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Advancing environmental assessment methodologies: A case study on Pentle's framework through component analysis for complex objective functions

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Abstract

This paper explores the evolution and refinement of environmental assessment methods in response to contemporary challenges. While various methodologies exist, R. Pentle's proposed calculation method, represented by a multiple linear regression equation, stands as a significant contribution. However, this method requires refinement. To address this, the paper uses a case study approach within the State National Natural Park (SNNP) Katon-Karagay to investigate the impact of recreational load on tourist routes and the associated environmental load. Through component analysis, a complex objective function is developed within Pentle's framework, emphasizing the need for a standard-setting procedure and offering a fresh perspective on environmental functions. Rather than conventional rating scales, the study advocates for an innovative approach to delineating environmental scenarios. Importantly, this approach extends beyond environmental data analysis, offering applicability across diverse datasets, including economic and social inputs. The findings contribute to advancing environmental assessment methodologies, offering a versatile framework for understanding and managing the impacts of recreational and environmental loads in protected natural areas.

Keywords: Component analysis, Kazakhstan, Normalization, Objective function, R. Pentle's calculation method, Tourist routes.

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1. Introduction

Climate change is getting worse and people's needs are growing. This has made research more important in finding the maximum amount of human-made stress that can be put on natural systems, especially in getting a full picture of the environment [1, 2]. Presently, the term "comprehensive environmental assessment" is fraught with ambiguity due to the diverse nature of the objects under evaluation, encompassing individual entities, their aggregates, and parameter aggregates used for object description [3-5]. This diversity is further compounded by variations in the objectives, methodologies employed, and the quantity of components subject to evaluation [6]. The literature proposes various methods for integrated environmental assessment, with developers frequently introducing notions such as assessment complexity, information content, and techniques for attaining a comprehensive evaluation, as well as the interrelation of parameters and their classification [7-9]. The imperative to consider the spatial distribution of parameters necessitates the formulation of novel criteria for environmentally zoning anthropogenic impact within the study area, with due consideration given to the potential self-restoration capabilities of natural systems [10-12].

Environmental assessment methods are systematic approaches used to evaluate the potential environmental impacts of a proposed project, plan, or policy [13, 14]. These assessments aim to identify and mitigate potential negative effects on the environment and human health [15]. There are various environmental assessment methods employed globally, and their selection depends on the nature of the project, local regulations, and the specific goals of the assessment [16, 17]. Here are some commonly used environmental assessment methods: Environmental Impact Assessment (EIA): Before approving a proposed project, this widely used method assesses its potential environmental, social, and economic impacts. EIAs are often required by regulatory authorities as part of the permitting process [18-20]; Strategic Environmental Assessment (SEA): SEA is applied at a higher level, focusing on policies, plans, and programs rather than individual projects. It evaluates the potential environmental effects of these broader initiatives [21-23]; Life Cycle Assessment (LCA): LCA examines the environmental impact of a product, process, or activity throughout its entire life cycle. It considers raw material extraction, production, use, and disposal [2, 24-26]; Ecological Risk Assessment (ERA): ERA is used to evaluate the potential adverse effects of stressors, such as chemicals, on ecosystems. It considers factors like exposure pathways and ecological sensitivity [27, 28]; Social Impact Assessment (SIA): While not exclusively an environmental assessment method, SIA evaluates the social implications of a project, including impacts on communities, cultures, and socioeconomic conditions [29-32]; Biodiversity Impact Assessment (BIA): This method specifically focuses on assessing the potential impacts of a project on biodiversity and ecosystems [33, 34]; Cumulative Impact Assessment (CIA): CIA evaluates the combined effects of multiple projects on the environment over time. It considers the cumulative impacts that individual projects may have when occurring in conjunction [35-37]; Carbon Footprint Assessment: This type of assessment measures the total greenhouse gas emissions, expressed in terms of carbon dioxide equivalents, associated with a particular activity, product, or organization [38-40].

However, the specific details and methodologies within each type of assessment vary, and new approaches may be developed over time. Researchers and practitioners continually refine and adapt environmental assessment methods to improve their effectiveness in addressing contemporary environmental challenges [41-43]. The task of choosing the most significant factors implies increasing the accuracy of developing comprehensive environmental assessments, the calculation method of which Pentle [44] proposed in the form of a multiple linear regression equation [44]. The main merit of Pentle [44] is that he proposed a model that is practically universal and applicable for development of environmental assessments of systems of any type and any rank. The universality of this model is due to the fact that Pentle [44] indicates in a generalized form "environmental factors" as its parameters, and R. Pentleassociated the role (load, weight, contribution) of these factors with the influence of each of them on the value of a comprehensive environmental assessment (environmental scenario) that R. Pentle called the objective (target) function. It should be noted that the methodology for development of objective (target) functions on the principal components has been refined over a long period of time.

The aim of this research is to present an updated version of R. Pentle's framework, with a specific focus on the logical integration of results from two multivariate models. The primary objective of the study is to formulate a methodology for constructing comprehensive objective functions by Pentle [44] particularly emphasizing component analysis, to assess environmental quality. The research employs a case study approach, utilizing the impact of recreational load on tourist routes within the State National Natural Park (SNNP) Katon-Karagay and the associated environmental load.

Recreational load, defined as the collective stress or demand imposed on natural and recreational areas due to human recreational activities, serves as a key component of the case study [45, 46]. This includes activities such as hiking, camping, picnicking, wildlife viewing, and other outdoor pursuits. The assessment of recreational load includes both quantitative and qualitative aspects, taking into consideration factors like visitor numbers, frequency of use, and the overall human presence. Carrying capacity, the maximum sustainable level of use that does not significantly harm ecological, cultural, or recreational values, closely aligns with the concept.

Additionally, the study examines environmental load, defined as the cumulative impact of all sources on the environment or individual components of the natural environment within the tourist area. The capacity in this context refers to the allowable total impact, considering the regulation of anthropogenic impact, including recreational use of the territory [47, 48]. The research aims to contribute to the advancement of methodologies for environmental assessment, with a specific emphasis on the integration of R. Pentle's framework, and provide insights into managing the impacts of recreational and environmental loads within protected natural areas.

2. Materials and Methods

Due to the large number of factors affecting the recreational capacity, the results of calculations of the permissible recreational load of the tourist routes of the State National Natural Park (SNNP) Katon-Karagay are used as the source material (Table 1). This is the largest natural park in Kazakhstan, founded in 2001. Its area is more than 640 thousand hectares, and the territory has a variety of flora and fauna, some of which are listed in the Red Book. The local sights, which have become state monuments, stand out in particular: RakhmanovskiyeKlyuchi mountain resort, Belukha Mountain, Kokkol waterfall, and Berel barrows.

Table 1.
Parameters for calculating the allowable recreational load of the SNNP Katon-Karagay.

Route name	**Sequence number of parameters**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Mount Belukha	3	73	3	73	0.01	0.3	1	6	1460	20	24.33	5.256	0.05	21.9
Forest roads	7.5	17	37.5	0.2	0.02	0.3	1	8	2920	100	2.27	28.032	0.36	140.16
Berkutaul	10	113	50	0.2	0.02	0.1	1	6	2920	20	11.3	7.008	0.12	35.04
Sarymsakty	5.5	757	25	0.2	0.01	0.5	1	10	2920	100	137.6	29.2	0.25	132.73
Irek	10	20	37.5	0.2	0.1	0.3	0.5	8	2920	100	2	70.08	0.9	262.8
Tasshoky	6	20	37.5	0.15	0.04	0.2	0.9	8	2920	100	3.33	25.229	0.32	157.68
Ozernyi	20	11	12.5	0.3	0.1	0.3	1	10	2190	100	0.55	197.1	1.13	123.19
Pacific lake	3.75	11	12.5	0.2	0.1	0.1	1	6	2920	100	2.93	35.04	0.15	116.8
Belaya Barel	37.5	483	12.5	0.2	0.04	0.1	1	8	2920	5	12.88	18.688	0.08	6.23
Bulandykol	5	5	12.5	0.15	0.01	0.1	1	8	2920	5	1	3.504	0.02	8.76
Maral trails	6	5	12.5	0.2	0.1	0.1	1	10	2920	100	0.83	58.4	0.25	121.67
Altai paths	25	706	37.5	0.3	0.1	0.1	1	10	2920	100	28.24	87.6	1.13	131.4
Rakhman's keys	1.75	1279	12.5	0.3	0.04	0.9	0.5	10	2920	100	730.9	157.68	0.68	1126.3
In the native land	0.75	15	12.5	0.3	0.01	0.1	1	10	2920	3	20	8.76	0.04	146

Note: The following parameters are numbered: 1 – Linear area, ha; 2 - Number of tourists, 2017; 3 - g, coefficient of vulnerability and the status of a specially protected area; 4 - Coefficient of the type of visit (Organized / Mass tourism); 5 – f, soil cover factor; 6 - q, coefficient of recreational development of the territory; 7 – Coefficient of psychocomfort; 8 - Load rate for landscapes, people / ha per hour; 9 - Duration of the season, hour; 10 - Recreational load according to the passport, people / ha; 11 – Actual recreational load, person / ha season; 12 – Recreational capacity of the route, person / ha; 13 - Permissible recreational load, people / ha / Hour; 14 - Permissible recreational load, people / ha (Per season).

To attain the stated objective of the study, it becomes imperative to assess the coherence of amalgamating the outcomes of two multivariate models: a linear multivariate regression model and a multivariate statistical model of component analysis, namely principal component analysis. The former, devised by Pentle [44] constitutes the method for crafting comprehensive environmental evaluations, grounded on the procedure for synthesizing environmental factors(f_i). This approach streamlines the assessment of the influence of specific environmental factors by delineating a set of parameters that best encapsulate these factors and constructing their evaluation scales [49]. As a result, the diverse initial parameters transform these factors into dimensionless entities. Comprehensive evaluations necessitate consideration not only of the magnitude of each environmental factor's impact but also of its significance in shaping favorable or adverse conditions for biosystem existence [50]. Given that the significance of each environmental factor and the direction (positive or negative) of its impact hinge on the objective of holistic assessments—whether favorable or unfavorable from the perspective of the affected object- Pentle [44] proposed designating the assessment function as the target function, as asserted by Pavlichenko, et al. [51]. Pentle [44] delineated the simplest manifestation of such comprehensive assessment through a linear multiple regression. Equation 1:

$$TF(CEA) = a_1 \cdot f_1 + a_2 \cdot f_2 + \ldots + a_n \cdot f_{n}„ \qquad (1)$$

Where TF(CEA) is the calculated value of the target function (comprehensive environmental assessment that assessed the degree of favorableness or unfavorableness from the standpoint of the object that is affected); f_i is the value of a specific environmental factor ($i = 1,2,\ldots, n$) at the observation point; a_i is a weight coefficient that takes into account the direction (plus or minus sign) and the significance (weight) of this factor in the formation of the total impact level.

The objective (target) function is understood not in the classical mathematical sense (where it is understood as a criterion when comparing alternatives using various optimization methods), but as a function that realizes the goal of the assessment [52]. Nevertheless, the formal similarity with the mathematical meaning is also observed here - the optimization procedure is reduced to enumeration of the significance coefficients a_i (estimates are almost always experts) in compliance with the condition of their justification. For the convenience of using Equation 1, weight coefficients are usually normalized by their sum of 100, 10, or 1. We used the latter method in our work. In this case, the average load on the parameter will be $1/n$. An increase in load above this value indicates an increased role of the factor described by the corresponding parameter in shaping the overall situation with anthropogenic impact. However, with a large number of parameters (n>10), the weight coefficients will differ very little, i.e., it will be very difficult to identify the most significant environmental factors in the analysis of natural systems, which may be different for different components of the system. Therefore, in our work, we use the recommendations of system analysis to build models.

Equation 1's form is universal notation for the analysis of geoecosystems of any rank. In section 1 of the mentioned monograph, it was shown that the recommendations of system analysis require considering the system at three levels: inputs to the system, the system itself and the supersystem-exits from the system. For Equation 1, this recommendation is fulfilled under the condition that significant environmental parameters f_i characterizing the system (TF) act as a subsystem, i.e. these environmental factors are a set of subsystems, or inputs to the system (TF). Then, as a supersystem, is chosen an output, i.e., the function of this system, which characterizes the ultimate goal of a comprehensive environmental assessment-to obtain a general quantitative assessment of the ecological situation of the geoecosystem as a whole. Such a function is the result of interaction with all other systems of the same level (for example, another component of the natural environment). Using the standard terminology for geosystems, we can (1) rewrite each *j*-th component of the geoecosystem (air, relief, soils, vegetation, underground and surface waters, anthropogenic load factors, etc.) in the form of Equation 2:

$$PTFj = a_1 j \cdot f_{1j} + a_{2j} \cdot f_{2j} + \ldots + a_{ij} \cdot f_{ij} + \cdots + a_{nj} \cdot f_{nj,} \qquad (2)$$

Where PTFj is a particular target function that characterizes the level of unfavorable (or favorable, depending on the formation of the assessment goal) state of the *j*-th component of the geoecosystem; f_{ij} is the i-th measurable environmental factor (parameter) chosen as important (significant) for describing the j-th component of the geoecosystem; $a_{ij}$is acontribution (role, weight) of the *i*-th environmental factor in the formation of the *j*-th component of the geoecosystem; *n* is the number of significant parameters taken into account for calculating PTFj.

Then the result of the interaction of particular target functions will be a supersystem - an integral objective (target) function for the studied geoecosystem as a whole - Equation 3:

$$ITF = b_1 \cdot PTF_1 + b_2 \cdot PTF_2 + \ldots + b_j \cdot PTF_j + \ldots + b_m \cdot PTF_{m,} \qquad (3)$$

Where ITF is an integral target function that characterizes the level of unfavorable (or favorable, depending on the formation of the assessment goal) state of the entire geoecosystem as a whole; PTF_j is a particular target function of the *j*-th component of the integral target function; $b_j$is the contribution (role, weight) of the *i*-th factor in the formation of the level of unfavorable (or favorable) state of the *j*-th component of the geoecosystem; m is the number of PTF_j selected for the integral assessment.

The notation and description in the equation of the objective function (1) indicate that the plus or minus sign at the weight coefficient $a_i$represents the direction of this factor’s influence in forming the total level of influence. Therefore, if the factor takes negative values, its contribution to the complex assessment will be opposite to the semantic purpose of the sign at the coefficient a_i. That is why traditional assessment measuring scales, even with negative values for the initial parameter, assign a positive number of points to the corresponding environmental factor.

The main goal of using component analysis to build integrated environmental assessments was to get rid of the problem of developing rating scales [53]. The motive for this was the similarity of approaches to the implementation of the first stage of the application of both multidimensional models, which is the conversion of initial data by different units of measurement to dimensionless parameters. In the traditional approach to constructing objective functions, this is obtaining scores and determining environmental factors for each object (target), and in component analysis, this is the procedure for normalizing the initial data with determining the type of principal components and calculating the values of the principal components for each object (target).

As is well known, component analysis stands as a prominent method within multivariate statistics, premised on the notion that the observed or measured parameters serve as indirect descriptors of the studied object or phenomenon. Indeed, there exist internal parameters or properties—often concealed and not directly measurable—in relatively small numbers that govern the observed parameter values. These internal parameters, termed principal components, are theorized to encapsulate all the information inherent in the set of observed variables.Although these components are not initially discernible, component analysis endeavors to represent the observed parameters as linear combinations of the principal components and ascertain them. Essentially, the goal is to assign each object its respective values for each principal component. You can formulate the component analysis model in this context as follows:

$$Y[n \times m] = F[n \times m] \cdot A[m \times m] \qquad (4)$$

Where Y[n×m] is the set of all *n*n standard-set observed values of all *m* parameters, F[n×m] is a matrix that includes the set of all *n* obtained values of all *m* principal components, this is the desired matrix of values of new variables at each sampling point, and A[m×m] is the so-called component load matrix, or weight matrix. To determine it, you must first calculate the eigenvalues (Λ[m×m]) and eigenvectors (U[m×m]) of the matrix of paired correlation coefficients (R[m×m]). which is calculated according to the normalized initial parameters.

$$R[m \times m] = U'[m \times m]\, \Lambda[m \times m]\, U[m \times m] \qquad (5)$$

$$A[m \times m] = U'[m \times m]\, \Lambda ½[m \times m] \qquad (6)$$

Where U[m×m] is an orthogonal matrix whose columns are the eigenvectors of the matrix R[m×m], and Λ is a diagonal matrix composed of the eigenvalues of the matrix R[m×m] corresponding to the eigenvectors, and the elements in the matrix Λ[m×m] are arranged in descending order: λ1 > λ2>...>λn>0. The eigenvectors and eigenvalues of the matrix R[m×m] are determined by standard computer algorithms for calculating the eigenvalues and eigenvectors of symmetric matrices. This solves the main problem of component analysis - the definition of a matrix of weight coefficients that take into account the tightness of the relationship between the features and the main components.

The second stage of component analysis is the solution of the inverse component problem. This solution is found from Equation 4 using the previously calculated component load matrix (6) and standard set input data matrix Y[n×m] according to the following equation:

$$F[m \times n] = A - 1[m \times m] \cdot Y[m \times n] \qquad (7)$$

Equation 7 is valid only for the case when the full matrix of component loads A[m×m] is calculated and the inverse matrix can be found. If only the first q components are searched for that satisfy the given accuracy, then the solution algorithms become somewhat more complicated, since the matrix A[m × q] must first be supplemented to a square one:

$$F[q \times n] = (A'[q \times m]\, A[m \times q])^{-1}\, A'[q \times m] \cdot Y[m \times n] \quad (8)$$

In terms of mathematical constructs, the solution from component analysis represents the definitive outcome. However, providing a meaningful and substantive interpretation of the selected components poses a significant challenge, as emphasized in theoretical literature on component analysis. Principal components do not merely aggregate parameters describing the system; rather, they emerge as a novel property resulting from the interplay among these parameters during system development. Interpreting principal components involves identifying the underlying causes that induce parallel or counter-parallel variations in the measured parameters. The complexity arises from the discrepancy between the number of factors influencing the system and the multitude of parameters representing their effects. For example, the manifestation of the climatic factor through variables such as temperature regime, zonality of groundwater levels, chemical composition, and landscape zonation illustrates this convolution of information.

In order not to violate the relationship between the values of the objective function, it is necessary to add a positive number to all the values of the objective function on the principal components. The rationale for choosing this number is determined by the fact that adding a number equal to the maximum negative value of the objective function in absolute value will lead to the appearance of a zero value of the score, which means the complete absence of anthropogenic impact, which can hardly be considered correct. Therefore, when constructing objective functions, it is proposed to add 1 as the lower limit of the range of changes in the values of the objective function to the maximum negative value of the main component in absolute value and round up to an integer.

3. Research Results and Discussion

As a result of processing the data in Table 1 by the model of multivariate statistics of component analysis, the first main result of component analysis was obtained-the matrix of loads of principal components (PC), presented in Table 2.

Table 2.
Matrix of PC loads.

Parameter designations	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Linear area-1	-0.0266	0.5762	-0.2472	0.4916	0.467
Number of tours. 2017-2	0.735	-0.2903	-0.0819	0.4314	0.2215
Vulnerability of PA status -3	-0.1075	0.2119	0.746	0.1858	0.4039
Attendance rate -4	0.6432	0.2372	-0.4836	0.1351	0.01163
Soil cover factor -5	0.316	0.7935	0.1157	-0.2253	-0.165
Recreational development coefficient -6	0.8122	-0.4622	0.03351	-0.1598	0.132
Psycho comfort coefficient -7	-0.6929	0.2014	-0.3951	0.186	-0.1476
Usual recreational load-8	0.6061	0.2223	-0.2649	0.3759	-0.4327
Continuation of season-9	0.1226	0.03164	0.5569	0.6674	-0.3987
Passport recreational load -10	0.5772	0.4046	0.4437	-0.2543	-0.2318
Actual recreational load -11	0.8247	-0.5273	-0.0284	0.06227	0.05206
Recreational capacity of the route -12	0.8238	0.3966	-0.2095	-0.1981	0.02811
Additional recreational load by hour -13	0.6288	0.6968	0.07077	-0.0951	0.2
Additional recreational load by season -14	0.8883	-0.3817	0.107	-0.0365	-0.021

Significant correlation coefficients for a series of 14 variables are marked in green; the minimum value taken into account should be greater than or equal to 0.426. The table shows only 5 columns out of 14, because all other loads do not exceed 0.426. Considering this matrix by columns, processes that form the conditions for the manifestation of combinations of features in each main component are: PC1(39%): [Additional recreational load by season, actual recreational load, recreational capacity of the route, recreational development coefficient, number of tours, 2017, attendance rate, additional recreational load by hour, usual recreational load, passport recreational load, –[psychocomfort coefficient]; PC2(19%): [Soil cover factor, Additional recreational load by hour, Linear area], – [Actual recreational load, Recreational development coefficient]; PC3(12%): [Vulnerability of PA status, Continuous seasonal passport recreational load], –[Attendance rate]; PC4(9%): [Continuous seasonal, Linear area, Number of tours, 2017]; PC5(7%): [Linear area], – [Usual recreational load].

The PC1 entry, which accounts for 39% of the total dispersion of system characteristics, combines almost all the actual and calculated characteristics of tourist routes into a positive load sign. At the same time, very close values of loads on the parameters of the actual recreational load (0.8247) and the recreational capacity of the route (0.8238) indicate, on the one hand, a slight excess of recreational loads over the ability of self-restoration of the natural environment of routes with a large number of tourists (the sign "the first component is the number of tourists"), and on the other hand, about the deterioration of the psychocomfort of tourists (negative load value). Another conclusion from the interpretation of PC1 is that the season's allowable recreational load plays a greater role than the intensity of hourly loads. The lowest among the statistically significant loads are the Usual recreational load and passport recreational load parameters. This fact reflects, most likely, the specifics of the methods of their calculations, since the standards of permissible recreational loads are calculated and practically met.

PC2 explains 19% of the total variance of the system of parameters characterizing the routes. When loads are positive, the parameters that stand out are the coefficient of accounting for soil cover (0.7935), the allowable recreational load per hour, linear area. Conversely, when loads are negative, the parameters that stand out are the actual recreational load and the coefficient of recreational development. In other words, this component characterizes part of the routes passing through soils with low stability, which is emphasized by the negative signs of loads on the parameters of the actual recreational load (- 0.5273) and the coefficient of recreational development (- 0.4622).

PC3, accounting for 12% of the total variance, combines with positive loads from the PA status vulnerability parameters (0.746), the season duration (0.5569) and the calculated passport value of the recreational load (0.4437), with a negative sign from the attendance type coefficient. The resulting combination of load signs reflects a natural increase in the vulnerability of the PA status with an increase in the duration of the season and the calculated value of passport recreational load. On the other hand, the negative sign of the load on the type of visit coefficient makes it possible to regulate the vulnerability of the PA status.

PC4 explains 9% of the total variance and also reflects a quite understandable parallel combination of the growth of the linear area of the route with the increase in the duration of the season and the number of tourists.

PC5 explains 7% of the total dispersion and reflects the antiphase change in the parameters of the linear area (0.467) and the standard load on the forest (-0.4327), i.e., the established normative load on forest areas limits the increase in linear routes in these areas. The second main result of the component analysis is the matrix of PC values presented below (Table 3).

Table 3.
Matrix of values of principal components according to the component analysis model.

Routes	PC1	PC2	PC3	PC4	PC5
Climbing Belukha mountain	-0.8949	-1.069	-1.373	-2.056	1.472
Forest roads	-0.3118	-0.0699	0.9305	0.0099	0.0216
Berkutaul	-0.959	-0.369	0.9904	0.5414	1.399
Sarymsakty	0.3071	-0.7345	0.2095	0.7981	-0.4707
Irek	0.52	0.7903	1.714	-0.8937	0.5487
Tasshoky	-0.3962	-0.0427	1.397	-0.2451	-0.1527
Ozernyi	0.8319	1.89	-1.603	-1.101	0.1709
To the Tikhyi lake	-0.4948	0.2523	0.428	-1.004	-0.9861
Belaya Berel	-0.648	0.1169	-1.03	1.829	1.158
To the lake Bulandykol	-1.022	-0.828	-0.2375	0.2709	-0.6647
Maral trails	0.1177	0.6451	-0.05483	-0.2563	-2.002
Altai paths	0.6756	1.814	-0.0999	1.296	0.7146
Rakhmanovkeys	2.934	-1.763	-0.0697	0.0371	0.2007
In the native land	-0.4241	-0.6337	-1.201	0.7736	-1.409

As a generalization of the results of the interpretation of the form of the five main components, which identified different combinations of initial parameters with statistically significant values of loads, it can be noted that they can be divided into two groups that differ in the absence (PC1 and PC3) or the presence of a sign of linear area (PC2, PC4, and PC5). The first group explains, in total, 51% of the total variance, and the second - 35%.

Traditionally independent ratings serve as the foundation for building rating scales. As an independent assessment in our case, the ratio of the calculated allowable values of recreational loads, recreational capacities, and the actual value of the recreational load of the route is taken.

The calculations carried out showed the following results: the ratio of the allowable recreational load to the actual one was 1.077; permissible recreational load to recreational capacity - 1.078; recreational capacity to the actual recreational load - 0.999. Those. almost all very close to unity. Thus, the maximum values of all PCs should have scores close to the maximum value, and the minimum value should be 1 point.

In order to assess the role of certain types of routes in the organization of tourist, recreational, and environmental activities in the SNNP Katon-Karagay by traditional scoring, the normalized values are converted into points. To do this, the range of changes in the normalized values is transferred to the region of positive values by highlighting the maximum negative values in absolute value of each of the five PCs for all routes. Since the addition of these values with normalized values for each PC will lead to the appearance of zero values, by such an assessment it is announced in advance the presence of routes that do not cause absolutely any anthropogenic impact on the environment, which clearly contradicts reality. As a result, the justification of the point scale will begin with its lower value.

To do this, the maximum negative value is selected as an absolute value, rounded up to an integer, and added to 1 so as not to get a zero score. This procedure can result in values greater than 10 in the columns, so the next step is to evaluate the resulting upper range value.

We draw it in the same way as the lower boundary, but without adding or subtracting any values. In this case, the obtained maximum value is rounded up to the nearest integer and assigned 10 points. Next, we calculate the correction factor and divide it by 10 to obtain 10 points. For columns with values greater than 10, this coefficient will be greater than 1, and for columns with small values, it will be less than 1.Table 4 below illustrates this operation.

Table 4.
Matrix of values of the principal components after the calculated ranges to the positive area.

Routes	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Climbing Belukha mountain	2.105	1.931	1.627	1.944	5.472
Forest roads	2.688	2.930	3.9305	4.01	4.022
Berkutaul	2.041	2.631	3.990	4.5414	5.399
Sarymsakty	3.307	2.266	3.21	4.798	3.529
Irek	3.52	3.7903	4.714	3.106	4.549
Tasshoky	2.604	2.957	4.397	3.755	3.847
Ozernyi	3.832	4.89	1.397	2.899	4.171
To the Tikhyi lake	2.505	3.252	3.428	2.996	3.014
Belaya Berel	2.352	3.117	1.97	5.829	5.158
To the lake Bulandykol	1.978	2.172	2.7625	4.271	3.335
Maral trails	3.118	3.645	2.945	3.744	1.1
Altai paths	3.676	4.814	2.900	5.296	4.715
Rakhmanov keys	5.934	1.237	2.930	4.037	4.201
In the native land	2.576	2.3663	1.799	4.774	2.591
	0.6	0.5	0.5	0.6	0.6

The bottom line shows the correction factors that will ensure the conversion of the obtained positive values into points, i.e., in fact, it is the price. After dividing each column value by the correction factors, we obtained the following matrix of PC values in points (Table 5).

Table 5.
Matrix of values of the main components in a 10-point scale.

Routes	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Climbing Belukha mountain	3.509	3.862	3.254	3.24	9.12
Forest roads	4.48	5.86	7.861	6.683	6.703
Berkutaul	3.402	5.262	7.981	7.569	8.998
Sarymsakty	5.512	4.531	6.419	7.997	5.882
Irek	5.867	7.581	9.428	5.177	7.581
Tasshoky	4.34	5.915	8.794	6.258	6.412
Ozernyi	6.387	9.78	2.794	4.832	6.952
To the Tikhyi lake	4.175	6.505	6.856	4.993	5.023
Belaya Berel	3.92	6.234	3.94	9.715	8.597
To the lake Bulandykol	3.297	4.344	5.525	7.118	5.559
Maral trails	5.196	7.29	5.89	6.24	3.33
Altai paths	6.126	9.628	5.8	8.827	7.858
Rakhmanov keys	9.89	2.474	5.861	6.729	7.001
In the native land	4.293	4.733	3.598	7.956	4.318

Particular objective functions are built according to scores in accordance with the selected groups, integral - is the sum of private estimates in accordance with the weight of the GC included in the objective functions. Private objective function 1 combined all types of recreational loads, recreational capacity, and assessments of the status of PAs. As a result, based on the scoring of the values of the principal components, the values of private and integral objective functions (Tables 6 and 7):

Table 6.
The results of the calculation of private and integral objective functions.

Routes	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PTF1**	**PTF2**	**PTF**
Belukha mountain	3.509	3.862	3.254	3.24	9.12	3.407	4.758	3.947
Forest roads	4.48	5.86	7.861	6.683	6.703	5.833	6.234	5.993
Berkutaul	3.402	5.262	7.981	7.569	8.998	5.233	6.586	5.774
Sarymsakty	5.512	4.531	6.419	7.997	5.882	5.875	5.668	5.792
Irek	5.867	7.581	9.428	5.177	7.581	7.291	6.98	7.167
Tasshoky	4.34	5.915	8.794	6.258	6.412	6.121	6.1	6.113
Ozernyi	6.387	9.78	2.794	4.832	6.952	4.95	7.977	6.161
Tikhyi lake	4.175	6.505	6.856	4.993	5.023	5.248	5.83	5.481
Belaya Berel	3.92	6.234	3.94	9.715	8.597	3.928	7.577	5.387
Bulandykol	3.297	4.344	5.525	7.118	5.559	4.188	5.281	4.625
Maral trails	5.196	7.29	5.89	6.24	3.33	5.474	6.235	5.778
Altai paths	6.126	9.628	5.8	8.827	7.858	5.996	**9.074**	7.227
Rakhmanov keys	9.89	2.474	5.861	6.729	7.001	**8.278**	4.443	6.744
In the native land	4.293	4.733	3.598	7.956	4.318	4.015	5.456	4.591

Table 7.
Classification of objective (Target) function values and their class boundaries.

Class number	Class boundaries, points		Color coding
	From	To	
1	0	2	🟩
2	2	4	🟨
3	4	6	🟧
4	6	8	🟪
5	8	10	🟥

The results of color differentiation of partial and integral objective functions give a more specific generalized idea of the state of recreational routes, i.e., from this differentiation, taking into account the type of particular target functions, one can obtain information on the management of various routes and on the development of specific measures to eliminate or at least regulate the constraining factors. However, quite often, there is a need to obtain more specific results to solve specific management problems. Such a specific issue in the tourism sector, in particular, is the question of the possibility of increasing loads on already existing routes.

4. Conclusion

In conclusion, it is crucial to establish that the universality of the objective function model holds significance both theoretically and practically, as its congruence with the principles of general systems theory and quantitative information theory is substantiated. The investigations into diverse geoecological systems and the evaluations of tourism potential attest to the broad applicability of this model in practical contexts. The extension of the scope of R. Pentle's objective function model, conventionally applied in integrated environmental assessments, can be realized by adopting its primary components as initial parameters, derived as the secondary outcome of a multivariate statistical method, such as component analysis. This augmentation enhances the model's versatility and underscores its potential utility in diverse analytical frameworks within the realm of environmental assessment. Application of the objective function necessitates a foundational reliance on independent sources of information. Specifically, in the formulation of objective functions based on primary components, reference books on mathematical statistics serve as a crucial source. Through consultation with these references, confidence intervals for errors associated with parameter loads during the development of primary components, are provided, contingent upon the sample length. This methodological approach makes the process of building the objective function more robust and reliable. It gives a structured way to deal with uncertainties and improves the accuracy of the parameters that are derived.

From a systemic analysis perspective, employing the component analysis model with a predefined element composition facilitates a comprehensive examination of the geoecological system, emphasizing systemic considerations. This approach enables the identification and prioritization of system functions based on their contributions to the overall system dispersion (emergence). The model accounts for the nature of relationships, delineating synergistic and antagonistic effects within components, and acknowledges the system's self-organization through the presence of closed loops in the relationship system, indicated by the inclusion of the same feature in different components. A noteworthy outcome of the model is not only the discernment of system functions (system-forming factors) derived from the interpretation of interrelations among initial features but also the delineation of territorial zones based on the intensity of the function's manifestation. However, it is essential to acknowledge that the quantitative characteristics of system-forming factors represent a notable vulnerability in simulation modeling. Addressing this limitation would be imperative for refining the precision and reliability of the model's quantitative outputs in future applications.

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