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DEVELOPMENT OF THE METHODOLOGICAL APPROACH TO THE SELECTION OF TECHNOLOGIES FOR ENVIRONMENTALLY-SAFE WATER DRAINAGE IN POPULATED AREAS

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Розроблено методичний підхід вибору технологічного заходу екологічно безпечного водовідведення в населених пунктах, розташованих на евтрофованих водних об’єктах. Використання такого підходу дозволяє задіяти спеціалістів місцевих органів влади різного профілю до управління екологічною безпекою населених пунктів з позицій їх сталого розвитку.

Сутність методичного підходу полягає у використанні методу аналізу ієрархій (МАІ). Для нього запропоновано і використано критерії, що сформульовані як складові сталого розвитку – екологічні, соціальні та економіко-технологічні. Відповідні спеціалісти, як експерти, спираючись на інформацію різного типу (статистичну, прогнозну, даних безпосередніх вимірів) по конкретному населеному пункту, дають власні судження відносно пріоритетності переваг критеріальних ознак. Результати оброблення суджень експертів за формальною процедурою МАІ є основою для прийняття рішень при виборі технологічних заходів екологічно безпечного водовідведення в конкретному населеному пункті.

Багатокритеріальна ієрархічна структура вибору технологічних заходів представлена послідовністю дій, що включають три етапи: побудову ієрархічної моделі порівняння критеріальних ознак; формування матриць попарних порівнянь елементів кожного рівня ієрархії та визначення їх локальних вагових коефіцієнтів; визначення глобальних вагових коефіцієнтів, індексу узгодженості та вибір найкращого варіанту. Перевагою запропонованого багатокритеріального методичного підходу є можливість ув’язати в єдиний алгоритм виробки рішення вихідні дані, що різняться як за своїм змістом (екологічні, соціальні та економіко-технологічні), так і за формою представлення (статистичні, прогнозні, дані безпосередніх вимірів, експертні оцінки).

Апробація розробленого методичного підходу проводилась на прикладі типового населеного пункту, розташованого на евтрофованому водному об’єкті – джерелі питного водопостачання та рекреаційного використання. Отримані результати, незважаючи на достатньо велику розмірність масиву елементів ієрархії, показали досягнення прийнятного рівня узгодженості, що свідчить про їх достовірність.

Розроблений методичний підхід може бути використаний при обґрунтуванні удосконалення чи побудові нової системи водовідведення населеного пункту розташованого на евтрофованому водному об’єкті

Ключові слова: екологічна безпека, населений пункт, технологічний захід екологічно безпечного водовідведення, метод аналізу ієрархій

1. Introduction

It is important to ensuring social and economic development of the state and of a separate populated area (PA), during which the quality of life of the population increases, and to reduce the impact on the nature. This leads to the creation of the environment, which is beneficial for human health and is a strategic goal of the policy of environmental safety.

Ensuring a beneficial environment for human life must be based on the criterial features of sustainable development. A beneficial environment can be defined as a safe environment, including water sites, sources of satisfying drinking and recreational needs of the population. In the face of deterioration of the state of environment, the scale of which led to the loss of stability of ecosystems, the development and substantiation of the ways of reducing the impact of the water factor on humans is becoming especially relevant. This is especially true for eutrophied water sites [1].

Eutrophied water sites (EWS) prone to "harmful flowering" are used by the population to meet their own needs and influence not only the state of health, but also act as a factor of decreasing the quality of life and the conditions of existence. In the European practice and in the practice of the United States, a significant role in the prevention of danger from the water factor in populated areas belongs to the implementation of "the best technologies available" [2], that is, the technological measures of the environmentally safe water use (TM of ESW), in which we preserve the state of protection of water consumption sources and systems from the hazard caused by violation of the environmental and social standards in the field of drinking water supply or recreational water use [1].

Systemic transformations of the society and integration processes in the European and world space need appropriate scientific support of the process of creating new organizational structures in different spheres of social life [3].

Today, the creation of methodological (software and analytical) approaches to support managerial decision making by the highest management segment of PA is becoming relevant. These approaches, first of all, based on a multitude of factors and criteria, will help solve the problem of the assessment of the final outcome of the decision made. Secondly, in the course of selection and implementation of priority drainage technologies, they will help analyze the alternatives or determine the effectiveness of passing the separate stages of the decision-making process.

2. Literature review and problem statement

When analyzing the components of the information technologies when selecting technologies of a drainage system and increasing the EWS protection level in PA, we should note that these problems are tackled in paper [4]. It considers the technological levers of reducing the levels of WS eutrophication, the existing European practices for improving the state of water drainage systems and the ways of increasing environmental and social component of the society. However, the problem of uniting the disparate criteria and factors of increasing the load on the EWS within a PA remains unresolved. It is also necessary to expand the application of the economic-technological approach used in the construction of new and reconstruction of existing water drainage systems. At present, the application of this approach is limited due to the lack of the mathematical approach to the solution of this problem.

An increase in loading and arrival of biogenic substances and the performed analysis of the change in nature use revealed that there is a risk of degradation of water ecosystems. Eutrophication of water sites due to arrival of biogenic substances is a serious problem of water quality all over the world [5]. The detected shortcomings in the water use organization require the formation of new approaches and the introduction of information technologies and mathematical apparatus to resolve them.

Chronic arrival of biogenic substances that lead to anthropogenic eutrophication of water sites increase on a large scale. European countries such as Denmark, Finland, Luxembourg, and the Netherlands referred all water sites on the territory of their countries to the category of "vulnerable zones" because of the hazard of their anthropogenic eutrophication [6]. The most "vulnerable zones" all over the world, separated in [6], determine the scale of the problem, but the adopted normative legal documents aimed at improving and reducing the negative impact of EWS do not regulate specific technologies and tools for improvement of the existing state.

One of the levers of the controlled and grounded decision-making on the technical re-equipment and reduction of the level of eutrophication of water sites are the methods of mathematical analysis. Paper [7] is dedicated to the substantiation of the decision-making method for the assessment of the influence and management of environmental safety on the example of hydraulic structures. However, despite the advantages of the adapted analytic hierarchy process (AHP) by T. Saaty, for the system of management of environmental safety of separate objects, the problem of its use in terms of a populated area remains open. While the criteria, factors and sources of influence in the transboundary context were determined, the mechanisms of the interaction between the levels of influence were not.

In paper [8], the authors consider the concept of environmental sustainability as a synonym to stability. The urgency of the development of nature protection measures and assessment of their environmental and economic efficiency increases with the increasing influence of the anthropogenesis on the environment. As a consequence, relevance of the development of the method for determining the relative weight coefficients of its main factors and criteria and their priority for balanced funding is also increasing. As a result, the authors of [8] determined that there appear a large number of both contradictory criteria, and the methods for multi-center decision making for assessment of material/intangible criteria. However, the unresolved question is the problem of validity of the selection of a certain decision-making method by an expert under specific conditions of PA. In paper [9], authors perform a comparative analysis and evaluation of various methods in order to determine why one method is better than the other and introduce 16 criteria that can be used for judgment and evaluation of different methods. Special levers and weights of each of the 16 criteria were identified, and the role of an expert, his experience and practical knowledge in the interpretation and analysis of results was clearly determined. It should be noted that the authors do not determine how to consider and interpret different views of experts and what approach to use for their agreement.

A decision support system tool for the evaluation of strategies of intervention (alternative) in the municipal water supply system using the integrated simulation model was presented in paper [10]. The model enables a user to identify one or more appropriate alternatives. The approach with multiple quantitative and qualitative criterion is used for decision making and comparison of certain alternatives, their ranking relative to a predetermined scheme of weighting for different scenarios. The problem of adaptivity of this approach to actual conditions using the example of PA taking into consideration socio-economic factors remains non-addressed.

The authors of paper [11] determined the process of water resources management within populated areas as a socio-technical problem. Combination of technologies with engineering and technological facilities, as well as socio-economic aspects both for the population and for institutions and organizations are shown by the example of the model for Mezogia, Greece [11]. This model is based on the mutual influence and consideration of different aspects of PA, however, the problem of formation of approaches to instrumental support of management decisions in this model remains unresolved.

In paper [12], evolutionary Pareto methods for calculation and optimization are included in the model system of water resources management on the example of the district Murrumbidge in Australia. It was determined in the work that the presented system is capable to provide detailed information about the optimal solutions to achieve the desired results, in response to various factors, but the problem of the inclusion of social factors and the reaction of the water resources management system in a particular PA remains unresolved.

The authors of article [13] explored the integrated water resources management (IWRM) at the level of a populated area for the city of Melbourne (Australia). It was determined that such indicators as the efficiency of sewage treatment, energy efficiency and other criteria and factors should be taken into consideration during the IWRM implementation. The methods for reasonable decision making taking into consideration the criteria and factors identified in the work were not determined for the governing management sector at the municipal level.

There are a lot of shortcomings in addressing the "subject-consequence" situation – "eutrophication – water site – populated area". We can highlight among them: labor consumption, non-uniformity of conditions in aquatic ecosystems and reaction of organism, the need to conduct additional studies with the involvement of leading specialists in different areas. A particular disadvantage is the lack of the adapted mathematical apparatus for uniting a multicriterial problem with the determining an alternative decision option for PA located on the EWS. In article [14], it was determined that in the European practice, integrated water resources management is achieved through the implementation of practical measures for achieving sustainable development in the field of water resources. A necessary element of integrated management is the management of water drainage systems, as well as the responsibility of all stakeholders: the state, local communities, users, operators and NGO [14]. The unresolved part of this problem remains the selection of indicators and factors for the implementation of practical measures and the involvement of experts of stakeholders to make grounded management decisions.

In article [15], to assess the sustainability of the water supply system within populated areas, a set of indicators, which includes 24 special indices, divided into eight categories, was implemented [15]. However, not all the indices were included in the indicators. Selection of criteria and factors largely depends on objective reasons (the environment), and on subjective reasons, that is the tasks that are set by the management section (internal environment) [16]. This indicates the necessity of introduction of additional indices of sustainable development, adapted in accordance with the research object in the formation of the criterial basis of the hierarchy of EWS ecological safety formation at the level of a populated area. The task was not set in this statement in the previously published research.

3. The aim and objectives of the study

The aim of this study is to develop a methodological approach to using the analytic hierarchy process when determining priority technologies of water drainage from the territories of populated areas, located at eutrophied water sites.

To accomplish the aim, the following tasks have been set:

– to develop the essential elements of the stated methodological approach;

– to check the consistency of the multicriteria hierarchical structure of the selection of technological measures by the original data of a specific populated area, located on the eutrophied water site;

– to obtain priority technological measures of environmentally safe water drainage for the studied drainage basins of a specific populated area.

4. Methodological approach to the selection of a technological measure of environmentally safe water drainage in populated areas

In accordance with [9, 17], AHP consists of three stages:

– construction of a hierarchical model of comparison of elements (features) of the problem;

– construction of matrices of pairwise comparisons of the elements of each hierarchy level and determining their local weight coefficients;

– determining global weight coefficients, consistency index and selection of the best variant of solution.

Stage 1. Construction of a hierarchical model of comparison of elements (features) of the problem. During construction of a hierarchical model, we used the concept of sustainable development of populated areas (PA), that is taking into account the socially, economically and environmentally balanced development of populated areas, aimed at creating their economic potential, the fully-fledged living environment for the contemporary and future generations [18, 19].

At stage 1, the aim was set (Fig. 1): "Increasing environmental and social safety of the populated areas, located on the eutrophied water sites through the implementation of environmentally safe water drainage" and in accordance with six hierarchical levels. Achievement of this aim is determined by solving the following common tasks (elements of level 2), which are formulated as the components of sustainable development – environmental, social, and economic-technological subcriteria of safety of populated areas: K1 – the state of surface water; K2 – living conditions of population; K3 – economic consequences of a change in water quality in a water site – a water supply source of PA.

Level 3 includes the factors of state (FS 1, 2, 3), which specify safety criteria in the part of the development of the process of eutrophication of a water site as a source of drinking water supply or for recreational purposes.

At level 4, there are techno-economic indicators (TEI 1, 2, 3, 4), that characterize the water drainage system of PA.

At level 5, the measures (M 1, 2, 3), aimed at improvement of the estimation features of techno-economic indices of water drainage systems, are presented.

Level 6 (the last one) gives the list of alternative variants of solution – technological measures for environmentally safe water drainage:

TM1: surface wastewater (SWW) treatment at bio-engineering facilities (BIF);

TM2: SWW treatment at communal biological wastewater treatment facilities (BTF);

TM3: construction of two accumulating capacities at BTF for SWW regulation and interception of shot wastewater discharges;

TM4: treatment of SWW from separate territories, which have an independent release in the WS at the pond for water treatment;

TM5: application of rain receivers with a sludge areaway;

TM6: local treatment of SWW from parking lots, gas stations, shopping centers with subsequent discharge into rain sewers of PA;

TM7: organizational and technical measures to reduce the amount of impurities carried by the surface runoff or to improve the sanitary condition of water catchment areas;

TM8: increase in the areas of drainage of PA territories;

TM9: improvement of the operation of water drainage systems.

We will note that the number of elements, which are directly compared pairwise at each hierarchy level, do not exaggerate nine, which meets guidelines [17].

Stage 2. The formation of matrices of pairwise comparisons of the elements of each hierarchy level and determining their local weight coefficients. To do this, a group of experts – specialists of the corresponding professional area of municipal controlling bodies of a particular NP are involved. Each expert according to his profile (Fig. 1) forms a square inversely symmetric domination (judgments) matrix, which is written in the form of:

$$A=\left(a_{ij}\right)_{n,n},\quad a_{ji}=\frac{1}{a_{ij}},\quad i=\overline{1,n};\quad j=\overline{1,n},\ a_{ij}=1 \text{ t } i=j, \qquad (1)$$

where $a_{ij}=\dfrac{w_i}{w_j}$, where w_i, w_j are the weights of corresponding elements (criteria and factors).

Pairwise comparisons w_1, w_2,..., w_n... of the elements is performed with the use of subjective judgments of an expert, numerically estimated from 1 to 9 by a special scale of relative importance [17].

During performing a description of dominance and assessing the degree of consistency in judgments of experts, the eigenvector (that is priority vector w) is determined and in accordance with the maximum eigenvalue of λ_{Max}. For each matrix, the matrix equation relative to λ_{Max} and vector w_i is solved.

$$A\begin{pmatrix} w_1 \\ w_n \end{pmatrix}=\lambda_{\max}\begin{pmatrix} w_1 \\ w_n \end{pmatrix}. \qquad (2)$$

The solution of this equation is performed by raising matrix A to high enough powers with subsequent summation of rows and normalization (dividing the sum in each line by the sum of all elements of the matrix), which results into obtaining priority vector $\mathrm{w}=(w_1, w_2,\dots, w_n)^{\mathrm{T}}$.

Stage 3. Determining weight coefficients, consistency index and selection of the best variant of solution. The filled matrices of domination (1) are used for determining weight coefficients and global priorities of local criteria and factors.

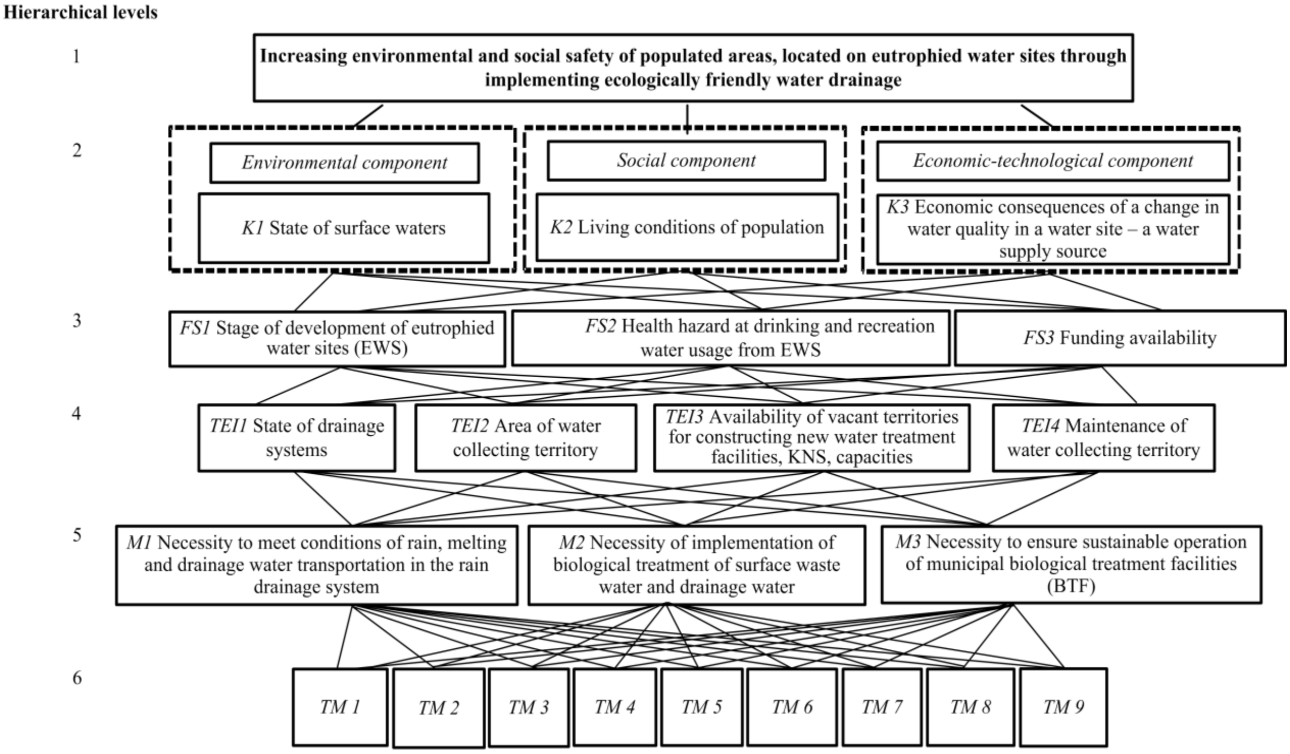

Fig. 1. Hierarchy of selection of the ecologically and socially safest TM of ESW

Global priority of the factor is calculated from formula:

$$w_{ij} = \sum_{j=1}^{m} u_{ij} v_{(i-1),j}, \tag{3}$$

where vi-1,1, vi-1,2,..., vi-1m are the weight coefficients or global priorities of local aims or factors (i–1) of the level; u_{i1}, u_{i2}, ..., u_{im} are the weight coefficients or local priorities of the *j*-th criterion or factor of the *i*-level in relation to local aims.

The consistency of the entire hierarchy is checked. It is possible to estimate it through multiplying each consistency index by the priority of the corresponding criterion, summing the obtained numbers, and comparing the result with the mean index of consistency of random matrices of the same order:

$$CI = (\lambda_{\max} - n) / (n - 1). \tag{4}$$

Consistency index is compared with the mean consistency index for random matrices of this same order [17], and if necessary, quantitative estimates are specified.

The consistency ratio is the ratio of consistency index to the mean statistical value of consistency index at a random choice of coefficients of the matrix of comparisons [17].

$$CR = CI/N, \tag{5}$$

where *N* in the number of random consistencies.

For each variant of TM of ESW (Fig. 1), a quantitative value of global priority is calculated by the highest value of this indicator, the option that is recommended to be implemented in a particular populated area is selected.

Thus, the selected variant of the TM of ESW will be best from the perspective of the requirements of sustainable development of PA and obtained with taking into consideration different types of information (statistical, predictive, direct measurement data, expert assessments).

The developed methodological approach was used to select M of ESW in the city of Odesa (Ukraine) for 3 basins of water drainage: Northern, Southern and Kotovsky district. In this case, all three stages of AHP were implemented, the basis of their implementation was the hierarchy shown in Fig. 1. The specialists of Odesa City Council were involved as experts. The results of their work at various hierarchy levels are shown in Tables 1–5.

Table 1

Matrix of pairwise comparisons of the level of subcriteria of environmental-social safety (K1, K2, K3)

Criteria	Northern basin				Southern basin				Kotovsky district			
	(K1)	(K2)	(K3)	*W*/weight	(K1)	(K2)	(K3)	*W*/weight	(K1)	(K2)	(K3)	*W*/weight
(K1)	1	2	2	0.4934	1	2	3	0.5499	1	1/2	1	0.2599
(K2)	1/2	1	2	0.3108	1/2	1	1	0.2402	2	1	2	0.4126
(K3)	1/2	1/2	1	0.1958	1/3	1	1	0.2098	1	1	1	0.3275
CR	0.04623				0.01577				0.04623			
CI	0.02681				0.009147				0.02681			
$\lambda_{\max}$	3.0				3.0				3.0			
W_{average}	1				1				1			

Table 2

Matrix of pairwise comparisons of the level of subcriteria of environmental-social safety for subcriteria of the state factor level (K1, K2, K3 to FS1, FS2, FS3)

Criteria	Northern basin			Southern basin			Kotovsky district		
	K1	K2	K3	K1	K2	K3	K1	K2	K3
FS1	0.5499	0.6738	0.1958	0.1692	0.2599	0.1634	0.4161	0.4161	0.1396
FS2	0.2098	0.2255	0.3108	0.4434	0.4126	0.297	0.4579	0.4579	0.3325
FS3	0.2402	0.1007	0.4934	0.03874	0.3275	0.5396	0.126	0.126	0.5278
CR	0.01577	0.0739	0.04623	0.01582	0.04623	0.00794	0.00794	0.00794	0.0462
CI	0.00914	0.04228	0.02681	0.00917	0.02681	0.00460	0.00460	0.00460	0.0268
$\lambda_{\max}$	3.0	3.01	3.0	3.01	3.0	3.0	3.0	3.0	3.0
W_{average}	0.4934	0.3108	0.1958	0.5499	0.2402	0.2098	0.2599	0.4126	0.3275

Table 3

Matrix of paired comparisons of subcriteria of state factors level for the level of technical and economic indicators (FS1, FS2, FS3 to TEI1, TEI2, TEI3, TEI4)

Criteria	Northern basin			Southern basin			Kotovsky district		
	FS1	FS2	FS3	FS1	FS2	FS3	FS1	FS2	FS3
TEI1	0.4326	0.357	0.4316	0.3796	0.3254	0.459	0.1122	0.3788	0.3465
TEI2	0.1606	0.1723	0.09114	0.2167	0.1858	0.1615	0.2157	0.1968	0.2036
TEI3	0.1691	0.2353	0.09114	0.1665	0.2855	0.1897	0.3497	0.2428	0.2036
TEI4	0.2377	0.2353	0.3861	0.2372	0.2034	0.1897	0.3225	0.1815	0.2463
CR	0.07673	0.09231	0.00230	0.07973	0.07973	0.02246	0.04368	0.04368	0.02246
CI	0.06905	0.08308	0.00207	0.07176	0.07176	0.02022	0.03931	0.03931	0.02022
$\lambda_{\max}$	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
W_{average}	0.5191	0.2348	0.2464	0.1898	0.4053	0.4049	0.3255	0.4169	0.2576

Table 4

Matrix of paired comparisons of subcriteria of the level of technical and economic indicators for the level of measures (TEI1, TEI2, TEI3, TEI4 to the LM1 LM2 LM3)

Criteria	Northern basin				Southern basin				Kotovsky district			
	TEI1	TEI2	TEI3	TEI4	TEI1	TEI2	TEI3	TEI4	TEI1	TEI2	TEI3	TEI4
LM1	0.259	0.4434	0.1488	0.1461	0.584	0.387	0.174	0.549	0.533	0.169	0.259	0.412
LM2	0.327	0.3874	0.6908	0.126	0.184	0.443	0.633	0.209	0.249	0.443	0.412	0.259
LM3	0.412	0.1692	0.1603	0.4579	0.231	0.169	0.191	0.240	0.157	0.387	0.327	0.327
CR	0.046	0.0158	0.0047	0.0079	0.046	0.015	0.007	0.015	0.046	0.015	0.046	0.046
CI	0.026	0.0091	0.0022	0.0046	0.026	0.009	0.004	0.009	0.026	0.009	0.026	0.026
λ_{max}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$W_{average}$	0.4146	0.1462	0.1654	0.273	0.389	0.181	0.224	0.204	0.283	0.204	0.267	0.244

Table 5

Matrix of paired comparisons of subcriteria of level of measures for level alternatives (LM1, LM2, LM3 to TM1, TM2, TM3, TM4, TM5, TM6, TM7, TM8, TM9)

Criteria	Northern basin			Southern basin			Kotovsky district		
	LM1	LM2	LM3	LM1	LM2	LM3	LM1	LM2	LM3
TM1	0.0476	0.1438	non-determined	0.12	0.1679	non-determined	0.169	0.05596	non-determined
TM2	0.07781	0.14	non-determined	0.1074	0.148	non-determined	0.1054	0.06535	non-determined
TM3	0.3024	0.2451	non-determined	0.2533	0.212	non-determined	0.1408	0.07632	0.2159
TM4	0.04742	0.04063	0.3613	0.08074	0.1151	0.3178	0.15	0.08914	0.1188
TM5	0.1385	0.1033	0.1204	0.1341	0.0671	0.2592	0.1195	0.1041	0.2297
TM6	0.06951	0.049	0.1749	0.07682	0.07015	0.1528	0.09444	0.1216	0.1025
TM7	0.1251	0.08881	0.1532	0.08295	0.07643	0.08773	0.0877	0.151	0.1175
TM8	0.07576	0.08623	0.104	0.07233	0.07735	0.08773	0.07668	0.1603	0.1078
TM9	0.1159	0.1032	0.08615	0.07233	0.06594	0.09476	0.05728	0.1763	0.1078
CR	0.0528	0.05968	0.049	0.04956	0.01454	0.02311	0.04912	0.03752	0.02657
CI	0.07656	0.08653	0.06076	0.07186	0.0210	0.02865	0.07122	0.0544	0.03507
λ_{max}	9.0	9.0	6.0	9.0	9.0	6.0	9.0	9.0	7.0
$W_{average}$	0.3111	0.3412	0.3477	0.4495	0.3372	0.2132	0.3733	0.3353	0.2914

Based on the performed calculations, the quantitative value of the global priority was calculated in accordance with the methodological approach of AHP for each variant of M of ESW, the option that is recommended to be implemented is selected by the highest value of this indicator (Fig. 2–4).

All the calculations were carried out on the PC in the environment of MAI (MS Excel, MPriority 1.0, etc.) using the appropriate commands with the accuracy of 0.001, recommended in [20].

The results of calculations for Northern basin were presented in Fig. 2. Total consistency score (CI) of hierarchy is 0.05408.

TM 3 – construction of two accumulation capacities on the BTF for the SWW regulation and interception of shot wastewater discharges obtained the highest value of the global priority (0.1777). Accumulation capacities under normal conditions ensure the regulation of SWW consumption and feeding for treatment within the hours of the least sewage inflow. In case of an accident (under extreme conditions), they ensure the interception of shot discharges of wastewater with the concentration of contaminants that exceeds the maximum permissible for BTF value. This stimulates the reliability of the sewage system and continuity in its work.

The results of calculations for the second basin of the water drainage system are presented in Fig. 3.

The total hierarchy consistency index CI is 0.0324. According to the numerical values (Fig. 3) of global priorities, the highest value (0.1854) was also obtained by TM 3 – construction of two accumulating capacities on the BTF for SWW regulation and interception of shot discharges of wastewater. For surface wastewater transportation to the BTF, it is necessary to ensure pumping domestic and industrial wastewater of the accumulation capacity in the pumping stations area for collection and regulation of the surface wastewater supply. In this case, the experts took into consideration that currently there is a considerable underloading of pumping stations and municipal collectors. Field observations of the places of pumping stations locations showed that the capacities for the accumulation of surface wastewaters can be designed near pumping stations.

The results of calculations for the form of hierarchy of selection (Fig. 4).

The hierarchy consistency index (CI) is 0.03898. Based on the obtained numerical results of global priorities (Fig. 4), TM 5 has the largest value (0.1464), this is the application of rain receivers with sludge areaway for the interception of surface wastewater discharges. The measure will ensure the termination of untreated surface wastewater flowing down along the relief into the Black Sea.

In addition, to reduce the pollutant removal by surface wastewater and their getting into the Black Sea, it is necessary to fully implement the organizational and technical measures and technologies, foreseen in DBN B.2.5-75:2013, in all three districts. These measures imply:

– necessary additional equipment of the system of mountain and water drainage channels for the improvement of sanitation and orderliness of the build-up territory;

– in the sections of the possible manifestation of karst-undermining processes (there are too many of them in Odesa), measures should be taken to reduce the infiltration of water into soil;

– it is necessary to foresee the drainage of surface waters from the territories of roads, paved areas, roofs of buildings with the use of the closed rainwater sewers;

– implementation of special structural elements (parapets, curbs, drainage ditches, etc.) to direct surface rainwater in the rainwater sewage network, and others.

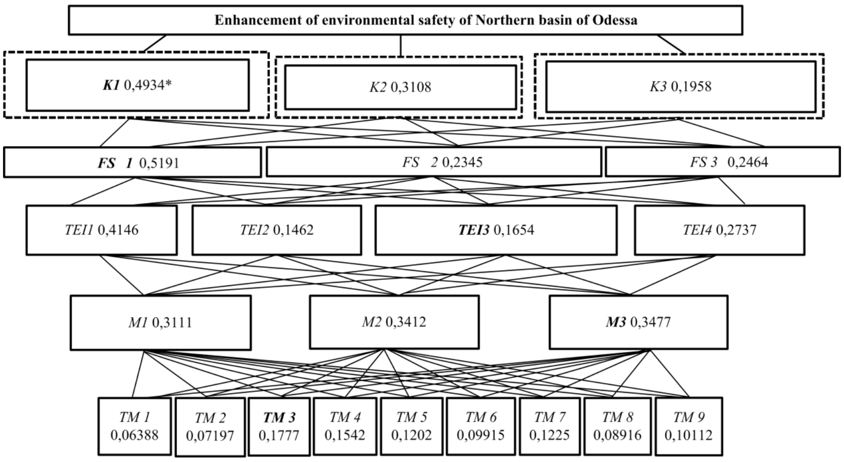

Fig. 2. Hierarchy of selection of the ecologically and socially safest TM of ESW of Northern basin, Odesa: * — weight coefficients

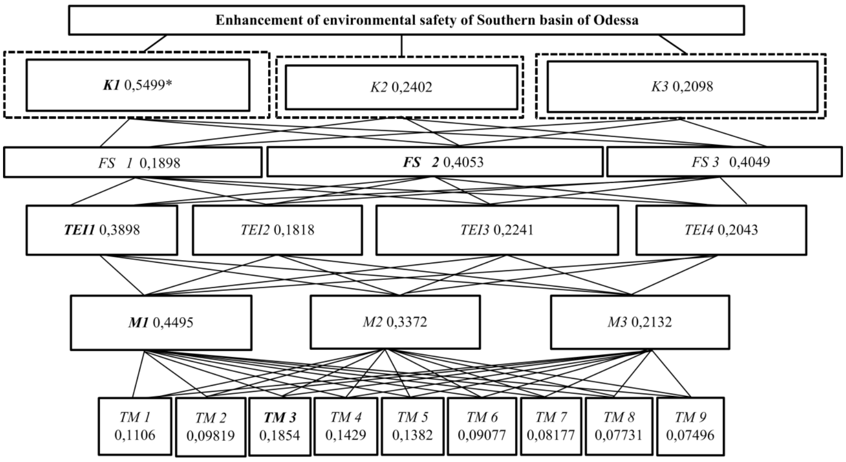

Fig. 3. Hierarchy of selection of the environmentally and socially safest TM of ESW of Southern basin, Odesa: * — weight coefficients

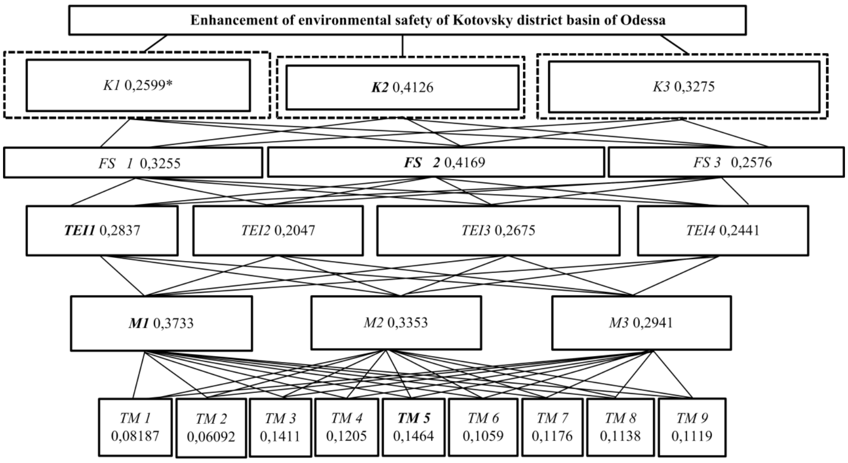

Fig. 4. Hierarchy of selection of the ecologically and socially safest TM of ESW of Kotovsky district basin, Odesa: * — weight coefficients

5. Discussion of results of research into methodological approach to selection of the technological measure of the environmentally safe drainage

The developed methodological approach enabled the specialists of local authorities of professional field (environmental, social, and economic-technological) to take part in the preparation of the consolidated recommendations for making managerial decisions on the selection of a technological measure of the environmentally safe drainage under conditions of a particular populated area.

The advantage of the proposed multi-criteria methodological approach is the ability to tie into a single decision-making algorithm the original data that vary both by their professional content, and the form of presentation (statistical, predictive, direct measurement data, expert assessments).

In addition, the advantages of the developed methodological approach include the fact that it is based on a rather developed and practically applicable analytic hierarchy process. In particular, for this method, there are several software products that make it possible to calculate source indicators effectively. In the course of working at the materials of this paper, we used program MPriority 1.0, which made it possible to conduct calculations and get consistency indices for the problem with high precision.

A limitation of this study is the actual limits of application of the proposed approach as there is the possibility of the influence of external factors and conditions, which can cause a loss of stability. In addition, in the future with the advent of new water drainage technologies, it is required to complement level 6 of the hierarchy of selection with them (Fig. 1). In this case, the number of alternatives that will need to be compared pairwise at this level of hierarchy will be exceeded (by the recommendations [17], their number should not exceed nine). In this case, it is necessary to take special measures for retaining an acceptable consistency in the problem, but it will lead to making its solution more complicated. This disadvantage may be partially offset by the exclusion from the analysis of water drainage technologies, which lose their relevance over time.

It is advisable to develop this study by the following directions:

– development of numerical multi-criteria hierarchies of selection of technological measures based of methods of analysis of systems (MAS) to increase stability and consistency of the methodological approach;

– testing on specific populated areas and development of recommendations as for the adaptation of the obtained toolset during substantiation of improvement or construction of a new drainage system of a populated area located on an eutrophied water site.

6. Conclusions

1. The methodological approach of AHP for determining priority technologies of water drainage from the territories of populated areas was designed. We proposed and used the criteria that were stated as the components of sustainable development – environmental, social and economic-technological for the decision-making method when selecting the technological measures of environmentally safe water drainage in populated areas, located on eutrophied water sites. The hierarchy elements were determined based on the management strategy in the system of ecological and social safety on the territories of populated areas.

The use of the proposed method makes it possible to order, algorithmize and adjust the procedure for expert evaluation of dissimilar factors and improve the quality of obtained results in the formation of the decision-making process.

2. Despite a rather large dimensionality of the array of elements of the multi-criteria hierarchical structure of selection of technological measures, a correct pairwise comparison with achievement of the specified consistency level ($CI \leq 10$ %) was performed for all three drainage basins of the studied populated area. It testifies to the correctness of the solution of the problem and reliability of the obtained results.

3. Based on the research of drainage basins in Odesa (Ukraine), the priority of the implementation of technological drainage measures was identified for each of them. This will make it possible to set priorities for implementing these measures depending on the availability of funds.

In addition, it is recommended to implement in full the organizational and technical measures and technologies, provided in DBN V.2.5-75:2013, in all studied regions in order to reduce the removal of pollutants by surface wastewater so that they do not penetrate the Black Sea.

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