Problems of effective use of the water resources of the transboundary rivers in the steppe zone

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Abstract. A comparative assessment of indicators of the water supply sufficiency of transboundary basins in the steppe zone is considered in the paper. It was noted that adequate water consumption problems in separate regions of the steppe zone have the maximal topicality due to hydrodynamic aspects and hydroclimatic specifics. We should pay attention to the account of existing water resources in areas with considerable long-term flow variations. Parameters of effective use of water resources were analyzed in the transboundary river-steppe zone within the Russian-Kazakhstan sector. The nonparametric method of multivariate analysis (PATTERN) was used for the first time to estimate the effectiveness of water resources use. As a result, four groups of the regions differed by the level of sufficient water resources use were selected. In conclusion, the topicality of development and realization of intergovernmental programs concerning the problematic use of water resources of the transboundary rivers in the steppe zone was considered.

1. Introduction
In the current modernization of the economy in regions of the Russian Federation, one of the critical conditions of stable dynamics of socio-economic indicators is introducing a regional program of innovative development occurring everywhere. One of the essential components of these programs is the water-resources part. Simultaneously, it should be mentioned that water is a multipurpose resource used by different sectors of the economy and population. In connection with it, priority directions of water resource component's development are the guaranteed sufficiency of water supply for people and the economy, conservation and restoration of water objects' ecosystems to the state providing ecologically favorable conditions to population living [1].

Long-term average annual renewable water resources in Russia are estimated at 4300 km³/year (2nd place globally) that forms ~ 10% of the global streamflow [2]. Despite considerable reserves of renewed water recourses, problems concerning the guaranteed water supply for the economy and population are exacerbated by the extremely irregular spatio-temporal distribution of the runoff in some RF regions. In particular, such areas are located within the steppe zone. Thus, minimal long-run annual averages of the streamflow are noticed in the following steppe regions – the Republic of Crimea (1.0 km³/year), the Republic of Kalmykia (1.1 km³/year), Kurganskaya oblast (4.3 km³/year), and Chelyabinskaya oblast (7.4 km³/year) [2]. Rivers of the steppe zone are characterized by
considerable divergence from long-term annual averages of streamflow, which is one of the critical moments in evaluating the modern and prospective sufficiency of the water supply. In the current conditions, the formation and distribution of water resources of steppe zone's rivers have happened in the background of severe transformation of the global climatic system. According to the Intergovernmental Panel report on Climate Change (IPCC), climate warming is an unquestionable fact and noticed, to the most degree, for the last 30-40 years. Within the Russian Federation, the speed of climate warming is more than 0.45°C/10 years and unequal in different parts of the country [3]. One of the consequences of climate change is an increase in intensity and reoccurrence of strange events, including extreme hydrologic situations – high- and low water level that reflects negatively in the population's hydro-ecological security and the economy.

That successful solution of problems concerning the achievement of the guaranteed water supply in the steppe zone's regions is difficult to realize without developing programs on effective water resources use. Problems of rational water consumption in the RF separate regions are maximally urgent due to the areas' water-economic aspects and hydroclimatic specifics [4].

2. Setting of the problem
Issues regarding the rational use of water resources of the transboundary rivers, water-collecting areas of which envelope landscapes of the steppe zone and divided by state borders of neighboring countries, arouse a particular interest. An example of such territories is the Russian-Kazakhstan transboundary region, including steppe space of the south-east part of the East European Plain and the West Siberian-Kazakhstan sector. A spatial specific of this region is identified by a presence of "mirror" interests in the sphere of water resources of transboundary rivers (table 1).

Table 1. The transboundary basins of the Russian-Kazakhstan region.

| River   | Indicators                  | Total     | Distribution by territory of states |
|---------|-----------------------------|-----------|-------------------------------------|
|         |                             |           | Kazakhstan | Russia                      |
| Ural    | S river’s basin, km²        | 231000    | 172530     | 55680                      |
|         | L river, km                 | 2428      | 1082       | 1346                       |
|         | W, km³                       | 9.2       | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
| Ilek    | S river’s basin, km²        | 413000    | 22430      | 18870                      |
|         | L river, km                 | 776       | 319        | 457                        |
|         | W, km³                       | 0.7       | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
| Or      | S river’s basin, km²        | 18600     | -          | -                          |
|         | L river, km                 | 391       | 248        | 143                        |
|         | W, km³                       | 0.4       | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
| Irtysh  | S river’s basin, km²        | 1650000   | 48000      | 917000                     |
|         | L river, km                 | 4248      | 1696       | 2040                       |
|         | W, km³                       | 26.6      | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
| Ishim   | S river’s basin, km²        | 163000    | 129200     | 33800                      |
|         | L river, km                 | 2450      | 1783       | 667                        |
|         | W, km³                       | 2.2       | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
| Tobol   | S river’s basin, km²        | 426000    | 99000      | 327000                     |
|         | L river, km                 | 1591      | 583        | 1008                       |
|         | W, km³                       | 0.5       | -          | -                          |
|         | (state border RF-RK)        |           |            |                            |
In the Kazakhstan regions, the large "donor" of streamflow is the Ural River and its inflows. The Ural river basin's total area is 231 thousand km², 172 thousand km² belonging to the RF regions. Sharp variations of streamflow characterize the river – to 20 times of average annual runoff and 1300 times duty of water for a year. The main part of the total streamflow (more than 80%) is formed within the upper and middle hydrographic sections. Within the Kazakhstan plot, lower of the Barbastau river mouth, the Ural River takes no flows and loses to 20% of yearly runoff in the transit part of the Caspian semi-deserts. Correspondingly, the stable functioning of separate sectors of the water economy in the Kazakhstan regions within the transboundary basin almost completely depends on a bulk of runoff passed by the Russian side [5]. A situation of the guaranteed water supply is exacerbated by a lack of large reserves of fresh groundwater within the Kazakhstan part of the basin.

As opposed to the Ural River, the upper reaches of the Irtysh River’s transboundary basin are located within China, but, despite an insignificant portion in the total area of the basin (1%), water resources of this sector are intensively used for different needs. The middle part of the Irtysh River’s water-collecting area coinciding with the zonal distribution of steppe landscapes lies within the Republic of Kazakhstan (55% of the total area of the basin). Rivers of the middle part (inflows – Tobol, Ishim, and others) are characterized by considerable runoff variations in seasonal and long-term aspect; in years with low water, the runoff of the Ishym River is lower than an annual average in 6-10 times [6]. Besides, the Irtysh basin's middle reaches are characterized by a considerable degree of anthropogenic load – the leading centers of metallurgy and power industry, large hydro-technical constructions (Bukhtarminskaya Hydro Power Station, etc.) are located within the basin. In Russia, the basin's runoff-forming area is about 0.7 million km², water-rich of the Irtysh River increases almost two times after the Tobol river inflow [4]. The Russian part of the Irtysh basin (44% of the total area) envelops steppe, forest-steppe, and natural forest zones; within such plot, the largest industrial-agricultural complex with a high degree of space development was formed. As a result, taking into account of spatio-temporal changeability of streamflow, one of the priority tasks of stable socio-economic development in regions of the transboundary basins of the Ural and Irtysh rivers is to provide economically profitable and ecologically safe water consumption.

It should be noted that effective use of water resources in RF and RK are paid special attention to the national and regional levels. Based on the defined role of the guaranteed water resource supply of the RF regions, the Water strategy was developed and realized. It directs to achieve a line of target indicators – reduction of reservoir capacity of GNP, an increase of the degree of wastewater treatment, an increase of a portion of hydro-technical constructions with the secure technical state, an increase of a part of flood-dangerous territories protected by engineering buildings and others [1]. The Republic of Kazakhstan is among countries suffering high water stress; it has 60th place of 68. The State Program of water resources management was approved for 2020-2030. The program's principal target is to achieve water security in the country at the expense of the realization of complex measures, including an increase of efficiency of water resources use [7]. Simultaneously, despite careful attention to the guaranteed and safe water supply issues from the side of RF and RK governmental structures, settlement of problems of the transboundary water consumption on the intergovernmental level has continued to be relevant.

### 3. Material and Methods

Statistical material on the presence, use, and conservation of water resources in regions of the Russian Federation and the Republic of Kazakhstan served as the study's initial data [2, 8]. Calculation of values of the sufficiency of water supply in the transboundary rivers' regions was made based on approaches used in foreign and Russian practice. One of these approaches is a calculation of Falkenmark criterion that measures some level of the deficit of water. Thus, the threshold amount of specific sufficiency of water supply (a bulk of water resources per capita) catheterizing a presence of water tension and water stress development is less of 1700 m³/year/person [9]. Another method estimating water resources supply considers a ratio of the bulk of water taken from natural sources and the total renewed water value (the stability index). The stability index values represents a lack of a
water consumption volume exceeding 20% of renewed streamflow and a catastrophic situation in water resources supply – if a water consumption volume exceeds more than 40% [10]. A real sufficiency of water supply is estimated. It is a ratio of water resources’ annual average value for the three-year low water period, irreversible water consumption, and population, [11].

A generalized indicator of effective water resource use is the specific water consumption at 1 ruble of gross regional products (GRP). Based on this indicator, an integral assessment is conducted. There are specific total water consumption (fresh and reused) and specific fresh water consumption at 1 ruble of GRP [12].

Rating of the regions in the transboundary river basins according to the efficiency of water resources use was conducted based on the following indicators: the coefficient of recycled water consumption, a loss of water in transportation (%); reservoir capacity of agriculture (m³/thousand rubles); withdrawal of water by agriculture per capita, m³/persons.

A nonparametric method of multivariate analysis (PATTERN) was used to obtain the total assessment. The technique was developed at the end of the 1960s in the USA and represented a variety of system analysis methodologies [13].

An algorithm of the integral assessment of efficiency of water resources consumption using PATTERN method includes the following stages:

1. An option and calculation of fundamental indicators of efficiency of water consumption.
2. Working out the total summary table of the principal indicators of water consumption efficiency in the transboundary regions.
3. Detection of maximal values of each indicator and the following reduction of rest indicators to this value: $P = Xti / Xt\ max$,

where $Xti$ – indicator values, $t=1, n$ – indicator numbers, $i=1…, n$ – region numbers.
4. Calculation of the rank – Rank Final – low, middle, high, and too high on the base of which four groups of the transboundary regions were selected according to water consumption efficiency.

4. Results and Discussion

It is well-known that rivers’ water resources belong to the category of renewed components of the environment. In condition with it, the sufficiency of water supply in regions is not stationary characteristics. Therefore, such an indicator’s value is identified by a spatio-temporal variation of hydroclimatic conditions and socio-economic situation in the regions. It should be noted that a necessity of effective water consumption of the transboundary rivers in the steppe zone is topical due to regional specifics of the water consumption structure, and physical-geographical conditions of water-collecting areas. The influence of the climatic factor on water consumption has a zonal character. It increases from north to south and west to east at the degree of reduction of natural humidification in Russia’s European part. However, in humid zones, this factor does not influence on a water consumption volume [11].

On the whole, according to the results of the conducted analysis of multi-year characteristics of water resources of the transboundary basins of the Ural and Irtysh rivers, the majority of the regions, even taking into account a considerable variation of streamflow, is characterized by optimal indicators of the sufficiency of water supply (table 2).

Indicators of specific sufficiency of water supply (Falkenmark’s index) show a lack of water supply tension in most regions, except North-Kazakhstanskaya and Kostanayskaya oblasts of the Republic of Kazakhstan. Minimal indicators of specific water supply sufficiency are typical for Chelyabinskaya and Orenburgskaya oblasts in the Russian regions. The stability index calculation promotes to reveal optimal water supply in the regions of the transboundary basins of the Ural and Irtysh rivers. The values of this index vary from 0.3% in Omskaya oblast to 13.8% in Aktyubinskaya oblast. Overall, the Kazakhstan areas are characterized by higher values of the stability index than the Russian regions that confirm particular problems in the guaranteed water supply of the economy and population.
Table 2. A long-term characteristic of water resources of the transboundary basins of the Ural and Irtysh rivers [2, 14].

| Область            | Total river flow, km³/year | Minimum value, km³/year | Local river flow, km³/year | Cv | Falkenmark Index, m³/year/person | Sustainability index,% |
|---------------------|-----------------------------|-------------------------|---------------------------|----|---------------------------------|------------------------|
| Chelyabinskaya      | 7.4                         | 2.8                     | 5.9                       | 0.40 | 2626.8                          | 8.6                    |
| Orenburgskaya       | 12.7                        | 4.2                     | 4.6                       | 0.52 | 4724.5                          | 13.0                   |
| Kurganskaya         | 4.3                         | 1.2                     | 0.7                       | 0.87 | 8237.6                          | 0.9                    |
| Omskaya             | 41.3                        | 23.5                    | 6.2                       | 0.52 | 29097.1                         | 0.3                    |
| Altai region        | 55.1                        | 38.7                    | 19.4                      | 0.24 | 26081.1                         | 0.6                    |
| W.-Kazakhstan region| 8.7                         | 2.6                     | 1.7                       | 0.64 | 13811.0                         | 6.8                    |
| Aktyubinskaya       | 3.25                        | 0.6                     | 2.8                       | 0.77 | 3890.4                          | 13.8                   |
| Atyrauskaya         | 6.6                         | 2.2                     | 0                         | 0.53 | 11350.4                         | 4.2                    |
| N. Kazakhstan region| 33.6                        | 18.3                    | 4.2                       | 0.73 | 1748.9                          | 6.1                    |
| Kostanayskaya       | 1.5                         | 0.3                     | 1.9                       | 1.03 | 1701.7                          | 8.9                    |
| E.-Kazakhstan region| 35.6                        | 20.6                    | 27.8                      | 0.25 | 25728.7                         | 1.7                    |
| Pavlodarskaya       | 29.1                        | 17.6                    | 0.05                      | 0.25 | 38503.3                         | 10.7                   |

Along with, at present, water resources formation happens in non-stationary conditions. Therefore, using long-time average annual values of water resources to estimate their current state does not reflect a real situation. In connection with it, it is reasonable to evaluate the sufficiency of water supply in regions taking into account existing water resources [10]. Based on such an approach, we calculated the actual adequacy of water supply for the Russian areas taking into account long-time average annual values for three years of low water (2009-2011). Results of the evaluation represent a considerable difference between indicators of actual and potential sufficiency of water supply (level of 2015), and, in the first line, in regions with a significant fluctuation in streamflow in long-term aspect, for example in Chelyabinskaya (1.21 and 2.63 thousand m³/persons) and Kurganskaya oblasts (1.98 and 8.24 thousand m³/persons, respectively.

The integral and universal indicator of adequate water consumption – the water capacity of gross regional product (GRP) reflecting the totality of changes in industrial processes in water infrastructure and its value, in the first line, will depend on the changeability of two indicators – generation of electric power and water expenditure for irrigation [12]. Also, it should be noted that in the realized RF Water strategy, only fresh reservoir capacity GNP in RK (3.4 m³/thousand rubles) is an enormous part of irretrievable water consumption for agricultural irrigation and flooding of pastures. GNP's reservoir capacity in RF is lower and can be compared with developed countries' indicators - 1.14 m³/thousand rubles [2]. In the regional context, low indicators of water capacity are noticed in the following Russian regions: Kurganskaya oblast (0.30 m³/thousand rubles) and Omskaya oblast (0.36 m³/thousand rubles), and the Kazakhstan regions: Atyrauskaya oblast (0.28 m³/thousand rubles), North-Kazakhstan region (0.34 m³/thousand rubles), and Kostanayskaya oblast (0.35 m³/thousand rubles). The regional economy's maximal values of water capacity are registered in Orenburgskaya oblast - 1.70 m³/thousand rubles and Pavlodarskaya oblast– 10.12 m³/thousand rubles [4].

An analysis of water resource use's effectiveness is reasonable to conduct in the frame of sizeable industrial water consumers [12]. In particular, a calculation of water consumption for agricultural production witnesses high reservoir capacity indicators in separate regions of the Republic of Kazakhstan shows a presence of considerable differences at national and regional levels.

Thus, the principal reason for a particularly high level of reservoir capacity GNP in RK (3.4 m³/thousand rubles) is the generation of electric power and water expenditure for irrigation [12]. In the regional context, low indicators of water capacity are noticed in the following Russian regions: Kurganskaya oblast (0.30 m³/thousand rubles) and Omskaya oblast (0.36 m³/thousand rubles), and the Kazakhstan regions: Atyrauskaya oblast (0.28 m³/thousand rubles), North-Kazakhstan region (0.34 m³/thousand rubles), and Kostanayskaya oblast (0.35 m³/thousand rubles). The regional economy's maximal values of water capacity are registered in Orenburgskaya oblast - 1.70 m³/thousand rubles and Pavlodarskaya oblast– 10.12 m³/thousand rubles [4].

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The integral and universal indicator of adequate water consumption – the water capacity of gross regional product (GRP) reflecting the totality of changes in industrial processes in water infrastructure and its value, in the first line, will depend on the changeability of two indicators – generation of electric power and water expenditure for irrigation [12]. Also, it should be noted that in the realized RF Water strategy, only fresh water consumption is as the control indicator, not taking into account reused water, that worsens an option of the optimal variant to solve problems concerning to reduction of reservoir capacity in regions [15].

The comparative analysis of total values of reservoir capacity in the Russian Federation and the Republic of Kazakhstan shows a presence of considerable differences at national and regional levels. Thus, the principal reason for a particularly high level of reservoir capacity GNP in RK (3.4 m³/thousand rubles) is an enormous part of irretrievable water consumption for agricultural irrigation and flooding of pastures. GNP's reservoir capacity in RF is lower and can be compared with developed countries' indicators - 1.14 m³/thousand rubles [2]. In the regional context, low indicators of water capacity are noticed in the following Russian regions: Kurganskaya oblast (0.30 m³/thousand rubles) and Omskaya oblast (0.36 m³/thousand rubles), and the Kazakhstan regions: Atyrauskaya oblast (0.28 m³/thousand rubles), North-Kazakhstan region (0.34 m³/thousand rubles), and Kostanayskaya oblast (0.35 m³/thousand rubles). The regional economy's maximal values of water capacity are registered in Orenburgskaya oblast - 1.70 m³/thousand rubles and Pavlodarskaya oblast– 10.12 m³/thousand rubles [4].

An analysis of water resource use's effectiveness is reasonable to conduct in the frame of sizeable industrial water consumers [12]. In particular, a calculation of water consumption for agricultural production witnesses high reservoir capacity indicators in separate regions of the Republic of
Kazakhstan (Pavlodarskaya, Atyrauskaya, and East-Kazakhstanskaya oblasts) that are characterized by a considerable volume of irrevocable water consumption for irrigated agriculture.

An important indicator of effective water resource use is recycled and reused water in the industrial sector. The volume of recycled water consumption exceeds direct-flow water use within the Russian regions; it is typical for most of the RF subjects. Fresh water-saving identified by a part of recycled water use varies from 60 to 92% within the Russian regions and from 40 to 78% in Kazakhstan regions (figure 1).

![Figure 1. The structure of regional water consumption and a part of recycled water use (%) in regions of the transboundary basins in the steppe zone.](image)

It is necessary to mention that in most parts of the regions of transboundary Rivers in the steppe zone, visible changes of indicators of water-saving, including an increase of recycled-reused water supply, have happened for the last 30 years. The most considerable growth of the water-saving was noticed in large industrial areas of the Republic of Kazakhstan (the Irtysh river basin) – from 13 % in East-Kazakhstanskaya oblast to 26 and 28 % in North-Kazakhstanskaya and Kostanayskaya oblasts, respectively. In the Russian territories, the growth has been less significant for the last 20 years – from 3 % in Novosibirskaya oblast to 12 % in Omskaya and 14 % in Orenburgskaya oblasts that can be explained by the reach of practically maximal part of recycled water in the whole structure of water use for the last decade. A line of regions represents the negative dynamics of fresh water saving. First of all, it is typical for Kazakhstan regions within the Ural transboundary basin. For example, in Aktyubinskaya oblast, a portion of recycled-reused water supply decreases at 22% (it was 4% in 2017), in Russian regions a part of recycled water reduced at 14% in Tyumenskaya oblast. Despite the positive dynamics of separate water-saving indicators, in most regions of transboundary river basins in the steppe zone, the problem of sufficient water resources use is still urgent.

The presence of specific problems is confirmed by the ranking of regions of transboundary basins according to the efficiency of water resources consumption (table 3).

As a result, four groups of the region were selected. They are distinguished by different levels of water resource-saving. A considerable part of the areas has average indicators of water use efficiency (Omskaya, Novosibirskaya, Atyrauskaya, Kostanayskaya, and other oblasts). Regions with a high part of the power- and wet sectors of industry and intensive development of agriculture form a group with
a low level of effective use of water resources (Pavlodarskaya, Orenburgskaya, Chelyabinskaya, Kurganskaya oblasts).

**Table 3.** Ranking of transboundary regions, according to indicators of effective water resources consumption (CRW-the Coefficient of recycled water use; LWT- a loss of water in transportation; % (2018 by 1995); WIAP – water intensity of agricultural products, m³/thousand rubles; CUWA – consumptive use of water by agriculture per capita, m³/persons).

| Oblast                | CRW  | Rank | LWT  | Rank | WIAP | Rank | CUWA  | Rank | ∑   | Final rank |
|-----------------------|------|------|------|------|------|------|-------|------|-----|------------|
| Orenburgskaya         | 0.63 | 1.00 | 0.70 | 0.80 | 0.90 | 0.52 | 6.9   | 0.69 | 1.71| high       |
| Chelyabinskaya        | 0.90 | 1.00 | -5   | 0.80 | 0.90 | 0.52 | 6.9   | 0.69 | 1.81| high       |
| Kurganskaya           | 0.81 | 0.90 | 8    | 0.91 | 0.90 | 0.52 | 6.9   | 0.69 | 1.82| high       |
| Omskaya               | 0.85 | 0.94 | -28  | 0.61 | 0.90 | 0.52 | 6.9   | 0.69 | 1.83| high       |
| Novosibirskaya        | 0.56 | 0.62 | -11  | 0.75 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| Altai region          | 0.69 | 0.76 | -51  | 0.41 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| Atyrauskaya           | 0.48 | 0.53 | -34  | 0.55 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| W.-Kazakhstanskaya    | 0.01 | 0.01 | -48  | 0.44 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| Aktyubinskaya         | 0.40 | 0.44 | -69  | 0.26 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| Kostanayskaya         | 0.79 | 0.87 | -58  | 0.35 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| N. Kazakhstan         | 0.47 | 0.52 | -50  | 0.42 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| Pavlodarskaya         | 0.52 | 0.57 | -87  | 0.11 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |
| E.-Kazakhstanskaya    | 0.39 | 0.43 | -35  | 0.55 | 0.90 | 0.52 | 6.9   | 0.69 | 1.85| high       |

5. Conclusion

Considering differences in the insufficiency of water supply in regions of the Ural and Irtysh rivers' transboundary basins, one of the priority tasks is an achievement of cost-efficient and environmentally safe use of water resources for state-water consumers. Successful solution of set tasks can be reached at the expense of increase of efficiency of water resources use of rivers, a reduction of irretrievable flow withdrawal and loss in transportation, decrease water capacity of gross regional and industrial products, the growth of a recycled water part in the structure of water consumption and others. In the central part of the examined transboundary regions, specific results were obtained within national water-economic plots for the last decades. To realize adequate transboundary water resources use, it is necessary to develop intergovernmental plans for complex consumption of water resources.

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