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CALCULATION OF THE MINIMUM NUMBER OF HYDROLOGICAL OBSERVATION STATIONS OF THE HYDROMETEOROLOGICAL SERVICE NETWORK IN THE REPUBLIC OF KAZAKHSTAN

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The article estimates the number of hydrological observation points taking into account the minimum density of their location and in accordance with WMO recommendations. The territories of Kazakhstan, distinguished by a great variety of climatic conditions and natural zones, have different water availability and require separate norms in the organization of observation points in river basins, known water management regions of the republic. For each river basin, the areas of physiographic regions belonging to different natural zones, including drainless areas, were calculated, which amounted to more than 700 thousand km². As a result of the calculation, the total minimum number of hydrological posts for the whole country was justified to be 500. However, with economic growth, this number should be increased in accordance with the developed principles and territorial zoning for more effective water resources management.

Key words: hydrological network, water basin, landscape, observations

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INTRODUCTION

Water resources, their control and rational use are extremely important for the sustainable development of nations. The development of cost-effective hydrological observation methods is one of the priorities identified by World Meteorological organization (WMO) in the Hydrological Investigations for 2022...2030 (Pechlivanidi I., Ickes L., Gute E., 2023; Ramos M.-H., Cudennec C. and et. all, 2022; Vision and Strategy for Hydrology..., 2023).

Long-term spatially distributed hydrological observations are necessary to understand spatial and temporal patterns and changes in water resources and their properties, which are characterized by significant variability for the plain rivers of Kazakhstan (Fekete B. and et. all, 2021).

In general, the main source of information for natural resource assessment is ground-based observation stations, despite the trends of widespread use of satellite remote sensing in the last few decades (Lettenmaier D., 2006). Reliable, sufficient and authentic observation materials for elements of hydrological regime of water bodies provide quality water resources management under constantly increasing anthropogenic pressure on them.

The observation network data should allow estimating water resources not only in a multi-year perspective with sufficient accuracy, but also provide the needs of economic sectors with more extensive operational information in a continuous mode (annual, monthly, daily, etc.), and ensure reliability of water management calculations and forecasts when planning the development of the country's regions. This is a priority task of the hydrometeorological service of the Republic of Kazakhstan.

Determination of optimal quantitative and spatial distribution of hydrological posts over the territory of Kazakhstan under the conditions of diversity of runoff formation factors and physiographic conditions is a rather difficult task.

The development of the hydrological network in the Republic of Kazakhstan over the past century is characterized by several key stages (kazhydromet.kz):

1) 1917...1981 – consistent increase in the number of hydrological stations (HS), reaching a maximum in 1981 (506 HS);

2) 1981...2000 – sharp decrease in the number of HSs to 165;

3) 2001...2023 – significant increase in the number of HSs to 377. In 2023, the hydrological network of RSE «Kazhydromet» includes 377 observation stations for water regime characteristics, including 329 river stations, 38 lake stations and 10 marine stations (kazhydromet.kz).

The organization of the existing hydrological network in the Republic of Kazakhstan was based on the geographic-hydrological method with the basin principal approach, developed in the State Institution «State Hydrometeorological Institute» in 1933 (Glushkov V.G., 1993). The density of placement of hydrological observation network on the territory of Kazakhstan was increased taking into account the demands of the economy and scientific research during the following years with maximum possible consideration of natural and anthropogenic factors affecting the obtaining of reliable data on the hydrological regime of water bodies with an error sufficient for scientific and practical purposes.

The research work carried out by the Federal State Budgetary Institution «State Hydrological Institute» on optimization of the state hydrological observation network of Kazakhstan using the technology «HydroNet-2011» on the basis of data, operating and closed 511 stations showed that the highest density of the hydrological network is characterized by annual and maximum runoff. Correlation analysis showed that its highest averaged values for active and closed posts are 0.50 for annual, 0.41 and 0.29 for maximum, 0.50 and 0.30 for minimum summer, 0.20 and 0.12 for minimum winter water discharges, respectively. In turn, the result of representativeness in terms of coverage of the territory by the data of operating posts was 53-58 % for annual, maximum, minimum summer discharge (Razrabotka meropriyatij po optimizacii..., 2011), which indicates the need for further development of the observation network.

The network of reference hydrological stations in a significant part of Kazakhstan has been functioning for a long enough period of time, which makes it possible to generally assess the dynamics of water resources in time and space, and to build and analyze effective links. Despite this, the location and density of the hydrological network of RSE «Kazhydromet» do not satisfy the requirements of spatial linear interpolation of the characteristics of the hydrological regime. This does not allow estimating river flows in unstudied catchments with the accuracy required for practice (Razrabotka meropriyatij po optimizacii..., 2011).

In this regard, at present, within the framework of the activities of the hydrometeorological service of Kazakhstan and in accordance with WMO recommendations, the task of substantiating the principles of optimal location of the observation group and calculation of the necessary minimum network for the territory of the Republic has become acute.

The minimum network is the optimal number of HSs that will avoid serious deficiencies in water resources accounting and exploitation at the level corresponding to the overall level of economic development of the country (Guide to hydrological practices..., 1994, Rukovodstvo po gidrologicheskoj praktike..., 2020).

The minimum network should provide a basis for further expansion to respond to specific goals and needs in the future (Guide to hydrological practices..., 1994, Rukovodstvo po gidrologicheskoj praktike..., 2020).

MATERIALS AND METHODS

The Republic of Kazakhstan with an area of 2 million 724.9 thousand square kilometers is located on the Eurasian continent (between 55° 26’ and 40° 56’ north latitude and between 45° 27’ and 87° 18’ east longitude) (HeritageNet, 2023). Most of the country’s territory is made up of deserts - 44% and semi-deserts - 14%. Steppes occupy 26% of the area of Kazakhstan, forests - 5.5%. There are 8.5 thousand rivers and 48 thousand large and small lakes in the country (Oficial’nyj sajt gosudarstvennyh organov RK, 2024; Oficial’nyj sajt Prezidenta RK, 2024).

The territory of the Republic of Kazakhstan is divided into 8 water management basins (WMBs), which are located in different physiographic zones: Aral-Syrdariya, Zhaiyk-Caspian, Nura-Sarysu, Tobyl-Torgai, Esil, Ertis, Balkash-Alakol, Shu-Talas (fig. 1) (Problemy v oblasti upravleniya..., 2024).

The calculation of the minimum number of the hydrological network is based on the methodology proposed by WMO, which provides for the calculation of the number of hydrological stations depending on climatic conditions

and the size of the area of territory (in km²) (Table 1) served by one hydrological station) (Razrabotka meropriyatij po optimizacii..., 2011; Guide to hydrological practices..., 1994).

Table 1

Normative area recommended by WMO (km² per station) (Rukovodstvo po..., 2020)

Physical-geographical areas	Mountainous	Plains* (in-country)	Hilly/Rough	Arid **
Area per 1 HS	1000	1875	1875	20000

*Note: *steppe and forest-steppe zones, **desert and semi-desert zones*

In this regard, their physiographic regions (mountainous, forest-steppe, steppe, semi-desert and desert), as well as the presence or absence of natural water bodies (Figure 1) were determined for 8 WMBs on the basis of the map of landscape zones and the map of hydrographic network of the National Atlas of the Republic of Kazakhstan (Nacional'nyj atlas RK, 2006).

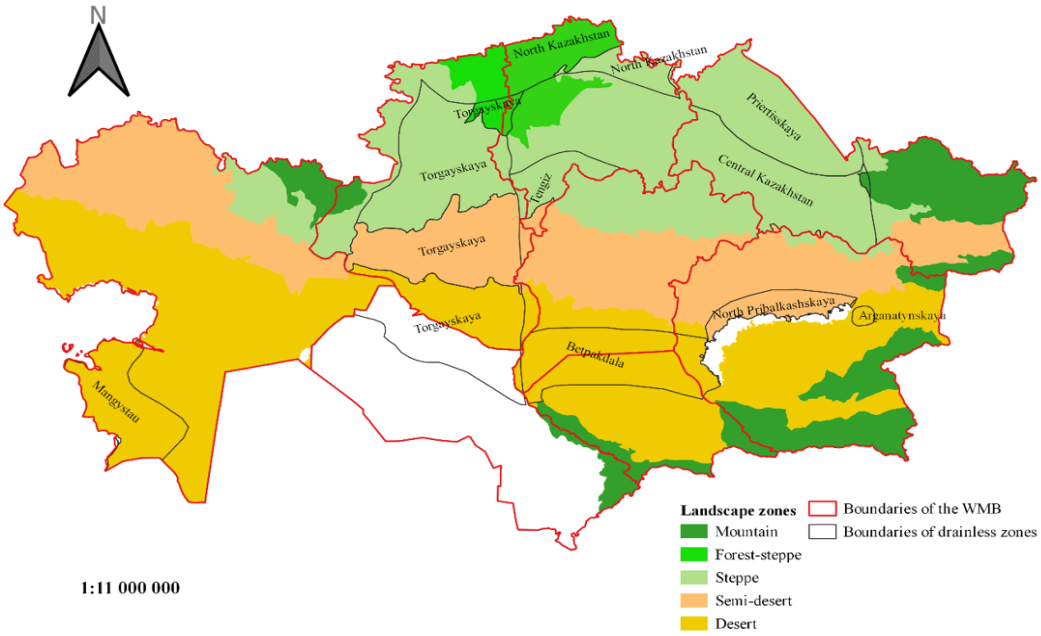


Fig. 1. *Map of landscape zones of Kazakhstan (signed drainage-free areas)*

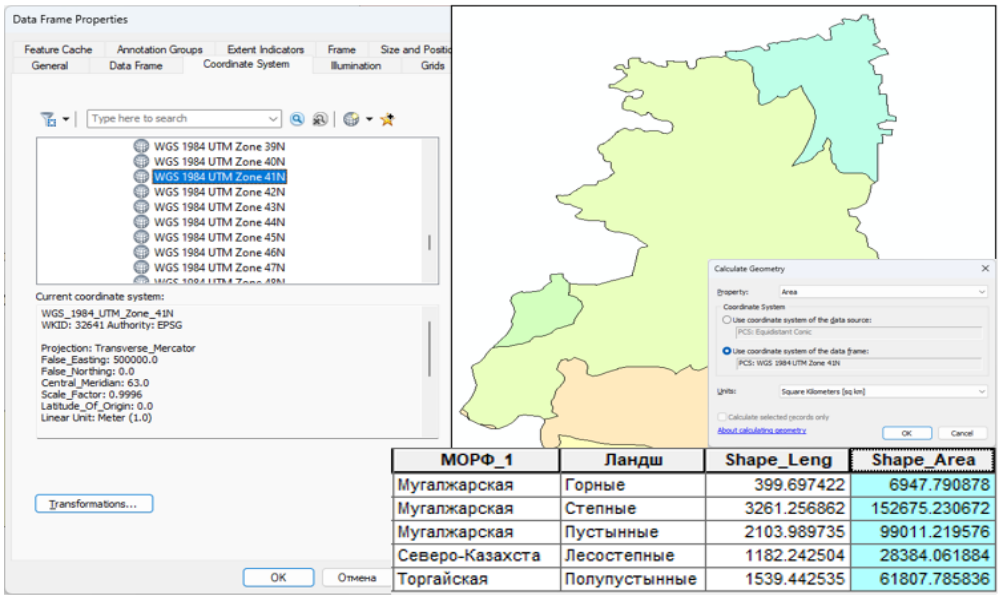
Having defined the geographical areas and hydrographic network for all WMBs, and taking into account the WMO recommended network density corresponding to different landscapes, a equation was derived to calculate the minimum required number of hydrological stations for the entire territory of Kazakhstan (1):

$$N_{min}^{WMB} = \frac{F_{moun}}{f_{moun}} + \frac{F_{f-st} - F_{DF\,f-st}}{f_{f-st}} + \frac{F_{st} - F_{DF\,st}}{f_{st}} + \frac{F_{semi-des} - F_{DF\,semi-des}}{f_{semi-des}} + \frac{F_{des} - F_{DF-des}}{f_{des}} \quad (1)$$

N_{min}^{WMB} – minimum required number of hydrological stations for one WHB; Areas of landscape zones: F_{moun} – mountainous area; F_{f-st} – forest-steppe area; F_{st} – steppe area; F_{s-d} – semi-desert; F_{des} – desert area; Areas of drainage-free landscape zones: $F_{DF\,f-st}$ – forest-steppe; $F_{DF\,st}$ – steppe area; $F_{DF\,semi-des}$ – semi-desert; $F_{DF\,des}$ – desert area; Normative area covered by one hydrological monitoring observation station according to WMO recommendations: f_{moun} – in the mountainous area, km²; f_{f-st} – in the forest-steppe area, km²; f_{st} – in the steppe area, km²; $f_{semi-des}$ – in the semi-desert area, km²; f_{des} – in the desert area, km².

The total area and the area of drainage-free areas (DFA) of different physiographic areas were calculated using ArcGIS tool (Table 2). To

calculate them, the «Calculate Geometry» tool is used to access the geometric properties of spatial objects in the map layer. This tool calculates coordinate, length and area values. For each WMB, we used their respective Universal Transverse Mercator (UTM) projection zones, from UTM-39 to UTM-44 (Figure 2).



МОРФ_1	Ландш	Shape_Leng	Shape_Area
Мугалжарская	Горные	399.697422	6947.790878
Мугалжарская	Степные	3261.256862	152675.230672
Мугалжарская	Пустынные	2103.989735	99011.219576
Северо-Казахста	Лесостепные	1182.242504	28384.061884
Торгайская	Полупустынные	1539.442535	61807.785836

Fig. 2. Calculation of areas of physiographic areas of the Tobyl-Torgai WHB

Table 2

Areas of landscape zones by WMB, km²

Water management basin	Mountainous	Forest-steppe		Steppe		Semi-desert		Deserted		General	Drainage-free
	general	general	drainage-free	general	drainage-free	general	drainage-free	general	drainage-free		
Aral-Syrdariya	15703							272746	58341	288449	58341
Balkash-Alakol	91542			9857	7926	127586	27650	151526	20215	380511	55791
Ertis	91491			218398	203976	37644				347532	203976
Zhaiyk-Caspian	20454			37564		193750		375345	70069	627114	70069
Esil		70609	47097	148234	31411	3946	3946			222788	82453
Nura-Sarysu				88928		118274		67362	43126	274564	43126
Shu-Talas	28685							125167	103077	153852	103077
Tobol-Torgai	6948	28384	7213	152675	113011	99011		61808	61808	348826	182031

RESEARCH RESULTS

Based on the WMO recommendation, separate calculations of the minimum number of hydrological posts for physiographic areas within each catchment basin have been carried out.

In accordance with the landscape map of the Republic of Kazakhstan (RK) (Nacional'nyj atlas RK, 2006) for the territory of each WMB, the areas of physiographic areas that are common in the region under consideration are defined. The areas of drainage-free zones, which do not possess permanent watercourses, were calculated, the values of which are presented in table 2. As can be seen, the areas of drainage-free zones on the territory of Kazakhstan are 798865 km², including Central Kazakhstan steppe zone (118 597 km²), Central Kazakhstan semi-desert zone (2141 km²), Central Kazakhstan desert zone (3690 km²), North-Pribalkash semi-desert zone (27650 km²), Betpakdala desert zone (159 425 km²), Arganatinsk desert zone (3303 km²), Priertis steppe zone (93305 km²), North Kazakhstan forest-steppe zone (43815 km²), North Kazakhstan steppe zone (25914 km²), Torgai forest-steppe zone (10,495 km²), Torgai steppe zone (118,508 km²), Torgai desert zone (120,149 km²), Tengiz semi-desert zone (1805 km²), Mangistau desert zone (70069 km²) and others.

The area values of the drainage-free zones were subtracted from the total area.

As a result, the equations for calculating the minimum required number of hydrological posts for the WMB is as follows:

for Aral-Syrdariya WMB:

$$N_{min}^{\text{Aral–Syrdarya}} = \frac{15703_{moun}}{1000_{moun}} + \frac{272746_{des} - 58341_{DF\,des}}{20000_{des}} = 26$$

for Balkash-Alakol WMB:

$$N_{min}^{Balkash-Alakol} = \frac{91542_{moun}}{1000_{moun}} + \frac{9857_{st} - 7926_{DF\,st}}{1875_{st}} + \frac{127586_{semi-des} - 27650_{DF\,semi-des}}{20000_{semi-des}} + \frac{159501_{des} - 20215_{DF\,des}}{20000_{des}} = 104$$

for Ertis WMB:

$$N_{min}^{\text{Ертис}} = \frac{91491_{moun}}{1000_{moun}} + \frac{218398_{\text{ст}} - 203976_{\text{бс ст}}}{1875_{\text{ст}}} + \frac{37644_{\text{ппуст}}}{20000_{\text{пупуст}}} = 101$$

for Zhaiyk-Caspian WMB:

$$N_{min}^{Zhaiyk-Caspian} = \frac{20454_{moun}}{1000_{moun}} + \frac{37564_{st}}{1875_{st}} + \frac{193750_{semi-des}}{20000_{semi-des}} + \frac{375345_{des} - 70069_{DF\,des}}{20000_{des}} = 65$$

for Esil WMB:

$$N_{min}^{Esil} = \frac{70609_{f-st} - 47097_{DF\,f-st}}{1875_{f-st}} + \frac{156035_{st} - 31411_{DF\,st}}{1875_{st}} + \frac{3946_{semi-des} - 3946_{DF\,semi-des}}{20000_{semi-des}} = 75$$

for Nura-Sarysu WMB:

$$N_{min}^{Nura-Sarysu} = \frac{88928_{st}}{1875_{st}} + \frac{118274_{semi-des}}{20000_{semi-des}} + \frac{70907_{des} - 43126_{DF\,des}}{20000_{des}} = 55$$

for Shu-Talas WMB:

$$N_{min}^{Shu-Talas} = \frac{28685_{moun}}{1000_{moun}} + \frac{131754_{des} - 103077_{DF\,des}}{20000_{des}} = 30$$

for Tobyl-Torgai WMB:

$$N_{min}^{Tobyl-Torgai} = \frac{6948_{moun}}{1000_{moun}} + \frac{28384_{f-st} - 7213_{DF\,f-st}}{1875_{f-st}} + \frac{160710_{st} - 113011_{st}}{1875_{st}} + \frac{99011_{semi-des}}{20000_{semi-des}} + \frac{61808_{des} - 61808_{DF\,des}}{20000_{des}} = 44$$

The total minimum number of hydrological posts for the whole country is determined by summing up the minimum required number of hydrological stations for each of the catchment areas:

$$N_{min}^{RK} = 26_{min}^{Aral-Syrdarya} + 104_{min}^{Balkash-Alakol} + 101_{min}^{Ertis} + 65_{min}^{Zhaiyk-Caspian} + 75_{min}^{Esil} + 55_{min}^{Nura-Sarysu} + 30_{min}^{Shu-Talas} + 44_{min}^{Tobyl-Torgai} = 500$$

CONCLUSION

Using the methodology for calculating the minimum number of hydrological observation network HSs recommended by WMO, formulas for calculating the number of observation stations for the RK territories by water basins were developed.

As a result of the calculation for Kazakhstan, the recommended minimum number of hydrological stations on rivers is 500 with 329 available. It is necessary to increase the number of hydrological observation stations on the rivers, for example, from 10 Shu-Talas to 44 Ertis. Also according to the obtained results, the Aral-Syrdarya basin corresponds to the calculated minimum number.

At the same time, the analysis conducted in (Razrabotka meropriyatij po optimizacii..., 2011) for 226 open and 285 closed stations, total number of 511, corresponding to such conditions as the observation period for each series of more than 20 years, the period of joint observations between each station and all other stations in the area of more than 7 years, indicates a significant improvement in the hydrological study of the territory of the Republic of Kazakhstan, with the appropriate number of observation stations of elements of the water regime of water bodies..

Major improvements are expected in the collection of annual water flow data, including the ability to use interpolation techniques for rivers that have previously remained unstudied.

Maximum runoff, minimum summer runoff and minimum winter runoff have large natural variability, in contrast to annual runoff, and in part

of the territory the errors in calculating these characteristics using interpolation will still be high.

Based on the above-mentioned, it can be concluded that the minimum number of 500 gauging stations is insufficient for a deeper assessment of the characteristics of the water regime of rivers and, in general, water resources of individual regions. The efficiency of water resources management increases with the quality of monitoring and the number of observation stations, which allows obtaining reliable information on changes in the elements of the water balance of the republic's water resources. In this connection, it is necessary to continue studies on optimization and improvement of the hydrological observation network corresponding to the plans of economic development of the Republic.

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РАСЧЕТ МИНИМАЛЬНОГО КОЛИЧЕСТВА ГИДРОЛОГИЧЕСКИХ ПУНКТОВ НАБЛЮДЕНИЯ СЕТИ ГИДРОМЕТЕОРОЛОГИЧЕСКОЙ СЛУЖБЫ В РЕСПУБЛИКЕ КАЗАХСТАН

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В работе дана оценка количества гидрологических пунктов наблюдения с учетом минимальной плотности их размещения и в соответствии с рекомендациями ВМО. Территории Казахстана, отличаясь большим разнообразием климатических условий и природных зон, имеют разную обводненность и требуют отдельных норм при организации пунктов наблюдения в речных бассейнах, известных водохозяйственных регионов республики. Для каждого речного бассейна рассчитаны площади физико-географических районов, относящихся к разным природным зонам, в том числе бессточные области, которые составили более 700 тыс км². В результате расчета общее минимальное количество гидрологических постов для всей страны обосновано составило 500. Однако, с ростом экономики данное количество необходимо увеличивать в соответствии с разработанными принципами и территориальным районированием для более эффективного управления водными ресурсами.

Ключевые слова: гидрологическая сеть, водохозяйственный бассейн, ландшафт, наблюдения

ҚАЗАҚСТАН РЕСПУБЛИКАСЫНДАҒЫ ГИДРОМЕТЕОРОЛОГИЯЛЫҚ ҚЫЗМЕТ ЖЕЛІСІНІҢ ГИДРОЛОГИЯЛЫҚ БАҚЫЛАУ ПУНКТТЕРІНІҢ МИНИМАЛДЫ САНЫН ЕСЕПТЕУ

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Жұмыста гидрологиялық бақылау пункттерінің саны оларды орналастырудың минималды тығыздығын ескере отырып және ДМҰ ұсынымдарына сәйкес бағаланады. Климаттық жағдайлар мен табиғи аймақтардың алуан түрлілігімен ерекшеленетін Қазақстан аумақтарының сулануы әртүрлі және республиканың белгілі су шаруашылығы өңірлеріндегі өзен бассейндеріндегі бақылау пункттерін ұйымдастыру кезінде жекелеген нормаларды талап етеді. Әр өзен бассейні үшін әр түрлі табиғи аймақтарға жататын физикалық-географиялық аудандардың, соның ішінде 700 мың км²-ден астам ағынсыз аймақтардың аудандары есептелді. Есептеу нәтижесінде бүкіл ел үшін гидрологиялық бекеттердің жалпы минималды саны 500-ді құрады. Алайда, экономиканың өсуімен бұл мөлшерді су ресурстарын тиімді басқару үшін әзірленген қағидаттарға және аумақтық аудандастыруға сәйкес ұлғайту қажет.

Түйін сөздер: гидрологиялық желі, су шаруашылық бассейні, ландшафт, бақылау

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Serikbai Nurgalym – creating software, conducting statistical analysis, conducting a research, resources, preparing and editing the text, visualization;
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