THE MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESSA STATE ENVIRONMENTAL UNIVERSITY

METHODOLOGICAL INSTRUCTIONS
for practical work in the discipline
"Assessing the technogenic loading on the environment"
for higher education level "Doctor of Philosophy"
in the specialty 101 - Environmental Science,
educational program "Ecological aspects of nature management"
(field of knowledge 10 – Environmental Sciences)

Odesa – 2024

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at the meeting of the specialty
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Head of the group ____________ A.V. Chugai

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Head of the department____________A.V. Chugai

Odesa - 2024

Methodological instructions for practical work in the discipline "Assessing the technogenic loading on the environment" for higher education level "Doctor of Philosophy" daytime and evening education in the specialty 101 – Environmental Science, educational program "Ecological aspects of nature management" (field of knowledge 10 – Environmental Sciences) / Compilers: Chugay A.V., Kudelina O.Yu. Odesa: OSENU, 2024. 40 p.

CONTENT

LIST OF ABBREVIATIONS

API – air pollution index
APMS – air pollution monitoring station
BOC – biochemical oxygen consumption
CAPI – complex air pollution index
COC – chemical oxygen consumption
CPIndex – combinatorial pollution index
CPIndic – complex pollution indicator
ChPI – chemicall pollution indicator
CTIO – critical transport infrastructure objects
ERC – enterprise risk coefficient
GE – geological environment
HM – heavy metals
LPI – limiting pollution indicator
MMSD – metric for measuring sustainable development processes
MPC – maximum permissible concentration
OCTI – objects of critical transport infrastructure
OP – oil products
PP – petroleum products
PSI – pollution susceptibility indicator
SD – sustainable development
SI – security indicator
SPI – soil pollution index
SS – synthetic surfactants
TLI – technogenic loading index
TLM – technogenic loading module
UW – underground water
WPI – water pollution index
WW – wastewater

INTRODUCTION

The discipline "Assessing technogenic loading on the environment" is taught when preparing the candidates for the "Doctor of Philosophy" Higher Educational Level in the specialty 101 "Ecology".

The educational discipline belongs to the list of mandatory disciplines of the Educational Curriculum "Ecological Aspects of Nature Management".

Studying the discipline is based on the knowledge obtained by the "Bachelor" level students and the "Master" level students, first of all, in the specialties 101 "Ecology" and 183 "Environmental Protection Technologies". The list of such disciplines includes "Environmental monitoring", "Environmental safety", "Systemic analysis of environmental quality", "Theoretical and methodological foundations of environmental safety", etc. Studying the discipline for the PhD candidates is based on the knowledge obtained from the course "Statistical Research Methods in Ecology". The knowledge gained when studying the course can then be used during the scientific and scientific-pedagogical practice.

The total amount of teaching time for studying the discipline is 45 hours for the lecture course and 30 hours for practical works.

The aim of the course is to familiarize applicants with existing approaches to assessing the technogenic impact on the atmosphere, water bodies, the soil cover and the geological environment, with the methods for assessing individual types of loading, as well as with the complex indicators for assessing technogenic loading on the environment when conducting scientific researches within the specific topic of dissertation preparing (PhD).

When studying the discipline "Assessing technogenic loading on the environment" the applicants studying in the specialty 101 "Ecology", the Educational Curriculum "Ecological Aspects of Nature Management", should ***know***:

– the basic methods and indicators of assessing technogenic impact on the environmental components;
– the methods of assessing individual types of loading and the conditions of their application;
– the methods of assessing technogenic loading on the environment using complex indicators.

The applicants must ***also be able to***:

– carry out assessing the pollution level and the technogenic impact on the individual components of the environment (the atmosphere, the water environment, the soil cover, the geological environment);
– carry out assessing the individual types of technogenic loading;

– carry out assessing and ranking the level of technogenic loading on the environment using complex indicators;
– determine the optimal assessment methods taking into account the available initial information.

The control of current knowledge is carried out by writing module test papers and oral examining at the practical classes. The form of the final control is credit.

The purpose of performing the practical works is to examine in details the theoretical principles and forming the ability to apply them in practice through doing the practical tasks; enlarging, deepening and detailing the knowledge obtained at the lectures and when working independently. It contributes to increasing the level of material assimilation and consolidating abilities and skills in calculating technogenic impact indicators on the environment. The methodological instructions consist of 7 practical works that corresponds to the theoretical course topics and are necessary for mastering the course.

Doing the practical tasks takes place at the practical classes. To perform a practical task, you need to familiarize yourself with the theoretical basis of calculating with the help of a teacher or independently (according to the methodical instructions). Using the variant of the task, the calculation is performed and the conclusion is made taking into account the obtained results.

1 ASSESSING THE TECHNOGENIC IMPACT ON THE AIR POOL

Assessing the atmosphere quality indicators is based on two main approaches (methods) [1]:

1) the method of comparison, which means the comparison of the determined or calculated value of any indicator (parameter) with the normative value – the method of maximum permissible concentration (*MPC*);

2) the method of integral assessing, which allows to provide assessing the quality of the air pool in a separate district or a settlement as a whole for the certain pollutants based on calculating complex indicators.

1.1 Calculating air pollution indexes

In practice, air pollution indexes (*API*) are most often used, their determining differs according to the methodical approach.

The most common is the method of calculating based on the results of normalization by the value of *MPC*, obtained at the network of air pollution monitoring points (APMS). Such *API (I)* is calculated according to the formula:

$$I=\left(\frac{q_m}{MPC_{ms}}\right)^{C_i}, \tag{1.1}$$

$$\text{or } I=\left(\frac{\bar{q}}{MPC_{ad}}\right)^{C_i}, \tag{1.2}$$

where q_m and $\bar{q}$ – respectively, the maximum and average concentrations of pollutant in the atmosphere, mg/m^3;

C_i – a constant that takes the value of 1.7; 1.3; 1.0; 0.9 respectively for the 1st; 2nd; 3^{d}; 4th risk class pollutants and allows to reduce the *i*-pollutant degree of harmfulness to the SO_2 degree of harmfulness [2].

With $API \leq 1$, it is considered that the quality of the air pool in terms of the content of a separate P meets the sanitary and hygienic requirements [2].

The complex atmosphere pollution index *(CAPI)* – is a quantitative characteristic of the atmosphere pollution level formed by *n* substances presenting in the atmosphere of the city. *CAPI* (I_n) is calculated according to the formula:

$$I_n = \sum_{i=1}^{n} I_i = \sum_{i=1}^{n}\left(\left(\frac{\bar{q}}{MPC_{ad}}\right)^{C_i}\right)_i. \quad (1.3)$$

CAPI can be calculated for one or more *(K)* APMS of the city as the sum of all *API* [2].

I_5 index, which takes into account the values of single *APIs* of those five pollutants for which these values are the largest, can also be used as *CAPI*:

$$I_5 = \sum_{i=1}^{5} I_i. \quad (1.4)$$

According to the value of I_5, the following classes of atmosphere air pollution are distinguished: $I_5 < 2.5$ – clean atmospheric air; $I_5 = 2.5 – 7.5$ – slightly polluted; $I_5 = 7.6 – 12.5$ – polluted; $I_5 = 12.6 – 22.5$ – heavily polluted; $I_5 = 22.6 – 52.5$ – highly polluted; $I_5 > 52.5$ – extremely polluted atmospheric air [2].

A.V. Priymak [2] suggests using the "pollution danger index" as *API*:

$$I_{dan} = \sqrt{\sum_{i=1}^{n} k_i^2}, \quad (1.5)$$

where k_i is the exceedance of *MPC* in the examined impurity [2].

The total indicator of the atmosphere air pollution is almost similar:

$$P = \sqrt{\sum_{i=1}^{n} K_i^2}, \quad (1.6)$$

where the concentrations of pollutants of the 1st; 2nd; 3d; 4th hazard class in the particles of *MPC* (K_i) were brought to the biologically equivalent 3rd class of danger for the isoefficiency coefficients (for the 1st class – 2.0; the 2nd class – 1.5; the 3d class – 1.0; 4th grade - 0.8) [2].

In Australia, the air quality index *AQI* is used. The content of 5 pollutants is analyzed, namely ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide and suspended solids. *AQI* is calculated according to the formula:

$$I_P = (C_P / C_{Ps}) \cdot 100\ \%, \quad (1.7)$$

where I_P is the pollution index;

C_P – the pollutant concentration;

C_{Ps} – the standard concentration of a pollutant [3].

According to *AQI* values, 5 categories of the atmosphere air quality are distinguished (Table 1.1).

Table 1.1 – Categories of the air quality by *AQI* value [3]

Category	***AQI* Range**
Very good (*VG*) air quality	0 – 33
Good (*G*) air quality	34 – 66
Normal (*F*) air quality	67 – 99
Poor *(P)* air quality	100 – 149
Very poor (*VP*) air quality	≥ 150

Tasks for practical work

1. Calculate the following *API*, according to the individual variant received from the teacher:

- indicators of the atmosphere pollution with individual pollutants I and I_{dan};
- complex indicators of the atmosphere pollution I_5, P, I_p.

2. Make up the classification of the atmosphere pollution level based on the results of I_5 and I_p calculations and the comparative analysis regarding the possibility of applying certain complex *API*.

3. At will the task can be made according to an individual variant proposed by the applicant on the topic of the dissertation research.

Initial information for making calculations

Variant 1:

Average annual content of the certain pollutants (mg/m^3) in the atmosphere of towns in the Kyiv region (2019)

Town	**Dust**	SO_2	CO	NO_2	O_3
Pereyaslav	0,01	0	0,7	0	0
Irpin	0,03	0,02	0,9	0,02	0,01
Vishneve	0,02	0,01	0,5	0,01	0
Bojarka	0	0	0,3	0	0

Variant 2:

Average annual content of the certain pollutants (mg/m^3) in the atmosphere of towns in the Kyiv region (2019)

Town	**Dust**	SO_2	CO	NO_2	O_3
Kaharlic	0,01	0	0,8	0,02	0
Uzin	0,01	0,02	0,8	0,02	0,02
Obuhiv	0,02	0,04	1,0	0,08	0,02
Ivankiv	0,03	0,01	0,8	0	0

Variant 3:

Average annual content of the certain pollutants (mg/m^3) in the atmosphere of towns in the Kyiv region (2020)

Town	**Dust**	***SO_2***	***CO***	***NO_2***	***NO***	***O_3***
Pereyaslav	0,14	0,03	3,48	0,08	0,03	0,1
Irpin	0,17	0,02	0,46	0	0,08	0
Vishneve	0,01	0,02	7,63	0,14	0,04	0,1
Bojarka	0,01	0,02	0,76	0,02	0,09	0

Variant 4:

Average annual content of the certain pollutants (mg/m^3) in the atmosphere of towns in the Kyiv region (2020)

Town	**Dust**	***SO_2***	***CO***	***NO_2***	***NO***	***O_3***
Kaharlic	0,01	0	0,8	0,02	–	0
Uzin	0,03	0,02	0,8	0,02	–	0
Obuhiv	0	0,049	0,7	0,14	0,04	0,1
Ivankiv	0,01	0,01	0,15	0,06	0,03	0,1

1.2 Calculating the enterprise risk factor

One of the methods of assessing technogenic loading on the air basin is calculating the enterprises risk coefficient *(ERC)*:

$$ERC = \sum_{i=1}^{n} \left(\frac{M_i}{MPCad_{\,i}}\right)^{\alpha_i}, \qquad (1.8)$$

where n is a number of harmful substances contained in the enterprise's emissions;

M_i – mass of the *i*-substance emission, t/year;

MPC_{ad} – average daily *MPC* of the *i*-pollutant, mg/m^3;

α_i is a constant that allows you to reduce the degree of harmfulness of the *i*-substance to the harmfulness of sulfur dioxide and takes values 1.7; 1.3; 1.0; 0.9 depending on the class of danger substances (1, 2, 3, 4) respectively.

The variant of assessing, if appropriate information is available, is to calculate *ERC* per one enterprise of the city ($\overline{ERC}$):

$$\overline{ERC}=1/k\sum_{i=1}^{k} ERC_i. \qquad (1.9)$$

where ERC_i is the risk coefficient for the *i*-enterprise [4].

The results of calculating the enterprise risk category, depending on the ERC_i value, are classified according to the developed characteristics of technogenic loading on the air basin (Table 1.2) [1].

Table 1.2 – Characteristics of technogenic loading on the city air basin according to *ERC* indicator [1]

***ERC* values**	**Risk category**	**Characteristics of technogenic loading**
$\geq 10^8$	I	high
$10^8 > ERC \geq 10^4$	II	increased
$10^4 > ERC \geq 10^3$	III	medium
$< 10^3$	IV	low

<u>Tasks for practical work</u>

1. According to the individual variant, received from the teacher, calculate *ERC* of the individual enterprises in the Mykolaiv region. Information on the MPC_{ad} and the risk class of the pollutants is given by the link [5].
2. Calculate the *ERC* indicator for the Mykolaiv region.
3. To provide a description of the technogenic loading on the air basin of the Mykolaiv region, taking into account the obtained results.
4. If desired, the task can be completed according to an individual variant proposed by the applicant on the topic of the dissertation research.

Initial information for making calculations

<u>Variant 1:</u>

Polluting substances emissions (tons) into the atmosphere from the enterprises of the Mykolaiv region (2014)

Pollutant's name	**Pollutant's code**	**South-Ukrainian NPP**	**Mykolaiv alumina plant**	**Yug-cement**	**Mykolaiv-vodokanal**	**Zorya-Mashproekt**
1	2	3	4	5	6	7
Arsenic and its compounds	1001	–	–	0,058	–	–
Iron and its compounds	1003	0,075	–	0,331	–	–
Nickel	1006	–	–	0,079	–	–
Mercury	1007	–	–	0,001	–	–
Lead and its compounds	1009	–	–	0,046	–	–
Chromium and its compounds	1010	0,004	–	0,146	–	1,091
Aluminum oxide	1101	–	204,961	–	–	0,166

Table continuation

1	2	3	4	5	6	7
Manganese and its compounds	1104	0,016	–	0,021	0,005	–
Soot	3004	0,084	0,026	–	0,004	1,542
Nitrogen dioxide	4001	3,917	809,520	650,594	0,266	41,867
Nitrous oxide	4002	0,013	1,451	1,177	2,103	0,382
Ammonia	4003	3,220	0,020	–	–	5,421
Nitric acid	4004	0,053	0,024	–	–	–
Sulfuric anhydride	5001	0,433	0,533	0,451	0,667	–
Hydrogen sulfide	5002	0,096	0,040	–	49,003	–
Sulfuric acid	5004	0,072		–	0,003	0,929
Carbon monoxide	6000	8,609	246,531	137,359	3,821	219,742
Acrolein	11004	–	–	–	–	0,054
Acetone	11007	–	0,001	–	0,098	7,379
Butyl acetate	11009	–	0,001	0,097	0,140	2,232
Ethylbenzene	11019	–	–	–	–	0,518
Ethyl acetate	11021	–	–	–	–	0,442
Acetic acid	11028	–	–	–	–	0,066
Xylene	11030	1,800	0,002	0,056	0,031	6,480
Styrene	11037	–	–	–	–	0,607
Toluene	11041	0,312	0,003	0,039	0,813	7,442
Phenol	11048	–	–	–	–	0,022
Formaldehyde	11049	–	–	–	–	0,014
Chlorine	15000	0,013	0,004	–	0,441	0,971
Hydrogen chloride	15003	0,005	0,004	–	0,001	–
Hydrogen fluoride	16001	0,016	–	0,010	0,005	0,348

Variant 2:

Polluting substances emissions (tons) into the atmosphere from the enterprises of the Mykolaiv region (2015)

Pollutant's name	**Pollutant's code**	**South-Ukrainian NPP**	**Mykolaiv alumina plant**	**Yug-cement**	**Mykolaiv-vodokanal**	**Zorya-Mashproekt**
1	2	3	4	5	6	7
Arsenic and its compounds	1001	–	–	0,066	–	–
Iron and its compounds	1003	0,167	–	0,331	–	–
Nickel	1006	–	–	0,086	–	–

Table continuation

1	2	3	4	5	6	7
Mercury	1007	–	–	0,001	–	–
Lead and its compounds	1009	–	–	0,050	–	–
Chromium and its compounds	1010	0,004	–	0,156	–	1,087
Aluminum oxide	1101	–	206,266	–	–	0,159
Manganese and its compounds	1104	0,016	–	0,021	0,005	–
Soot	3004	0,033	0	–	0,004	9,673
Nitrogen dioxide	4001	2,679	822,840	515,156	0,266	63,068
Nitrous oxide	4002	0,012	1,473	1,192	2,103	0,504
Ammonia	4003	3,220	0,020	–	–	5,426
Nitric acid	4004	0,053	0,024	–	–	–
Sulfuric anhydride	5001	0,430	0	0,451	0,667	–
Hydrogen sulfide	5002	0,096	0,040	–	49,003	–
Sulfuric acid	5004	0,072	–	–	0,003	0,939
Carbon monoxide	6000	8,920	–	305,116	3,821	179,789
Acrolein	11004	–	–	–	–	0,008
Acetone	11007	–	0,001	–	0,098	6,285
Butyl acetate	11009	–	0,001	0,097	0,140	1,931
Ethylbenzene	11019	–	–	–	–	0,272
Ethyl acetate	11021	–	–	–	–	0,405
Acetic acid	11028	–	–	–	–	0,068
Xylene	11030	1,800	0,002	0,056	0,031	4,075
Styrene	11037	–	–	–	–	0,413
Toluene	11041	0,312	0,003	0,039	0,813	6,202
Phenol	11048	–	–	–	–	0,022
Formaldehyde	11049	–	–	–	–	0,014
Chlorine	15000	0,016	0,004	–	0,441	1,007
Hydrogen chloride	15003	0,005	0,004	–	0,001	0,939
Hydrogen fluoride	16001	0,016	–	0,010	0,005	0,346

Variant 3:

Polluting substances emissions (tons) into the atmosphere from the enterprises of the Mykolaiv region (2016)

Pollutant's name	**Pollutant's code**	**South-Ukrainian NPP**	**Mykolaiv alumina plant**	**Yug-cement**	**Mykolaiv-vodokanal**	**Zorya-Mashproekt**
Arsenic and its compounds	1001	–	–	0,030	–	–
Iron and its compounds	1003	0,252	–	0,359	–	–
Nickel	1006	–	–	0,040	–	–
Mercury	1007	–	–	0	–	–
Lead and its compounds	1009	–	–	0,022	–	–
Chromium and its compounds	1010	0,004	–	0,072	–	1,061
Aluminum oxide	1101	–	218,402	–	–	0,159
Manganese and its compounds	1104	0,016	–	0,017	–	–
Soot	3004	0,016	0	–	0,004	11,275
Nitrogen dioxide	4001	2,849	884,483	631,501	0,266	71,146
Nitrous oxide	4002	0,011	1,535	3,523	2,103	1,028
Ammonia	4003	3,220	0,050	–	–	5,412
Nitric acid	4004	0,056	0,024	–	–	–
Sulfuric anhydride	5001	2,539	7,128	0	0,667	–
Hydrogen sulfide	5002	0,096	0,126	–	49,003	–
Sulfuric acid	5004	0,072	–	–	0,003	0,926
Carbon monoxide	6000	9,029	259,223	107,823	3,821	196,074
Acrolein	11004	–	–	–	–	0,009
Acetone	11007	–	0,001	–	0,098	4,175
Butyl acetate	11009	–	0,001	0,262	0,140	1,076
Ethylbenzene	11019	–	–	–	–	0,138
Ethyl acetate	11021	–	–	–	–	0,256
Acetic acid	11028	–	–	–	–	0,060
Xylene	11030	1,800	0,002	0,056	0,031	2,155
Styrene	11037	–	–	–	–	0,267
Toluene	11041	0,310	0,003	0,039	0,813	3,539
Phenol	11048	–	–	–	–	0,022
Formaldehyde	11049	–	–	–	–	0,014
Chlorine	15000	0,016	0,004	–	0,441	1,076
Hydrogen chloride	15003	0,005	0,004	–	0,001	0,930
Hydrogen fluoride	16001	0,016	–	0	0,005	0,346

2 ASSESSING THE TECHNOGENIC IMPACT ON THE SURFACE WATERS

There are 3 main groups of surface water assessment methods: the comparison method; the methods of assessing water quality as a habitat for hydrobionts; the methods of comprehensive assessing the water body quality or the water body pollution using integral indicators [1].

The comparison method is based on the comparison of chemical, physical and biological indicators of the water quality with the corresponding regulatory characteristics [1].

The methods of assessing the water quality as a habitat involve an assessment based on the data from the hydrobiological observations. In practice, the methods of comprehensive assessment using integral (complex) quality indicators are most often used.

Comprehensive assessing the surface water pollution is an idea of their pollution or quality degree, which is expressed through a certain system of indicators or a limited set of characteristics of the water composition and properties, which are compared with the water quality criteria or standards for a given type of water using (water consumption) [6].

The list of comprehensive assessment methods using in different countries is quite large. Let's list some of them.

1. *The graphic method* is based on drawing up a graphic model of the surface water quality, which is a circular diagram with the scale-radii corresponding to a certain hydrochemical indicator [2] (Fig. 2.1). The application of this method makes it possible to determine whether MPC are exceeded by the content of all quality indicators, which are monitored simultaneously.

2. Calculating *the water pollution index (WPI)* based on 6 indicators (ammonium nitrogen, nitrite nitrogen, petroleum products (PP), phenols, dissolved oxygen, BOC_5) according to the formula [6]:

$$WPI=\frac{1}{6}\sum_{i=1}^{n}\frac{C_i}{MPC_i}, \tag{2.1}$$

where C_i – an average arithmetic value of the water quality indicator.

There is a modification of *WPI* [6], which takes into account 2 mandatory (BOC_5 and dissolved oxygen) and 4 other indicators with the greatest ratio to *MPC*. These 4 indicators are selected from the following list: sulfates, chlorides, *COC*, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, phosphates, total iron,

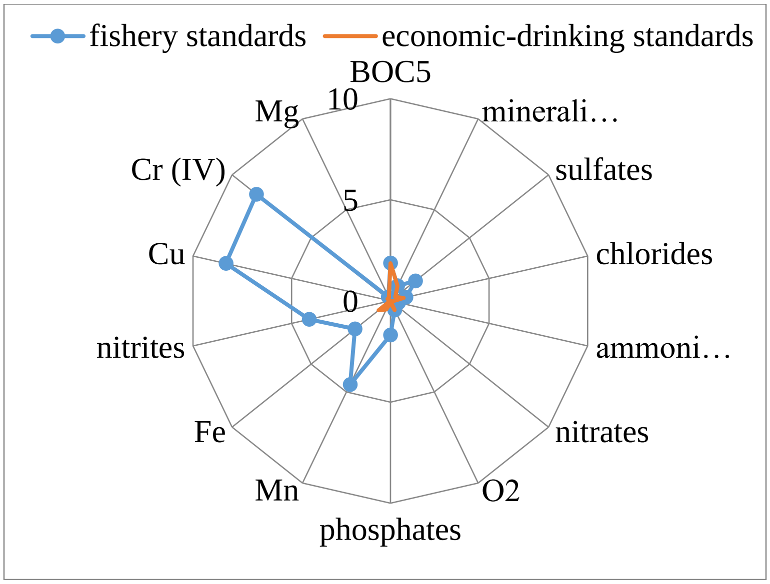

Figure 2.1 – The example of implementing the graphic method of surface water quality assessing

manganese, copper, zinc, chromium (VI), nickel, aluminum, lead, mercury, arsenic, PP and *SS*.

3. *Methodology of ecological assessing the surface water quality* according to the relevant categories. The assessment can be of two types: thorough or indicative. Three block indexes are calculated: the saline composition pollution index *(I_1)*; the tropho-saprobiological (ecological-sanitary) index *(I_2)*; the index of toxic and radiation action specific indicators *(I_3)*. At the end, the integral (ecological) index (I_E) is determined [7]:

$$I_E = \frac{(I_1 + I_2 + I_3)}{3}. \qquad (2.2)$$

4. *The chemical pollution indicator ChPI-10* is determined by 10 ingredients. Among them, there are general ones that are mandatory for assessing (dissolved oxygen, *BOC*, suspended substances, nitrogen group substances, etc.), and there are substances that are most characteristic for a specific water body. *ChPI-10* is determined by the formula:

$$ChPI\text{-}10 = \sum_{i=1}^{10} \frac{C_i}{MPC_i}. \qquad (2.3)$$

Moreover, for pollutant's concentrations that do not exceed their *MPC*, the ratio *C* / *MPC* is taken to be equal to 1. Thus, only above-standard pollution is taken into account. When using this indicator, it is necessary to develop one's own water quality classification, which can vary widely: from 10, which corresponds to unpolluted water, and higher [10].

5. *Methodology for assessing the land surface water quality based on hydrochemical indicators* (the Hydrochemical Institute methodology). This methodical approach allows to define a quality level and a quality class based on the value of the combinatory pollution index (*CPIndex*), to identify the priority pollutant's based on the number and the composition of limiting pollution indicators (*LPI*), as well as to perform differentiated assessing. To define the water quality level, the classification based on the recurrence of pollution cases, the frequency of exceeding standards and the pollution nature is carried out [8].

Assessing technogenic loading on the surface water bodies is also performed using various methodological approaches.

To analyze the ecological state and the technogenic impact on the river basin, it is possible to use the method of assessment based on the degree of its water resources using. The following indicators are used:

- W_i – the volume of water intake from the river network, million m^3;
- W_l – the volume of river runoff loss due to the groundwater abstraction, which is hydraulically connected to the river network, million m^3;
- W_a – the actual volume of the river flow, million m^3;
- W_d – the total volume of wastewater (WW) discharge into the river network, million m^3;
- W_{pw} - the volume of polluted WW discharge into the river network, million m^3 [8].

Taking into account the above indicators, the following parameters are calculated:

- using the river flow q_1;
- irreversible water consumption q_2;
- WW inflow to the river network q_3;
- WW discharge q_4 [8].

In accordance with the specified parameters, certain criteria for assessing the state of the river were adopted.

To estimate the level of technogenic loading from the utility facilities, the indicator of the specific multiplicity of *MPC* exceedings ($K_{sp.exc}$) can be used. The methodology makes it possible to assess the pollution of municipal enterprises wastewaters according to 5 indicators, which most fully characterizes the work of biological treatment facilities (BOC_{tot}, nitrogen nitrate, nitrite, ammonium, phosphates) [2].

In order to count the influence of the wastewater discharges volumes on the water bodies, the correction coefficients that take into account the actual drainage of biological treatment stations have been introduced:

$$K_{sp.exc} = \left[\frac{1}{n} \cdot \sum \frac{C_i}{MPC_i}\right], \tag{2.4}$$

where $K_{sp.exc}$ – the specific multiplicity of MPC exceedings;

C_i – the i-pollutant concentration in the treated WW, respectively, mg/dm^3;

$$C_Q = 0.4666 \cdot Q_{actual}^{\,0.2545}, \tag{2.5}$$

where C_Q – the correction coefficient;

Q_{actual} - the actual drainage volume, m^3/day [2].

The technogenic loading index on the water bodies (TLI_{WO}) is determined by the formula [12]:

$$TLI_{WO} = K_Q \cdot K_{sp.exc.} \tag{2.6}$$

The classification of technogenic loading levels according to the developed classification is given in the Table 2.1.

Table 2.1 – Classification of technogenic loading levels on water bodies [2]

Loading level	$K_{sp.exc}$	TLI_{WO}
Insignificant	< 1	< 2
Low	1 – 5	2 – 8
Medium	5 – 10	8 – 16
High	10 – 20	16 – 33
Critical	> 20	> 33

Also, one of the approaches is assessing the efficiency of water consumption and water drainage in the region using the following coefficients [2]:

– the water supply efficiency coefficient

$$C_1 = \frac{Q_{withd} - Q_{tl}}{Q_{withd}}, \tag{2.7}$$

– the water drainage efficiency coefficient

$$C_2 = 1 - \frac{Q_{wt}}{Q_{dis} - Q_{n/clean}}, \tag{2.8}$$

– the complex coefficient of water using efficiency assessment

$$C = C_1 \bullet C_2, \tag{2.9}$$

where Q_{withd} – the water withdrawal from natural water sources for using, million m^3;

Q_{tl} – water losses during the transportation, million m^3;

Q_{wt} – WW discharging without treating, million m^3;

Q_{dis} – WW discharging into the water bodies, million m^3;

$Q_{n/clean}$ – the volume of normatively clean WW (which do not require treating), which is discharged into the water bodies, million m^3 [13].

Tasks for practical work

1. According to the individual variant received from the teacher, to evaluate the efficiency of water using in the certain regions of Ukraine.
2. To analyze changing the water supply efficiency coefficients C_1 and the water drainage efficiency coefficients C_2 during the calculation period.
3. To carry out a comparative analysis of the water using efficiency in the certain regions, as well as to determine the indicators by which changes in the water consumption and drainage indicators are noted.
4. If desired, the task can be done according to an individual variant proposed by the applicant on the topic of the dissertation research.

Initial information for performing the calculations

Variant 1:

Water consumption and water drainage indicators in the regions of the Western Ukraine, million m^3

Region	Year	Q_{withd}	Q_{tl}	Q_{wt}	Q_{dis}	$Q_{n/clean}$
the Volynsk region	2017	71,18	8,03	0,01	29,82	5,88
	2018	69,24	9,0	0,428	28,4	4,833
	2019	67,69	8,311	0,425	29,1	4,972
the Transcarpathian region	2017	46,01	9,97	0,379	36,08	2,905
	2018	47,2	9,38	0,381	36,5	3,907
	2019	39,74	10,28	0,361	39,112	7,984
the Ivano-Frankivsk Region	2017	82,8	12,7	0,028	60,11	8,06
	2018	90,62	12,48	0,012	62,46	9,5
	2019	89,09	11,97	0,007	61,08	8,587
the Lviv region	2017	175,8	54,03	1,191	167,6	14,41
	2018	172,3	47,0	1,256	164,9	14,77
	2019	168,6	45,46	1,532	156,1	11,79
the Rivne region	2017	126,3	5,404	0	4,498	20,41
	2018	119,7	6,6	0	4,449	18,01
	2019	124,9	6,378	0	4,631	17,56

Variant 2:

Water consumption and water drainage indicators in the regions of the Central Ukraine, million m^3

Region	Year	Q_{withd}	Q_{tl}	Q_{wt}	Q_{dis}	$Q_{n/clean}$
the Vinnytsia region	2017	101,9	13,82	0,013	62,54	34,77
	2018	101,7	14,2	0	65,5	36,43
	2019	91,11	14,55	0	59,73	30,03
the Kirovohrad region	2017	181,76	6,241	0	43,65	20,49
	2018	146,78	5,605	0	24,88	12,94
	2019	171,2	5,105	0	34,57	11,38
the Poltava region	2017	47,71	16,72	0	70,55	2,555
	2018	41,28	15,18	0	71,2	2,861
	2019	39,97	15,46	0	68,72	2,549
the Cherkasy region	2017	179,6	9,91	1,168	106,5	59,67
	2018	172,6	9,62	1,564	87,62	40,28
	2019	184,4	9,68	0,06	87,57	42,52

Variant 3:

Water consumption and water drainage indicators in the regions of the Southern Ukraine, million m^3

Region	Year	Q_{withd}	Q_{tl}	Q_{wt}	Q_{dis}	$Q_{n/clean}$
the Zaporizhzhia region	2017	1171	67,93	0,384	956,1	847,1
	2018	1214	60,2	0,37	888,4	777,2
	2019	1151	61,86	0,019	819,6	714,9
the Mykolaiv Region	2017	247,1	90,54	0	60,29	37,08
	2018	241,1	86,6	0	64,9	42,84
	2019	233,2	76,29	0,053	75,14	53,5
the Odesa region	2017	1851	610,2	87,45	381,5	115,7
	2018	2071	713,4	34,29	388,0	179,4
	2019	832,9	246,7	32,59	154,6	42,07
the Kherson region	2017	1668,24	186,7	0,54	69,35	38,16
	2018	2983,6	212,2	1,997	71,7	36,59
	2019	2551,0	237,6	0,639	86,18	42,55

3 ASSESSING THE TECHNOGENIC IMPACT ON THE SOIL COVER AND THE GEOLOGICAL ENVIRONMENT

There are several basic approaches to assessing the condition and technogenic loading on the soil cover and geological environment (GE). They contain indicators of quantitative assessment based on the comparison with *MPC*, background values, the methods of territory ranking according to the level of technogenic loading, etc.

The level of chemical soil pollution can be estimated by indicating the concentration coefficient (K_c) [2]:

$$K_c = \frac{C_i}{C_b}, \tag{3.1}$$

where C_i – the concentration of the *i*-th type chemical element;

C_b – the background value of the *i*-th type chemical element.

Instead of a background value of a chemical element, *MPC* of the specific pollutant can be used; at the same time, the coefficient of technogenic geochemical loading (K_i) is calculated [2]:

$$K_i = \frac{C_i}{C_{MPC}}. \tag{3.2}$$

In the case of a polyelement composition of the technogenic or natural anomaly, the total pollution index (Z_c) or the total loading index (Z_p) is calculated:

$$Z_C = \sum_{i=1}^{n} K_c - (n - 1), \tag{3.3}$$

$$Z_P = \sum_{i=1}^{n} K_i - (n - 1), \tag{3.4}$$

where n is the number of anomalous components which are taken into account.

Taking into account the obtained Z_c values, it is possible to assess the danger of technogenic soil pollution with a complex of metals (Table 3.1) [2].

In the case of polycomponent technogenic pollution, it is possible to determine the complex pollution indicator (*CPIndic*) according to the formula [9]:

$$CPIndic = \sum_{i=1}^{n} K_i, \tag{3.5}$$

where n is a number of pollutants.

Table 3.1 – Oriented scale for assessing the danger of soil pollution by the total pollution index (Z_c)

Soil pollution categories	**Z_c value**	**Changing the population health indicators in the pollution centers**
Permissible	Less than 16	The lowest child sickness rate and the minimum frequency of functional abnormalities.
Moderately dangerous	16-32	Increase in overall morbidity.
Dangerous	32-128	Increasing the general morbidity, a number of children who are often sick, children with chronic diseases and disorders of the cardiovascular system functional state.
Extremely dangerous	More than 128	Increasing the child morbidity, impairing the reproductive woman function (increasing pregnancy toxicosis, premature births, stillbirths, baby hypotrophy)

The scale of soil pollution assessment according to the value of *CPIndic* is given in Table 3.2 (*n* – the number of elements included in the calculations).

Table 3.2 – Oriented scale for assessing the danger of soil pollution according to the *CPIndic*

A level of soil pollution	***CPIndic values***
Moderate	$N < CPIndic < 3n$
High	$3n < CPIndic < 10n$
Extremely high	$CPIndic > 10n$

Also, one of the soil quality indicators is the soil pollution index (*SPI*) [2]:

$$SPI=\sum_{i=1}^{n}\left(\frac{C_i}{C_{MPC}}\right)/n. \tag{3.6}$$

According to the *SPI* value the following categories of the soil quality are distinguished: *SPI* < 0.75 – clean soils; *SPI* = 0.75 – 1.0 – problem soils; *SPI* > 1.0 – contaminated soils.

There are also well-known methods for assessing the condition of GE components. For example, the groundwater pollution susceptibility indicator (*PSI*) is used to characterize the relationship between the groundwater pollution (*GW*) and the general environmental pollution, [2]:

$$PSI = TLM / SI, \tag{3.7}$$

where *TLM* – the sum of weight units of all waste types (solid, liquid, gaseous) from the industrial, agricultural and communal objects for a period of time (1 year), assigned to the administrative district or region within these objects are located, t/km^2 per year;

SI - the security indicator, expressed in points.

The following *PSI* gradations are distinguished:

1) *PSI* < 0.01 (very low susceptibility degree);
2) *PSI* = 0.01 – 0.1 (low susceptibility degree);
3) *PSI* = 0.1 – 1 (moderate degree of propensity);
4) *PSI* = 1 – 10 (average susceptibility degree);
5) *PSI* = 10 – 100 (high susceptibility degree);
6) *PSI* > 100 (very high susceptibility degree) [2].

To assess the *GE* stability quantitatively, the stability coefficient *(Cs)* which value varies from 0 to 1 is suggested to use [2]. In the case when a decrease in the ecological and geological quality of the system is accompanied by a decrease in any indicator, the value of the stability coefficient is determined by the formula:

$$Cs = N_t / N_o, \tag{3.8}$$

where N_t – an indicator of any feature of soil or other GE component, which was affected by technogenic impacts;

N_o – the same impact indicator.

In the case when a decrease in the system quality is characterized by an increase in any indicator, *Cs* is determined by the formula:

$$Cs = N_o / N_t. \tag{3.9}$$

According to the value of the stability coefficient, the following categories of the *GE* components resistance to the technogenic impact are distinguished:

– very high (*Cs* = 1.0–0.95);
– high (*Cs* = 0.95–0.8);
– average (*Cs* = 0.8–0.5);
– low (*Cs* = 0.5–0.1);
– unstable (*Cs* = 0.1–0).

To identify the patterns of spatial distribution and the nature of the variability of technogenic impacts in a certain territory, as well as to assess the multidirectionality degree of technogenic impacts, such indicators as the coefficients of the plane technogenic loading (C_{ptl}) distribution and the linear technogenic loading (C_{ltl}) distribution are used (Table 3.3) [2].

When calculating the coefficients of plane and linear technogenic loading, a square of the building plan coordinate grid on the scale of 1:1000 is used as an area

Table 3.3 – Quantitative indicators of the technogenic impact sources [2]

Quantitative indicator of technogenic impact sources	**Formula**	**Range of indicator changes**	**Name of the technogenic loading range**
the coefficient of the plane technogenic loading distribution	$C_{ptl} = S_{to} / S_s$	$0 \le C_{ptl} \le 0{,}2$ $0{,}2 < C_{ptl} \le 0{,}8$ $0{,}8 < C_{ptl} \le 1{,}0$	absent average high
the coefficient of the liner technogenic loading distribution	$C_{ltl} = L_{tlн} / S_s$	$C_{ltl} = 0$ $0 < C_{ltl} \le 0{,}01$ $0{,}01 < C_{ltl} \le 0{,}03$ $0{,}03 < C_{ptl} \le 0{,}05$ $C_{ptl} > 0{,}05$	absent very weak weak average high

unit. In the formulas in Table 3.3 S_{to} is a square area occupied by technogenic objects; L_{tl} – the length of the transport line; S_s is a square area [2].

According to the typification of technogenic impact sources, the coefficients of plane and linear technogenic loading are quantitative characteristics of the spatial distribution and the technogenic impact multidirectionality degree of the volume-plane (buildings, structures) and linear (engineering communications, roads) direction objects (C_{ptl} – "down", C_{ltl} – "along"). In order to assess the joint impact of different type technogenic impact sources on the GE, the total impact coefficient (C_{sti}), which is the weighted average value of quantitative indicators of the technogenic impact sources on the GE, is proposed as a generalizing criterion:

$$C_{sti} = \frac{\sum_{i=1}^{n} C_i \cdot P_i}{\sum_{i=1}^{n} P_i} . \qquad (3.10)$$

where *Ci* – the coefficient of technogenic loading (linear, plane, volumetric, etc.);

Pi – the weight (the degree of impact or significance) of the *i-th* coefficient;

n – the number of factors which are taken into account [2].

<u>Tasks for practical work</u>

1. According to the individual variant received from the teacher, to calculate the following indicators: *CPIndic* and *SPI*.
2. To assess the degree of soil pollution with heavy metals (HM) according to both indicators (HM *MPC* are given in Table 3.4).
3. To give a conclusion about the advantages (disadvantages) of using the methods.
4. If desired, the task can be done according to an individual variant proposed by the applicant on the topic of the dissertation research.

Table 3.4 – Heavy metals *MPC* in soils, mg/kg

Standard	**Metal**					
	Cd	***Pb***	***Cu***	***Zn***	***Co***	***Hg***
MPC	0,7	6,0	3,0	23,0	5,0	2,1

Initial information for performing the calculations

Variant 1:

The content of HM in the soils of the Poltava region, mg/kg

Year	***Cd***	***Pb***	***Hg***	***Cu***	***Zn***
2017	0,21	1,36	0,02	0,3	0,69
2018	0,21	1,38	0,025	0,47	1,27
2019	0,2	1,37	0,013	0,55	3

Variant 2:

The HM content in the soils of the certain districts of the Lviv region (2019), mg/kg

Region	***Cd***	***Pb***	***Cu***	***Zn***	***Co***
Drohobytskyi	0,28	1,47	1,1	1,26	1,46
Zhovkivskyi	0,3	1,42	1,1	1,24	1,68
Zolochivskyi	0,2	1,36	0,9	1,08	1,74

Variant 3:

The HM content in the soils of the certain districts of the Lviv region (2019), mg/kg

Region	***Cd***	***Pb***	***Cu***	***Zn***	***Co***
Brodovsky	0,25	1,42	1,0	2,44	1,42
Pustomitovskyi	0,3	1,62	0,9	1,81	1,56
Busky	0,35	1,74	1,05	1,42	2,32

Variant 4:

The HM content in the soils of the certain districts of the Lviv region (2019), mg/kg

Region	***Cd***	***Pb***	***Cu***	***Zn***	***Co***
Yavorivskyi	0,2	1,61	0,9	1,14	1,32
Horodotskyi	0,25	1,45	0,9	0,78	1,8
Przemyslyanskyi	0,45	3,56	2,2	1,68	3,51

4 COMPLEX INDICATORS FOR ASSESSING THE TECHNOGENIC LOADING ON THE ENVIRONMENT

The indicator system for assessing the technogenic loading is conditionally divided into 2 main groups:

1) indicators for assessing a particular type of loading or the load on a certain natural environment;
2) complex assessing indicators.

4.1 Assessing the individual types of loading

Transport loading for a separate territory can be calculated using several indicators. These include, for example, the *Ti* indicator, which is determined by the formula:

$$T_i = \frac{1}{S_i}\sum l_k \cdot B_k, \tag{4.1}$$

where *Si* is the district area;

l_k is the length of the road that has the k^{th}-evaluation of the transport tension index B_k [1].

Another indicator that characterizes the motor vehicles technogenic loading in a certain territory is the autoroad relative length coefficient (*d*):

$$d = \frac{l}{S}, \tag{4.2}$$

where *l* is the autoroads total length in a certain territory;

S is the territory square [1].

Traffic intensity can be used as an indirect indicator of the load level. Thus, the coefficient *d* can be determined for a certain category of autoroads, which, for example, are characterized by the maximum traffic intensity. In this case, the spatial changes of this indicator make it possible to determine the areas with the maximum technogenic loading created by auto transport [1].

The state of the environment in a region or in a city also depends on the state of the landscape, that is, the structure of land using. The anthropogenic influence level and direction, the degree of landscape resistance to various types of anthropogenic loading can be evaluated as a characteristic of the ecological and economic state of the territory [2].

Taking into account the data of the land cadastre, it is possible to calculate the natural protection coefficient (*Knp*), the coefficients of absolute (*Ka*) and relative (*Kr*) anthropogenic stress. The main initial data for calculating are the information about the land area occupied by one or another type of activity. The proposed data system of land using is shown in Table 4.1 [2].

Table 4.1 – Land using data system in the j^{th} region [2]

Type of land using	**area of this type using**
1. Building land, including industrial buildings and structures	Sj_1
2. Land under roads	Sj_2
3. Disturbed and other lands (waste landfills, sands, ravines, etc.)	Sj_3
4. Lands under water	Sj_4
5. Agricultural lands	Sj_5
6. Swamp	Sj_6
7. Lands under trees and bushes, which are not included in the forest fund	Sj_7
8. Forest lands	Sj_8
The total area of the j^{th} district	Sj

The coefficients of absolute and relative intensity of the ecological and economic state of the territory make it possible to estimate the anthropogenic transformation of the territory. The coefficient of absolute anthropogenic tension is determined by the formula:

$$Ka = Sj_1 / Sj_8. \tag{4.3}$$

This coefficient shows the ratio of the land area which is heavily disturbed by construction, industry and transport to the land area which is lightly disturbed or undisturbed [2].

The coefficient of relative anthropogenic intensity (*Kr*) is the ratio of the land area with high anthropogenic transformation to the land area with lower anthropogenic transformation [2]:

$$K_r = \frac{Sj_1 + Sj_2 + Sj_3}{Sj_4 + Sj_5 + Sj_6 + Sj_7 + Sj_8}. \tag{4.4}$$

In general, the ecological and economic state of the territory is mainly characterized by the coefficient of relative tension, since it covers the entire territory under consideration. The coefficient of relative intensity can be used as an integral indicator, which is defined as the ratio of the land area with low anthropogenic loading to the land area with high loading. Decreasing the intensity of the situation reduces the value of the coefficients, and if *Kr* values equal to or close to 1.0, the intensity of the area is balanced by the degree of anthropogenic transformation and the nature stability potential [2].

The natural protection coefficient is determined by the formula [2]:

$$Knp = \frac{Sj_8 + 0{,}8Sj_7 + 0{,}6Sj_6 + 0{,}4Sj_5 + 0{,}2Sj_4}{Sj}. \qquad (4.5)$$

Each anthropogenic influence or their combination corresponds to its own sustainability threshold for natural and natural-anthropogenic landscapes. The more diverse the landscape is, the more sustainable it is. First of all, this is expressed through a large number of natural biogeocenoses and their equable distribution, nature conservation zones and natural territories subject to special protection. The larger it is, the higher natural protection of the territory and the stability of the landscape are. At the same time, the level of natural protection depends on the land distribution according to the degree of its anthropogenic transformation. The lands characterized by a high degree of anthropogenic loading have low natural protection [2].

<u>Tasks for practical work:</u>

1. Determine the regions of Ukraine for assessing transport loading (Western, Southern, Northern or Central Ukraine).
2. Determine the length of international, national, regional and territorial autoroads according to the literary sources for each region and the districts within it.
3. Calculate the autoroad relative length coefficient for the selected study area for each type of autoroads and for districts in total.
4. Carry out an analysis of transport loading on the study area.
5. If desired, the task can be completed according to an individual variant proposed by the applicant on the topic of the dissertation research.

4.2 Complex indicators for assessing technogenic loading on the environment

Currently, there is no unified approach to complex assessing the state of the environment under the influence of technogenic loading in Ukraine. A variety of methods have been developed and are used for assessing. It allows to assess loading on the environment in total.

It is proposed a definition of the rating, which is based on the total forming hazardous substances in the components of the environment by the fields of industry [2]. The average conditional rating of the influence danger (*P*) is determined by the formula:

$$P = (B_G + B_L + B_S) / 3, \tag{4.6}$$

where B_G, B_L, B_S are the volumes of gaseous, liquid and solid hazardous substances [2].

The principles of classifying the danger of industries are given in the Table 4.2.

Table 4.2 – Classification of production industries according to the conditional rating indicators [2]

Conditional rating	The danger degree of the industry
< 5	Extremely dangerous
5 – 10	Very dangerous
> 10	Dangerous

According to the table, the conditional rating of a certain branch of production is determined. The presented methodology can also be used to estimate technogenic loading on the environment from each pollution source (enterprise) separately.

Another indicator is a complex indicator of technogenic impact on the environment in a certain territory:

$$K_k = \left(\frac{M_{EM}}{S_m} + \frac{V_{WD} - V_D}{S_m} + \frac{M_W}{S_m}\right) \cdot P_I, \tag{4.7}$$

where M_{EM} is the mass of the pollutants emission, t/year;

Sm – the area of the region, ha;

V_{WD} – the water mass that is withdrawn for the consumers needs, m^3/year;

V_D – the waste water discharge mass, m^3/year;

M_W – the waste mass generated on a given territory, t;

P_I – the number of inhabitants living in the given territory, thousands of people [2, 11].

The technogenic impact complex indicator varies in a wide range and allows to divide the study area into several ecological regions according to the level of loading. Each ecological region is characterized by a certain level of technogenic loading on the components of the environment and by the state of the biota. As an example, the following gradations of ecological districts are proposed:

1) $Kk < 10 \cdot 10^{-2}$;
2) $Kk = (10 – 100) \cdot 10^{-2}$;
3) $Kk = (100 – 1000) \cdot 10^{-2}$;
4) $Kk > 1000 \cdot 10^{-2}$ [11].

It is also proposed to determine the technogenic loading coefficient on the region taking into account the objects of critical transport infrastructure (OCTI) [12]. The OCTI composition includes spatially developed networks of railway tracks, main gas pipelines, power grids and autoroads, a large part of which are a part of the international transport corridors. Spatially distributed railway tracks, oil and gas pipelines, bridges, potentially dangerous objects, main power grids are a particular threat among OCTIs [12].

The OCTI specific density is determined by the formula:

$$M_i = \frac{N_i}{S_i} \equiv \frac{L_i}{S_i}, \tag{4.8}$$

where N_i is the number of OCTIs in the given region;

L_i is the length of the corresponding OCTI in the territory of a certain region;

S_i is the area of the given region [12].

As Mi indicators the following ones are used:

– M_1 – the specific density of railways, km/thousand km^2;
– M_2 – the specific density of bridges, units/thousand km^2;
– M_3 – the specific density of potentially dangerous objects, units/thousand km^2;
– M_4 – the specific density of main power grids, km/ thousand km^2 [12].

The technogenic loading coefficient of the regions in Ukraine, which characterizes specific density relative levels of the OCTI characteristics is determined by the formula:

$$m_i = \frac{M_i - M_{min}}{M_{max} - M_{min}}, \tag{4.9}$$

where M_{min} and M_{max} are the minimum and maximum values of the OCTI specific density indicators, respectively [12].

Based on this, the complex indicator of the technogenic loading level of the regions of Ukraine *Y* is determined by the formula:

$$Y = \sum_{i=1}^{n} \frac{M_i - M_{min}}{M_{max} - M_{min}}. \tag{4.10}$$

Accordingly, the smaller the *Y* value, the lower the level of technogenic loading is. 6 verbal gradations of technogenic loading levels for Ukraine are offered: *insignificant, moderate, medium, increased, high and critical.* Numerical values of the gradations may vary depending on the obtained calculation results [12].

A complex indicator for assessing the enterprise environmental safety has been developed [13]. This indicator is based on the following integral indicators:

– the environmental damage integral coefficient;
– the integral coefficient of economic factors influence;
– the integral coefficient of environmental and economic factors influence.

The integral coefficient of environmental damage K_{ED} is an indicator that reflects the conditional average ecological damage to the environment from the enterprise economic activity and is calculated according to the formula:

$$K_{ED} = \sqrt[n]{\frac{B_1}{MPC_1} \cdot \frac{B_2}{MPC_2} \cdot \ldots \cdot \frac{B_n}{MPC_n}}, \tag{4.11}$$

where $B_1, B_2, \ldots, B_n$ are the actual volumes of the *i-th* pollutants emissions into the atmosphere and/or discharges into the water bodies, and/or waste disposing, and/or generating the radioactive waste [13].

The lower the value of this indicator, the higher the enterprise environmental safety level is. Since the environmental damage integral coefficient is a disincentive indicator, it is included in the formula for assessing the general level of the enterprise environmental safety in the reverse value, i.e. $(1 – K_{ED})$ [13].

The economic factors influence integral coefficient (K_{ECON}) is used due to the need to assess the state of main means and the level of capital investments, since they significantly affect the enterprise environmental safety level. At the same time, the higher the value of this indicator, the higher the total enterprise environmental safety level is. This indicator is calculated according to the formula:

$$K_{ECON} = \sqrt[3]{K_{st} \cdot K_{ren} \cdot d_{capinv}}, \tag{4.12}$$

where K_{st} is the main means suitability coefficient;

K_{ren} is the main means renovating coefficient;
d_{capinv} is a share of capital investments in the main means of environmental protection [13].

The K_{ECON} components are determined by the formulas given in the Table 4.3.

Table 4.3 – Methodology for calculating economic indicators that characterize the state of the main means [13]

Indicators	**Calculating Methods**	**Characteristics**
The main means suitability coefficient	*Kst = RVst / ICst,* where *RVst* – is the residual value of the enterprise main means on a certain date; *ICst* – the initial cost of the enterprise main means on a certain date	It characterizes the degree of main means suitability for exploiting taking into account their physical and moral wear and tear.
The main means renovating coefficient	*Kren = ICren / ICend,* where *ICren* – the initial cost of new main means put into exploiting for the reporting year; *ICend* – the initial cost of main means at the end of the year.	It characterizes the intensity of main means putting into exploiting.
A share of capital investments in the main means of environmental protection	*dcapinv = КIекол / КIзаг,* where *CIenvir* – the amount of capital investments in the environmental protection main means; *CItot* – the total amount of capital investments in the main means.	It displays the specific weight of the capital investments in the environmental protection main means, in the capital investment total amount for the year.

The integral coefficient of ecological and economic factors influence ($K_{ENVIR\text{-}ECON}$) is determined due to the need to assess the impact of eco-destructiveness, eco-capacity, the environmental costs specific weight and the share of recycled waste in the volume of their generation on the level of the enterprise environmental safety. Its value should exceed 1. The higher the $K_{ENVIR\text{-}ECON}$ value, the higher the level of the enterprise environmental safety is. The indicator is calculated according to the formula [13]:

$$K_{ENVIR-ECON} = \sqrt[4]{P_{destr} \cdot EE \cdot d_{envcost} \cdot d_{waste}}, \qquad (4.13)$$

where P_{destr} is the production destructiveness;
EE is the production eco-efficiency;
$d_{envcost}$ is the environmental costs specific weight in the production cost;
d_{waste} is the recycled waste specific weight in the total volume of their forming.

The production eco-destructiveness indicator P_{destr} characterizes the amount of the environmental tax, which corresponds to products produced for 1 hryvnia. Its increase leads to a decrease in $K_{ENVIR\text{-}ECON}$. The calculation of the P_{destr} indicator is carried out according to the formula:

$$P_{destr} = 1 - (ET / Q), \tag{4.15}$$

where ET is the amount of the environmental tax;

Q is the volume of produced products (goods, works, services) [13].

The product eco-intensity (EE) is determined by the ratio of the amount of the environmental costs to the manufactured product cost and reflects the level of the environmental costs per products produced for 1 hryvnia:

$$EE = EC / Q, \tag{4.16}$$

where EC is the sum of the environmental costs [13].

The specific weight of the environmental costs in the manufactured products cost ($d_{envcost}$) is calculated according to the formula:

$$d_{envcost} = EC / PC, \tag{4.17}$$

where PC is the manufactured products cost [25].

The specific weight of recycled waste in the total volume of its forming (d_{waste}) is determined by the formula:

$$d_{waste} = RECYCL / GENERAT, \tag{4.18}$$

where $RECYCL$ is the recycled waste volume;

$GENERAT$ – the generated waste volume [13].

The integral indicator of the enterprise environmental safety general level (ESL) is calculated according to the formula [13]:

$$ESL = \sqrt[3]{(1 - K_{ED}) \cdot K_{ECON} \cdot K_{ENVIR-ECON}}. \tag{4.19}$$

The rating of medical and ecological intensity of the territory (Im-e) is calculated according to the formula:

$$Im\text{-}e = I_1 + I_2 + I_3 + I_4 + I_5 + I_6, \tag{4.20}$$

where I_1 is the the general morbidity of the adult population (cases per 1,000);

I_2 – the neoplasms morbidity of the adult population (cases per 1000);
I_3 – the general morbidity of the children population (cases per 1000);
I_4 – the total emission loading on the air basin (t/year/km^2);
I_5 – the total technogenic loading on the surface water (thousand m^3/year);
I_6 – specific technogenic loading on the land resources (kg/ha/year) [2].

Another group of indicators for assessing the level of technogenic loading on the environment is calculating the individual modules of loading on the components of the environment [14]. Such modules include:

1) the module of technogenic loading on the air basin *(M_{AB})* based on the indicators of the hazardous substances emission volume from the stationary and mobile sources (this indicator assumes the sum of two values);

2) the module of technogenic loading on the water objects *(M_{WO})* based on the indicators of wastewater and hazardous substances discharges in their composition (this indicator does not involve summation, since the hazardous substances amount in the wastewater and in the other return waters is their component);

3) the module of technogenic loading on GE *(M_{GE})* conditionally according to the indicators of the waste generated and accumulated in the region (this indicator can also include the sum of two values).

Tasks for practical work:

Practical work 1:

1. According to the individual variant received from the teacher, calculate the technogenic impact complex indicator on the environment in a certain territory of Ukraine.
2. Rank the territory into the ecological districts according to the loading level.
3. If desired, the task can be completed according to an individual variant proposed by the applicant on the topic of the dissertation research.

Initial information for performing calculations

Variant 1:

Indicators of the technogenic impact on the regions of the Southern Ukraine (2019)

Indicator	Zaporizhzhya region	Mykolaiv region	Odesa region	Kherson region
M_{EM}, t	252678	57476	183922	127143
Sm, ha	2718300	2458500	3331400	2846100
V_{WD}, m^3	1133000000	175300000	866500000	2614000000
V_D, m^3	843600000	78260000	403400000	89210000
M_W, t	5404100	2410146,3	640100	375900
P_I, thousand people	1687	1120	2368,107	1120

Variant 2:

Indicators of the technogenic impact on the regions of the Central Ukraine (2019)

Indicator	Vinnytsia Region	Kirovohrad Region	Poltava Region	Cherkasy Region
M_{EM}, t	164900	12800	130664	107917
Sm, ha	2649200	2458800	2875000	2091600
V_{WD}, m^3	106900000	187600000	84000000	155800000
V_D, m^3	64040000	39800000	78440000	103800000
M_W, t	2711200	37405770	189834166	1259300
P_I, thousand people	1545	933,109	1387	1192

Variant 3:

Indicators of the technogenic impact on the regions of the Western Ukraine (2019)

Indicator	Volyn region	Ivano-Frankivsk region	Lviv region	Rivne region
M_{EM}, t	48182	244071	177730	49500
Sm, ha	2014400	1392700	2183300	2005100
V_{WD}, m^3	53500000	81510000	168600000	124900000
V_D, m^3	39790000	61080000	168200000	52210000
M_W, t	668100	2991705,3	2159665	553000
P_I, thousand people	1031	1368	2512	1153

Practical work 2:

1. At the choice of the educator seeker, choose a region of Ukraine and assess the technogenic loading on the environment according to the following indicators for it:

- the complex indicator of the technogenic loading level *(Y)* in the regions of Ukraine, taking into account the presence of OCTI;
- the module of technogenic loading on the air M_{AB};
- the module of technogenic loading on the water objects M_{WO};
- the module of technogenic loading on the geological environment of the M_{GE}.

2. Based on the received data, make a conclusion about the advantages and disadvantages of the assessing methods that have been used for the calculations.

4.3 Assessing the technogenic impact on the environment according to sustainable development individual indicators

Sustainable development (SD) is such a development that allows to meet the needs of the present generation without harming future generations.

A list of individual indexes and indicators, which are used to evaluate SD, has been developed. According to the metric for measuring sustainable development processes (MMSD) [15], SD is evaluated from the economic, environmental and social-institutional nature standpoints.

The environmental dimension index *(Ie)* can be determined taking into account three categories of the environmental policy: 1) environmental systems (I_{SYS}); 2) environmental loading (I_{STR}); 3) regional environmental management (I_{REG}). In turn, these categories contain 13 indexes and 44 indicators [15].

An index of sustainable development is an indicator that reflects economic, social and/or environmental development in a certain region, and has such properties as easy interpretation, a wide range, sensitivity to changes, quantitative certainty. It allows to make forecasts and to identify trends in a timely manner [15].

The list of indicators and parameters for assessing the state of the environment on the sustainable development basis is given in Table 4.4.

To perform the calculations, it is necessary to normalize the initial data so that all parameters take values from 0 to 1 using the principle of linear normalization:

$$\tilde{x}_i = \frac{x_i - x_{max}}{x_{max} - x_{min}}. \tag{4.21}$$

In this case, minimum values close to 0 characterize the best conditions, and maximum values close to 1 represent the worst ones.

Tasks for practical work

1. To choose the region of Ukraine for which the index of the ecological dimension will be calculated using the indicators and parameters of the Metric for measuring sustainability parameters, according to the applicant's choice. Selecting the initial information must be done no less than for 5 years.

2. Determine the indexes of the environmental policy different categories.

3. Determine the parameters that are the worst from the position of sustainable development in the region.

4. Based on the received data, make a conclusion about the advantages and disadvantages of the MMSD.

Table 4.4 – Policy categories, indicators and *Ie* parameters [15]

Policy Category	Indicator	Parameter
Environmental systems I_{SYS}	Air I_{AIR}	Average concentrations of nitrogen dioxide I_{NO2}, sulfur dioxide I_{SO2} and dust I_{TCP} в in the atmospheric air of cities
	Biodiversity I_{BIO}	Species of I_{PFA} fauna and I_{PFL} flora which are under threat
		Objects of nature reserve fund I_{PZF}
	Land I_{LAN}	Technogenic loading on the natural environment I_{ANT}
		Spreading the exogenous geological processes I_{EGP}
		Contaminated areas I_{WLN}
		Disturbed, waste and rehabilitated lands I_{EXH}
	Water quality I_{WQL}	Average annual concentrations of suspended solids I_{SS} and nitrates I_{NIT}, average annual mineralization I_{MIN}
	Water amount I_{WQN}	Water intake from natural I_{WAV} and underground I_{GAV} sources per 1 person
	Radiation and environmental hazard I_{RAD}	Radiation pollution of the territory I_{RTR}
		Potential radiation hazard I_{RHZ}
		Radioactively contaminated lands I_{RLN}
		Environmentally hazardous enterprises I_{IHZ}
		Storing and using the hazardous chemicals I_{HZW}
Ecological loading I_{STR}	Emissions into the atmosphere I_{EMS}	Emissions of nitrogen oxides I_{NOX}, sulfur dioxide I_{SOT} and volatile organic compounds I_{VOC}
		Emissions from the auto transport I_{CAR}
		Emissions from the stationary and mobile sources per 1 km^2 I_{EKM} and per 1 person I_{EPC}
	Loading the ecosystems I_{ECO}	Change in the ratio of the area of cut down and dead forest plantations to the area of created forest plantations over the last 3 years I_{FRS}
		Arable land I_{EF1}
		Hay fields and pastures I_{EF2}
		Forests and other wooded areas I_{EF3}
		Built-up lands I_{EF4}
		Using fresh water per person I_{EF5}
	Waste generating and using I_{WST}	Waste using I_{REC} and waste accumulating I_{ACC}
		Generating the wastes of the I - III hazard classes per 1 km^2 I_{WKM} and per 1 person I_{WPC}
		Areas with solid waste I_{WAR}
	Water loading I_{WAT}	Discharging pollutants I_{CNT} and return water I_{REW} into the surface water objects

Table 4.4 continuation

Policy Category	**Indicator**	**Parameter**
Regional environmental management I_{REG}	Participation in environmental projects I_{COL}	Public environmental organizations in the territory of the region I_{ORG}
		The amount of actual funds from the state and regional funds for environmental protection measures I_{FND}
	Greenhouse gases emissions I_{GHG}	Emissions to gross regional product I_{GDP} and per capita I_{GPC}
	Transboundary ecological pressure I_{GPC}	Waste of of the I - III hazard classes transferred to other enterprises, other countries, etc. I_{EXP}

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