ISSN 1070-3632, Russian Journal of General Chemistry, 2011, Vol. 81, No. 13, pp. 2694–2704. © Pleiades Publishing Ltd., 2011.
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Harrington's Desirability Function for Natural Water Quality Assessment

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Received June 22, 2011

Abstract—The theoretical analysis of the possible application of Harrington's desirability function for the state of natural ecosystems assessment was made. It was shown that the desirability function with double limiting should be used for water quality objects assessment. The function makes it possible to eliminate arbitrary rule while the number of quality classes at different ways of optimization (typification, classification etc.) of information was determined. This resulted in mathematically valid limitation to the maximum 5 types of the first level. It was underlined that if even one particular response or a particular desirability function does not satisfy the requirements, the general estimation should be considered unsatisfactory, in spite of the fact that the other parameters (properties) of the studied system were satisfied. The tables were made which gave the possibility to assess the up-to-date state of the Rybinsk Reservoir ecosystem according to the content of nutrients and organic matters on the basis of future mesurments. The seasonal pattern of hydrophysical, hydrochemical and hydrobiological processes should be taken into account in order to make more accurate the water quality assessment at the concrete time in the definite site in the Rybinsk Reservoir area.
DOI: 10.1134/S1070363211130111

INTRODUCTION

There are many approaches to assess water quality of natural hydroecosystem — hydrophysical, hydrochemical, hydrobiological and environmental [1–6]. Each of them relies on its own system of indicators. Systematization of chemical ingredients and quality of the surface waters show that they can be subdivided into natural and relative. The data obtained by direct measurement are regarded to be natural, while the results of converting the analytical data in one way or another are relative [7]. Natural indicators (perhaps, better to say analytical ones) possessing the highest degree of specificity are not always assist in direct assessment of the degree of pollution or water quality, since the latter are fundamentally ambiguous and substantially dependent on water users, i.e. relationship of an individual to facility. Not only people but also the mass of all other living beings, including aquatic organisms are meant by water users. Experimentally obtained metrics against which evaluations are carried out, is a characteristic feature of the direct use of natural indicators in studies of natural ecosystems. The most developed and often used in the hydrochemistry is a measure of a maximum permissible concentration (MPC) of a component in the aquatic environment, according to which the normalization is carried out. However, the MPC system has long and reasonably been criticized [2, 6]. In particular, MPC has the following limitations:

1. non–applicable to all water reservoirs in different geographical zones, for different water masses of the same water body and even for different seasons. This is especially true for the components that form the structure of water reservoirs and watercourses in natural conditions;

2. restriction of components is only from above, i.e. implicitly is assumed that if the waterbody contains distilled water, it is considered to be ideal;

3. there are serious problems with the logical inter-

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pretation of the experimentally obtained quantitative values into qualitative scale, in connection with which the authors offer a variety of 3 to 12 gradations of linguistic (verbal) assessments of the typology of the first level [8].

It is stated that "the drawbacks of the MPC concept question the viability of existing environmental control, i.e. diagnostic methods, valuation, forecasting, management, and in addition the economic problems, legal and social instruments of environmental activities" [3]. Thus, the inadequacy of use in daily practice the previously proposed integrated water quality indicators, such as CISE (a composite index of state of the environment), WPI (water pollution index), SCIWP (specific combinatorial index of water pollution), and similar indices based on the concept of MPC are pointed out.

In recent years different types of desirability function (DF) to assess water quality by hydro–physical, hydro–chemical and hydro–biological indicators came into use [1, 3].

The aim of the present study is the formation of universal tables to estimate the level of environmental safety and the nutrient contents of organic matter in the Rybinsk Reservoir on the basis of DF proposed by Harrington [9, 10].

THEORETICAL PART

It was already mentioned that the MPC has long and reasonably been subjected to argued criticism. On the other hand, criticism was valid with respect to the major components of salt composition, most of the nutrients, content of natural organic and inorganic substances. The developed MPS system, despite its criticism, yet seems to remain enough unique to assess the suitability of water for different uses concerning such pollutants as xenobiotics. Intensively developing in recent years, the concept of biotic control over the natural environment on the basis of environmentally acceptable level (EAL) [3] has not gained wide application yet. Hereafter, elements and compounds that determine the quality of water not exposed to significant pollution are focused on. The use of DF is particularly preferable for the analysis of such components, although it can be also used for analysis of anthropogenic compounds.

All the basic membership functions are given in [11], which in this case, both in form and meaning are actually equivalent to DF. The authors emphasized that in solving multicriterion problems and the construction of a generalized index by one of the most convenient ways of presenting information is a Harrington's generalized function of desirability. This function exhibiting remarkable properties is used to solve the widest range of tasks in various fields of knowledge: from private practical applications to general classification problems of entire sciences, geography, economics, ecology, etc. Being the following words "Harrington desirability function" just typed in any searching system in Internet, over a thousand sites on the same topic appear.

Particular Harrington desirability function (d_i) is given by:

$$d_i = exp\ (–exp\ \{–x_i\}),\ 0 \le d_i \le 1,$$

where x_i is coded value of i–index, i.e. its value in the representative scale.

This function provides the possibility of obtaining values of desirability in four ways [3]:

1. by indicating the most desirable parameter values based on the type of empirical functions of distribution;

2. by the left and right edges of the desired range of values;

3. by the left edge and the location of the optimum desirability;

4. by the right edge and the location of the optimum desirability.

The construction of DF in the empirical distribution function being excluded, which can be extremely varied depending on the nature of the task, the remaining forms of Harrington's desirability functions can be displayed on a single graph (Fig. 1).

The curves show such useful properties as continuity, monotonic intensity and smoothness. The Harrington's function demonstrates some critical points, i.e. the points of inflection, which have the following ordinates 0.8, 0.63, 0.37, 0.2 [12]. Two specific points of minima and maxima of the function should be added. The latter is the natural point of inflection at the ordinate of 1.0 for the most common Harrington's DF, i.e. a function with a two–way restriction on the optimization parameter. Together, they set the standard graduations of desirability: "very well" (1.00–0.80), "well" (0.80–0.63), "satisfactory" (0.63–0.37), "bad" (0.37–0.20) "very bad" (0.20–0.00). Thus, inflection points of DF can be taken as class boundaries and thereby eliminate the outrage

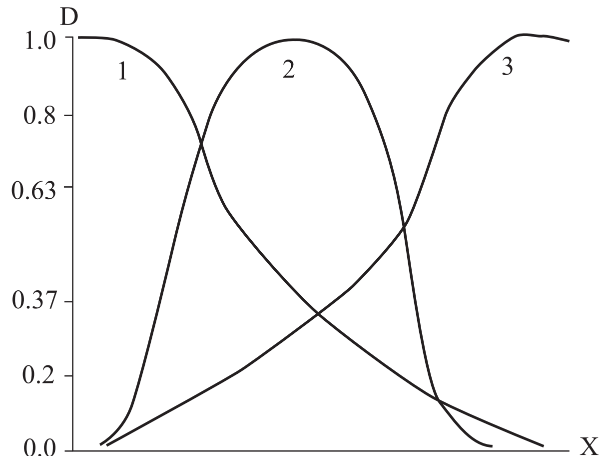

Fig. 1. Desirability function for unilateral (1, 3) and bilateral (2) restrictions on the optimization parameter.

Table 1. Psychophysical Harrington's scale (first three columns) with the authors' addition

Linguistic evaluation	Intervals of DF values		Linguistic evaluation (quality)
Very well	1.00–0.80	1.00–0.63	Good
Well	0.80–0.63		
Satisfied	0.63–0.37	0.63–0.37	Average
Bad	0.37–0.20	0.37–0.00	Low
Very bad	0.20–0.00		

mistakes at estimation of class number at different ways of their optimization (typing, classification, etc.).

Desirability function possessing values in the range (0–1) classifies the conversion of the quantity value of a specific indicator into the assessment of the desirability (preference) of a certain condition of evaluated subject (in our case, environmental safety of the contents of some chemical components). Among the specific ways to implement the desirability function for the corresponding estimation, a psychophysical scale of Harrington is chosen providing universal application (Table 1). The numerical system of preferences given in this table is a dimensionless.

The scale serves to establish the correspondence between physical and psychological parameters. All the coded values of measured parameters which classify the operation of the investigated subject are regarded as physical, and a purely subjective assessment of a researcher, which on a scale of desirability can be expressed in terms of scores or through linguistic psychological evaluation system. In the absence of a sufficient array of reliable experimental data for quite a rough estimation (first approximation) construction of a three–interval quality scale is advisable (Table 1, columns 3 and 4).

To use this method in the evaluation and selection of the optimal solution, it is firstly necessary to develop the mechanisms of transformation of the measured quantitative values into the levels of desirability according to Harrington's scale. This mechanism should establish the lower and upper boundaries of the initial data corresponding to the region as "satisfactory" and higher. The choice of these boundaries is quite arbitrary and to a large extent depends on the skills of researchers. The choice for variable BOD_5 is given in [3]. The cited authors note that "in this example the value X_{left}= 1.953 is taken arbitrarily. The value X_{right} = 5.122 is taken for the right boundary in accordance with the 6-point classifier for water quality in hydro-chemical indicators

[6]." The value of the right boundary corresponds to the safe class of water quality by BOD_5. These assumptions can serve as illustration, but for a correct description of the ecosystem are insufficient.

Mechanism of transformation of the measured quantitative values into the levels of the desirability by Harrington's scale in order to establish the ecological wellbeing of water body, should be based on fairly strict mathematical background.

Since the Harrington's function is symmetrical [12, 13], the optimal value of the descriptor is equal to the arithmetic middling. Therefore, in the given, and in general case, the total arbitrary choice of bilateral borders can be to a large extent eliminated by using the arithmetical average (X_{aver}) according to their standard, or root-mean-square deviation [14], the most common indicator of scatter values of the random variable over its ensemble expectation. The root-mean-square deviation (σ) plays an important role in the analysis of variation distribution series. It is appropriate at this point to recall that in a normal or symmetrical distribution, the following relationship between the root-mean-square deviation and number of observations presents:

1. Within (X_{aver} + 1σ) is 0.683, or 68.3% of the total number of observations;

2. Within (X_{aver} + 2σ) — 0.954, or 95.4%;

3. Within (X_{aver} + 3σ) — 0.997, or 99.7% of the number of observations.

In practice, deviations that exceed 3σ are very rare, so such deviations are usually regarded as the maximum possible (three sigma rule) provided the value is true, rather than received by processing the samples.

The root-mean-square deviation as well as the mean deviation show the absolute deviation of the measured values from the arithmetical average, i.e. how on the average specific variants of a descriptor deviates from the mean observation. They are expressed in the same units as the descriptors (in mg l^{-1}, m, gr., etc.).

Then, that being said, to assess the wellbeing of water body according to a particular initial index (in presence of a sufficient representative number of measurements) for the right border (X_{right}) corresponding to the "satisfactory" interval or higher, the arithmetical average plus the root-mean-square (X_{aver} + σ) can be taken, while for the left (X_{left}) corresponding to the arithmetical average minus the root-mean-square (X_{aver} – σ). If the range of desired results is determined by the values of X_{right} and X_{left}, then to construct the Harrington's DF at the location of left and right borders, an auxiliary correlation function of "x" must be introduced:

$$\rightarrow z(x) = (2x - X_{left} - X_{right}) / (X_{right} - X_{left}).$$

Then the desirability of each component at a point "X" is calculated by the formula [3]:

$$di = \exp(-z^2(X_i)).$$

All data element been converted into their dimensionless desirabilities, the construction of common estimation parameter starts, i.e. generalized Harrington's desirability function. The generalized DF is an abstract construction. It should be noted that selection of the function depends on a number of human factors which certainly exist, since the choice is carried out by a person who makes a decision. One of the most often practised ways of solving a problem is presenting it as a geometric mean of the partial desirabilities:

$$\sqrt[n]{\prod_{i=1}^{n} d_i} = \sqrt[n]{d_1 d_2 d_3 ... d_n},$$

where d_i is a partial desirability function, n is number of indicators.

An extreme manifestation of this integrated approach to assess the status of aquatic ecosystems is the plotting of the average compound out of a wide variety of indicators generalized by the subject areas of science. For example, $D = \sqrt{d_{chem} d_{biol}}$, while "for a complete description of the ecological state of hydrobiocenosis d_{biol} the data on key environmental groups, i.e. phytoplankton, zooplanctone, periphyton, zoobenthos, nekton, bacterioplankton, macrophytes, etc." should be obtained [1]. Considering every environmental hydrobiocenosis group is characterized by a large number of its peculiar parameters, the simultaneous receipt of such information is extremely difficult, if not impossible.

The selection of the average power mean is known to have a significant impact on its numerical quantity. The geometric middling gives the most accurate result of averaging, if the task is to find that trait value which is equidistant from both of maximum and minimum values of the trait.

In some cases while constructing a generalized DF, the arithmetic middling might be used, since it strongly depends on a relatively small number of values of small particular functions.

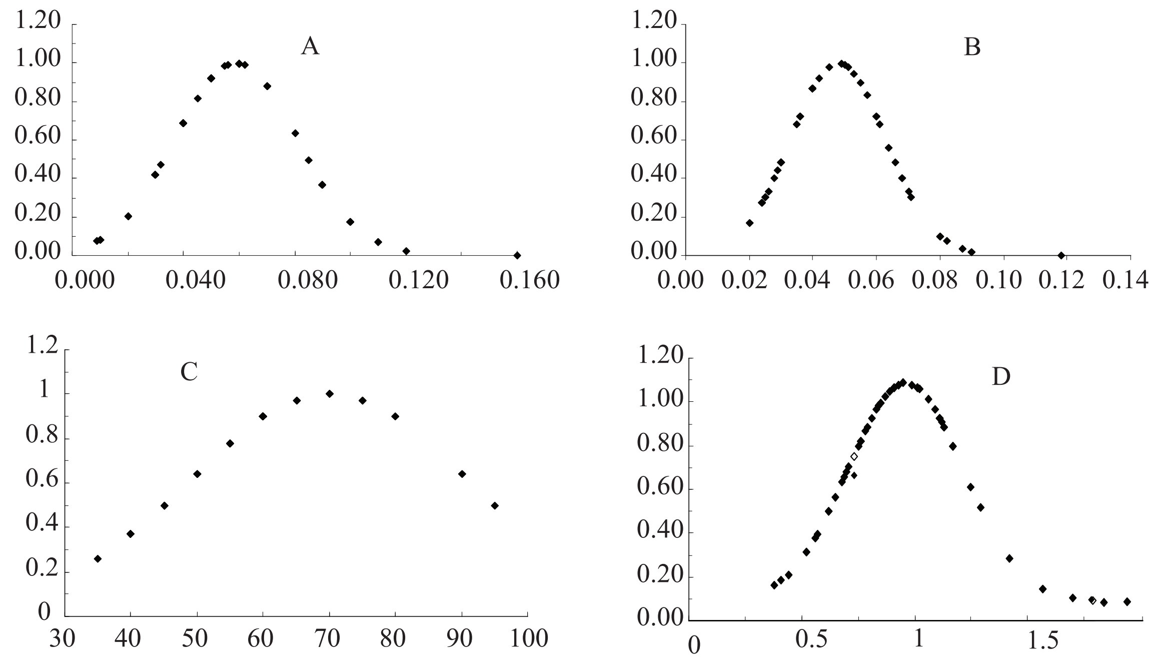

Fig. 2. Desirability function for some variables based on the information of the left and right boundaries of the optimal range. A is an ammonia at the station Sredny Dvor, mg l^{-1}, B is a total phosphorus at the station Izmailovo, mg l^{-1}, C is a colour of water at the station Navolok, degrees of the chromium–cobalt scale, D is a total nitrogen at the station Mologa, mg l^{-1}.

The most commonly used method of setting a generalized DF (by average compound) is as follows: if at least one of the variables $d_i = 0$, then $D = 0$. To eliminate the zero values different approaches can be used, for example, a "conditional" boundaries technique that differs from the real boundaries to a certain percentage in each case. In general, the generalized DF is very sensitive to small values of partial desires. It follows inevitably that if at least one partial response does not satisfy the requirements, then no matter how good the other parameters (properties) of the system are, the overall evaluation should be considered unsatisfactory. This statement will be valid even if generalized DF calculated on a set of indicators is in the range of acceptable values. A very good example of the discussed problem is given in [13]. "Suppose, an applicant has received on various subjects the following examination results: 5, 5, 5, 5, 2 in various subjects. It's perfectly clear that the overall result is not satisfactory, while an applicant has not even participated in the contest. At the same time the amount of points is very high (equal or higher than 22) and exceeds another applicant's results, who has obtained a 4 in all subjects. In fact, even an applicant who has received a 3 in all subjects (the smallest positive result), is in a better position, while he is participating in the competition and retains some chance of success".

Similar situations can often happen at environmental assessments of aquatic ecosystems. For example, some natural water in all indices except one (high radiation) can be characterized as having excellent quality. The generalized DF (average compound of partial functions) in this hypothetical example can also denote its high quality. The same assessment applies to the water when so-called complex, integrated and another indicators are used. However, the expert system for assessing will inevitably notify it as extremely hazardous for most types of water use. In general, if at least one of the dozens of commonly accepted indicators of water quality indicates its unsuitability for one or another type of water use, it must be regarded as of poor quality. Hence, the results of water quality assessments solely on the basis of broad generalizations of its partial indices must be published with great care. Assessment of water quality in like manner should always be accompanied by noting the specific indicators by which it can be regarded as poor. Therefore, in addition to the generalized DF, it is useful to indicate partial DF, according to which a water body or a system must be considered beyond the established or accepted standards. Otherwise, the absence or lack of such information may have a negative reflection on administrative management documents in dealing with the use of specific water bodies for a particular type of water use, as well as interference or noninterference in the natural course of development (restoration or reconstruction) of water (and other) ecosystems.

Stated approaches in analyzing the data obtained at the Rybinsk Reservoir, one of the largest reservoirs of the Volga-Kama cascade.

EXPERIMENTAL PART

The data has been collected over many years at six standard stations of the Rybinsk reservoir and can characterize separate stretches of water, as well as the entire water body in general. The scheme of the stations is given in the monograph [15]. Tests on the content of ammonium, nitrites, nitrates, phosphates and BOD_5 are carried out on board of the expedition ship in a specially equipped laboratory. The values of chemical oxygen demand (COD), contents of total nitrogen and phosphorus forms, organic carbon (C_{org}) are set in a coastal laboratory after being preserved by sulfuric acid and stored in the refrigerator for 3 days before analysis. The standard certified methods of analysis are used. The initial series of observations are varied according to different indicators from 40 to 60 units and cover the period from 2001 to 2009 year. Mathematical processing of tests results is conducted using the Harrington's DF, which allows passing to dimensionless quantities and evaluate the results on a single scale.

The selected optimal range of values makes it possible to reflect visually a specific situation in the reservoir. Graphics for a number of indicators of biogenic elements and organic matter are presented as examples (Fig. 2).

For the variable COD the corresponding graphic is given above [16].

Based on these graphs, the ranges of parameters for different states of the ecosystems were calculated. The tables, which using the results of subsequent measurements allow immediately assess the current state of the ecosystem on nutrient elements and organic matter are given (Tables 2 and 3).

The full tables in accordance with the psychophysical Harrington's scale are given. The tables produced using the above mentioned three-interval scale might be enough to evaluate natural water quality. The corresponding reduced tables for the discussed indicators of the Rybinsk reservoir can be easy made on the basis of the data from Tables 2 and 3. It should be noted that a significant amount of experimental data falls into the category of "bad" or "very bad". This situation is unlikely to be absolute true. Indeed, the original block of experimental data refers to the entire period of open water from early spring until late autumn. The optimal values of the measured parameters for different hydrological phases in the life of the reservoir vary greatly. The situation in the summer low-flow period is not adequate to the situation of the spring floods period to say nothing about winter and autumn periods. So, the next stage in discussing the ecosystem assessment should be based on the specified hydrological factors. This needs greater amount of experimental data for specific seasons (separately spring, summer, autumn and winter) in order to avoid unproved conclusions about the water quality of natural water bodies at any given time.

To avoid possible contradictions in the assessment of water quality of the Rybinsk reservoir at the given moment by integrated indicators, in particular, the generalized Harrington's DF or by differential parameters, such as partial DF, it is quite reasonable to make a table based on long-term observations for specific components of the DF of the ecosystems, taking into account the seasonality with relying further estimations on them.

The presented research eliminates many drawbacks of the above mentioned approaches in the assessment of ecosystems. Similar psychophysical tables can also be made for hydro-physical and hydro-biological parameters. They will be of fundamental importance in normal and pathological assessment of ecosystems.

CONCLUSION

Theoretical analysis of the Harrington's desirability function used to assess the state of ecosystems shows that it lets eliminate the arbitrariness in determining the total number of quality classes for different ways of optimization (typing, classification, etc.). For this purpose the natural properties of this function are used, i.e. four points of inflection in conjunction with its extremes, which lead to limitation of the number of classes to five.

For a number of specific cases, the three-interval psychophysical scale for assessment the water quality, instead of the original five-interval scale is proposed to be used.

The desirability function with a two-way restriction is exclusively shown to be used for evaluation of water quality. The use of one-way functions can lead to paradoxical results. For example, the most environmentally-friendly body of water should be considered a reservoir with distilled water.

It is shown that if only one particular response or partial desirability function does not satisfy the require-

Table 2. Differential standards for nutrient contents (mg L^{-1} of nitrogen and phosphorus, respectively) at standard stations of Rybinsk reservoir

Estimation	Intervals of DF values	NO_3^-	NO_2^-	NH_4^+	N_{tot}	PO_4^{3-}	P_{tot}
Koprino							
Very well	1–0.8	0.14–0.35	0.006–0.012	0.07–0.12	0.87–1.15	0.035–0.056	0.045–0.068
Well	0.8–0.63	0.08–0.14 0.35–0.40	0.004–0.006 0.012–0.014	0.06–0.07 0.12–0.14	0.79–0.87 1.15–1.22	0.030–0.035 0.056–0.061	0.040–0.045 0.068–0.073
Satisfied	0.63–0.37	0.02–0.08 0.40–0.45	0.002–0.004 0.014–0.016	0.04–0.06 0.14–0.15	0.70–0.79 1.22–1.32	0.025–0.035 0.061–0.068	0.030–0.040 0.073–0.083
Bad	0.37–0.20	<0.02 0.45–0.52	0–0.002 0.016–0.018	0.03–0.04 0.15–0.16	0.60–0.70 1.32–1.40	0.019–0.025 0.068–0.072	0.025–0.030 0.072–0.086
Very bad	0.20–0.0	>0.52	0 >0.018	<0.03 >0.16	<0.6 >1.40	<0.019 >0.072	<0.025 >0.086
Mologa							
Very well	1–0.8	—	0.003–0.007	0.06–0.08	0.79–1.13	0.016–0.034	0.041–0.074
Well	0.8–0.63	—	0.002–0.003 0.007–0.008	0.05–0.06 0.08–0.09	0.71–0.79 1.13–1.20	0.013–0.016 0.034–0.038	0.034–0.041 0.074–0.082
Satisfied	0.63–0.37	—	0.001–0.002 0.008–0.009	0.04–0.05 0.09–0.10	0.59–0.71 1.20–1.30	0.007–0.013 0.038–0.043	0.024–0.034 0.082–0.090
Bad	0.37–0.20	—	0–0.001 0.009–0.01	0.03–0.04 0.10–0.11	0.52–0.59 1.30–1.42	0.003–0.007 0.043–0.049	0.013–0.024 0.090–0.100
Very bad	0.20–0.0	—	0 >0.01	<0.03 >0.11	<0.52 >1.42	<0.003 >0.049	<0.013 >0.100
Navolok							
Very well	1–0.8	0.080–0.200	0.002–0.006	0.05–0.07	0.65–1.22	0.010–0.020	0.034–0.055
Well	0.8–0.63	0.052–0.080 0.200–0.220	0.001–0.002 0.006–0.007	0.04–0.05 0.07–0.08	0.48–0.65 1.22–1.38	0.008–0.010 0.020–0.023	0.022–0.029 0.055–0.060
Satisfied	0.63–0.37	0.020–0.052 0.220–0.250	0–0.001 0.007–0.008	0.03–0.04 0.08–0.09	0.34–0.48 1.38–1.47	0.005–0.008 0.023–0.026	0.029–0.034 0.060–0.068
Bad	0.37–0.20	0.002–0.020 0.250–0.290	0.008–0.009	0.02–0.03 0.09–0.10	0.30–0.34 1.47–1.70	0.003–0.005 0.026–0.028	0.018–0.029 0.068–0.072
Very bad	0.20–0.0	0–0.002 >0.290	>0.009	<0.02 >0.10	<0.30 >1.70	<0.003 >0.028	<0.018 >0.072

Table 2. (Contd.)

Estimation	Intervals of DF values	NO_3^-	NO_2^-	NH_4^+	N_{tot}	PO_4^{3-}	P_{tot}
Ismailovo							
Very well	1–0.8	0.084–0.190	0.002–0.006	0.04–0.07	0.71–1.02	0.009–0.018	0.038–0.058
Well	0.8–0.63	0.060–0.084 0.19–0.022	0.001–0.007	0.03–0.08 0.08–0.09	0.64–0.71 1.02–1.18	0.006–0.009 0.018–0.020	0.031–0.038 0.059–0.062
Satisfied	0.63–0.37	0.030–0.060 0.022–0.024	0–0.001 0.007–0.008	0.02–0.03 0.09–0.10	0.54–0.64 1.18–1.25	0.004–0.006 0.020–0.022	0.028–0.031 0.062–0.068
Bad	0.37–0.20	0.005–0.030 0.240–0.280	0.008–0.009	0.01–0.02 0.10–0.11	0.45–0.54 1.25–1.35	0–0.004 0.022–0.025	0.020–0.028 0.068–0.072
Very bad	0.20–0.0	<0.005 >0.280	>0.009	<0.01 >0.11	<0.45 >1.35	>0.025	<0.020 >0.072
Srednii dvor							
Very well	1–0.8	0.070–0.18	0.002–0.006	0.05–0.07	0.71–1.12	0.010–0.018	0.037–0.061
Well	0.8–0.63	0.050–0.070 0.180–0.210	0.001–0.002 0.006–0.007	0.04–0.05 0.07–0.08	0.62–0.71 1.12–1.20	0.008–0.010 0.018–0.021	0.032–0.037 0.061–0.067
Satisfied	0.63–0.37	0.016–0.050 0.210–0.240	0–0.001 0.007–0.008	0.03–0.04 0.08–0.09	0.50–0.62 1.20–1.32	0.005–0.008 0.021–0.023	0.024–0.032 0.067–0.075
Bad	0.37–0.20	0–0.016 0.240–0.270	0.008–0.009	0.02–0.03 0.09–0.10	0.38–0.50 1.32–1.50	0.003–0.005 0.023–0.025	0.020–0.024 0.075–0.080
Very bad	0.20–0.0	>0.270	>0.009	<0.02 >0.10	<0.38 >1.50	<0.003 >0.025	<0.020 >0.024
Brejitovo							
Very well	1–0.8	0.063–0.170	0.003–0.007	0.05–0.07	0.81–1.08	0.010–0.022	0.044–0.060
Well	0.8–0.63	0.041–0.063 0.170–0.190	0.002–0.003 0.007–0.008	0.04–0.05 0.07–0.08	0.73–0.81 1.08–1.14	0.008–0.010 0.022–0.024	0.040–0.044 0.060–0.065
Satisfied	0.63–0.37	0.002–0.041 0.190–0.210	0.001–0.002 0.008–0.009	0.03–0.04 0.08–0.09	0.66–0.73 1.14–1.22	0.004–0.008 0.024–0.028	0.034–0.040 0.065–0.070
Bad	0.37–0.20	0–0.002 0.210–0.260	0–0.001 0.009–0.010	0.02–0.03 0.09–0.10	0.58–0.66 1.22–1.30	0.002–0.004 0.028–0.032	0.029–0.034 0.070–0.076
Very bad	0.20–0.0	>0.260	>0.010	<0.02 >0.10	<0.58 >1.30	<0.002 >0.032	<0.029 >0.076

Table 3. The values of the desirability function indicators of organic matter in the standard stations of Rybinsk reservoir

Estimation	Intervals of DF values	MPC_5	COD	Colour	C_{org}
Navolok					
Very well	1.0–0.8	1.07–1.45	33.8–39.4	50–65	12.9–15.0
Well	0.8–0.63	0.98–1.07 1.45–1.52	32.7–33.8 39.4–40.7	46–50 65–68	12.4–12.9 15.0–15.6
Satisfied	0.63–0.37	0.85–0.98 1.52–1.65	31.5–32.7 40.7–42.2	40–46 68–73	11.8–12.4 15.6–16.3
Bad	0.37–0.20	0.75–0.85 1.65–1.80	29.5–31.5 42.2–43.5	38–40 73–75	11.2–11.8 16.3–16.8
Very bad	0.20–0.0	<0.75 >1.80	<29.5 >43.5	<38 >75	<11.2 >16.8
Koprino					
Very well	1.0–0.8	1.12–1.50	30.6–35.0	50–63	11.2–13.2
Well	0.8–0.63	1.03–1.12 1.50–1.63	29.7–30.6 35.0–36.3	46–50 63–67	10.9–11.2 13.2–13.6
Satisfied	0.63–0.37	0.89–1.03 1.63–1.80	28.1–29.7 36.3–37.4	42–46 67–72	10.0–10.9 13.6–14.4
Bad	0.37–0.20	0.72–0.89 1.80–1.90	26.8–28.1 37.4–38.8	38–42 72–75	9.5–10.0 14.4–14.9
Very bad	0.20–0.0	<0.72 >1.90	<26.8 >38.8	<38 >75	<9.5 >14.9
Mologa					
Very well	1.0–0.8	1.17–1.98	31.6–36.3	49–61	12.3–15.0
Well	0.8–0.63	0.99–1.17 1.98–2.15	30.8–31.6 36.3–38.0	47–49 61–64	11.8–12.3 15.0–15.5
Satisfied	0.63–0.37	0.73–0.99 2.15–2.42	29.0–30.8 38.0–38.9	42–47 64–68	10.8–11.8 15.5–16.3
Bad	0.37–0.20	0.50–0.73 2.42–2.70	27.6–29.0 38.9–40.1	40–42	10.1–10.8 16.3–17.1
Very bad	0.20–0.0	<0.50 >2.70	<27.6 >40.1	<40 >68	<10.1 >17.1

Table 3. (Contd.)

Estimation	Intervals of DF values	MPC_5	COD	Colour	C_{org}
		Ismailovo			
Very well	1.0–0.8	1.05–1.52	34.3–39.2	49–64	12.6–14.9
Well	0.8–0.63	0.93–1.05 1.52–1.62	33.1–34.3 39.2–40.2	46–49 64–68	12.2–12.6 14.9–15.4
Satisfied	0.63–0.37	0.78–0.93 1.62–1.80	31.5–33.1 40.2–42.0	43–46 68–72	11.6–12.2 15.4–16.0
Bad	0.37–0.20	0.62–0.78 1.80–1.93	30.0–31.5 42.0–43.3	36–43 72–78	10.9–11.6 16.0–16.7
Very bad	0.20–0.0	<0.62 >1.93	<30.0 >43.3	<36 >78	<10.9 >16.7
		Srednii dvor			
Very well	1–0.8	1.05–1.59	33.9–39.2	49–65	12.8–15.1
Well	0.8–0.63	0.92–1.05 1.59–1.72	32.6–33.9 39.2–40.8	46–49 65–69	12.2–12.8 15.1–15.5
Satisfied	0.63–0.37	0.71–0.92 1.72–1.87	30.7–39.2 40.8–42.6	42–46 69–74	11.4–12.2 15.5–16.4
Bad	0.37–0.20	0.59–0.71 1.87–2.01	28.9–30.7 42.6–44.8	36–42 74–79	10.6–11.4 16.4–17.0
Very bad	0.20–0.0	<0.59 >2.01	<28.9 >44.8	<36 >79	<10.6 >17.0
		Brejitovo			
Very well	1.0–0.8	1.24–1.64	34.9–40.4	55–74	13.4–16.1
Satisfied	0.63–0.37	0.94–1.13 1.82–1.97	31.8–33.7 41.6–43.5	44–51 79–86	11.8–12.7 16.8–17.7
Bad	0.37–0.20	0.83–0.94 1.97–2.10	30.4–31.8 43.5–45.1	39–44 86–90	11.0–11.8 17.7–18.5
Very bad	0.20–0.0	<0.83 >2.10	<30.4 >45.1	<39 >90	<11.0 >18.5

ments, then, no matter how good the other parameters (properties) of the system are, the overall assessment should be considered unsatisfactory. Therefore, a method of presentation of environmental information using the generalized Harrington's desirability function or any of the integral indicators should be interpreted with caution. To avoid gross errors in making administrative decisions based on the composite indices, additional specific factors in the produced researches that do not conform to the established standards should be noted.

Tables allowing the assessment of the current state of the ecosystem of Rybinsk Reservoir in the biogenic elements and organic matter on the basis of subsequent measurements have been made.

The necessity of taking into account seasonal hydro-physical, hydro-chemical and hydro-biological processes for more accurate assessment of water quality at a particular time in a given area at the Rybinsk reservoir is noted.

The authors believe that this research will eliminate many drawbacks of previously proposed approaches to the assessment of ecosystems based on the integral characteristics.

This work was supported by RFBR grant 10-05-00593.

REFERENSES

1. Gelashvili, D.B., and Karandashova, A.A., *Izv. Samar. nauch. tsentr. RAN*, 2002, vol. 2, no. 4, p. 252.
2. Dmitriev, V.V. and Frumin, G.T., *Ecologicheskoe normirovanie i ustoichivost prirodnich ekosistem* (Ecological Rationing and Stability of Natural Systems), SPb.:Nauka, 2004.
3. Levich, A.P., Bulgakov, N.G. and Maksimov, V.N., *Teoreticheskie i metodicheskie osnovi technologii regionalnogo kontrolya prirodnoi sredi po dannim ekologicheskogo monitoringa* (Theoretical and Methodical Bases of Technology of the Regional Control for the Environment According to Ecological Monitoring), M: NIA Priroda, 2004.
4. Maksimova, M.P. and Brusilovsky, S.A., *Ecological systems and devices,* 2000, no. 6, p. 25.
5. Nikanorov, A.M., *Nauchnie osnovi monitoringa kachestva vod* (Scientific Fundamentals of Monitoring of Quality of Waters), SPb.: Gidrometeoizdat, 2005.
6. Oksijuk, O.P, Zhukinsky V.N, Braginskij, L.P., Linnik, G. N, Kuzmenko, M. I. and Klenus, V.G., *Hydrobiol. J.*, 1993, vol. 29, no. 4, p. 62.
7. Nikanorov, A.M. and Yemelyanov V.P., *Mater. Sci. Conf. "Modern problems of hydrochemistry and formation of quality of waters"*, Rostov-on-Don, 2010, p. 45.
8. Kitaev, S.P., *Osnovi limnologii dlya gidrobiologov i ichtiologov* (Bases Limnology for Hydrobiologists and Ichthyologists), Petrozavodsk, the Karelian centre of Science of the Russian Academy of Sciences, 2007.
9. Harrington, E.C., *Industr. Control*, 1965, vol. 21, no. 10, p. 494.
10. Adler, J.P., Markova, E.V. and Granovsky, J.V., *Planirovanie experimenta pri poiske optimalnich uslovii* (Planning of Experiment by Search of Optimum Conditions). M:, Nauka, 1976.
11. Altunin, A.E. and Semuchin, M.V., *Modeli i algoritmi prinatya reshenii v nechetkich usloviyach* (Models and Algorithms of Decision-Making in Indistinct Conditions), Tyumen: Publishing house Tyumen Gos. Univ., 2000.
12. Dmitriev, V.V., *http://www.terrahumana.ru/arhiv/09_04/09_04_16.pdf.*
13. Egorshin, A.A. and Malyarez, L.M., *The Scientific and Technical Collection "Municipal Services of Cities"*, 2004, no. 50, p. 54.
14. Magomadov, V.D., *Extended Abstr. Cand. Ski. (Econ) Dissert.*, M:, 2008.
15. *Rybinskoe vodohranilicshe i ego jizn* (The Rybinsk Reservoir and Its Life), L.: Nauka, 1972.
16. Bikbulatov, E.S., Stepanova, I.E. and Bikbulatova, E.M., in *Mater. Sci. Conf. "Modern problems of hydrochemistry and formation of quality of waters"*, Rostov-on-Don, 2010, p.191.