usage up to 15.5 km^3/year, the surface water volume could be decreased to 5 km^3/year. Optimization of water resource use should be based on the introduction of the water-efficient process of reinjecting and recycling the water supply in all branches of industry, and a reduction in losses during distribution.

KEYWORDS

Ecosystems; water balance; underground water; resources

Introduction

The analysis of water supplies worldwide shows a rapid per capita reduction because of the increase in population and depletion of freshwater resources. In order to meet all the future water needs of all ecosystems, it is necessary to implement systematic hydroecological monitoring of the existing water resources and improve sustainable water usage. Accordingly, the United Nations declared the 22nd of March the World Water Day [1], and declared the years of 2005–2015 to be a period of dynamic actions under the Water for Life Programme [2].

About 50.5% of Kazakhstan's fresh water supply is identified as being from underground lateral flow, with surface flow comprising about 49.5% [3]. This paper concerns the interrelationship of the underground lateral flow water and the surface water based on the hydrological and hydrogeological model of underground runoff formation which was introduced by Kudelin. His model analyses the parameters of the total river surface flow with the underground lateral flow [4].

Kudelin segregated three dominating factors to quantify the formation of underground water runoff: climate, terrain and hydrogeology. These factors are interrelated. The size of the underground water flow or runoff is determined by the general characteristics of more complex natural phenomena that combine the processes of feeding, moving and

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unloading the underground water. The volume of the underground water is determined by the amount of precipitation, the space-time distribution of which is subject to geographic location. Another factor is evapotranspiration whose annual rate in the northern hemisphere increases from the north to the south.

Terrain greatly affects the formation of underground watersheds. Within the Alpine orogeny of eastern and south-eastern Kazakhstan (Altai, Dzungaria, and Tien Shan), the latitudinal and vertical geographic location has a complex effect on the conditions of the underground water formation. Other influences include any acute fluctuations of elevation in the terrain, the increase in the amount of precipitation with increase in elevation, and the distribution of permafrost rocks.

Deep erosions in the terrain, drainage network density, and various slopes of the ground surface and the level of groundwater within mountain structures have put pressure on underground watersheds. Underground watershed formation is closely associated with the zone of distribution of precipitation, i.e. with the climatic vertical zone. An increase in the amount of precipitation with the terrain elevation up to known ranges (so-called 'orographic precipitations') results in the improvement of the conditions for feeding underground water resources.

The effect of terrain elevation in mountain topography is seen also in normal underground flow or runoff layers. The factor combined with the orographic increase of precipitation intensifies underground water flow or runoff on highlands compared to plains. The intensity of underground water flow or runoff decreases in relation to the regional depressions of the relief (endorheic basins of inland seas such as the Caspian and Aral, and lake systems such as Balkhash, Alakol, and Teniz).

In contrast, within intermountain cavities of Kazakhstan, as a rule, the capacity of a freshwater zone is greatly increased. These cavities have more significant resources of underground water (Kopa-Ili, Balkhash-Alakol and other cavities) because they are fed from adjacent intermountain cavities.

The influence of the local hydrogeological conditions on underground water resource formation is most apparent in the areas of development of watered karsting rocks – Carbonic and Devonian limestone (Karatau, Ulytau, etc.). This localised phenomenon is associated with the absorption of precipitation and surface runoff in caverns and leads to the rearrangement of the underground water within comparatively small areas.

The influence of the rock permafrost on underground water flow in the mountain regions of Kazakhstan is unknown. There are incomplete data on the physical and geographic features within the permafrost areas, and very little quantitative assessment of underground water flow or runoff in these regions.

The structural and hydrogeological factor of underground runoff formation is closely related to the geotectonic structure of the territory. Three of Kazakhstan's largest, complicated and diverse sub-global geostructural oblasts are located in these territories:

1. Ancient Pre-Cambrian East-European (Russian) platform – in the outermost north-west;
2. Recent Epi paleozoic Ural-Siberian platform – in its central part;
3. Epi platform region of the Alpine orogenesis of the Central Asia – in the east and south-east of the country [5].

On the basis of these segregated geological and structural regions, the following structural and hydrogeological regions [6] are formed within it:

(1) The Pre-Caspian cavity in the south-east of the ancient East-European platform;
(2) The Turanian and West-Siberian plates of the Ural-Siberian epipaleozoic platform with the rocks yield of heterogenetic foundation in the form of mountain fold systems: Uraltau-Mugodzhary, Central-Kazakhstan shelf, West Altai, Saur-Tarbagatai, Karatauand Ugama;
(3) Central and eastern parts of Tien Shan, Dzungaria, Saur-Tarbagatai, Altai as a part of epi platform area of the Alpine orogeny of the Central Asia.

The separate structural and hydrogeological regions show various specific hydrogeological features. These depend on the shapes of hydrogeological bodies and structures, types of rock penetration, degree of rock penetration, spatial variability of rock penetration, character of water content of rocks by area, water-bearing nature of rocks through time, conditions of hydraulic interrelation of hydrogeological bodies, indicators of reservoir characteristics of the geological substrata, hydrodynamic zones of the hydrodynamic potential, and, as a result, quantity and quality of natural and operating resources of underground water.

The main types of hydrogeological bodies and structures are: (a) artesian basins of plates, which are located on sub-mountain troughs of plateaus and intermountain troughs of folded areas; and (b) hydrogeological massifs – offsets of folded areas and crystalline foundations of plateaus containing veined hydrogeological bodies.

The territory of the first structural and hydrogeological region is represented exclusively by hydrogeological bodies and artesian type structures. The groundwater here has a wide salinity range – from marginal brines to brackish medium production varieties near the Uraltau-Mugalzhar areas.

Two types of hydrogeological bodies and structures have been developed in the second structural and hydrogeological region where various levels of fresh water flow rates (from low to medium high) and qualitative composition (from fresh to sodium chloride) are formed.

Fast flowing fresh underground water exists in the third structural and hydrogeological region represented by hydrogeological bodies and structures such as artesian massifs in the premountain and intermountain zones and hydrogeological massifs in mountain structures. These were formed and increasingly appeared during the Alpine orogeny period.

The three main types of underground water runoff to the rivers (feeding of rivers) exist in differing terrain [7]: seasonal and permanent groundwater (hydrogeological massifs), artesian basins (in plateaus and intermountain cavities of folded areas), and ground-artesian (mixed) aquifers (sub mountain troughs of platforms).

The assessment of natural resources of underground water according to Kudelin's model [4] is lacking because of the variety of natural causes of underground water formation. Therefore, an assessment of natural resources of underground water was carried out in the 1960s and 1970s in the Institute of Hydrogeology and Hydrophysics of the Academy of Science of the Kazakh Soviet Socialist Republic under the supervision of U.M. Akhmedsafin. The amount of underground water at that time was understood to be 37.84 and 48.3 km^3/year, respectively [8]. In other words, they differed by 10.46 km^3/year (28%), but the deviation of long-term annual average values of the river runoff from the standard did not exceed 5% for the discharge gauges.

Study area

There are about 85,000 rivers and temporary water courses in Kazakhstan, with 8000 of them being longer than 10 km. The average area of most river basins is about 30 km^2. Many rivers belong to the closed basins of the Caspian and Aral Seas and Balkhash, Alakol and Teniz lakes. Only the Yertys River belongs to the basin of the Arctic Ocean (Kara Sea). A higher drainage network density is registered in the highlands such as Altai, Zhetysu, Alatau and Ile, and less density is registered in the areas of sandy deserts of Pre-Aral and Pre-Caspian (less than 0.03 km per km^2). The largest rivers of the country are Yertys with a length (within Kazakhstan) of 1700 km, Syr-Darya (1400 km) and Zhaiyk (1082 km). Six larger rivers of Kazakhstan have water flow rates which range from 30 to 900 m^3/sec (average annual values). Seven rivers have flow rates ranging from 50 to 100 m^3/sec and 40 rivers from 5 to 50 m^3/sec [9].

The river network of Kazakhstan combines six hydro-ecological basins:

(1) Zhaiyk-Zhem (basin of the Caspian Sea),
(2) Tobyl-Essil (basin of Kara Sea),
(3) Yertys (basin of Kara Sea),
(4) Nura-Teniz (basin of Teniz lake, closed),
(5) Balkhash-Alakol (basin of Balkhash lake closed),
(6) Aral-Syr-Darya (basin of Aral Sea, closed) [9].

The distribution of river surface flow in the territory varies. Large surface flow volumes are formed in the Yertys and Balkhash-Alakol basins (73–86% of the total resources). There is almost no local surface flow in the Nura-Sarysu, Yessil and Tobyl-Torgai basins in the years of low water flows. The river surface flows are characterized by significant inter-annual variability: the maximum and minimum values of an annual surface flow are three times the norm and two times below the norm, respectively. There are also changes in levels of low water every 7 years and the abundance of water every 1–3 years. Because of climatic features in Kazakhstan, up to 90% of the annual surface flow occurs in spring, and up to 70% of the mountain river surface flow occurs in summer months.

The major feature of the orography and hydrology of Kazakhstan is the dividing range of Europe and Asia, forming the Atlantic-Arctic and Indian-Pacific drainage sub-global orographic regions. From the eastern boundaries of the country, it goes through the ridges of the Chingiz-Tau Saur-Tarbagatai mountain system, and moves southwards from KushmurunLake (Kustanai saddle), past the head of the Tobyl River and its feeders to the north, and beyond Kazakhstan to the ridges of the Ural mountain system. The north and east of Kazakhstan have areas belonging to the Atlantic-Arctic sub-global region, but its greater part is located in the Euroasian region without any surface flow. Generally, the orographic dividing range goes through the southern boundaries basins of the Tobyl-Yessil, the Nura-Teniz without runoff and the Yertys [9].

The large river arteries, their snow and rain feeding and minor salinity of water in surface runoff are typical in the area of the Atlantic-Arctic sub-global region. The closed Euroasian basin has very different features. There is a variegated distribution of the density of permanent river network. For example, many areas are completely deficient in permanent surface flow; there is great variety in size of rivers and their regimes; difference in conditions of the river feeding; and a great range of water salinity measures. The general features of the hydrology of both areas are the relatively poor development of the river network, which is explained by intercontinental aridity of the climate [9].

Kazakhstan's water network is mostly internal, except for the Yertys River basin which extends to the Arctic Ocean. Some of the country's water has also been engineered into canals and channels for domestic, agricultural and industrial use.

The channel network of the river basin depends on the lithologic structure, its geography and elevation, orography, vegetation and precipitation. The density of the river network is measured in this manner: $d = \left(\sum_n L_n\right)/F$, which is determined by the ratio of the length of all watercourses in the river basin $\sum_n L_n$ to the area of the basin F, in addition the entire area of F the number of streams (n) and each has a length L_n.

Pursuant to the latitudinal and zone diversity, the density of the hydrographic network (from north to south) is different [10]. The central region of the country with the steppe and deserts is characterized by rather poor development and the absence of a network of permanent rivers. Farther southwards, with the transition to the sub-mountain regions, the density of the permanent river network increases; reaching its greatest density at the south and south-east region. The denser river network (40–180 km per 100 km^2) in the basin of the Kara Sea is confined to the mountain regions of Altai, Saur-Tarbagatai, Chingiztau, Zhetysu Alatau.

In the central plains (steppe), the water is distributed through small inland lakes without permanent tributaries. The pools measure between 0 and 2 km per 100 km^2.

The largest territories have a hydrographic network density from 4 up to 6 km per 100 km^2, and it increases up to 8–10, and rarely expands to 12 km per 100 km^2 in the highest elevated areas.

The Ile-Balkhash basin consists of two distinct zones – the steppe and mountains. The first has few rivers, but the second has many. The network density of Ily-Balkhash basin in its steppe is 0–2 km with an elevation up to 6 km within the areas of the Balkhash river basins–tributary.

The river network density in the steppe and desert areas of the Aral Sea basin decreases from north to south, from 4–6 up to 2–0 km. The desert area of the Aral basin is almost waterless. Zones with a permanent river network density from 2–4 up to 4–6 km per 100 km^2 extend only along the Syr-Darya, Sarysu and Shu Rivers.

In the Torgay flat area, the temporary river network has a density of 6–10 km, and in the lower reaches of the Torgay river, the density is over 16 km per 100 km^2.

The higher river network density of 10 km per 100 km^2 is in the Caspian basin and those greater than 12 km per 100 km^2 are observed in the north and north-west – within the steppe zone. The density in the desert zone is as low as 2–4 km per 100 km^2, and there are territories without permanent surface flow in the deserts and sand massifs. The territories with the most surface flow are along the great rivers (Zhaiyk, Zhem, and Oral).

The temporary river network has maximum density in the areas of low-mountain and medium-mountain elevations located within the steppe and desert geographic zones. For example, Mugodzhary has a value of 6–8 km per 100 km^2, and has two individual spots more than 12 km per 100 km^2. The density of the temporary river network in the west-central-Kazakhstan hilly regions is 6–8, 8–10, 10–12 km per 100 km^2. Individual spots with density of 14–16 km and those more than 16 km per 100 km^2 also exist. The north part of the Central-Kazakhstan hilly areas has density of 4–6 and 6–8 km per 100 km^2.

Methods of assessment

All water in the Earth is in constant motion. The source of energy for global water circulation is the sun, which heats water areas of the hydrosphere and land surface and vegetation surface. These areas are the sources of evaporation and evapotranspiration, the values of which mainly depend on direct and dispersed solar radiation, temperature, humidity, wind speed and surface roughness. An average of 1030 mm of water evaporates from the surface each year. Evaporation over the oceans within the area of equatorial latitudes range from 1500 to 2000 mm/year, but wherever there is vegetation cover, the on-shore evaporation exceeds the evaporation over the oceans substantially. In dry on-shore conditions, where the main consumable element of water balance is physical evaporation, its value is comparable to that for precipitation, amounting to about 100 mm per year [9].

The water balance of river basin territories has usually been measured using this equation:

$P = R + \mathrm{ET}$, where P is precipitation, R is river flow, and ET is for evapotranspiration/evaporation.

Since this equation can only estimate the main or primary water resources of river basins, an adjustment of the components has helped to measure its differential form [11]:

$P = S + U + \mathrm{ET} = S + U + N + T = R + \mathrm{ET}$, where P is atmospheric precipitation, S is surface (flood) river flow, U is underground flow (more stable part of the total river flow $R = S + U$), $\mathrm{ET} = (N + T)$ is evapotranspiration, N is evaporation out of the soil or physical evaporation, and T is transpiration of plants or biological evaporation.

Next, the differential equation of the water balance when considering glacier-derived flow has a universal form $P = R + E + L + U_1 + Q + J$, where L, underground water flow to the sea along the coast line U_1, moisture condensation from the atmosphere Q (portions of the atmospheric moisture P:$Q = mP$, where $m <<1$) and sublimation J, which is transition of a substance from the solid as snow, ice, to the gas phase as evaporation, without passing through the intermediate liquid phase.

The water balance equation also allows the determination of a lithological link of the water circulation, i.e. hydrological processes related to the geological substrate, particularly, the soil. Indeed, the water balance equation shows the important hydrologic and hydrogeological ratios [12].

$$W = P - S = U + E,\ K_U = U/W,\ K_E = E/W,\ K_P = U/P,\ K_R = U/R$$

Where W – gross soil moistening that characterizes precipitation filtered into the soil and used to recharge the natural resources of underground water, further feeding of rivers by means of underground flow, evaporation and transpiration; $K_U = U/W$ – coefficient of feeding of rivers by underground water (share of infiltration forming the underground flow of water to rivers); $K_E = E/W$ – evaporation coefficient (share of infiltration and gross soil moistening spent for evapotranspiration); $K_R = U/R$ – coefficient of underground feeding of rivers (ratio of the underground run-off value to the total river run-off value, i.e. share of underground water in the total river flow shall be calculated for regions where underground flow derives from drainage of water bearing horizons by rivers; $K_P = U/P$ – coefficient of underground flow (ratio of the underground flow value to the value of atmospheric precipitation over the same period [4].

The water balance equation is based on precipitation, surface and underground water flow, evaporation, transpiration and sublimation. The evapotranspiration elements are not clearly analysed or assessed because the river flow is the integral index of formation of the river basin water balance, which reflects both surface and underground components of the unified biospherical hydrologic and hydrogeological cycle of water exchange. Furthermore, the river discharge is the only reliably definable water balanced characteristic of the river basin.

The main difficulties in using the water balance equation of the onshore surface are the lack of proper evapotranspiration assessment and data. The evapotranspiration uncertainty error values are in the range of 10–15%, which creates error in the water balance calculations [13].

In order to reduce these uncertainty error values we refer to the analysis of the differential equation of the onshore water balance within the period of low winter runoff, when the surface runoff takes the minimum value $S_{\min}$ and is formed at the expense of underground water flow of the winter flow low period $U_{\text{runoff low}}$ and evapotranspiration $E_{\text{runoff low}}$. Therefore, we transpose the original Equation (1) as follows

$$R = 2S_{\min} + E_{\text{runoff low}} = 2U_{\text{runoff low}} + E_{\text{runoff low}},$$

Whence it follows that

$$S_{\min} = U_{\text{runoff low}}.$$

Therefore, the long-term average annual value of the evapotranspiration $E_{\text{ave.low water}}$ within the period of low water level may be obtained on the basis of long-term average annual data $R_{\text{ave.low water}}$ and $S_{\text{ave.low water}}$. This may be calculated according to the long-term average annual data of the hydrological monitoring:

$$E_{\text{ave.low water}} = R_{\text{ave.low water}} - 2S_{\text{ave.low water}} = R_{\text{ave.low water}} - 2U_{\text{ave.low water}} \tag{1}$$

Subject to

$$U_{\text{ave.low water}}/R_{\text{ave.low water}} = 0.5, \text{ i.e. } R_{\text{ave.low water}} = 2U_{\text{ave.low water}}, \tag{2}$$

We obtain

$$E_{\text{ave.low water}} = 0,$$

considering that within the period of low winter surface flow the physical evaporation (mainly through sublimation) and transpiration have the minimum values, which is confirmed by the Penman-Monteith theory of evapotranspiration and experimental data [14], given in Figure 1.

We may accept the following as a limiting condition

$$E_{\text{ave.low water}} = 0,$$

and upon analysing the water balance Equation (1) come to the analogue conclusion:

$$U_{\text{ave.low water}}/R_{\text{ave.low water}} = 0,\ 5,\ t.e.R_{\text{ave.low water}} = 2U_{\text{ave.low water}},$$

accepted as an initial condition in the first case (2).

Thus, the share of the long-term average annual value of the low winter period flow (underground flow to river $U_{\text{ave.low water}}$) in the long-term average annual value of the river flow $R_{\text{ave.low water}}$ may not exceed 50%. In other words, $U_{\text{ave.low water}}/R_{\text{ave.low water}} \leq 0.5$.

But we must note the cases:

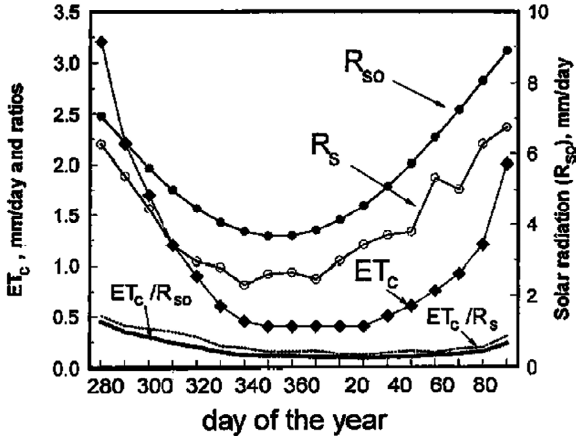

Figure 1. Mean evapotranspiration measured during non-growing, winter periods at Kimberly, Idaho, United States by Wright (1993): ETc – crop evapotranspiration under standard conditions [mm day^{-1}], R$_s$ – solar or short ware radiation [MJm^{-2} day^{-1}], R$_{so}$ – clear-sky solar or clear-sky shortware radiation [MJm^{-2} day^{-1}]. Source: Ref. [14].

$U_{\text{ave.low water}}/R_{\text{ave.low water}}$ ≥0.5, recorded in the mountain territories of Tien Shan and Dzungaria as well as at Pamir and/or Kamchatka [2], and the Swiss Alps [15]. In these cases the basins of rivers such as Sharyn and Arys (belonging to the mountain territories of Tien Shan) are glacier-fed by flow of these rivers, which is confirmed by the maximum values of the coefficient of underground flow $K_{\text{u.r.}} = U_{\text{ave.low water}}/P_{\text{ave.low water}} \approx 0.5$ (Table 1). During winter flow, evapotranspiration has a minimum value, which is confirmed by the theory of Penman-Monteith and the experimental data in Figure 1.

Coefficients K_U and K_E show the proportion of two ratios of the gross soil moistening: the sum of the coefficients of feeding (infiltration) K_U and evaporation K_E as per above mentioned proportions of the water balance elements equals to 1 (see Table 1)

$$KU + KE = 1$$

Within the regions of glacier feeding (mountain territories of the Alpine orogenic belt of Kazakhstan) and occurrence of condensation, the underground water flow coefficient K_P may be more than 1 and the coefficient of underground feeding of rivers K_R (the share of underground feeding of rivers) reaches and even exceeds 50%. The share of the glacier feeding of the river runoff changes from 12 to 13% (Karatal, Bukturma Rivers, respectively) up to 20% (Shu, Sharyn Rivers), and the total value of feeding of these rivers by subsoil and glacier water reaches (%) 47–57–60–75 (Bukturma, Karatal, Shu, Sharyn Rivers, respectively) [16].

The coefficient values of the underground feeding of rivers $K_R = U/R$ within the selected hydro-ecological regions of Kazakhstan are shared as follows (%): Zhaiyk-Zhem – 23.44; Tobyl-Yessil – 13.37; Yertys – 49.18; Nura-Teniz – 9.5; Balkhash-Alakol – 45.35; Aral-Syr-Darya – 47.8, and the average value in the country is 42.86 (Table 1). These data fully conform to the theoretically substantiated assessments of the coefficient of underground feeding of rivers: $K_R \leq 50\%$ (Table). Therefore, an appropriate volume of underground flow (natural resources of underground water of the Republic of Kazakhstan) reaches 52.44 km^3/year, considering our estimates related to the standard of water flow for all the rivers in Kazakhstan (104.88 km^3/year) (see Table 1).

Table 1. Water resources of the main areas of runoff, hydrogeoecological regions and river basins of the Republic of Kazakhstan.

Runoff area	Hydrogeo – eco-logical region	River basin	Basin area, thousand. km^2	R, m^3/sec	$K_R = U/R$	$K_U = U/W$	$K_E = E/W$	Underground runoff, km^3/year
Caspian Sea	I Zhaiyk-Zhem	Zhaiyk	190.0	380.00	0.20	0.24	0.75	2.87
		Yelek	37.3	48.50	0.25	0.34	0.67	0.52
		Op	13.0	10.80	–	0.11	–	0.037
		Oiyl	25.8	10.80	–	0.08	–	0.029
		Zhem	38.8	15.50	–	0.12	–	0.057
		Karaozen	10.7	10.80	0.15	0.17	0.82	0.058
		Saryozen	3.93	5.20	0.10	0.11	0.89	0.018
		Saghiz	19.0	1.90	–	0.07	–	0.004
		TOTAL	338.53	483.50	0.23	–	–	3.593
Kara Sea	II Tobyl-Yessil	Yessil	118.0	71.00	–	0.13	–	0.3
		Terisakkan	19.4	8.90	–	0.07	–	0.02
		Tobyl	44.8	13.50	0.15	0.18	0.83	0.076
		TOTAL	182.2	93.40	0.13	–	–	0.396
	III Yertys	Yertys	196.0	895.00	–	0.45	–	12.7
		Shagan	1.89	0.94	–	0.13	–	0.004
		Ulbi	4.99	3.15	0.25	0.33	0.67	1.04
		Buktyrma	14.90	247. 00	0.35	0.54	0.46	4.21
		Selety	18.5	7.00	0.12	0.15	0.85	0.028
		TOTAL	212.79	1153 .1	0.49	–	–	17.982
Teniz Lake	IV Nura-Teniz	Nura	48.1	26.50	0.08	0.10	0.93	0.083
		Kulanotpes	13.9	5.9	0.08	0.096	0.90	0.015
		TOTAL	48.1	32.40	0.09	–	–	0.098
Balkhash-Alakol-LakeSystem	V Balkhash-Alakol	Ile	111.0	447. 00	–	0.46	–	6.79
		Sharyn	7.37	36. 60	0.55	1.01	0.18	0.632
		Ayagoz	12.1	14.80	0.15	0.17	0.83	0.08
		Lepsy	2.2	27.40	0.25	0.33	0.66	0.28
		Karatal	16.5	72. 10	0.45	0.83	0.18	1.02
		Aksu	1.33	11.60	–	0.33	–	0.12
		Tokyrauyn	2.92	2.19	0.20	0.27	0.86	0.019
		Bakanas	2.97	2.83	0.10	0.12	0.91	0.011
		Tentek	3.3	47.80	–	0.44	–	0.66
		Yemel	21.6	16.60	–	0.28	–	0.15
		Katynsu	2.45	7.28	–	0.35	–	0.08
		Urzhar	4.25	19.40	–	0.50	–	0.305
		TOTAL	187.99	705. 60	0.45	–	–	10.147

(Continued)

Table 1. (*Continued*)

Runoff area	Hydrogeo – eco-logical region	River basin	Basin area, thousand. km^2	R, m^3/sec	$K_R = U/R$	$K_U = U/W$	$K_E = E/W$	Underground runoff, km^3/year
Aral Sea	VI Aral-Syr-Darya	Syrdariya	219.0	703. 00	0.50	–	–	11.08
		Arys	13.2	46.10	0.50	0.99	0,01	0.725
		Shu	22.0	55.50	0.40	0.71	0,32	0.704
		Torgai	155.5	10.40	0.20	0.25	0,75	0.066
		Yrgyz	33.3	10.10	–	0.33	–	0.105
		Sarysu	65.0	7.58	0.12	0.17	0,82	0.041
		Kengir	9.86	3.80	0.05	0.04	0,95	0.004
		Uly – Zhilanshik	11.0	3.00	0.10	0.09	0,91	0.01
		TOTAL	436.76	839. 48	0.48	–	–	12.735
TOTAL in the RK	1 406.4	3307.47	0.43	–	–	44.951		

The runoff of all the rivers of Kazakhstan is estimated to be 102.3 km^3/year [9], of which 57.6 km^3/year forms in the territory of the country, and 44.7 km^3/year in the adjacent countries (20.4 km^3/year – China, 14.4 km^3/year – Uzbekistan, 7.01 km^3/year – Russia, 2.59 km^3/year – Kyrgyzstan).

Kazakhstan's environment and industries are sensitive to any change in river flow. A strategy of stable water provision should focus on the negative combination of two destabilizing factors: climate-dependent change of the local surface flow (10–20%) and anthropogenic decrease of trans-border surface flow (up to 50%). If climatic and trans-border hydrological threats materialize, water resources of the river flow may eventually decrease in Kazakhstan by 2020 to a level of 81.6 km^3/year, as follows: trans-border – up to 33.2 km^3/year; local – up to 48.3 km^3/year; by 2030 – up to 72.4; 22.2, and 50.2 km^3/year, respectively [9].

Discussion

This study shows that in the process of water cycling, underground water is hydraulically interrelated to the surface water of river basins, forming a unified water resource potential. This is equivalent to a layer of moisture for the entire territory of Kazakhstan (2.7 million. km^2) of about 50 mm per year [9] with an average value of 250 mm of precipitation per year and an estimated evapotranspiration of 200 mm per year [14].

With the possible impact of the global climate and regional trans-border hydrological threats, the underground water resources may eventually decrease in Kazakhstan by 2020 by up to 40.8 km^3/year. A possible change of the underground drain water could be the value of ± (1–2)%, i.e. on ± (0.5–10) km^3/year. This equates to a modern selection of Kazakhstan's groundwater for economic-drinking water supply amounting to 0.84 km^3/year [9].

The increased environmental concern in Kazakhstan and worldwide is confirmed by the ecosystem restrictions in use of water resources, i.e. regulation of the environmental demand for water resources. Sustainable water use is necessary.

Renewable resources of the river runoff of Kazakhstan are the integral environmental component providing for the stability of the salt-water regime of internal and marginal impoundments, watering of floodplains and estuaries and for the water resource balance of the territory. Hence, the standards for the ecological surface flow of rivers have been established for river waters of Kazakhstan and allow a stable balance of water ecosystems to be maintained: ecological potential 37% (now 37.85 km^3/year), production resource 63% (now 64.45 km^3/year) from the rate of water flow [9].

If the proportion of the surface and underground water flow is 2:1, the rated environmental demands of the natural and domestic ecosystems of the country for water resources will be18.93 km^3/year. In this case, the rated underground ecological water flow in the volume of ecological demand should meet the following conditions:

- Provide gross subsoil moistening sufficient for the terrestrial biota;
- Be changeable in time within a year as in natural conditions;
- Ensure maintenance of underground water flow parameters within the range of its optimal values, i.e. levels of subsoil water and piezolevels of artesian water and their salt regime.

Consequently, in the case of limiting water intake of groundwater with the volume of 1.5 km^3/year, Kazakhstan's underground water reserve will be 21.5 times more.

Conclusions

The estimated general water need in Kazakhstan is planned to provide: surface water – 19.8 km^3/year; ground water – 1.5 km^3/year (10% of explored reserves); sea water – 1.1 km^3/year; other water sources – 0.9 km^3/year and it should actually tend to the level of 23.3 km^3/year, including irrevocable water consumption – 15.3 km^3/year, on agriculture and water disposal – 8.0 km^3/year (industry – 4.0 km^3/year; municipal services – 2.2 km^3/year; other branches – 1.8 km^3/year). Plans for the immediate future (to 2020) coefficients of the growth of using groundwater resources in priority sectors of Kazakhstan's economy comprises: 1.12–1.56 for public water supply, 1.27–1.22 for industrial water supply, 1.36–1.33 for agricultural water supply and 1.12–1.21 for other productions [17].

Consequently, at the lowest estimate for groundwater in volume of 1.5–2.0 km^3/year, the requirement would be 20 times the reserved water supply of Kazakhstan .

The Ak Bulak programme is estimated to use 15.44 km^3 of underground water per year [7]. Because of the surface and groundwater connection, the surface water level would be decreased to 5 km^3 per year.

The excessive and inefficient use of water leads to the deterioration of hydro-geoecological conditions in Kazakhstan [18].

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by British Council [grant number 216416278] and by the Royal Academy of Engineering [IAPP\1516\59].

References

[1] United Nations, 1993, Resolution of United Nations General Assembly No. A/RES/47/193, New York.
[2] United Nations, 2003, International Decade for Action: "Water for Life."Resolution of United Nations General Assembly No. A/RES/58/217, New York.
[3] Smoljar, V.A., Burov, B.V. and Mustafaev, S.T., 2012, Vodnye resursy Kazahstana: ocenka, prognoz, upravlenie: T. VIII: Resursy podzemnyh vod Kazahstana / - 21-m tome. - Almaty [Water resources of Kazakhstan: assessment, prognosis, management: T. VIII: Groundwater resources of Kazakhstan / - 21 tome. – Almaty], Kazakhstan: VITBRAND LTD, p. 634 [in Russian].
[4] Kudelin, B.I., 1960, Princypy regionalnoj ocenki estestvennyh resursov podzemnyh vod, Moskovskij Gosudarstvennyj Universitet [Principles of regional assessment of natural groundwater resources, Moscow, Moscow University], p. 308 [in Russian]
[5] Volvovsky, I.S., Garetsky, R.G., Schlesinger, A.E. and Shraybman, V.I., 1966, Tektonika Turanskojplity [The Turan plate tectonics]. (Moscow: Nauka), p. 285 [in Russian].
[6] Kamenskij, G.N., Tolstihina, M.M. and Tolstihin, N.I., 1959, Gidrogeologija SSSR [Hydrogeology the Union of Soviet Socialist Republics, Moscow, State scientific-technical publishing house of literature on Geology, geodesy and conservation of resources (Stategeotechpublish)], (Moskva), p. 366 [in Russian].

[7] Ahmedsafin, U.M. and Sydykov, Zh.S, 1964, Stokpodzemnyhvod Kazahstana, zony intensivnogo vodoobmena [The flow of underground waters of Kazakhstan, the zone of intensive water exchange]. (Alma-Ata: Nauka) (Almaty: Science), p. 88 [in Russian].

[8] Makarenko, F.A., 1947, O zakonomernostjah podzemnogo pitanija rek. Dokl.AN SSSR.s.57, No. 5 [About the patterns of the underground supply of rivers. Moscow, Report of the Academy of Sciences the Union of Soviet Socialist Republics (USSR)]. [in Russian].

[9] Programma «Ak Bulak» na 2011–2020 gody, 2011, Utverzhdena postanovleniem Pravitelstva Respubliki Kazahstan ot 24 maja [Approved by the resolution of the Governments of the Republic of Kazakhstan from may 24]. No. 570. [in Russian].

[10] Gerasimov, I.P., 1952, *Ocherki po fizicheskoj geografii Kazahstan* [Essays on physical geography of Kazakhstan]. (Alma-Ata: Nauka) (Almaty: Science), p. 312. [in Russian].

[11] Poryadin, V.I., Akynbaeva, M.G. and Adenova, K., 2016, Fundamental'naja jekosistemnaja vzaimosvjaz' zagrjaznenija I istoshhenija resursa presnoj vody gidrosfery. News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences. Izvestie NAN RK. Serija geologii i tehnicheskih nauk [Fundamental ecosystem the relationship of pollution and depletion of the fresh water of the hydrosphere. Almaty, News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences], **1**(415), 68–78. [in Russian].

[12] L'vovich, M.I., 1969, Vodnyj balans SSSR i ego Preobrazovanija [The water balance of the Union of Soviet Socialist Republics (USSR) and its Transformations], (Moskva: Nauka) (Moscow: Science), p. 338 [in Russian].

[13] Poryadin, V.I., 2014, Jekosistemnye resursy podzemnyh vod Kazahstana: metodologija ocenki. Izvestie NAN RK.Serija geologii i tehnicheskih nauk [Ecosystem groundwater resources of Kazakhstan: estimation methodology, Almaty, News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences], **5**, 47–57.

[14] Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 2006, Crop Evapotranspiration. FAO Irrigation and Drainage Paper 56, Rome, Italy, p. 330.

[15] von Freyberg, J., Rao, P.S.C., Radny, D. and Schirmer, M., 2015, The impact of hillslope groundwater dynamics and landscape functioning in event-flow generation: a field study in the Rietholzbach catchment, Switzerland. Hydrogeology Journal, **23**(5), 935–948. doi: 10.1007/s10040-015-1238-1.

[16] Ahmedsafin, U.M. and Sydykov, ZhS, 1970, Formirovanie podzemnogo stoka na territorii Kazahstana [The formation of groundwater runoff on the territory of Kazakhstan], (Alma-Ata: Nauka) (Almaty: Science), p. 148 [in Russian].

[17] Malkovskij, I., 2012, *Vodnaja bezopasnost Kazahstana: problem I puti reshenija* [Water security of Kazakhstan: the problem and solutions. The biggest deficit], (Central Asia Monitor: Glavnyj v mire deficit) (Almaty: Central Asia Monitor), [in Russian].

[18] Alamanov, S.K., Lelevkin, V.M., Podrezov, O.A. and Podrezov, A.O., 2006, *Izmenenie klimata I vodnye problemy v Central'noj Azii* [Climate change and water problems in Central Asia]. (Moskva-Bishkek: UNEP-WWF) (Moscow-Bishkek: UNEP-WWF), p. 188 [in Russian].