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Scientific article

METHOD OF ASSESSING INDIRECT ANTHROPOGENIC LOADS IN RIVER BASIN CATCHMENT AREAS USING THE GENERALIZED HARRINGTON DESIRABILITY FUNCTION

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KEY WORDS

river basin catchment, assessment of indirect anthropogenic loads, generalization of the Harrington function, assessment scale

ABSTRACT

The subject of the study is the processes of assessing indirect anthropogenic loads in the catchment area of river basins by applying a point scale of desirability using the method of constructing a generalized indicator. The purpose of the article is to develop a methodological approach to assessing indirect anthropogenic loads in the catchment area of river basins based on the generalized Harrington desirability function. The objective of the article is to analyze existing approaches to assessing indirect anthropogenic loads in the catchment area of river basins, methodological aspects of using the generalized desirability index and justification for using the generalized Harrington function. The developed method for assessing indirect anthropogenic loads on the territory of the catchment area of river basins makes it possible to avoid an additive integral assessment indicator and can be used to solve many problems, and is also applicable for territorial organization and management of water use.

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1. INTRODUCTION

In the natural system, the activity of the catchment area of river basins is defined as a spatial basis for population and nature management, performing environment-forming and ecological functions. However, over several millennia, with the emergence and formation of populations in the catchment areas of river basins with different conditions and directions of economic and political development, their attitude to water has changed. In modern conditions, river basins perform not only a runoff-forming function, but also a function of recycling return waters formed in the process of municipal and domestic water supply, industrial and agricultural water consumption, which has become the reason for manifestations of anthropogenic load, the danger of which has led to irreversible changes in the ecosystem of the watershed.

In this regard, in modern water management studies there are various approaches to assessing anthropogenic impacts on the catchment area of river basins, where the entire set of anthropogenic impacts is conventionally divided into direct (organized), caused by water intake and wastewater discharge, and indirect (mediated), associated with economic activity on the catchment area of river basins.

There are a large number of works on the assessment of direct anthropogenic impact within the catchment areas of river basins using integral criteria, among which the works of should be highlighted M. Falkenmark [1], P. Raskin, P. Gleick, G. Pontius, K. Strzepek [2], V.I. Danilov-Danilyan , K.S. Losev [3], I.A. Shiklomanova [4], A. Boulay, J. Bare, L. Benini, M. Berger, I. Klemmayer, M. Lathulliere, P. Loubet, A. Manzardo, M. Margni and B. Ridoutt [5], Zh.S. Mustafayev [6], in which an attempt is made to assess the water availability of the territory and the population using the Falkenmark indexer ($\boldsymbol{CMF}$),

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sustainability index ($\boldsymbol{SI}$), water resources utilization coefficient ($\boldsymbol{WRUF}$), indicator of specific water availability of the population ($\boldsymbol{SWSP}$), indicator of specific water availability of the territory ($\boldsymbol{SWST}$), indicator of «water stress» ($\boldsymbol{IWS}$) and complex indicator of specific water availability of the catchment area of river basins ($\boldsymbol{CISWS}$).

One of the fundamental directions for assessing direct anthropogenic impact within the catchment areas of river basins is the direction developed in the works of J. Hernández-Bedolla, A. Solera, J. Paredes - Arquiola, M. Pedro-Monzonís, J. Andreu , S. T. Sánchez - Quispe [7], Simon Damkjaer, Richard Taylor [8], M. Karamouz, P. Mohammadpour, D. Mahmoodzadeh [9], R. L. Oxley, L.W. Mays [10], N. N. Kourgialas, G. P. Karatzas, Z. Dokou, A. Kokorogiannis [11], Felipe I. Arreguin-Cortes, J. Raul Saavedra-Horita, J. Manuel Rodriguez-Varela, Velitchko G. Tzatchkov, Petronilo E. Cortez-Mejia, Oscar J. Llaguno-Guilberto, Arizabeth Sainos-Candelario [12], B. D. Moyle, D. B. Weaver, S. Gössling, C. L. McLennan, A. Hadinejad [13], O. Salehie, T. B. Ismail, S. Shahid, M. M. Hamed, P. Chinnasamy & X. Wang [14], G. Sabia, D. Mattioli, M. Langone, L. Petta [15], M. Jiang, Z. Wu, X. Guo, H. Wang, Y. Zhou [16], Zh. Mustafayev, A. Medeu, I. Skorintseva, T. Bassova, G. Aldazhanova [17], Zh. Mustafayev, I. Skorintseva, A. Toletayev, G. Aldazhanova, A. Kuderin [18] related to improving the modification of sustainability indicators for integrated water resources management based on the ecological, environmental and hydrological integrity of river basins swimming pools.

When solving multi-criteria problems, indirect anthropogenic impacts on the catchment areas of river basins associated with the economic activities of the population, industry and agricultural enterprises, including agriculture and livestock farming, which have become an integral part of water resource assessments using various methods for constructing a generalized indicator, are also taken into account.

For the first time, the basic principles of assessing the indirect anthropogenic load on landscapes, based on environmental geography, were formulated by A. G. Isachenko [19], where the quantitative measure of impact on them is determined in natural absolute or relative (specific) indicators, within the framework of the density of industrial production, emissions of harmful substances into the atmosphere, public roads, arable land, livestock per unit area of agricultural land and population, and for each of the indicators an eight-point conditional scale of intensity of anthropogenic load was adopted.

One of the fundamental directions for assessing the level of total anthropogenic load on the catchment areas of river basins is the direction developed in the works of I. D. Rybkin, N. V. Stoyashchev, N. Yu. Kurepin [20] of the Institute of Water and Environmental Problems of the Siberian Branch of the Russian Academy of Sciences in the conditions of Siberian regions for two groups of indicators of direct (immediate) and indirect (mediated) impact, based on the methodology of A. G. Isachenko [19], using such indicators as population density in the catchment area, industrial production density (according to S. V. Odesser [21]), that is, the volume of industrial output in thousands of dollars per 1 km^2 of production, as well as agricultural development, including plowing (%) and livestock load (the number of conventional heads of cattle (cattle) per 1 km^2), which were tested in the basins of the Ob, Irtysh, Yenisei and Angara rivers.

The total indirect anthropogenic load was defined as the arithmetic mean of the demographic, industrial and agricultural points, with a distinction made between agricultural (plowing) and livestock loads [20], where the intensity of the load for each of the indicators was adopted as an eight-point conditional scale based on the methodology of A. G. Isachenko [19]:

- population density (people/km^2): low or absent (1 point) - 0.00, very low (2 points) - <0.10, low (3 points) - 0.20...1.00, low (4 points) - 1.10...5.00, average (5 points) - 5.51...10.00, high (6 points) - 10.10...25.00, high (7 points) - 25.10...50.00 and very high (8 points) - >50.00;

- industrial production density (thousand dollars/km^2): insignificant or absent (1 point) - 0.00, very low (2 points) - <0.35, low (3 points) - 0.36...3.50, low (4 points) - 3.60...35.00, average (5 points) - 36.00...105.00, high (6 points) - 106.00...140.00, high (7 points) - 141.00...170.00 and very high (8 points) - >170.00;

- ploughing (%): low or absent (1 point) - 0.00, very low (2 points) - <0.10, low (3 points) - 0.20...1.00, reduced (4 points) - 1.10...5.00, average (5 points) - 5.10...15.00, increased (6 points) - 15.10...40.00, high (7 points) - 40.10...60.00 and very high (8 points) - >60.00;

- livestock load (conventional heads of cattle/km^2): insignificant or absent (1 point) - 0.00, very low (2 points) - <0.10, low (3 points) - 0.20...1.00, reduced (4 points) - 1.10...2.00, average (5 points) - 2.10...3.00, increased (6 points) - 3.10...6.00, high (7 points) - 6.10...10.00 and very high (8 points) - >10.00.

Thus, when assessing the anthropogenic load on the catchment areas of river basins, A. G. Isachenko [19], I. D. Rybkina, N. V. Stoyashcheva [20] mainly used a linear point scale of varying length, and as a function of the generalized indicator they used an additive convolution, which allows comparing different alternatives based on objective data and taking into account their interaction with each other.

Based on the development and deepening of natural scientific ideas about mathematical modeling of multifactorial technological processes, which include the assessment of indirect anthropogenic loads on the catchment area of river basins, Zh.S. Mustafayev [22; 23] developed a mathematical model that allows aggregating many factors into a single indicator, based on the geometric mean equation, which is one of the classical Pythagorean means, and has the following form:

$$AIAI_i = AII_i = \sqrt{\Pi_{i=1}^{n} AAC_i} = \sqrt{\Pi_{i=1}^{n}[1 - exp(-AIDC_i)]}, \quad (1)$$

where $\boldsymbol{AIAI_i}$is the indicator of aggregation of types of anthropogenic loads or $\boldsymbol{AII_i}$is the indicator of total anthropogenic loads; $\boldsymbol{AAC_i = 1 - exp(-AIDC_i)}$ - relative values of the level of anthropogenic loads or the coefficient of anthropogenic activity.

Application of the geometric mean equation, which is one of the modifications of the desirability function Harrington, for solving multi-criteria problems in the context of assessing indirect anthropogenic loads on the territory of the catchment area of river basins, makes it possible to theoretically substantiate the path of modernization of this methodological approach.

Thus, the conducted comprehensive studies show that one of the tools for creating a mathematical model for assessing indirect anthropogenic loads on the territory of the catchment area of river basins is the so-called desirability function proposed by E. Harrington [24], which allows for bringing the real values of their parameters into a single dimensionless numerical scale with fixed boundaries from 0 to 1 and the subsequent mapping of private quantitative scales into generalized scales of quality criteria.

The **aim of the study** is to improve the methods for assessing the types of indirect anthropogenic loads on the territory of the catchment area of river basins based on the multidimensional Harrington desirability function, based on multiparameter data on economic activity in spatial and temporal aspects.

2. MATERIALS AND METHODS

The methodological basis of the research is the materialistic theory of scientific knowledge, which is the basis modeling, analysis and synthesis based on long-term information and analytical materials on economic activities in the catchment area of river basins.

The methodological basis of the study is the generalized desirability function of Harrington [24], which has become a useful tool in the field of nature management [22, 23], engineering [25], chemistry [26], ecology [27], geography [28], economics [29], management [30], and, where various methods of constructing a generalized indicator are used to solve multi-criteria problems, that is, the Euclidean concept, linear and nonlinear objective function in optimization problems.

To solve this problematic task, a technique of qualimetric evaluation of optimization indicators can be used, using the mathematical apparatus of the generalized Harrington desirability function, where each parameter has its own physical meaning and its own dimension. The construction of this function is based on the transformation of abstract values of particular indicators of various physical nature into a single dimensionless numerical desirability scale with fixed boundaries from 0 to 1, allowing them to be presented in the form of a generalized scale of quality criteria in a strict interval range: from 0 to 0.20 («very bad»); from 0.20 to 0.37 («bad»); from 0.37 to 0.63 («satisfactory»); from 0.63 to 0.80 («good»); from 0.80 to 1.00 («excellent») [7].

3. RESULTS AND DISCUSSION

Quantitative assessment of indirect anthropogenic load on the territory of river basin catchment areas, as a spatial basis for population and nature management, is a necessary element in the development of a monitoring system and territorial organization of water use.

To assess the indirect anthropogenic load on the catchment area of river basins, one can use the properties of the Harrington desirability function, which to some extent models the activity of river basins as a spatial basis for population and nature management.

Based on the proposed methodological approach, based on the generalized desirability function of E. Harrington [24], where average geometric desirabilities were used to assess indirect anthropogenic loads on the catchment area of river basins, according to the following mathematical expression:

$$AIAI_i = AII_i = \sqrt[n]{\Pi_{i=1}^{n} AAC_i^{\alpha}}, \qquad (2)$$

where $\boldsymbol{AIAI_i}$ is a generalized indicator of a comprehensive assessment of anthropogenic load or impact in the catchment areas of river basins; $\boldsymbol{AAC_i}$is the desirability function for types of anthropogenic load in the catchment areas of river basins; $\boldsymbol{\alpha}$ is the significance or weighting coefficient of types of indirect anthropogenic loads; $\boldsymbol{n}$is the number of types of indirect anthropogenic loads.

The generalized indicator of the integrated assessment of anthropogenic load or impact on the catchment areas of river basins ($\boldsymbol{AIAI_i}$) is defined as the geometric mean desirability indicator ($\boldsymbol{AAC_i}$), for each assessment indicator, within the framework of population size, volume of industrial production, area of agricultural land and number of domestic animals.

The totality of anthropogenic load and impact on the catchment area of river basins ($\boldsymbol{AIAI_i}$), obtained on the basis of aggregation of many factors into a single indicator in relative values ($\boldsymbol{AAC_i}$), which is based on the desirability function, where, with one-sided or two-sided restrictions, is determined by the following exponential equation:

$$AAC_i = 1 - \exp(-MDCIAL_i), \qquad (3)$$

$$AAC_i = 1 - [exp - \exp(-MDCIAL_i)], \qquad (4)$$

where $\boldsymbol{MDCIAL_i}$ – coded value of the density of types of indirect anthropogenic loads.

Basically, the tendency of changes in indirect anthropogenic loads in the catchment area of river basins occurs with a unidirectional change in the indicator, that is, the limitation is one-sided, and then it is advisable to use unilateral restrictions.

The density of demographic ($\boldsymbol{PD_i}$), industrial ($\boldsymbol{ID_i}$) and agricultural, with a distinction made between agricultural (plowed) ($\boldsymbol{DAI_i}$) and livestock ($\boldsymbol{DIF_i}$) loads, is determined by the following expression:

$$PD_i = PS_i/AAD_i;\ ID_i = IPV_i/AAD_i; \tag{5}$$

$$DAL_i = AAI_i/AAD_i;\ DIF_i = CNI_{i_i}/AAD_i, \tag{6}$$

where $\boldsymbol{PS}$ is the population size, people; $\boldsymbol{IPV_i}$ - volume of industrial production, thousand dollars; $\boldsymbol{AAI}$- area of agricultural land (plowed area), km^2; $\boldsymbol{CNI_i}$- conditional number of domestic animals, converted to the number of cattle in administrative divisions, conventional heads; $\boldsymbol{AAD_i}$- area of administrative divisions, km^2;

The coded value of the density of types of indirect anthropogenic loads ($\boldsymbol{MDCIAL_i}$), characterizing the relationship of the time-varying density of population ($\boldsymbol{PD_i}$), industrial ($\boldsymbol{ID_i}$) and agricultural, with a distinction made between agricultural (plowing) ($\boldsymbol{DAL_i}$) and livestock ($\boldsymbol{DIF_i}$) loads to its optimal value, is determined by the following expression:

$$MCPD_i = PD_i/ODDA_i;\ MCPD_i = ID_i/ODI_i; \tag{7}$$

$$MCALD_i = DAL_i/ODAL_i;\ MCDDA_i = DIF_i/ODDA_i, \tag{8}$$

where $\boldsymbol{MCPD_i}$ is the modular coefficient of population density; $\boldsymbol{ODDA_i}$ - optimal population density; $\boldsymbol{MCPD_i}$ - modular density coefficient of industry; $\boldsymbol{ODI_i}$ - optimal industrial density; $\boldsymbol{MCALD_i}$ - modular coefficient of agricultural land density; $\boldsymbol{ODAL_i}$ - optimal density of agricultural land; $\boldsymbol{MCDDA_i}$ - modular density coefficient of domestic animals; $\boldsymbol{ODDA_i}$ - optimal density of domestic animals.

At the same time, the scientific substantiation of the optimal density by types of anthropogenic load in the system «population - industry - agricultural land – livestock» is one of the important environmental indicators, in which the catchment area of river basins retains the ability to function almost indefinitely without abrupt changes in their structure. If we consider the scale of intensity of anthropogenic load on catchment areas of river basins proposed by I. D. Rybkina and N. V. Stoyashcheva [31], within the framework of the criteria «insignificant (absent) - very low - low - reduced - average - increased - high - very high», we can see that the permissible measure of deviation from the normal state is within the limits of «reduced-average», which enables the system to exist stably in these conditions and which can be eliminated by the system itself over time:

$$ODDA_i = (PD_{mini} + PD_{maxi})/2; ODI_i = (ID_{mini} + IDmax_i)/2; \tag{9}$$

$$ODAL_i = (\ DAL_{mini} + DAL_{maxi})/2;\ ODDA_i = (DIF_{mini} + DIF_{maxi})/2, \tag{10}$$

where $\boldsymbol{PD_{mini}}$ - is the minimum population density, people/km^2; $\boldsymbol{PD_{maxi}}$- is the maximum population density, people/km^2; $\boldsymbol{PD_{mini}}$- is the minimum density of industrial production, thousand dollars/km^2; $\boldsymbol{PD_{maxi}}$ - is the maximum density of industrial production, thousand dollars/km^2; $\boldsymbol{DAL_{mini}}$- minimum density of agricultural land, %; $\boldsymbol{DAL_{maxi}}$ - maximum density of agricultural land, %; $\boldsymbol{DIF_{mini}}$- minimum density of domestic animals, conventional heads/ km^2; $\boldsymbol{DIF_{maxi}}$ - domestic animals, conventional heads/ km^2.

Harrington desirability function is based on the idea of transforming natural values of particular responses into a dimensionless scale of desirability or preference for assessing indirect anthropogenic loads on the catchment area of river basins (Table 1).

The proposed methodological approach to assessing indirect anthropogenic loads on the catchment area of river basins, based on the generalized desirability function of E. Harrington, allows assessing and comparing anthropogenic loads from linear-area sources of indirect anthropogenic loads in spatial and temporal aspects using digital technology.

Table 1

Number of intervals of the Harrington desirability scale for assessing indirect anthropogenic loads in the catchment area of river basins

Desirability	Intervals of values of the desirability function	Desirability	Intervals of values of the desirability function
Minor	0	Average	0.475...0.743
Very low	<0.024	Increased	0.744...0.941
Low	0.025...0.095	Tall	0.942...0.988
Reduced	0.096...0.474	Very high	0.989...1.00

4. CONCLUSION

The application of the generalized Harrington desirability function as an integral indicator for assessing indirect anthropogenic loads on the catchment area of river basins is considered, which makes it possible to avoid an additive integral assessment indicator.

The proposed methodological aspects of assessing indirect anthropogenic loads on the territory of the catchment area of river basins, based on the Harrington desirability function, make it possible to take into account the multifactorial nature of the controlled parameters, without being tied to specific units of measurement, and to reflect the result in the form of a single numerical value with a linguistic assessment.

The model for assessing indirect anthropogenic loads on the territory of river basin catchments, firstly, reflects general trend modeling of a technological process based on digital technology, secondly, the adaptability of the model to specific task scenarios is becoming a key area of research, thirdly, it is a universal tool, where for each indicator the assessment is maximally consistent with the objective relations to which the corresponding indicator is subordinated, and can be used to solve many problems, and is also applicable for territorial organization and management of water use .

AUTHORS' CONTRIBUTION

Conceptualization – ZhM; resources - KM; formal analysis – KM ; methodology - ZhM; software - KM; supervision - ZhM; visualization – KM; writing -original draft preparation – ZhM; writing—review and editing - KM .

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ХАРРИНГТОННЫҢ ЖАЛПЫ ҚАЛАУЛЫҚ ФУНКЦИЯСЫН ПАЙДАЛАНУ АРҚЫЛЫ ӨЗЕННІҢ СУЖИНАУ АЛАБЫНЫҢ ЖАНАМА ТЕХНОГЕНДІК ЖҮКТЕМЕЛЕРІН БАҒАЛАУ ӘДІСІ

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ТҮЙІН СӨЗДЕР

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АБСТРАКТ

Зерттеуде пәні - жалпылама көрсеткішті құру әдісін пайдалана отырып, мақсатты баллдық бірлігін қолдану арқылы өзен алаптарының су жинау алабы аумағында жанама техногенндік жүктемелерді бағалау жүйесін құру.Мақаланың мақсаты - Харрингтонның жалпыламалық қолайлылық функциясының негізінде өзен алаптарының су жинау алаңына түсетін жанама техногендік жүктемелерді бағалаудың әдіснамалық тәсілін әзірлеу.Мақаланың мақсаты өзен алаптарының су жинау алаңына жанама техногендік жүктемелерді бағалаудың қолданыстағы тәсілдерін, жалпыламалық қолайлылық көрсеткішін пайдаланудың әдістемелік негізін және Харрингтон жалпыламалық функциясын пайдаланудың негіздемесін талдау болып табылады. Өзен алаптарының су жинау алабы аумағында жанама техногендік жүктемелерді бағалауға арналып әзірленген әдісі қосымша интегралдық бағалау көрсеткішін қарастырмауға мүмкіндік береді және көптеген мәселелерді шешу үшін пайдалануға болады, сонымен қатар суды пайдалануды аумақтық ұйымдастыру және басқару үшін де қолдануға болады.

МЕТОДИКА ОЦЕНКИ КОСВЕННЫХ АНТРОПОГЕННЫХ НАГРУЗОК НА ТЕРРИТОРИЯХ ВОДОСБОРА РЕЧНЫХ БАССЕЙНОВ С ИСПОЛЬЗОВАНИЕМ ОБОБЩЕННОЙ ФУНКЦИИ ЖЕЛАТЕЛЬНОСТИ ХАРРИНГТОНА

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АБСТРАКТ

Предметом исследования являются процессы оценки косвенных антропогенных нагрузок на территории водосбора речных бассейнов путем применения балльной шкалы желательности с использованием метода построения обобщенного показателя. Целью статьи является на основе обобщенной функции желательности Харрингтона разработать методический подход к оценке косвенных антропогенных нагрузок на территории водосбора речных бассейнов. Задача статьи состоит в анализе существующих подходов к оценке косвенных антропогенных нагрузок на территории водосбора речных бассейнов, методических аспектов использования обобщенного показателя желательности и обоснование использования обобщенной функции Харрингтона. Разработанный метод оценки косвенных антропогенных нагрузок на территории водосбора речных бассейнов дает возможность избежать аддитивного интегрального показателя оценки и может быть использована для решения многих задач, а также применима и для территориальной организации и управления водопользованием.