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EXPERT-ANALYTICAL ESTIMATION OF ENVIRONMENTAL SAFETY OF SOLID HOUSEHOLD WASTE HANDLING PROCESSES

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Одним з ключових показників розвитку регіонів є екологічно безпечне поводження з відходами, у тому числі побутовими. Виконання таких завдань потребує створення ефективної системи управління побутовими відходами. Механізм вирішення цієї проблеми було запропоновано в представленій роботі. На відміну від існуючих, в ньому комплексно враховані як формування екологічних небезпек на всіх етапах життєвого циклу поводження, так і обґрунтовані та визначені пріоритети необхідних заходів управління місцевого, регіонального та державного рівнів, що мають якісну та кількісну експертну оцінку.

Проведене дослідження ієрархії відходів за директивою ЕС 2008/98/ЄС саме методом аналізу ієрархій дозволило визначити не тільки пріоритети заходів по забезпеченню екологічної безпеки процесу поводження ТПВ, а й вплив (значення) заходу на кожному з етапів. За проведеними розрахунками внески в загальну небезпеку склали: видалення – 46,15 %; утилізація – 24,02 %; знешкодження – 10,95 %; утворення – 10,95 %; збір – 5,14 %; транспортування – 2,79 %.

Оцінка характеристик чинників дозволила з'ясувати, що найбільшої уваги під час формування небезпеки потребують умови поводження, внесок яких складає – 54,95 % від усіх чинників.

Дієвість впровадження заходів для забезпечення нормативної екологічної безпеки має розподілятися так: місцеві – 60,22 %, регіональні – 22,55 %, загальнодержавні – 17,23 %.

В ході дослідження встановлено, що формування освіченості, свідомості та раціонального споживання є найбільш дієвим із заходів забезпечення екологічної безпеки і складає – 27,55 % серед тринадцяти оцінюваних заходів.

Використання запропонованого методу дозволить приймати обґрунтовані управлінські рішення по відношенню не тільки до всієї системи поводження з побутовими відходами, а й відносно кожного з етапів – від утворення до оперування.

Даний метод є досить простим у використанні та може бути застосований як на державному або регіональному рівні, так і на рівні місцевої влади

Ключові слова: екологічна безпека, системний аналіз, поводження з відходами, метод аналізу ієрархій

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1. Introduction

2.1 billion tons of solid household waste (SHW) are generated annually in the world and 30–40 % of this amount is not treated in an environmentally safe way. The World Bank report was released in 2018 on this issue and a forecast of this industry development up to 2050 was made. According to the report calculations, the amount of waste generated will double and reach a staggering level of 3.76 billion tons per year as a result of rapid urbanization, population growth and economic development [1].

Solid waste handling is a worldwide problem affecting literally each person. More than 90 % of waste is landfilled or incinerated in low-income countries [2]. This is one of the factors of long-term pollution of atmospheric air, soil, and groundwater.

In view of [2], study of SHW handling processes should be comprehensive and multicriterial in assessing environmental hazards and impact on the environment. It also requires qualitative and quantitative prioritization of environmental safety measures when making effective managerial decisions.

2. Literature review and problem statement

Ideas of «zero waste» [3] have become widespread in the 2000s, however, they are considered just as an ideology so far. To achieve the goals, comprehensive and reliable tools are required that will facilitate decision-making in the best way and support sustainable development. Decisions should have a systemic perspective, consider all actions, and make a clear estimation of alternatives.

Effectiveness of the waste management and handling system for the waste of different nature and origin depends primarily on the objects and entities generating waste. According to the factor analysis, the basic danger is associated with an inevitable waste accumulation and the derivative objects of waste handling (disposal, storage, neutralization, burial, etc.).

It is shown in [4] that about 90 % of SHW is disposed of in open dumps and waste grounds. The authors attempted to provide a comprehensive overview of management, the impact of waste recycling, its properties and handling on the environment. However, the study was concluded with only some suggestions that may be useful to encourage competent authorities and project developers to further improve the existing system. There is no comprehensive structured approach to decision making.

Assessment of the adverse effect of landfills on the environment was made in [5]. The authors have given a detailed description of groundwater and corresponding initial values established before burial. The comprehensive multi-parameter approach is useful for improving the strategy and scheme of groundwater protection and management in landfills and industrial waste-related areas.

The main objective of [6] is the study of SHW management and its place among other sectors of urban environment. A waste management index has been elaborated that can be used to compare urban areas and select management methods. In addition, a conclusion was drawn that the process of handling municipal solid waste and related infrastructure remains a serious problem for many local administrations.

An overview of national systems of municipal waste management in the context of circular economy in some European countries is presented in [7]. The article has a dual purpose. The first of them is the identification of various municipal waste management practices used in individual countries and their approaches to coverage of the circular economy. The second purpose is to determine the extent to which technologies play some role in this context.

Lack of information on SHW flows at the stages of collection and processing does not allow the policymakers and planning professionals to find appropriate environmentally and economically sound solutions. As a partial approach to solving the problem, the authors of [8] describe structure and functions of the SHW management platform based on the product-service system, in particular, data acquisition and processing, documenting SHW flows and identifying impacts on environment and human health and ways to exclude or at least reduce waste generation rate.

The study [9] compared corrections for reclamation of soils and their quality resulting from composting, turfing and pyrolysis. The financial value was established and tradeoffs between product cost and conversion efficiency were quantified.

In order to create an effective waste handling system, best international practices were considered and adapted by those European countries that have already harmonized their regulatory base with the EU laws (Fig. 1) and brought it into line with the directives considered in [10, 11].

The waste hierarchy remains a key component of the EU strategy concerning waste management. Transition to higher levels of waste hierarchy is an integral part of achieving sustainable waste management and moving to a circular economy.

Study [13] proposes a series of measures for working out routes and recovery methods that facilitate reuse of relevant products. A purposeful policy of adapting the waste recycling technology that enhances recovery of critical raw materials will encourage the use of a waste hierarchy focused on efficiency of resource use.

It is especially important to note that in order to qualitatively solve the problem of making rational decisions, it is advisable to use the methods taking into account psychological characteristics of decision-makers. One of the versions of applying the systems approach of coordinated managerial decisions is proposed in [14]. The T. Saati's hierarchy analysis method (HAM) described in detail in [15] is one of the best known and accessible to a wide circle of researchers.

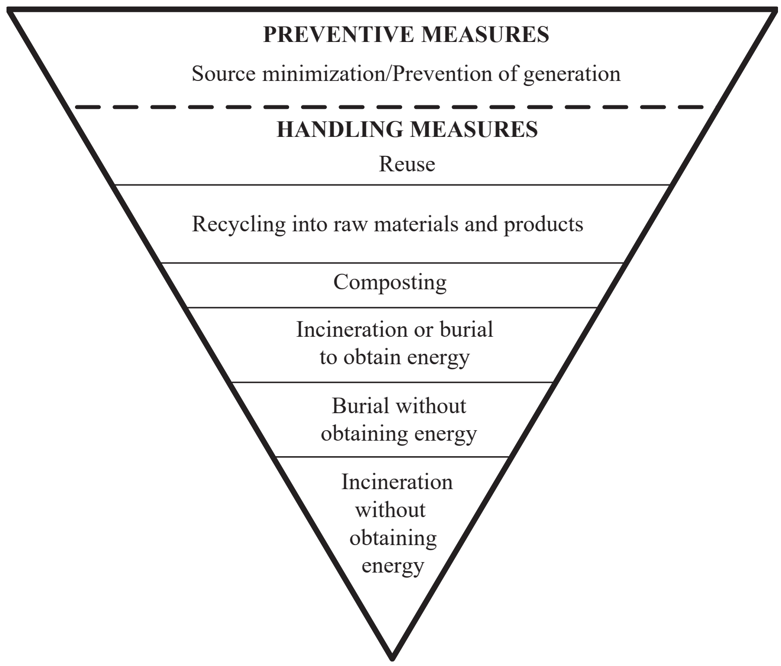

Fig. 1. Waste hierarchy [12] as the basic principles of developing environmentally safe waste management

Therefore, the development of a new approach to the system study of feasibility of applying one or other SHW handling measures listed in Directive 2008/98/EC is an important scientific and practical objective. This will provide a comprehensive combination of objective, criteria, many factors and characteristics of conditions of their interaction.

Necessity of taking into account territorial and socio-economic features of settlements, their development, level of socio-cultural consciousness of population, concerned consumers of waste as raw materials and possibilities of waste processing is equally important.

An additional task consists in determining composition and properties of the waste itself, areas of its origin, line of production activity, climatic conditions regarding the possibility of composting, etc.

The use of a comprehensive expert-analytical approach by applying the hierarchy analysis method generally meets the requirements to complexity and multicriterial approach. The method discussed in [16] is promising for solving a series of scientific and practical problems of ensuring environmental safety and effective managerial decision making.

A substantial advantage of HAM consists in the fact that this method includes checking consistency of experts' estimates in the course of study. Consistency of entire hierarchy can be estimated by multiplying each consistency index by priority of the corresponding criterion, summing the obtained numbers and comparing the result with the average index of consistency of random matrices of the same order. Ratio of consistency indexes up to 10 % is considered acceptable.

The current state of the SHW handling field remains a priority line of scientific and applied studies.

3. The aim and objectives of the study

The study objective is to improve the methodological apparatus of assessment and management of ecological safety concerning the solid waste handling processes through the use of expert-analytical procedures and comprehensive use of T. Saati's hierarchy analysis method. In contrast to the existing methods, it comprehensively takes into account both generation of environmental hazards at all stages of the life cycle of waste handling as well as substantiated and determined priorities of necessary management measures to be taken at local, regional and national levels after their qualitative and quantitative expert assessment.

To achieve the study objective, the following tasks were set:

– to develop hierarchical structures of the solid waste handling processes;

– to decompose the process of environmental safety management at each of the key stages using a comprehensive multi-criterion systems approach;

– to study the process of solid waste handling through the use of procedures of expert analytical estimation.

4. Development of hierarchical structures of solid waste handling processes for the purpose of further analytical estimation

The proposed system analysis reveals the scientific and methodological approach to multicriterial expert-analytical estimation of environmental safety of the solid waste handling processes.

Ideology and approaches of the study are in line with Directive 2008/98/EC of the European Parliament and Council (19.11.2008) and the objective set in Resolution A/RES/70/1 (UN General Assembly, 25.09.2015, summary document titled Transforming Our World: the Agenda for Sustainable Development up to 2030).

In this study, we used an expert-analytical estimation procedure using the adapted HAM for multicriterial integrated assessment (MIA) based on standard procedures of environmental impact assessment (EIA) [17]. The procedure was implemented and tested during studies of environmental safety of lengthy hydrotechnical facilities (LHF) and described in a algorithmic form shown in Fig. 2.

The study procedure used is outlined in [17, 18]. These studies detail the conducted expert-analytical procedures and application of a modified pairwise comparison scale. This allowed the authors to shorten statements of the procedure of assessment and management of environmental safety according to the waste handling hierarchy.

The conducted study has proved the possibility of simplified use of an expert team for solving the tasks that were stated.

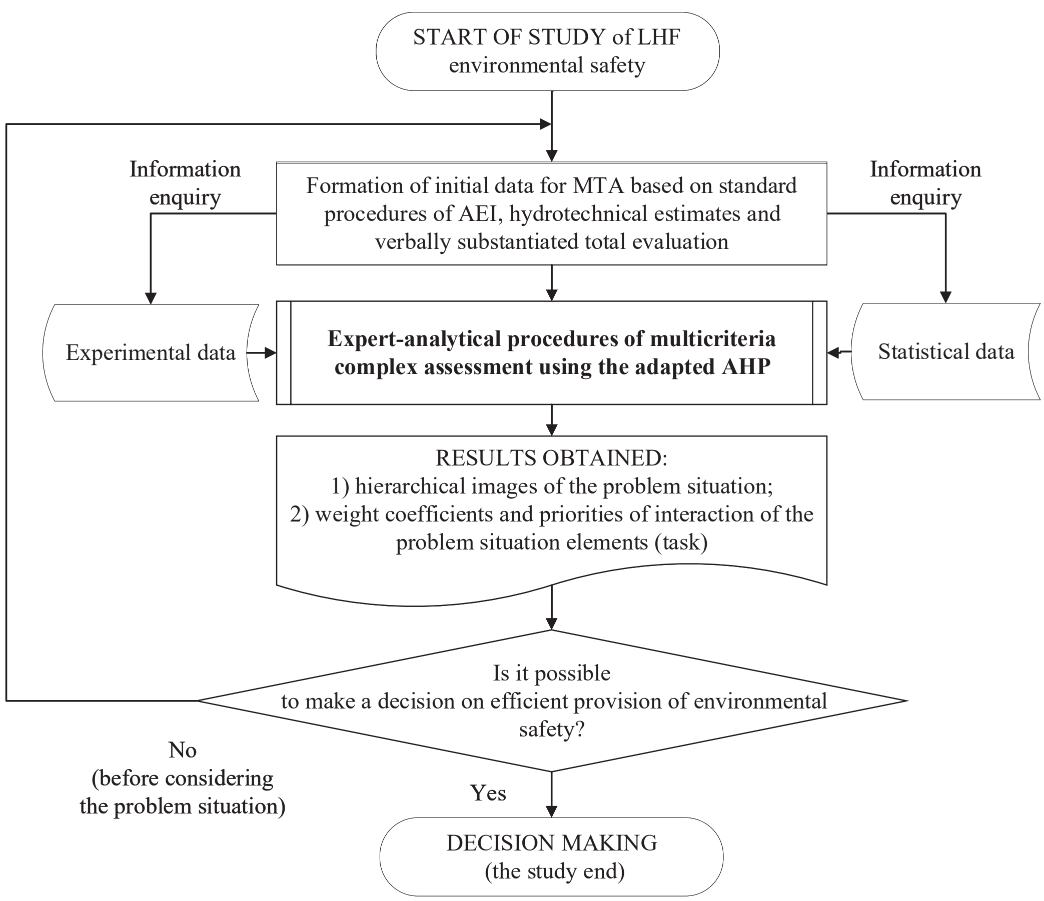

Fig. 2. The scheme of using expert-analytical procedures in environmental safety studies using the adapted HAM [17]

Only two criteria were taken as the basis for experts' choice: occupation field and experience. A level of 5 years was established according to the minimum admissible experience using the general rule. All experts had more than a 10-year professional experience in the proposed study area.

To ensure maximum support for the experts to attain the study objective, they were chosen according to the areas corresponding to the hierarchy levels, namely: estimation of environmental impact, environmental safety, national administration and control and service organization activities. This choice of experts has made it possible to cover each of the study areas and structural elements of hierarchies as much as possible.

For each of the hierarchy levels, the experts were asked only one question: which of the two elements being compared is the most dangerous or significant for the top level element?

The study used both individual and group expert estimations. The results of pairwise comparisons were analyzed using the HAM procedure. One of the criteria for admissibility of experts' opinions is consistency which was less than 10 % for each of the studied hierarchies.

Decomposition of the generalized system of SHW handling processes by the levels consistent with the principles of HAM structuring for construction of hierarchical structures in a general formalized form is presented in Fig. 3 where:

– the task objective that is assessment of danger to the environment caused by processes of SHW handling is formed at the first hierarchy level Ob (Objective);

– sub-criteria, that is, the processes of SHW handling that create danger (generation, collection, transportation, handling) are represented at the second level SCr (Sub-criteria);

– criteria, that is, components of environment that are adversely affected or contaminated and assessed from the standpoint of possible hazards are represented at the third level C (Criteria);

– characteristics of factors that create or contribute to the negative impact (quantitative and qualitative components of pollution, etc.) are considered at the fourth level ChF (Characterization of Factors);

– grouped objects that have a negative impact on environment are considered at the fifth level Go (Object Groups);

– sources of danger whose impact on the possibility of environmental safety management of the SHW handling hierarchy to be assessed in the synthesis process are considered at the sixth level SD (Sources of Danger);

– territorial level of implementation of the measures according to the authority principle (local, regional, national) is formed at the seventh level TLI (Territorial Level of Implementation);

– environmental measures that provide mitigation of negative impact and aimed at achievement of a normative level of environmental safety are considered at the eighth level SM (Security Measures).

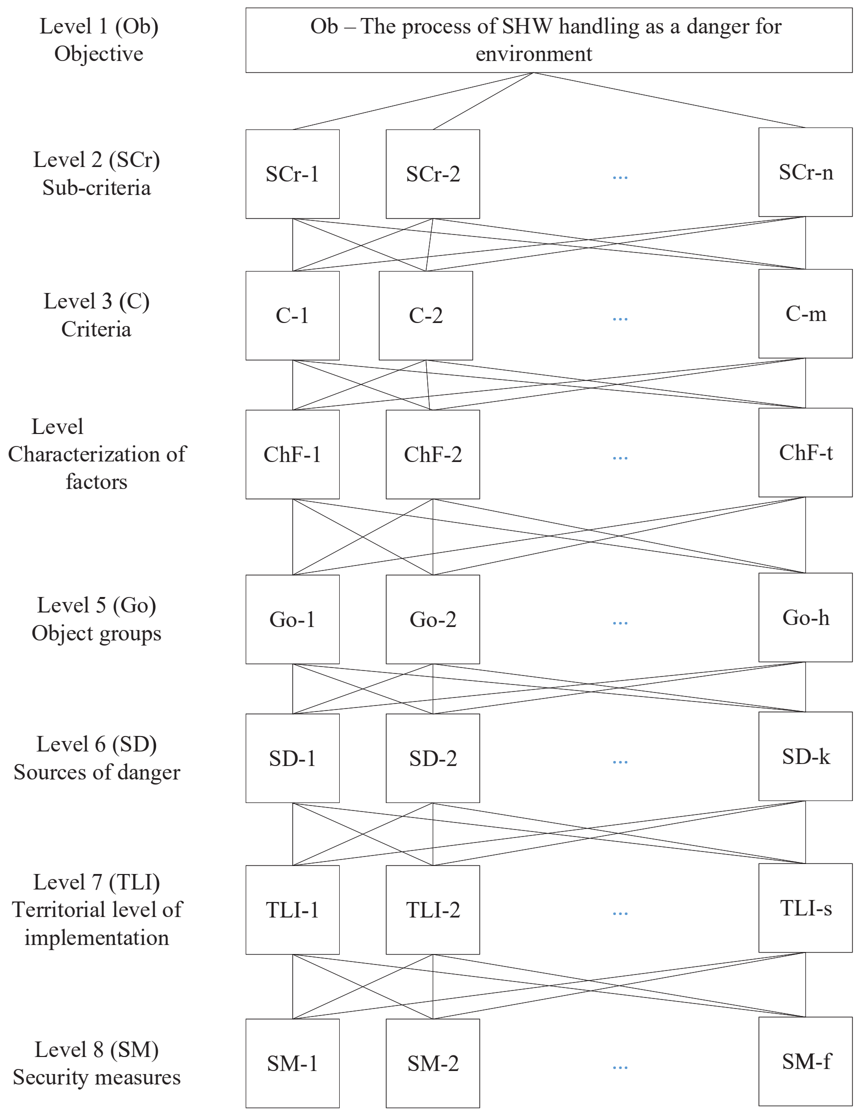

Fig. 3. The proposed approach to decomposition of SHW handling processes and construction of appropriate hierarchical structures

All the SHW handling processes listed in Fig. 3 are sub-criterial which are discussed below as separate hierarchical structures obtained by decomposition on a similar principle with exception of the intermediate levels.

5. Decomposition of environmental safety management tasks and expert-analytical studies of all processes of solid waste handling using a multi-criterion comprehensive systems approach

The proposed hierarchical structure of environmental hazard formation in the process of SHW generation and application of measures to reduce negative impact on environment is presented in Fig. 4. The overall consistency of experts' opinions for the whole scheme is 0.03371 which satisfies the HAM requirements [15]. The values of generalized weight coefficients and priorities in percentages obtained by the use of expert-analytical procedures with application of the program that implements the HAM are given in brackets.

Relationships between the hierarchy elements were established on the basis of characteristics of interaction of the elements of adjacent hierarchy levels.

An example of the developed approach to formulation of characteristics of contents of connections between elements of the adjacent upper and lower levels of the hierarchical structure and formulation of questions to the experts in the assessment process are given in Table 1.

The results of assessment of environmental hazard of the SHW generation process and the priority of measures to reduce negative impact on environment depend significantly on the formulations set forth.

Similarly to the SHW generation operation, decomposition of the task of environmental hazard assessment has been carried out and priority of management and control measures in the SHW collection process was established (Fig. 5).

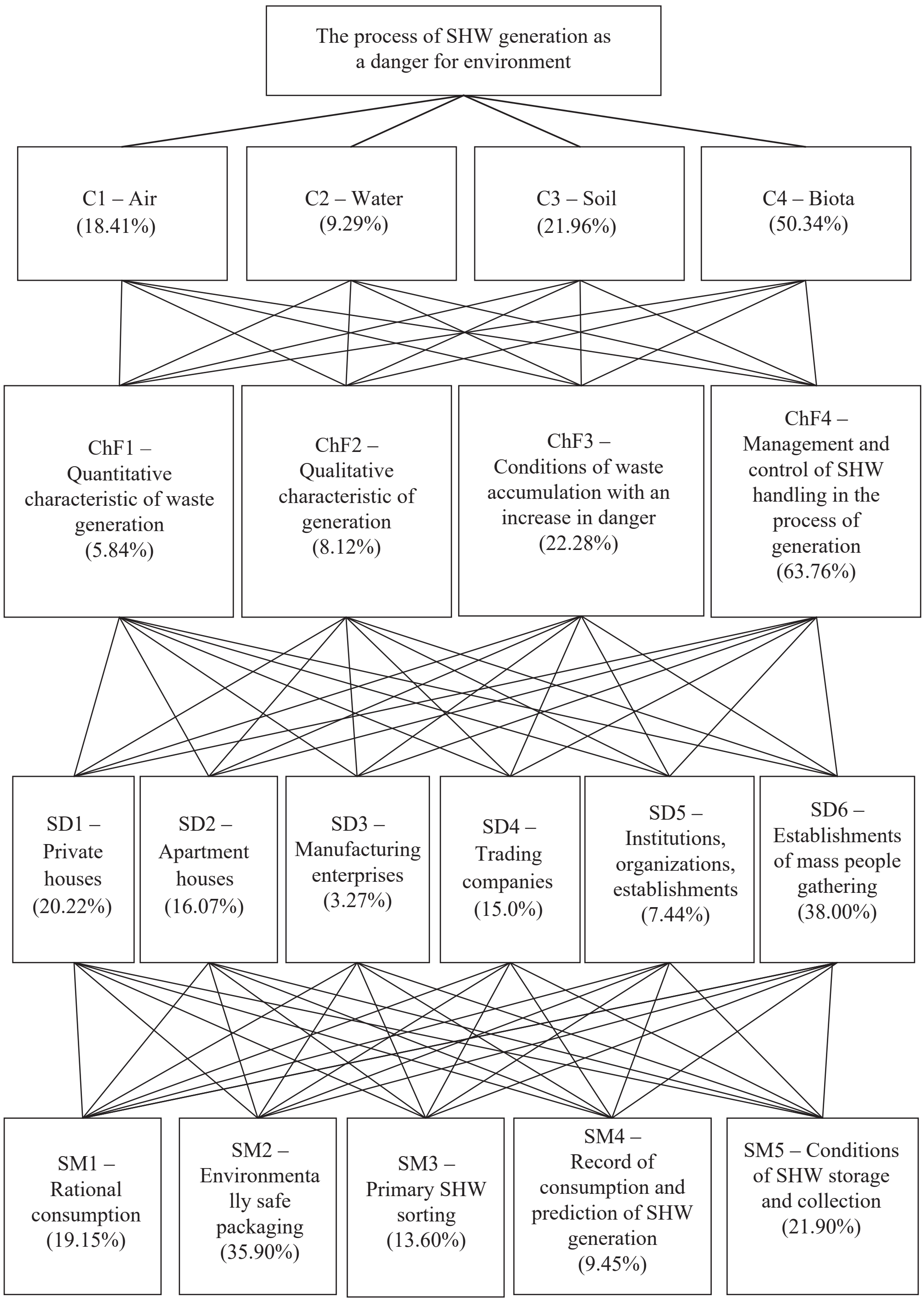

Fig. 4. Decomposition of the task of environmental safety management in the process of SHW generation

Table 1

An example of the developed approach to formulation of characteristics of content of relationship between elements for the process of SHW generation

The hierarchy level name	The lower-level elements associated with the corresponding higher-level hierarchy element	The relationship characteristic that reveals essence of interaction or influence between elements of the assessed level from the position of existing higher level and aspects of the overall purpose of assessment
1	2	3
Relationships between an element of Level 1 (Objective) and the elements of Level 2 (Criteria). Setting the task for experts for pairwise comparison of Level 2 elements: Which of the environment components can be subjected to a more direct impact in the process of SHW generation?		
Level 2. C (Criteria). Objective formulation: Assess environmental hazard of the SHW generation and the measures aimed at its mitigation Process and Measures to Reduce It	C1_Air	Possible impact of hazard of the process of SHW generation on air as a component of environment is assessed
	C2_Water	Possible impact of hazard of the process of SHW generation on water resources as a component of environment is assessed
	C3_Soil	Possible impact of hazard of the process of SHW generation on soil as a component of environment is assessed
	C4_Biota	Possible impact of hazard of the process of SHW generation on biota as a component of environment is assessed
Relationships between an element of Level 2 (Criteria) and elements of Level 3 (Characterization of factors). Setting a task for experts for pairwise comparison of the Level 3 elements: Which of the compared characterizing factors of Level 3 is likely to create greater risk for the assessed environment component of Level 2 in the process of SHW generation?		
Level 3. (Criteria) Complex impact factors (waste impact characteristic)	ChF 1: Quantitative characteristic of generation	Impact (dependence) of waste amount expressed in weight, volume, etc. on safety of the environment component. As the amount of waste increases, its impact (danger) on the environment component increases
	ChF 2: Qualitative characteristic of generation	Impact (dependence) of waste quality expressed in physical, chemical or biological properties of waste with an increase or occurrence of danger, etc., on safety of the environment component. With deterioration of the waste quality (change in physical, chemical or biological properties of the waste with an increase in or occurrence of hazard), their impact on the environment component increases
	ChF 3: Conditions of waste accumulation with an increase in danger	Influence (dependence) of conditions of waste accumulation with an increase in danger (technical characteristics of the accumulation site, timely removal of waste, mixed or separately collected waste, etc.) on safety of the environment component. Long-duration accumulation of waste is accompanied by putrefaction and decomposition processes
	ChF 4 – Management and control of SHW handling in the process of generation	Management and control of the process of SHW generation which can affect environmental safety of the environment component. Absence or poor functioning of systems of management and control of the process of SHW generation lead to aggravation of negative impact on the environment component
Relationships between elements of Level 3 (Characterization of factors) and elements of Level 4 (Sources of Danger). Setting a task for the experts for pairwise comparison of Level 4 elements: Which of the sources of SHW generation may pose a greater threat to environment provided that character of the Level 3 factor in the process of SHW generation is available?		
Level 4. (Sources of danger) Sources of SHW generation (appearance of hazard)	SD1: Private houses	Contribution of the source of SHW generation to the general (complex) characteristic of impact
	SD2: Apartment houses	Contribution of the source of SHW generation to the general (complex) characteristic of impact
	SD3: Manufacturing companies	Contribution of the source of SHW generation to the general (complex) characteristic of impact
	SD4: Trading Companies	Contribution of the source of SHW generation to the general (complex) characteristic of impact
	SD5: Institutions, organizations, establishments	Contribution of the source of SHW generation to the general (complex) characteristic of impact
	SD6: Establishments of mass people gathering	Contribution of the source of SHW generation to the general (complex) characteristic of impact
Relationships between elements of Level 4 (Sources of Danger) and elements of Level 5 SM (Security Measures). Setting a task for the experts for pairwise comparison of Level 4 elements: Which measures of the Level 5 will significantly reduce negative impact on environment for the assessed source of Level 4 in the process of SHW generation?		
Level 5. (Security Measures) Environmental safety raise measures	SM1: Rational consumption	Impact of the measure on the source of the hazard. Rational consumption is used as a set of economic or social instruments that promote efficient consumption of resources and, consequently, minimize waste generation. Spread of reuse and/or recovery of certain discarded products or their components through the use of educational, economic, and other measures

Continuation of Table 1

1	2	3
	SM2: Environmentally safe packaging of consumer products	Impact of the measure on the source of hazard. For example, the use of environmentally safe packaging materials that can decompose into environmentally safe components on their own, including promotion of clean purchases
	SM3: Primary waste sorting	Impact of the measure on the source of hazard. Waste sorting (usually packaging and packaging materials) as they are formed. This type of sorting makes it possible to qualitatively separate waste as a salvage which facilitates or increases the number of options for further treatment, reduces their quantity and improves qualitative composition
	SM4: Accounting for waste consumption and waste generation forecasting	Impact of the measure on the source of the hazard. Accounting consumption and forecasting the SHW generation (waste handling plans) take into account: – geographical features of the waste generation area, type, quantity and source of waste produced in the area, organizational aspects related to waste handling including description of distribution of responsibilities between public and private waste handling entities; – assessment of usefulness and applicability of economic and other tools in solving various waste problems taking into account the need to support proper functioning of the domestic market; – use of awareness-raising campaigns and provision of information aimed at general public or a specific set of consumers; – historic sites of contaminated waste disposal and measures of their rehabilitation
	SM5: Waste storage (accumulation) conditions before collection, transportation, or subsequent handling	Impact of the measure on the source of hazard. This choice of optimal conditions of waste accumulation for subsequent operations that minimize impact on environment components (choice of storage location, amount of accumulation before transfer, etc.)

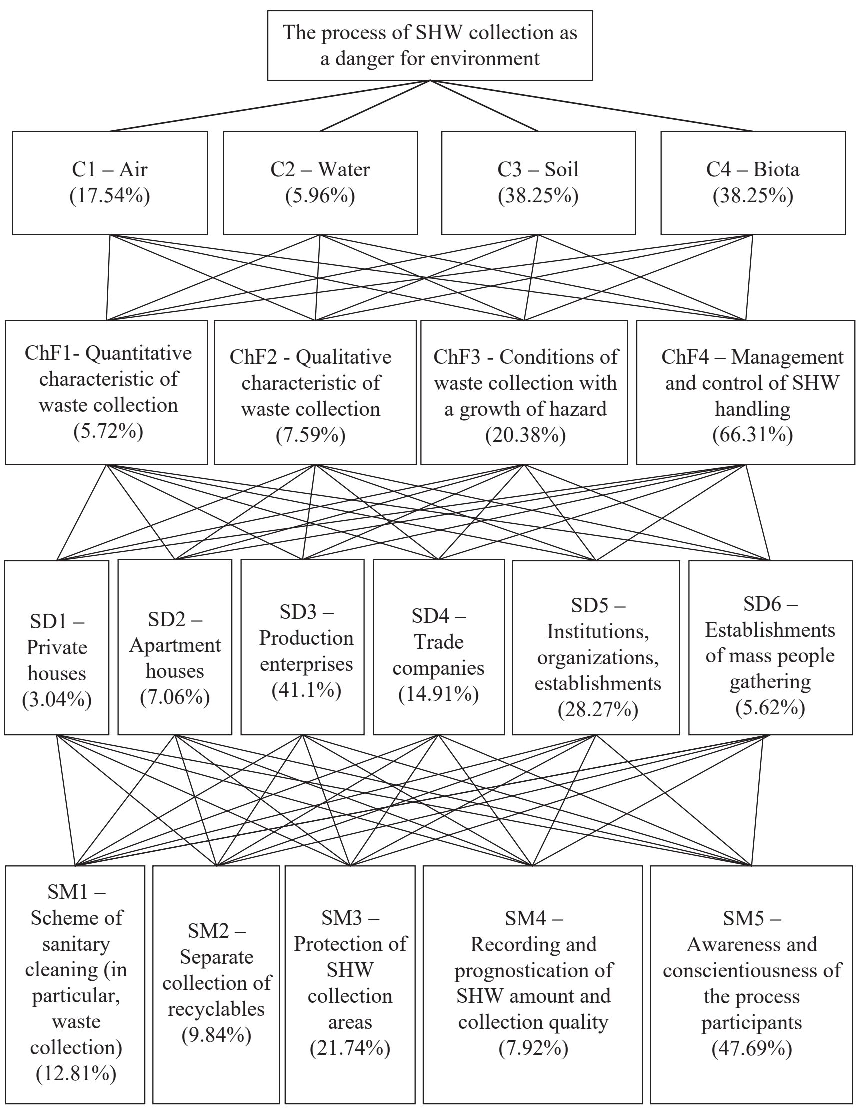

Fig. 5. Decomposition of the task of environmental safety management in the process of SHW collection

Overall consistency of experts' opinions for the whole scheme was 0.0385 which satisfies the HAM requirements [15]. The values of generalized weight coefficients and priorities in percentages obtained by application of the expert-analytical procedures using the program that implements the HAM are given in brackets.

The task of decomposition of the SHW transportation process and assessment of environmental hazards and priority of management and control measures is shown in Fig. 6. The overall consistency of the experts' opinions for the whole diagram was 0.049 which satisfies the HAM requirements [15]. The values in brackets show generalized weights and priorities in percentages obtained by application of expert-analytical procedures using the program of HAM implementation.

Assessment of the SHW operation process is shown in Fig. 7. The overall consistency of the experts' opinions for the whole diagram was 0.046 which meets the HAM requirements [15]. The values in brackets show generalized weight coefficients and priorities in percentages obtained by application of expert-analytical procedures using the program of HAM implementation.

As a result of the expert-analytical study of SHW operation, it was established that the danger of this process can be ranked according to the components as follows: 75.14 % for disposal, 17.82 % for recycling, 7.04 % for neutralization (processing, reprocessing). These values fully confirm the European ideology of waste handling set forth in Directive 2008/98/EC.

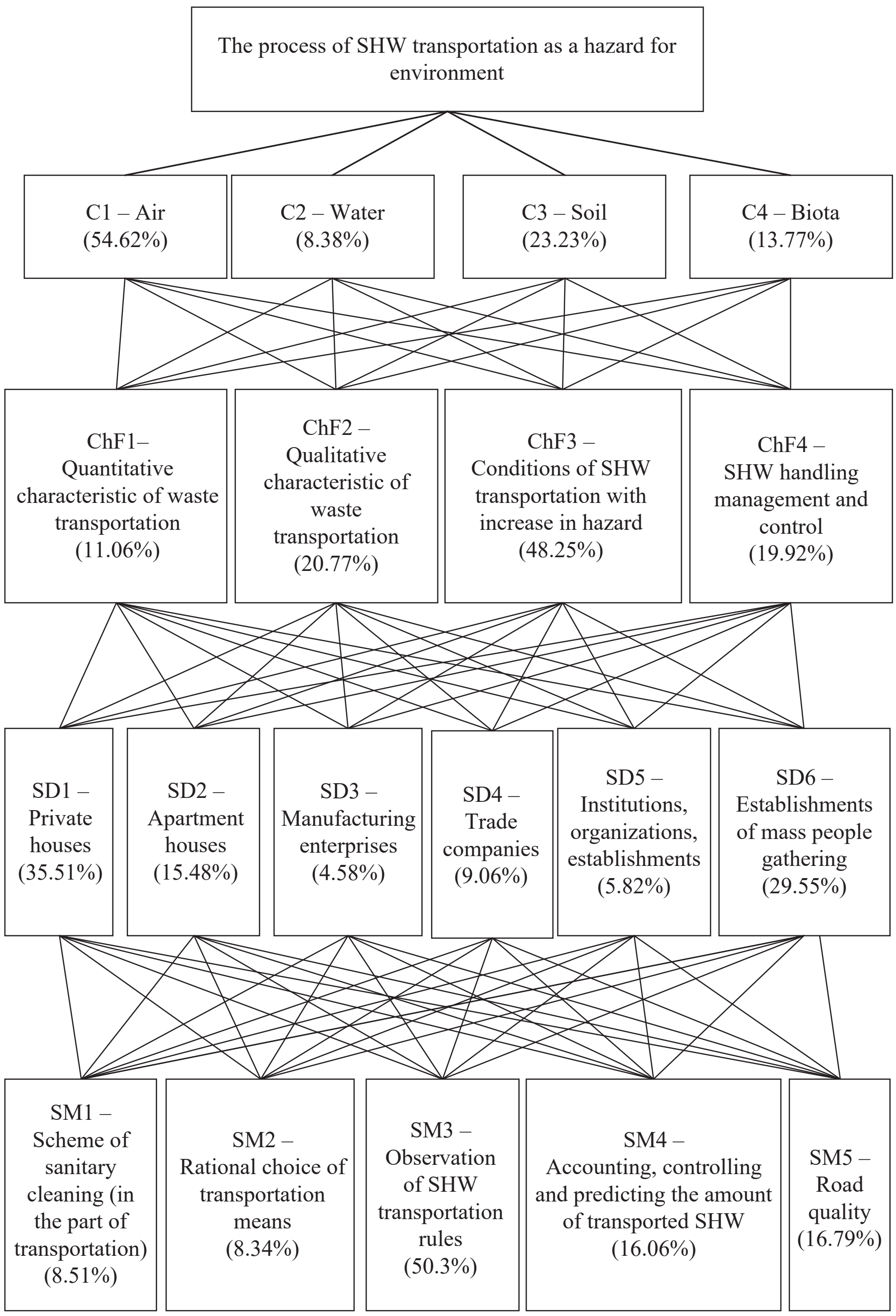

Fig. 6. Decomposition of the task of environmental safety management in the process of SHW transportation

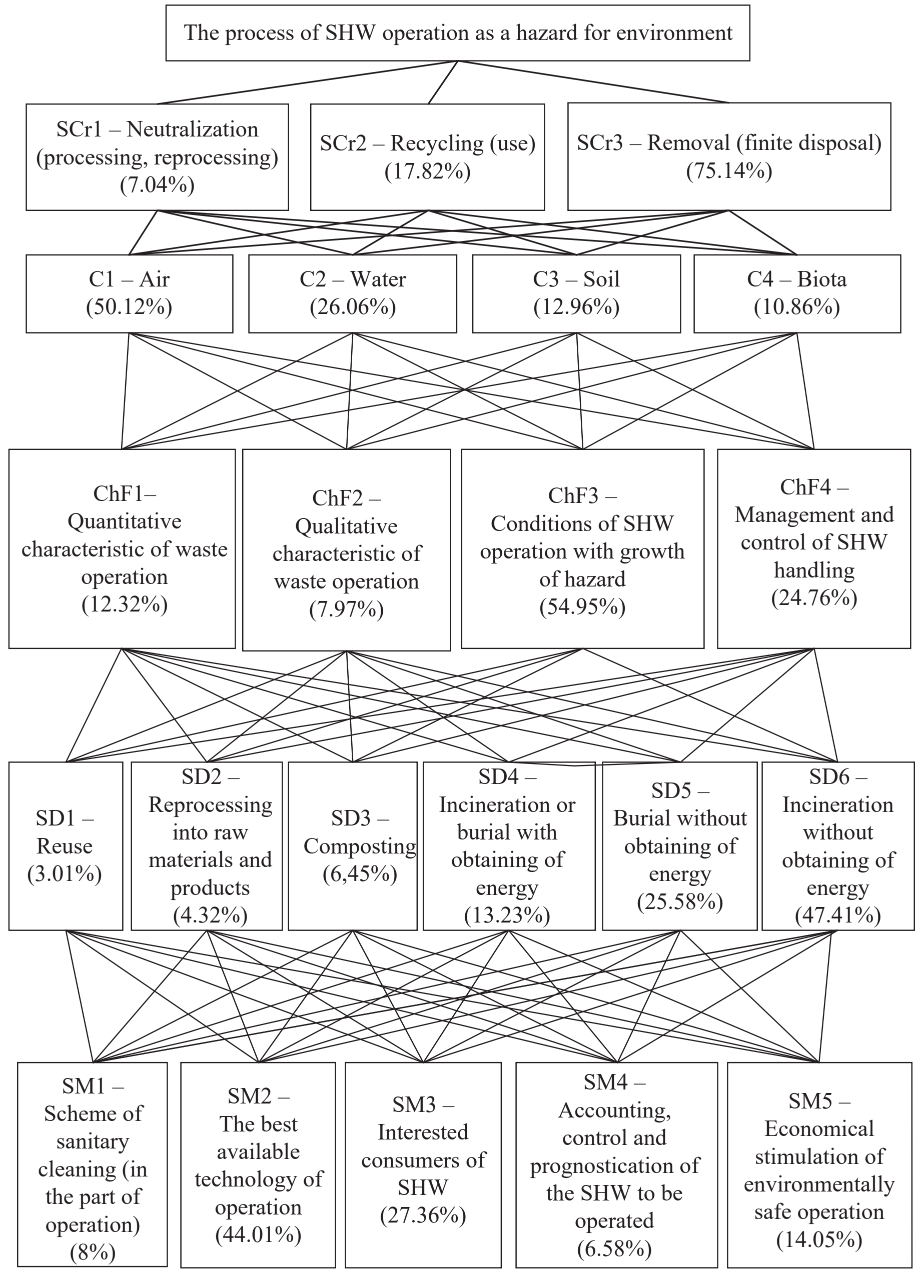

Fig. 7. Decomposition of the task of environmental safety management in the process of SHW operation

6. Synthesis of an SHW handling system with subsequent hierarchy analysis

Summarizing the results of decomposition of the tasks of each of the SHW handling operations with grouping the objects that have a negative impact, it is advisable to add a territorial level of measure implementation in the synthesis process. This is an important criterion for assessment during implementation of the policy of decentralization of public administration in Ukraine and focusing on objectives of sustainable development (Fig. 8). The overall consistency of the experts' opinions for the whole scheme was 0.056 which satisfies the HAM requirements [15]. The values in brackets show generalized weight coefficients and priorities in percentages obtained by application of the expert-analytical procedures using the program that implements the HAM.

Contents of the elements of Level 6 marked in Fig. 8 is as follows:

– SDf1: private houses;
– SDf2: apartment houses;
– SDf3: manufacturing enterprises;
– SDf4: trading companies;
– SDf5: institutions, organizations, establishments;
– SDf6: establishments of mass people gathering;
– SDo1: reusable objects;
– SDo2: facilities for processing to raw materials and products;
– SDo3: composting facilities;
– SDo4: reusable objects for obtaining energy;
– SDo5: objects for burial without obtaining of energy;
– SDo6: objects for incineration without obtaining of energy.

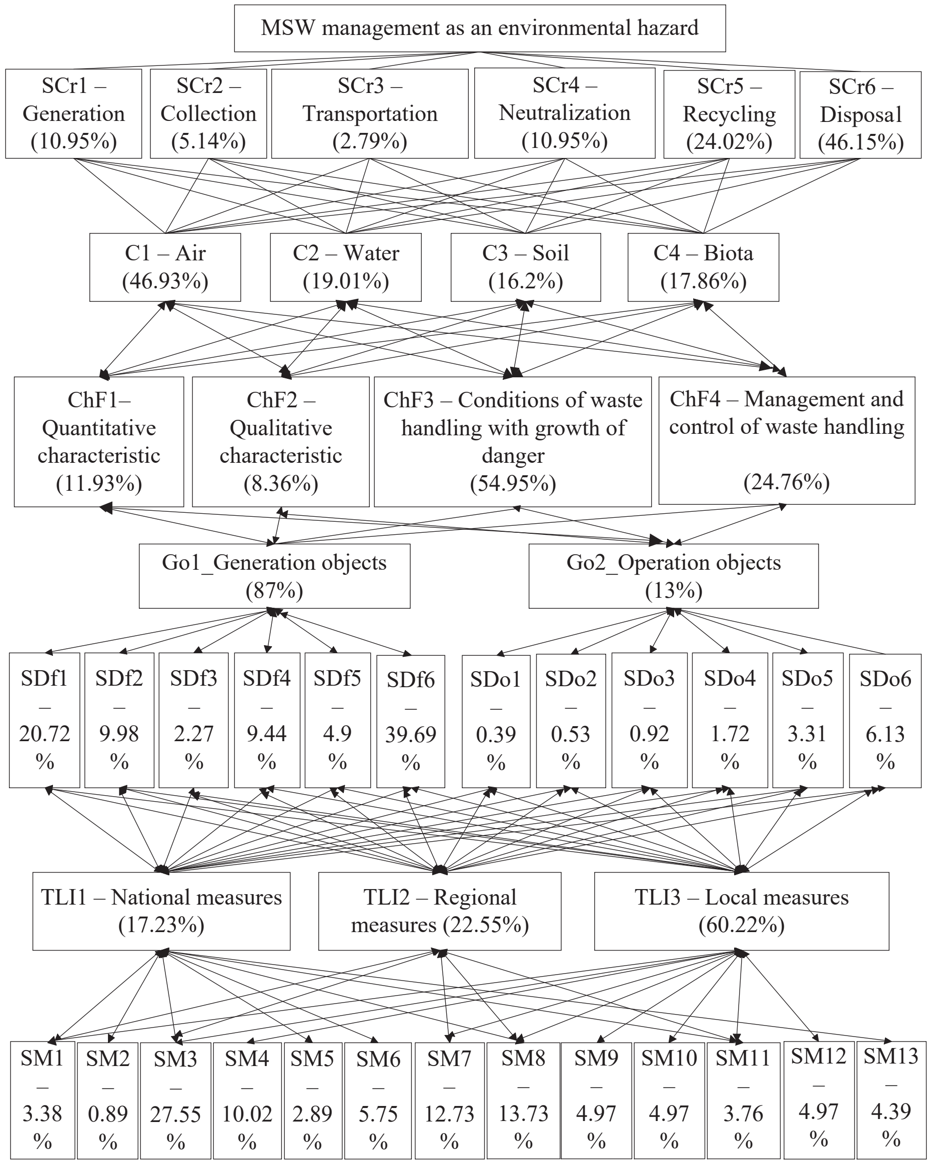

Fig. 8. Decomposition of the task of environmental safety management for all SHW handling processes

Contents of the elements of level 8 marked in Fig. 8 is as follows:

– SM1: accounting, control and forecasting of SHW handling management;

– SM2: use of environmentally safe packaging materials;

– SM3: generation of awareness, consciousness and rational consumption;

– SM4: primary sorting of SHW;

– SM5: use of the best available technologies in the process of SHW handling management;

– SM6: interested consumers of SHW;

– SM7: development of schemes of sanitary cleaning of settlements;

– SM8: separate collection of secondary raw materials;

– SM9: compliance with the rules of transportation safety;

– SM10: creation of conditions of safe waste storage (accumulation) and collection;

– SM11: quality of roads;

– SM12: protection of SHW collection sites;

– SM13: economic promotion of environmentally safe waste handling.

7. Discussion of results of expert-analytical studies

7. 1. Study of the process of SHW generation

Expert-analytical studies of the process of solid waste generation (Fig. 4) have made it possible to find out that biota (C4) can be subjected to the most dangerous impact which makes up 50.34 % of total contribution and is characterized exclusively by anthropogenic influence. Hazard for other complex environmental components is ranked as follows: 21.96 % for soil (C3); 18.41 % for air (C1); 9.29 % for water (C2).

Analysis of characteristics of the factors that create a negative impact has shown that the greatest contribution (63.76 %) to the danger of the SHW generation process for environment is caused by absence or poor quality of management and control of SHW handling management (ChF4). Growth of waste danger (22.28 %) in the process of accumulation caused by influence of external factors and climatic conditions is the second most important factor (ChF3). Quantitative (ChF1) and qualitative (ChF2) characteristics of SHW composition have the lowest contribution to hazard generation and do not exceed 10 % each.

Generalized contributions made by the types of sources of hazard generation for environment can be represented as follows:

– SD6: establishments of mass people gathering (38.0 %);
– SD1: private houses (20.22 %);
– SD2: apartment houses (16.07 %);
– SD4: trading companies (15.01 %);
– SD5: institutions, organizations, establishments (7.44 %);
– SD3: manufacturing enterprises (3.27 %).

Assessment of measures to reduce negative impact on environment based on the principles of Directive 2008/98/EC has identified priority and quantitative contribution of each of the proposed measures:

– SM2: use of environmentally safe packaging materials (35.9 %);
– SM5: provision of high-quality storage conditions prior to SHW collection (21.9 %);
– SM1: rational consumption (19.15 %);
– SM3: implementation of primary waste sorting (13.6%);
– SM4: consumption accounting and prediction of SHW generation (9.45 %).

7. 2. Study of the SHW collection process

As a result of the expert-analytical study of the SHW collection process (Fig. 5), it was found that biota (C4) and soil (C3) can have the most dangerous impact (up to 38.25 % of the total contribution of all components). The result is characterized by both peculiarities of location of collection sites and the impact of the waste itself.

Distribution of hazards for other environmental components is as follows: 17.54 % for air (C1); 5.96 % for water (C2).

Analysis of the characteristics of the factors that create a negative impact has revealed that the greatest contribution to the risk of the SHW collection process for environment includes absence or poor quality of ChF4 management and control of SHW management measuring 66.31 %. The second by importance factor is the increase in danger of waste in the process of accumulation caused by biochemical processes of decay and decomposition, influence of external factors and climatic conditions measuring 20.38 %. The quantitative (ChF1) and qualitative (ChF2) characteristics of the SHW composition make the lowest contribution to hazard generation and do not exceed 10 % each.

Generalized contributions of types of the sources of generation (SD) to hazards for environment can be ranked as follows:

– SD3: manufacturing enterprises (41.1 %);
– SD5: institutions, organizations, establishments (28.27 %);
– SD4: trade companies (14.91 %);
– SD2: apartment houses (7.06 %);
– SD6: establishments of mass people gathering (5.62 %);
– SD1: private houses (3.04 %).

Assessment of measures aimed at reduction of negative impact on environment based on the principles of Directive 2008/98/EC has identified priority and quantitative contribution of each of the proposed measures:

– SM5: raising awareness and conscientiousness of the participants of the SHW collection process which was estimated at a level of 47.69 % of the total impact;
– SM3: protection of SHW collection sites (21.74 %);
– SM1: scheme of sanitary cleaning (in the part of SHW collection) (12.81 %);
– SM2: implementation of separate collection of recyclables (9.84 %);
– SM4: accounting and forecasting the SHW amount and quality of collection (7.92 %).

7. 3. Study of SHW transportation process

As a result of the expert-analytical study of the SHW transportation process (Fig. 6), it was found out that air (C1) can be subjected to the most dangerous impact: 54.62 % of the total contribution. According to the experts, this is caused by intensive processes of waste biodegradation and additionally by transport activities which are the main air pollutants. Hazard for other environmental components is as follows: 23.23 % for soil (C3); 13.77 % for biota (C4); 8.38 % for water (C2)

Analysis of characteristics of the factors that create a negative impact has revealed that the greatest contribution (48.25 %) to the danger of the SHW transportation process is caused by violation of safe conditions of waste transportation (because of the threat of unauthorized waste disposal). The next most significant factors include unsatisfactory level of management and control of SHW handling and the qualitative characteristics of SHW composition: about 20 % each. Quantitative characteristics of SHW composition have the lowest contribution to hazard generation: 11.06 %.

Generalized contributions to the hazard generation for environment made by the types of SHW sources are as follows:

– SD1: private houses (35.51 %);
– SD6: establishments of mass people gathering (29.55 %);
– SD2: apartment houses (15.48 %);
– SD4: trading companies (9.06 %);
– SD5 institutions, organizations, establishments (5.82 %);
– SD3 manufacturing enterprises (4.58 %).

Estimation of the measures aimed at reduction of negative impact on environment based on the principles of Directive 2008/98/EC has identified priority and quantitative contribution of each of the proposed measures:

– SM3: compliance with traffic safety rules (50.3 %);
– SM5: road quality (16.79 %);
– SM4: accounting, control, forecasting of the amount of SHW transported (16.06 %);
– SM1: scheme of sanitary cleaning (in the part of transportation): (8.51 %);
– SM2: rational choice of transport means (8.34 %).

7. 4. Study of the SHW operation process

Expert-analytical studies of the SHW operation process (Fig. 7) have allowed us to establish the following.

Hazards for environmental components can be ranked as follows: 59.83 % for air (C1); 16.79 % for soil (C3); 14.39 % for biota (C4); 8.99 % for water (C2). This is caused by high anthropogenic loads from the operating processes on atmospheric air including aerobic and anaerobic processes of decomposition of the waste mass as well as waste burial prevailing over safer disposal methods.

Analysis of the characteristics of factors (ChF) that create negative impact has shown that the conditions of operation with increasing danger (ChF3) make the greatest contribution to the dangerous impact of the SHW operation process on environment (54.95 %), for example, the obvious prevalence of pollution caused by waste incineration without obtaining energy compared to composting.

The next most significant factors include unsatisfactory level of management and control (ChF4) of the operation process (24.76 %). Quantitative (ChF1) and qualitative (ChF2) characteristics of SHW operation have the lowest contribution to hazard generation: 12.32 % and 7.97 %, respectively.

Generalized contributions of the SHW source types to hazard for environment are as follows:

– SD6: waste incineration without energy generation (47.41 %);
– SD5: waste burial (25.58 %);
– SD4: recycling with energy generation (13.23 %);
– SD3: composting (6.45 %);
– SD2: SHW processing into raw materials and products (4.32 %);
– SD1: SHW reuse (3.01 %).

Assessment of the measures aimed at reduction of negative impact on environment based on the principles of Directive 2008/98/EC has identified priority and quantitative contribution of each of the proposed measures:

– SM2: use of the best available technologies in the operating processes (44.01 %);
– SM3: interested consumers of SHW: (27.36 %);
– SM5: economic incentives for environmentally safe operation (14.05 %);
– SM1: development of sanitary cleaning schemes in the part of SHW operation (8.00 %);
– SM4: accounting, control and forecasting of amount of SHW to be operated (6.58 %).

7. 5. Final study of the process of SHW handling

Due to the expert-analytical study, it was possible to determine for the first-time contributions of each of the components of the SHW handling process (Fig. 8) to the overall danger for environment:

– SCr6: disposal (46.15 %);
– SCr5: recycling (24.02 %);
– SCr4: neutralization (10.95 %);
– SCr1: generation (10.95 %);
– SCr2: collection (5.14 %);
– SCr3: transportation (2.79 %).

The hazards for environmental components can be ranked as follows: 46.93 % for air (C1); 19.01 % for water (C2); 17.86 % for biota (C4); 16.20 % for soil (C3).

Analysis of characteristics of the factors that create a negative impact has shown that the greatest contribution to the danger for environment is made by ChF3, that is, the conditions of SHW handling (54.95 %). The next most significant factors include unsatisfactory level of management and control (ChF4) of the handling process (24.76 %), quantitative and qualitative (ChF1 and ChF2, respectively) characteristics of SHW handling have the lowest contribution to hazard generation measuring 11.93 % and 8.36 %, respectively.

According to the calculations, the contribution of Go1, that is, the sources of waste generation to the overall hazard (87 %) is almost 7 times higher than the contribution of Go2, that is, the sources of operation (13 %). The above result is important in development of measures to improve environmental safety since most studies and government programs are aimed specifically at combating pollution consequences rather than the causes of their occurrence.

Generalized contributions of the SHW source types to cause hazard for environment are as follows:

– SDf6: establishments of mass people gathering (39.69 %);
– SDf1: private houses (20.72 %);
– SDf2: apartment houses (9.98 %);
– SDf4: trading companies (9.44 %);
– SDo6: combustion facilities without energy generation (6.13 %);
– SDf5: institutions, organizations, establishments (4.90 %);
– SDo5: burial facilities without energy generation (3.31 %);
– SDf3: manufacturing enterprises (2.27 %);
– SDo4: recycling facilities with energy generation (1.72 %);
– SDo3: composting facilities (0.92 %);
– SDo2: facilities of reprocessing into raw materials and products (0.53 %);
– SDo1: reuse facilities (0.39 %).

Assessment of measures to reduce negative impact on environment by the principles of «waste hierarchy» of Directive 2008/98/EC has identified priority and quantitative contribution of each of the proposed measures:

– SM3: generation of awareness, conscientiousness, and rational consumption (27.55 %);
– SM8: implementation of separate collection of secondary raw materials (13.73 %);
– SM7: development of schemes of sanitary cleaning of settlements (12.73 %);
– SM4: implementation of primary SHW sorting (10.02 %);
– SM6: interested SHW consumers (5.75 %);
– SM: protection of SHW collection sites (4.97 %);
– SM9: compliance with traffic safety rules (4.97 %);
– SM10: creation of SHW safe storage (accumulation) and collection (4.97 %);
– SM13: economic promotion of environmentally safe waste handling (4.39 %);
– SM11: quality of roads: (3.76 %);
– SM1: accounting, control and forecasting of SHW handling (3.38 %);
– SM5: use of the best available technologies in the SHW handling processes (2.89 %);
– SM2: use of environmentally safe packaging materials (0.89 %).

Establishment of territorial features of implementation of measures to improve environmental safety of SHW handling is an important result of the study. It is essential in conditions of implementation of public authorities at regional and local levels. According to the calculations, contributions of implementation of measures were distributed as follows: 60.22 % for local level; 22.55 % for regional level; 17.23 % for national level.

Contributions of SHW handling processes to the overall danger for environmental components are presented in Table 2. The results obtained make it possible to compare dangers for environments components at each stage of the SHW handling life cycle. The bottom row of the table by its values is not the arithmetic mean of all processes which indicates the presence of system-wide emergent properties.

Table 2

Contributions of SHW handling processes to the overall hazard for environmental components, %

SHW handling processes	Contribution of hazards for environmental components, %			
	Air (C1)	Water (C2)	Soil (C3)	Biota (C4)
Generation (SCr1)	18.41	9.29	21.96	50.34
Collection (SCr2)	17.54	5.96	38.25	38.25
Transportation (SCr3)	54.62	8.38	23.23	13.77
Operation (SCr4)	54.12	26.06	12.96	10.86
Handling in general	46.93	19.01	16.2	17.86

It should be noted that competence of the specialists involved, their experience in using expert-analytical methods is the main limitation of adequacy and reliability of studies by similar methods. Ability of experts to harmonize individual and team work is of significance for making coordinated decisions.

In view of the above, application of a comprehensive expert and analytical approach using the hierarchy analysis method to assess the processes and objects of SHW handling is a promising way of supporting effective managerial decisions. Its further development and implementation in securing environmental safety are expedient for use as a methodological tool for implementing the public authority principles.

8. Conclusions

1. The hierarchies developed in this study reveal the content of SHW handling processes at all stages of their life cycle: generation, collection, transportation and operation (neutralization, recycling, disposal). Ideology of T. Saati's hierarchy analysis method (HAM) makes it possible to comprehensively analyze and take into account mutual influence of all elements. The hierarchical structures that were elaborated describe in a clear and spatial way how the SHW handling processes endanger environmental components, their nature and principles of generation. Current management and control measures were considered as well.

2. The expert-analytical assessment that was carried out through a consistent review of all waste handling processes has provided an opportunity to synthesize the results obtained. The generalized hierarchical structure has allowed us to take into account additional emergent system properties for application of effective measures for managing environmental safety of waste handling.

3. The obtained values of generalized weight coefficients of hierarchy reveal in a new way the essence of generation of environmental hazards caused by waste handling. Priorities of integrated management and control measures aimed at reduction of hazards were defined more exactly as well. As a result of the expert-analytical study, it was possible to establish contributions to the overall environmental hazard made by each of the SHW handling components: disposal (46.15 %), recycling (24.02 %), neutralization (10.95 %), generation (10.95 %), collection (5.14 %), transportation (2.79 %). Hazards of the waste handling processes for environmental components are ranked as follows: 46.93 % for air, 19.01 % for water, 17.86 % for biota, 16.20 % for soil. Assessment of the factor characteristics has made it possible to find out that conditions of waste handling require the greatest attention during hazard generation. Its share is 54.95 % of all factors. According to the calculations, contribution of waste generation sources to the general hazard is almost 7 times higher than the contribution of consumption sources. Formation of environmental hazards was taken into account for all stages of the waste handling life cycle. Priorities of the measures aimed at environmental safety management to be taken at local, regional and national levels were substantiated and their values determined. Effectiveness of implementation of the measures ensuring normal ecological safety can be ranked as follows: 60.22 % for the local level, 22.55 % for the regional level and 17.23 % for the national level. It has been found that formation of people's awareness, conscientiousness and rational consumption are the most effective measures accounting for 27.55 % among the thirteen environmental safety measures assessed according to the principles of Directive 2008/98/EC.

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