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# Environmental standards and norms

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Издание ориентировано на студентов магистратуры, обучающихся по экологическим направлениям и программам, а также желающих самостоятельно ознакомиться с международной практикой экологического регулирования. В книге представлены шесть тем для изучения: теоретические основы экологических стандартов и норм, регулирование в области защиты атмосферы, водной среды, почвы, регулирование в области обращения с отходами и регулирование конкретных загрязнений - нефтью и сверхтоксичными соединениями. Также есть задания для самостоятельной работы и контрольные вопросы по каждой из обсуждаемых тем.

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## Foreword

Environmental regulation is the most important tool for creating scientific foundations for limiting anthropogenic impacts on the environment and, at the same time, for regulating the impact of the environment on humans.

The establishment of adequate, clearly substantiated environmental standards requires, in turn, a clear understanding of natural processes associated with maintaining the stability of natural systems, the processes of migration and accumulation of pollutants, self-purification of the air and water environment, and soils. Countries' efforts to ensure sustainable development ultimately face the need to substantiate “growth limits”, the limits of permissibility of anthropogenic impacts, and to choose the best technologies for the preservation or restoration of damaged ecosystems. However, in different countries of the world, different approaches are used to substantiate the boundaries of anthropogenic impacts and criteria for the normal state of natural environments. In this regard, it is extremely important to jointly solve the problems of preventing pollution and unnecessary stress on natural systems. An analysis of international experience in this area is required.

This is what this tutorial is about. The book presents six topics for study: theoretical foundations of environmental standards and norms, regulation in the field of protection of the atmosphere, aquatic environment, soil, regulation in the field of waste management and the regulation of specific pollution - oil and supertoxic compounds. There are also tasks for self-study and control questions for each of the topics discussed.

The publication is intended for master students studying in environmental areas and programs, as well as those who want to independently familiarize themselves with the international practice of environmental regulation.

*Authors*

## Chapter 1. Introduction. Sustainability and sustainable development

Sustainability is one of the properties of all systems, regardless of whether they are natural or technogenic. Each system undergoes several development stages, and one of such stages (or periods of the development) is a sustainability period.

Currently the term “sustainable development” is widely used to indicate a combination of conditions of the social and economic system development. This term was proposed by the United Nations International Commission on Environment and Development and was originally an environmental term. It played an important ideological role, contributed to the realization of the need to maintain the balance of humans with nature. In the conditions of increasing dynamics of social systems, the problem of sustainability began to acquire a larger scale and was extended to economic and social processes.

The foundation of the modern concept of sustainability is the 1987 Brundtland Report [1] and the earlier ideas about sustainable forest management [2] and twentieth century environmental concerns. With the development of the concept, the attention has shifted to the issues of economic development, social development and environmental protection for future generations. Now, we understand the sustainability of humanity as the goal of the human-ecosystem equilibrium (homeostasis). "Sustainable development" is the holistic approach and the "way" to the sustainability" [3]. One of the most widely used schemes to present the unity of social, economic and environmental purposes is a scheme of three crossing spheres (economy, environment, society). And in the middle, on the intersection there is a sustainability zone.

Therefore, maintaining the sustainable development, the society tries to achieve some goals belonging to different sides of life. Sometimes we speak about 3E concept (Sustainability = Energy + Economy + Environment) or about the 4E (Sustainability = Energy + Economy + Environment + *Education*). These approaches show the most important strategic goals of the development.

For the social-environmental-economic systems of different levels we need to speak about different specificities of the sustainability manifestation and sustainable development goals.

First of all, it is necessary to begin with the international level where the sustainable development goals and world sustainability policy have been worked out.

Currently, a list of the sustainable development goals includes 17 positions, and at least 7 of them are clearly connected with the quality of the environment. Generally, no component of the sustainability can be maintained alone: it is impossible to protect the environment without finance, as well as it is impossible to achieve the perfect economical state in the destructed environment. The 17 sustainable development goals itemize these interactions (fig. 1.1).



Fig. 1.1. Sustainable development goals

Currently these goals are presented in the UN documents. The main document is *Transforming our world: the 2030 Agenda for Sustainable Development*. The agenda is understood as a plan of action for people, planet and prosperity in the areas of critical importance for humanity and the planet:

*People* – the document declares a commitment to “... end poverty and hunger..., and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment” [5]. Environmental component is an essential part because only a healthy environment can guarantee a realization of the human potential and prevent famine (real prevention of famine, not addressing the issue of low-quality food).

*Planet* – the document claims “... to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations” [5].

*Prosperity* – this item means a long-term coexistence of nature and humanity achieving welfare goals: “... all human beings can enjoy prosperous and fulfilling lives and economic, social and technological progress occurs in harmony with nature” [5].

*Peace* – it is declared, that humanity needs “... to foster peaceful, just and inclusive societies which are free from fear and violence. Sustainable development is impossible without peace and peace entirely depends on sustainable development” [5]. Generally, it is clear that all the military conflicts lead to environmental violations; environmental problems as such fading into the background despite their real significance.

*Partnership* is another essential part of the sustainability ideology. It emphasizes the need of the implementation “... of the Agenda through a revitalised Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focused in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders and all people” [5].

As shown, all the goals are interconnected and based on the need of environment protection. The rational use of available resources can ensure the sustainability as a goal for the future generations.

The modern nature management models are not perfect, although the problem is not new. Throughout its history the humanity has been experiencing one environmental crisis after another. And every time the humanity tries to overcome the crisis, accomplishing a revolution. The specific of a current situation is the scale of crisis and the speed of changes.

It is possible to list the most important and real global problems of the humanity:

- exhaustion on the water resources;
- deforestation;
- loss of biodiversity;
- global pollution with transboundary spread of hazardous substances;
- destruction of soil resources;
- climate change, ozone layer destruction, etc.

In each case it is possible to find the initial mistakes in the organization of nature management, and the more time we lose, the more profound are the problems. So, it is necessary to establish the rules, norms and regulations in this sphere. Unfortunately, despite the extensive academic knowledge and an international collaboration we don't see a large progress in addressing the indicated issues.

*Nature management and setting environmental norms*

Currently there are some models of the nature management. They are based on the assessments of the real state of environmental resources, establishment of the development goals and evaluation of the real state of system using indicators of sustainable development. To identify a global indicator framework for the goals and targets, the United Nations Statistical Commission established 2015 an Inter-Agency Expert Group (IAEG) on SDG Indicators, whose structure reflects equitable regional representation. Among the main conditions, for the adequate assessments the initial data quality is in the first place. Thus, the UN elaborated a special report on statistics for the sustainability - *Data for Development. A Needs Assessment for SDG Monitoring and Statistical Capacity Development*. A list of the UN indicators proposed by Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) was presented in a document *Final list of proposed Sustainable Development Goal indicators* [7]. This list, published in the Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators (E/CN.3/2016/2/Rev.1), Annex IV, includes 230 indicators of all sides of social, economic and environmental spheres of the countries.

Using these indicators, it is possible to understand the state of a social-environmental-economic system (i.e., a state) and to set some goals for the future depending on the problems in the development of the country.

The achievement of the set goals depends on the extent to which we understand the current situation. Thus, we need “markers”, the critical levels of the state of the environment and environmental impacts. Therefore, environmental standards of different types are an essential part of the general scheme of the sustainability regulation. These values have to be justified from the scientific point of view and they should adequately reflect the state of natural and natural-technogenic systems. So, it is necessary to introduce a concept of the *norm*.

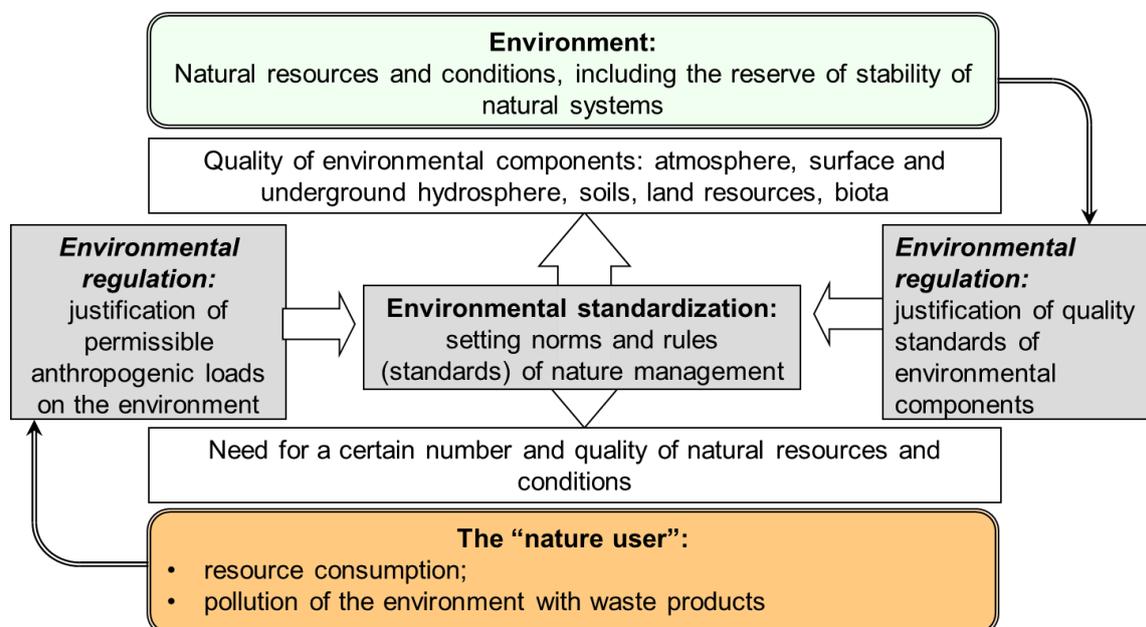


Fig. 1.2. Environmental regulations in the nature management

Generally, we use different types of environmental norms. Some of them regulate environmental quality, i.e. water quality indexes, maximum allowable concentrations of substances in the atmosphere, maximum permissible levels of physical impacts and others. Another group of environmental standards regulate anthropogenic influences on the environmental components. These can be maximum permissible levels of emissions or limits of use of biological resources (for fishery,

forestry...) or limits of application of fertilizers. In any case the level of impacts or the environmental quality characteristics should be very well justified.

So, the *main task of the development of the environmental norms* is to work out and to justify the scientific and methodological basis for standardization in the field of human life safety and gene pool conservation, environmental protection and rational nature management. The tasks of environmental regulation also include the approbation of technological developments in practice, bringing them to standards and introducing the rank of standards.

In general terms, there exist the following steps of the environmental standard justification (fig. 1.3).

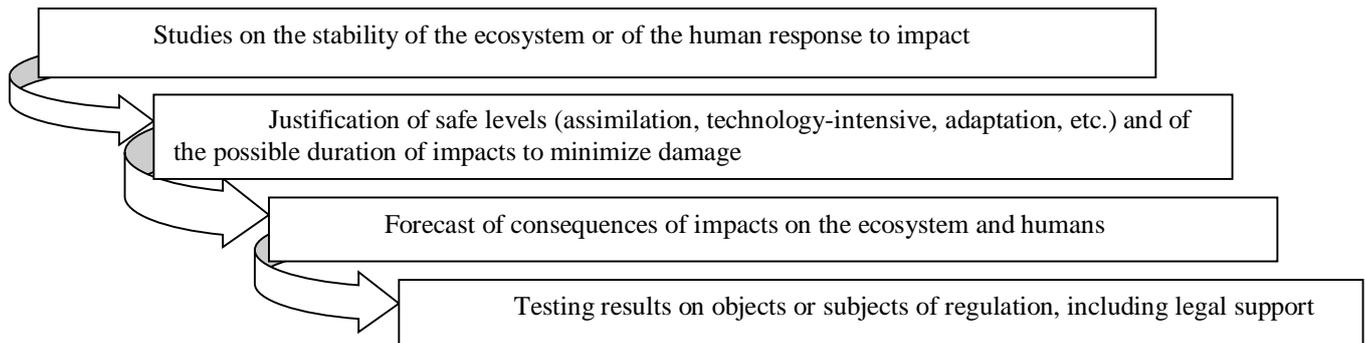


Fig. 1.3. Scheme of the environmental standards development

So, the development of environmental regulations is development of scientific and methodological basis of standardization in the field of natural resources management and environmental protection. It is based on the knowledge about the ecosystem stability and human tolerance to the harmful effects, the safe levels and duration of the impact on the environment, prediction of these effects, as well as testing results.

*The norm of the state* is the state of the ecosystem, in which its structure and species diversity are preserved, the mode of functioning does not change.

This norm is expressed as a function of the condition of the system that characterizes the condition of the system with the help of a qualimetric scale (for example, the condition table of an object from an "ecological disaster" to a "relatively satisfactory condition").

The intensity of the processes of exchange of matter and energy depends on the condition and phase of the development of the natural object. The object itself can exist without noticeable changes for an unlimited time. These factors must be taken into account when determining the norm.

### *Norms – standards – regulations*

*The exposure standard* ("the impact norm") is the permissible anthropogenic impact, under which the conservation is ensured for:

- the structure and dynamic properties of ecosystems,
- the ecosystem stability,
- the species diversity,
- the natural course of the succession processes of productivity;
- the most vulnerable parts of the trophic chain.

Speaking about the norms, according to the way of their formation (or we can say "justification") we distinguish:

- *statistical norm* is established on the basis of the application of probability-statistical calculations of mean and extreme values; to calculate it we need a set of data about the studied system,

and this data set has to be of significant size;

- *theoretical norm* is determined based on the laws of distribution or theoretical considerations; however, here we need to understand the rules and laws of the development of the studied system;

- *empirical norm* is established on the basis of conducting experiments with populations and communities;

- *expert norm* is determined by a group of competent persons (experts).

The norm is determined on the basis of the following approaches:

- as some average value of the parameter: taking into account possible statistical deviation from the norm;

- as an optimal ("good") condition of the system;

- representation of the norm on the basis of variability: the norms cannot be the same for different natural conditions and types of nature use. The example here are different regional norms for different natural conditions. We can remember here dramatic variations of the mineral composition of water or of soils in the regions of the world. As a consequence, it is necessary to introduce the regional standards for the quality of soils or waters.

Establishing the norm of the system condition and the norm of the load makes it possible to evaluate the existing ecological loads.

Environmental load is a change in the external environment that leads (or can lead) to a deterioration in the quality of the object, i.e. to undesirable from the point of view of the subject of assessment of changes in its condition.

The maximum permissible environmental load is the maximum load, which does not yet cause a deterioration in the quality of the object of rationing.

One of the widely distributed schemes of the "norm" concept in the ecology is the Shelford law (fig. 1.4).

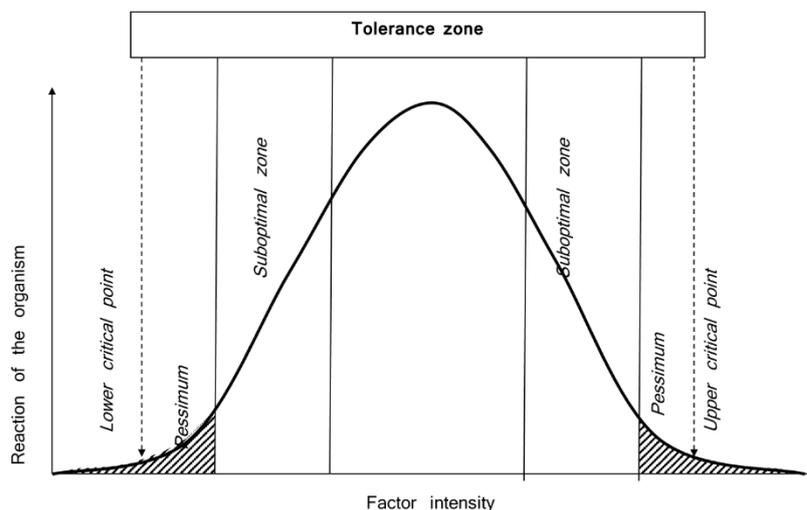


Fig. 1.4. The "norm" concept

Thus, the main task in the development of the environmental norms is to find the optimal intensity of the anthropogenic factors effecting the natural system. To make the task easier, it is possible on the first stage of the studies to dismiss the joint effects of different influences. Of course, in reality, we always face a complex of different factors, and each of them can enhance others or reduce their influence.

So, we can see the interaction of a combination of factors on the development of a natural

system. Fig. 1.5 indicates the role of moisture and heat. In this case two extreme cases with the distribution of heat and moisture in geosystems (relative to their optimal ratio) are possible:

- excessive moistening and insufficient heat supply;
- Insufficient moistening and excessive heat supply.

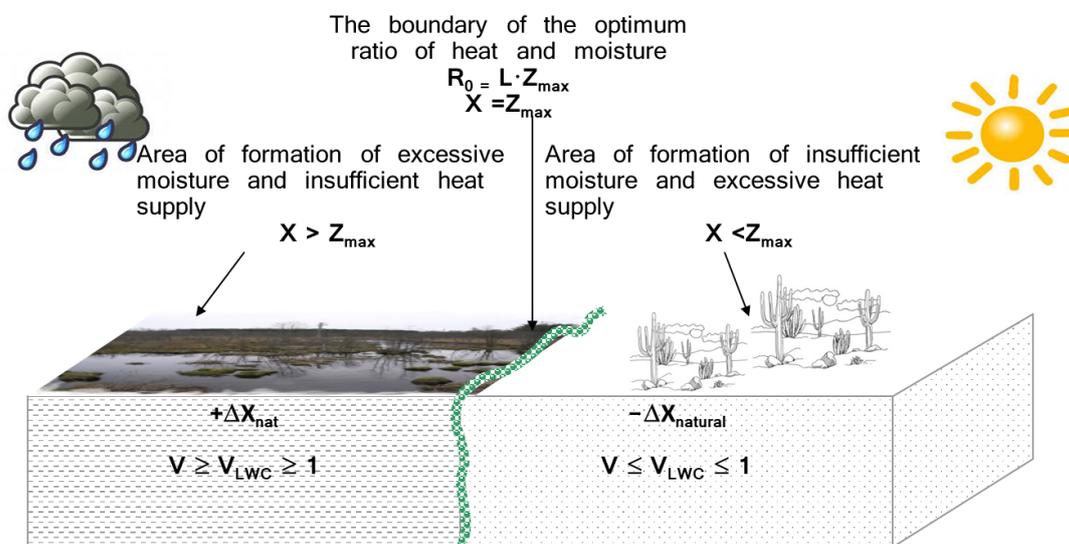


Fig. 1.5. The role of the distribution of heat and moisture in geosystems in the development of natural systems: scheme for the development of the hydrological-climatic process (A.N. Naprasnikov, 2012)

On the scheme:  $X$  – atmospheric precipitation, mm;  $R_0$  – radiation balance of the humidified surface, kcal/cm<sup>2</sup>·year;  $L$  – specific heat of evaporation of water: 0.06 kcal/cm<sup>2</sup>·mm;  $Z_{max}$  – maximum possible evaporation, mm;  $V_{LWC}$  – soil moisture at the level of the lowest moisture capacity;  $V$  – humidity in fractions of the lowest moisture capacity;  $+\Delta X$  – excess moisture in soil, mm;  $-\Delta X$  – moisture deficit, mm

On the border of the two opposites, there are equilibrium conditions between excessive and insufficient moisture, as well as excessive and inadequate heat supply. In other words, the two zones mentioned are divided according to the criterion of the equivalent equality of heat and moisture. With its help, the interaction of heat and moisture of the atmosphere and the earth's surface is estimated, the initial development of ground flow, the formation of soil-ground structures of geosystems and atmospheric moisture flow of topological, regional and planetary levels are predetermined. This is the role of thermal resources in the formation of geosystems.

### Stability – sustainability - resistance

When reacting on the influence, the natural system can give different types of response: from total tolerance and absence of any reaction, to the total destruction and impossibility to be restored. The type of the reaction depends not only on the intensity of the factor. The most important here are the type of the system and its “assimilation capacity” – the ability to resist the influences.

And here it is very important to understand the mechanisms of the stability of the natural systems: they are different for the **geosystems** and for the **biological** systems.

The geosystems (like hydrosphere and its elements, atmosphere, components of geological environment) are about the mechanisms ensured by dilution and sorption of substances, their migration between the media – these are the regeneration mechanisms. A stable state of such system is connected i.e. with physical and chemical processes of distribution of substances in media which ensures hazard reduction.

In biological systems there are processes of the adjustment to the new conditions – here we see the adaptation mechanisms. The models of such reactions are most widely used for the development of environmental regulations. Thus, the main reason for most environmental regulations and standards is to establish the minimal hazard (risk) to the biological objects that suffer from the technogenic impacts.

So, we face different reactions of the natural systems to the influences. Regulating the anthropogenic impact, it is necessary to consider three types of the natural systems stability:

- inert – as the ability of the system to maintain its state under the external influence during a certain time period,
- plastic - the ability to move from one state of equilibrium to another, keeping the internal connections,
- recoverable – the ability to return to the initial state after the external action.

The first two types are adaptive: the system attempts to resist despite the external influences. The last type is regenerative – the system recovers its properties after the impact.

Finally, it is necessary to provide the safe state of some media (object to be protected) knowing the main laws of the development of this object. Taking into account a variety of factors affecting the natural systems and of the internal factors (using it the system try to resist the influences), it is possible to illustrate the “fate” of a conditional natural system as shown on fig. 1.6.

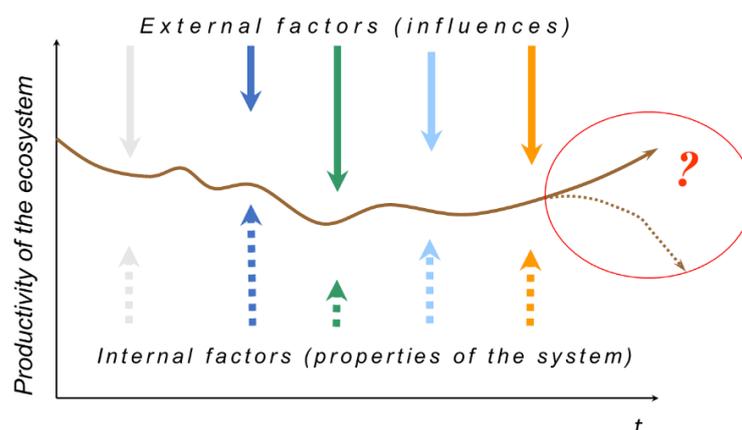


Fig. 1.6. Trajectory of the natural system development

Thus, contacting with the external factors, the system will stay stable or will show some reactions, up to visible changes and to the destructive consequences. The result of interactions between external factors (influences) and the own properties of the natural systems (assimilation potential, stability capacity etc.) forms the trajectory of its development.

It is interesting to show the interaction of some aspects of the systems sustainability. Let us demonstrate the constituents of sustainability in the case study of an environmental-economic system of an enterprise (fig. 1.7).

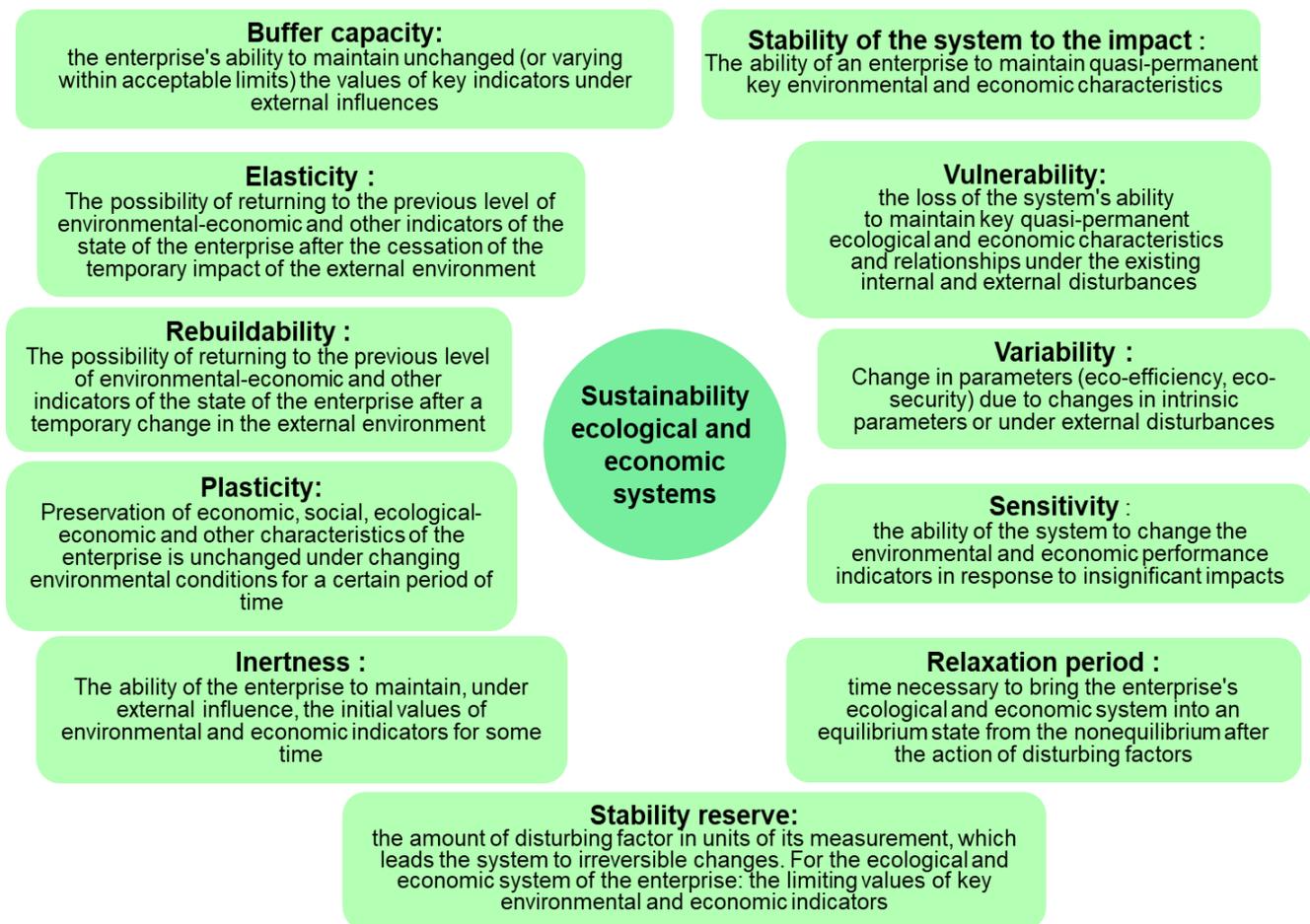


Fig. 1.7. Aspects of environmental-economic system sustainability

Thus, the *sustainability* is connected with *buffer capacity* of a system. In case of pollution we could speak about the amounts of an impurity that can enter the media without providing some visible negative effects.

*Elasticity* of a system is practically a base for its self-restoration after some influences. It is possible to find examples of such restoration processes after different disturbances or even catastrophic events.

*Rebuildability* is expressed in the fact that the characteristics of functioning go back to the previous level. So, we can say that the system is rebuilt after the destruction if, e.g. the biomass production is now equal (comparable) to the prior amount. If some area was polluted because of the oil spill, the efficiency of remediation will be estimated using the levels of pollutants in soil. It will be necessary to compare the concentrations of oil in soil with an environmental norm (maximum permissible concentration).

*Plasticity* is again a property of different types of system: social, ecosystems, economic etc. In case of ecosystems or other natural systems it is possible to remember the ability of a system to anticipate for a certain period of time and to preserve the characteristics of a system. Only after the level of impact is higher than the resistance capacity, the reaction of a system will become visible – the characteristics of a system will change.

One of the most interesting aspects of the stability of systems is a *relaxation period*. This characteristic is very individual for each system. It is possible to remember how we all suffer from various infectious diseases. Whereas some individuals demonstrate better resistance and fall ill later, others fall ill earlier, but sooner demonstrate a relapse period. Some individuals might entirely resist the infection, despite permanent exposure. This incidence is similar to natural systems under

anthropogenic influences, as the same landscapes can demonstrate different degrees of pollution resistance. And the recovery process will be approximately equal, although the recovery time may vary.

This is the complexity of creating load standards: one can select test objects for which the maximum exposure bars will be measured. But then these standards have to be reliably transferred to another group of objects. It is necessary to be sure that it is permissible! One can give an example of the maximum norms of loads on various biological species (table 1.1).

**Table 1.1. Toxicity of certain pesticides for animals**

Pesticides: Insecticides	LD <sub>50</sub> , mg / kg				
	Laboratory animals	Lan, goat	Wild duck	Pheasant	Trout, Hupia
Lindane	150–230	200	200	–	0.02
Tiodan	40–100	–	33	–	0.01
Toxaphene	50–70	139	70	40	0.1
Sevin	310–850	300	2180	2000	1.75
Furadan	5	6	0.4	4.2	0.28
Diazinone	76–130	–	3.5	4.3	8.0
Metaphos	100-180		10.0	8.2	3.0
Dimetab (B-58)	100-230	200	42.0	–	–
Metation	470–516	727	–	56.0	8.6

As can be seen from the table, the limits of changes in critical levels of impact are very wide.

Another problem is the multiple ways of influencing specific negative factors on the state of the object under consideration. This is taken into account when setting standards. For example, for hazardous substances it is taken into account that they can enter the human body through the skin (percutaneously), with food (orally), by inhalation (aspiration route). All these will be direct penetration by direct contact with the substance. However, substances can enter the body not by direct contact, but during movement through the food chain.

These points are taken into account when developing environmental standards. So, for example, it is necessary to divide standards for lands for various purposes: some of them are used for the production of agricultural products (hence, this is the path for the penetration of substances into the body with food). Another type of land is used for housing or recreational areas. When pollutants are found in soils in such areas, they can enter the body by aspiration (contact with particles of soil that enter the air in the form of dust).

Generally, it is a common scheme, applicable to different systems – not the natural ones only, but also economic systems and environmental-economic ones. Such reflection of the development of system can be used to demonstrate the processes in nature management. In this case we speak about the ability of natural systems to give their utilities to produce some welfare components of the society. Besides it is necessary to understand, whether the system can resist human impact in form of the resources consumption or in form of the pollution (as a type of use of the resource named “assimilation capacity”).

Of course, the scheme is simplified. In reality, having a combination of the affecting factors we cannot just add their effects to measure the final effect. The factors can create different

combinations:

- absence of the interaction – they do not provide any common effect;
- antagonism: suppression of one factor by another (and this is a good way to find a mechanism for the protection of a system against the negative factors):

$$(A + B) < (A) + (B)$$

- synergism:
  - the interaction is additive – the final effect is equal to a sum of two effects
 
$$(A + B) = (A) + (B);$$
  - for all other types of synergism – generally  $(A + B) = (A) + (B)$ , but the following variants are possible:
    - each factor enhances the effect of the second one less than additively;
    - each factor enhances the effect of the second one stronger than additively;
    - the first factor intensifies the effect of the second one less than additively, while the second factor intensifies the effect of the former one more than additively.

If we try to visualize the effect of such interactions, it is possible to show the following scheme (Fig. 1.8):

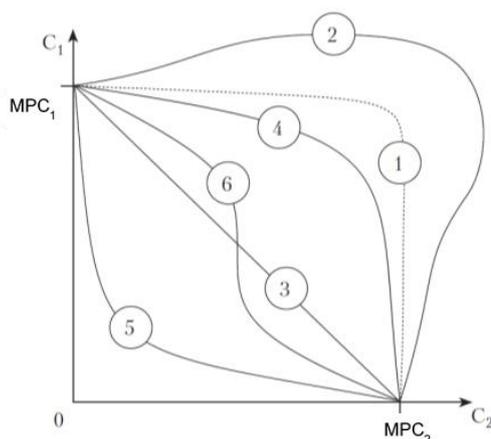


Fig. 1.8. Combination of MPCs of two substances with different types of interaction (Shuiskiy V.F. et al., 2004)

- 1) almost not interacting with each other;
- 2) interacting antagonistically;
- 3-6) interacting synergistically:
  - 3) the interaction of the two substances is additive;
  - 4) each of the substances intensifies the effect of the second one less than additively;
  - 5) each of the substances enhances the effect of the second one more than additively;
  - 6) the first substance enhances the effect of the second one less than additively; and the second factor enhances the effect of the former one more than additively

Existing ecological assessments of the state of ecosystems most often implement the additive model, in which the interaction of components is mapped as the result of "addition" (except for several compounds for which potentiation is characteristic - stronger interaction). If the substances are not included in the summation group, then their concentrations should be compared with the MPC separately, without taking into account the interaction.

But similar models of impacts are very primitive: in reality, any object is influenced

immediately by a whole set of factors (both harmful and contributing to the stability of the object). These factors have a different nature, can interact with each other, which determines the overall impact of factors on the body. It is well known that a combination of diverse harmful substances impacts the body in a different way than each of them individually. Thus, strictly additive interactions of factors are quite rare. In particular, even substances traditionally combined into a common summation group, in fact, interact with each other in a non-additive way. Antagonism factors can be the case. Thus, the total effect of two substances on the body is less strong than the effect of each of them separately. The causes of antagonism can be the properties of substances, and the characteristics of the body's reaction to them. As an example, we can cite a joint effect on the body of a variety of harmful (poisonous) substances and antidote substances (antidotes).

In the modeling of the anthropogenic influences and reactions of the natural systems these concepts are very important. They are necessary not only to understand the scale of the consequences, but also to find the best ways for the natural systems protection.

### *Norms: hygienic or environmental?*

We speak about the sustainable use of some resources (water, forest, some individual biological species) and we need to know the rules of these natural systems development. It is necessary to find the equilibrium of consumption and reproduction. And these environmental norms and standards should contain the requirements for the resources consumption to save this equilibrium.

Nowadays there are two different approaches to the elaboration of the environmental norms and to their application.

The first one is a **hygienic approach**. In this case biological species are the objects and the standards (environmental norms) should be calculated and established to protect them. Another important aspects are:

- limiting loads are determined for the individual substances (or their mixtures, but with a known ratio of the components);
- laboratory experiments are the basis for standards;
- parameters of organisms are studied, not the ecosystem level.

For the xenobiotics we use the following representation of environmental effects and their influence on the organisms. The most often used criteria of norms justification are toxicological and hygienic assessment of pesticides. The following ways of pesticide introduction into the human body are distinguished (short and long):

- soil - human organism;
- soil - atmosphere - human organism;
- soil - groundwater - human organism;
- soil - a body of water - human organism;
- soil - plant products - human organism;
- soil - plant products - animals – human organism.

The example of such approach is presented in the scheme of the justification of maximum allowable concentration of cadmium considering the scheme of food chains in the ecosystem. Only one difference: in this case the target-object is a predator bird on the top of the food chain.

There was 4 main ways of the pollutant (Cd) to enter the organism from the environment, four possible food chains:

- Soil - plant - bird,
- Soil - invertebrate - bird,
- Soil - plant – mammal,
- Soil - invertebrate – mammal.

Generally, the number of chains increases exponentially with detailed and separate accounting of organs and groups of invertebrates and plants. Plants, leaves, seeds, fruits and roots are taken

separately. Groups of invertebrates can include earthworms, gastropods, insect larvae, etc. It is necessary to remember, that predators are always more sensitive than their victims.

The main purpose of the environmental standard is to protect the most vulnerable component of the environment. In the Table 2 there are some food chains reflecting the pathways of Cd in the ecosystems.

**Table 1.2. Some food chains to the development of MAC for Cd in soil (Jongbloed et al, 1994)**

Food chain	Critical Cd concentration in soil, mg/kg	
	predator	victims
Soil - leaf – bird	37	2.3
Soil - Seed – Bird	7.2	0.44
Soil - worm – bird	1.5	0.08
Soil - insect – bird	6.4	0.40
Soil-leaf-mammal	48	3.6
Soil - seed - mammal	9.4	0.68
Soil - worm - mammal	1.9	0.12
Soil - insect - mammal	8.3	0.61

Thus, according to this study, the chain with the predator bird represents the lowest critical concentration for Cd exposure, which gives a very low critical Cd concentration for soils (about 0.1 mg/kg).

The second approach is the development of the **ecosystem standards**. When defining the standards and the evaluation criteria for the state of natural systems, we take into account the local ecosystem multifunctionality. These are essential functions – providing the necessary input to the biosphere processes, meeting the economic, social and aesthetic needs of society. The following aspects are to be considered:

- regulations of limit loads must be variable (different for different purposes ecosystems);
- regulations differentiate depending on the physical and geographical conditions of the region and the type of ecosystem;
- regulations differentiate in time: less stringent for existing technologies, more stringent for the current period, even tougher for the projected production and new technologies;
- normalized cumulative load, expressed in relative units rather than the concentration of individual pollutants;
- among the indicators of the biota the core ones, reflecting the most important laws of its functioning, are chosen;
- preference is given to the integral parameters;
- the definition of standards is only possible in the studies of real ecosystems located in the load gradient, e.g. only on the basis of the analysis of dose - effect on the ecosystem.

Of course, the second approach is much more complicated. Practically we need to create an individual standard for each system and for each set of the impacting factors. That is why in the praxis of nature management the hygienic standards are traditionally used. They are targeted at the protection of some species or on the maintaining of the ecosystem in the “good” state (from the point of view of the “users” – consumer of natural resources).

The entire variety of environmental standards can be presented as shown on the Fig. 1.9.

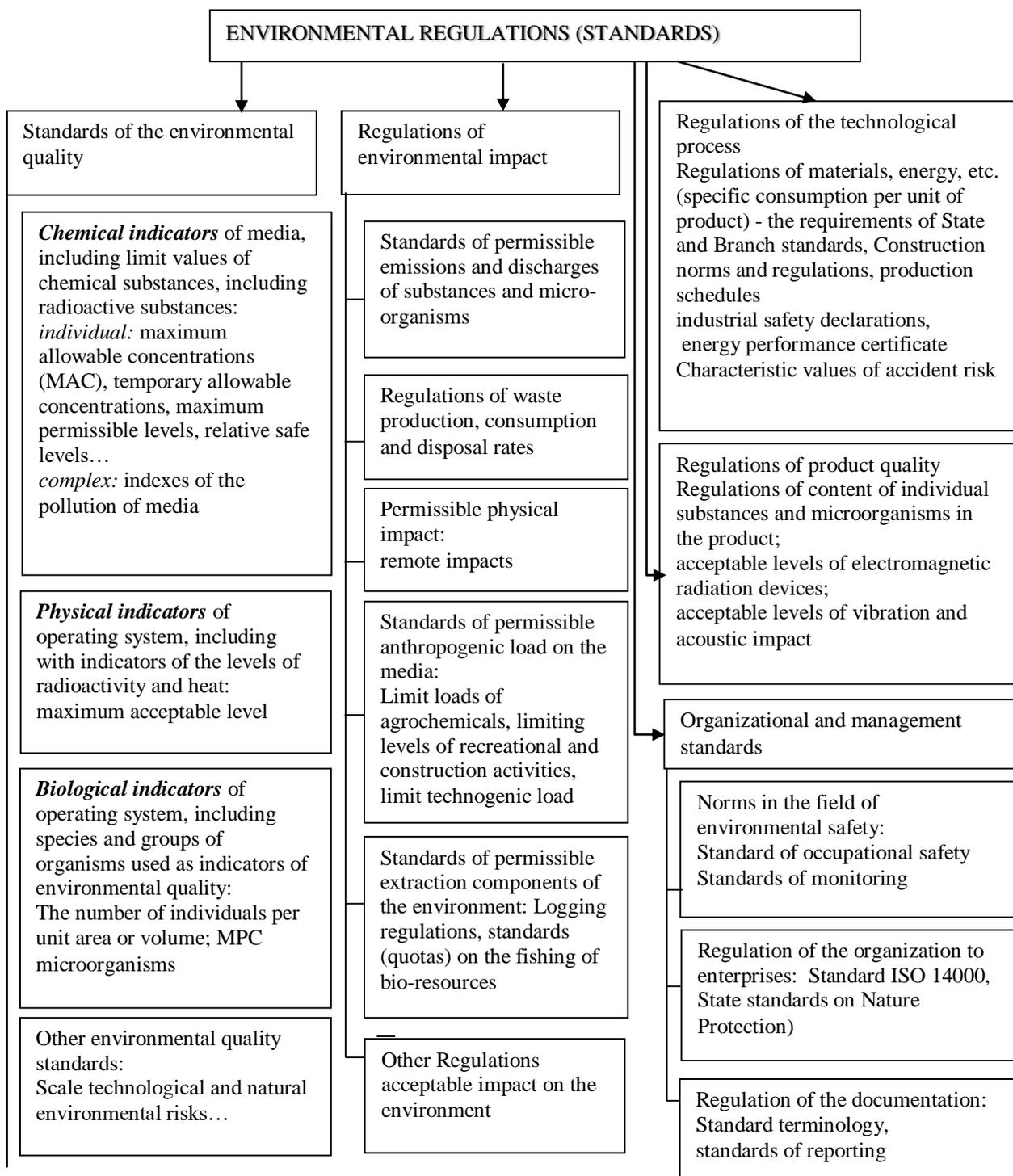


Fig. 1.9. Types of the environmental standards

**Standards of the environmental quality**

First of all, these are the norms of the quality of individual natural media: atmosphere, water, soil. We develop and use standards of the chemical, physical, biological parameters of the ecosystems. These can be maximum allowable concentrations, maximum permissible levels of the impacts, temporary permissible concentrations of some individual pollutants. Besides, we need to control the average concentrations of the pollutants during some periods (day, month, long term periods...) and their variations in comparison with the permissible levels. Generally, when speaking about the environmental standards, these types of critical values should be kept in mind.

Some types of the MAC (MPC) values are presented on the fig. 1.10.

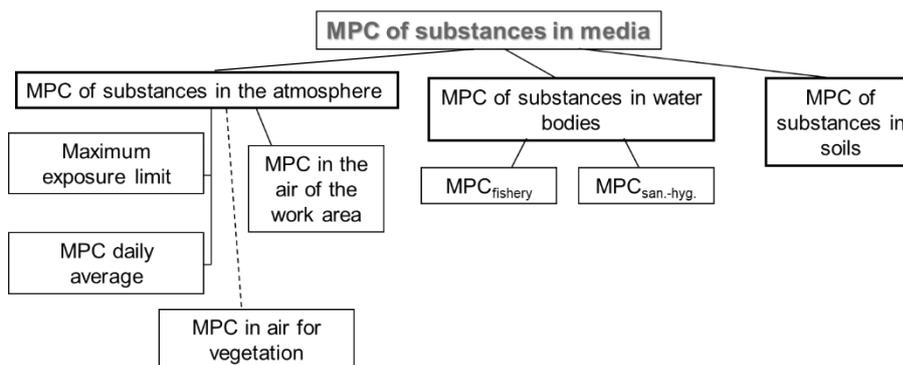


Fig. 1.10. MPC of substances in environmental media

To set the MPC values, the following core principles are to be taken into account:

- the only basis is the biological principle (for sanitary and hygienic values of MPC – effects on humans);
- experimental and field studies are used, the results of them are harmonized;
- the three-coordinate system "dose-time-effect" is based on the finding of probabilistic quantitative thresholds of harmful action;
- for the whole complex of primary, secondary and mediated effects, a limit is allocated;
- rationing is carried out taking into account the expected physiological adaptation of a person;
- principle of the threshold of action: as the basis of hygienic regulation, the minimum concentration of harmful substance is established, which causes intoxication of the organism;
- the principle of acceptable risk: it is used in a *no-threshold model* to evaluate mutagenic and carcinogenic effects with long-term consequences, in the absence of experimental data confirming the quantitative relationship between the force of action and the effect. It is often used to assess the threat in emergency situations.

The principle is most often used for the development of environmental norms, regardless of whether these are MPCs or emission levels or environmental characteristics of products.

The condition of an ecosystem can be evaluated based on a set of relevant norms. As a result, we classify the condition of the system as one of the following types:

- *zone of ecological norm*: the territories capable of sustaining the existing (and, perhaps, additional) ecological load without reducing the level of ecological quality; The activities of the facilities are carried out without significant growth of risks of economic losses;
- *zone of environmental risk*: territories with a violation of environmental quality; return to a stable state is possible, but the level of anthropogenic impact should be either lowered or a complex of restoration measures carried out. The risk of damage to operations is significantly increased if measures are not taken to protect against adverse effects due to a decrease in the quality of the environment;
- *zone of ecological crisis*: destruction can be eliminated only with complete cessation of anthropogenic load and carrying out a complex of restoration works. The measures taken to reduce the risk are insufficient to avoid the risks of economic losses;
  - *zone of ecological disaster*: territories with practically irreversible ecosystem disturbances. Economic damage during operations is inevitable in any protective measures.

*Norms of the environmental impact*

The second type of the environmental norms is equally important. These are the regulations of the environmental impacts. The main approaches to calculation of such norms will be discussed in the next chapters of this course. Generally, to set the maximum allowable level of the impact, it is necessary to know the properties of the polluted (affected) ecosystem and the laws of dilution of pollutants. Knowing the critical level of pollution, we allocate the pollutant: whether it can be diluted so that the critical level of pollution will not be exceeded because of the impact. For the calculations different models can be used, but to set the standard of an impact it is necessary to use the calculation methods approved in the regulatory documents. In different countries there exist national regulations on the establishment of the maximum allowable emissions or maximum acoustic loads or limit levels of biological resources use.

*Norms of technological processes and of product quality*

Norms and regulations of the technological processes and of product quality are very important parts of the environmental standards system. As an example of such norms it is possible to remember the SAR standards for mobile phones or content of some chemical elements of compounds in food. But these standards can be called "secondary". Let's demonstrate an example of how norms are maintained when moving along the food chain (Table 1.3).

**Table 1.3. The level of heavy metals in the food chain "water - soil - feed - milk" (Volgograd region, Russia; according to materials Gorlov et al., 2011).**

Heavy metals	Concentrations of heavy metals							
	In water of water bodies, mg/dm <sup>3</sup>		In pasture soils, mg/kg		In feed, mg/kg		In milk, mg/l	
	Fact	MPC	Fact	MPC	Fact	MPC	Fact	MPC
Zn	3.18	5	38.4	60	25	50	2.5	5
Cd	0.0008	0.001	0.063	1	0.034	0.2	0.0007	0.03
Pb	0.0079	0.03	15.4	60	0.6	2	0.003	0.1
Cu	0.044	1	13.7	50	9	30	0.023	1

A very special direction of the regulation is development of the best available technologies. Generally, the term "technology" here means not only some approach to the production of something. The concept of technology includes the *best available techniques as well as best praxis of management*. The "best" and "available" means that this technology or technique is available and applicable technically and economically, and also is environmentally friendly. 1984 in the Directive 84/360/EEC the term "Best available techniques not entailing excessive costs" (BATNEEC), sometimes referred to as best available technology, was introduced. It was about the air pollution emissions from large industrial installations. In 1996, this document was superseded by the Integrated pollution prevention and control directive (IPPC), 96/61/EC. It applied the framework concept of Best Available Techniques (BAT) to the integrated control of pollution to the three media - air, water and soil. This concept is a part of the directive's recast in 2008 (2008/1/EC) and its successor directive, the Industrial Emissions Directive 2010/75/EU published in 2010.

For the introduction of the concept of BAT in Europe it was necessary to develop the common rules on the justification and selection of technologies meeting all the requirements. Currently there is a complex system of interactions between a groups of stakeholders developing the regulations on BAT. The system includes elaboration of manuals on BAT for the relevant branches (i.e. steel

production, large incinerators, wood or glass production). After that, the lists of the technologies are necessary (the register of BAT) for each branch. And, finally, the authorities have to develop a system of regulation mechanisms to stimulate the stakeholders for implementing the BATs.

So, in Russia, implementation of BAT ideology requires significant changes of the entire environmental legislation. A new classification of enterprises was introduced considering their threat for the environment. These are four groups of enterprises, from most dangerous to practically safe. For these groups there are special sets of control and regulating mechanisms. And the first, most dangerous group, required the BATs implementation to minimize the negative influence on the environment. The danger criteria were developed for each branch separately, and now it is possible to select the group of enterprises, that have to use the nature management approach based on BAT. A part of this list is presented below:

1. Realization of economic and (or) other activity:

- production of coke; of crude oil and natural gas, including processing of natural gas; of petroleum products; extraction and enrichment of iron ores;
- extraction and preparation of non-ferrous metal ores - aluminum (bauxite), copper, lead, zinc, tin, manganese, chromium, nickel, cobalt, molybdenum, tantalum, vanadium, and precious metal ores (gold, silver, platinum) except for precious metal ores and sands, tin ores, titanium ores, chrome ores in loose deposits;
- supply with electric power, gas and steam with the use of equipment (with an installed electric power of 250 MW and more when consumed as the main solid and (or) liquid fuel or with an installed electric power of 500 MW or more when consumed as the main gaseous fuel);
- metallurgical production using equipment:
  - production of pig iron or steel (primary or secondary smelting), including continuous casting (with a capacity of 2.5 tons per hour or more);
  - processing ferrous metals using hot-rolling mills (with a design capacity of 20 tons of unrefined steel per hour or more);
  - application of protective sprayed metal coatings (with the supply of 2 tons of unrefined steel per hour or more);
  - foundry production of ferrous metals (with a design capacity of 20 tons per day or more);
  - production of non-ferrous metals from ore, concentrates or recycled materials (using metallurgical, chemical or electrolytic processes);
  - melting, including alloying, refining, and casting of non-ferrous metals (with design capacity (smelting) 4 tons per day or more for lead and cadmium, or 20 tons per day or more for other metals).

The detailed list of industrial objects includes more than 30 positions with qualitative and quantitative description of hazard criteria of enterprises.

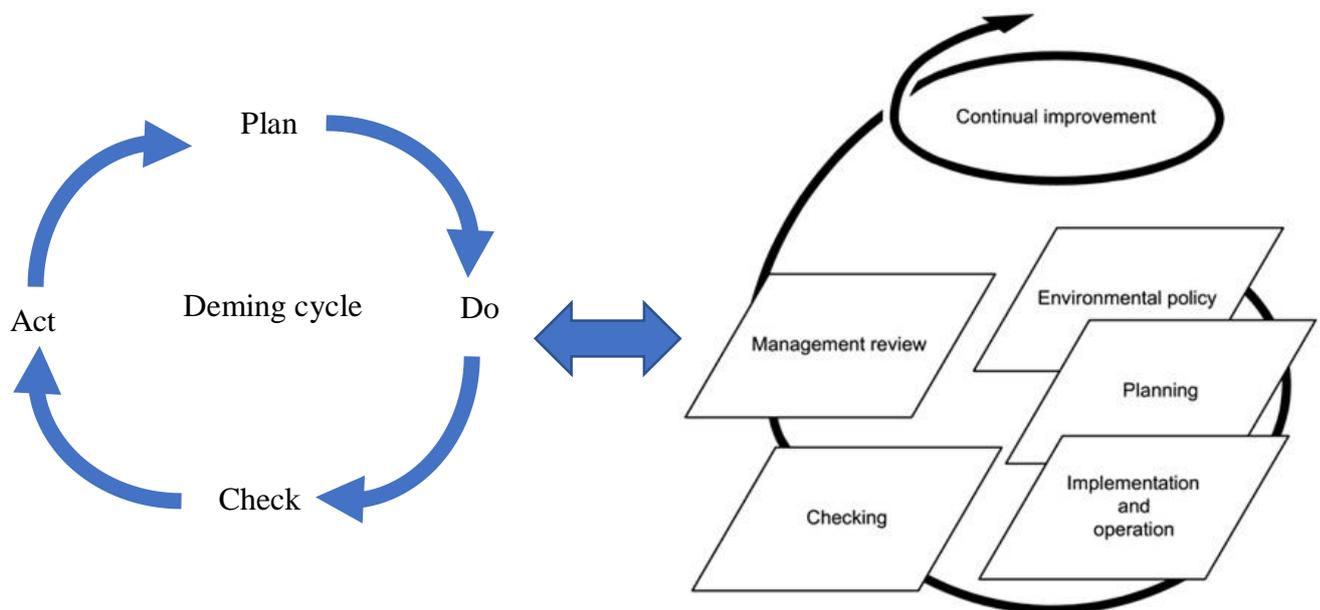
These economical objects are to be strictly regulated from the point of view of environmental norms. So, in contrast to other categories, it is necessary to conduct periodic environmental assessments, develop a special program of actions to reduce the negative impact on the environment. And the main moment – implementation of BATs to reduce emissions of pollutants and minimize environmental risk.

*“Ancillary environmental regulations”*

And finally, the special types of the standards are the “ancillary regulations”: management standards, monitoring standards, standards of terminology, reporting, accounting.

There are national and international environmental management standards, regulations on different types of environmental monitoring and industrial environmental control and assessments. These standards regulate procedures of management or approaches to the organization of sampling and measurements.

So, the international management standards of the ISO 14000 series include some groups of documents that can be combined according to the stage of management cycle. This cycle called the “PDCA Deming cycle” is a base of the management scheme including the stages of elaboration of a plan, the implementation stage “do”, the control stage “check” and the improvement and development stage “act”. Generally, in the ISO 14001 this scheme has been transformed into a 5-stage scheme (Fig. 1.11).



*Fig. 1.11. Cycle of environmental management*

The main ISO 14000 documents are presented in the following table.

**Table 1.4. Standards of ISO 14000 series**

Plan	Do	Check	Act
<p>ISO 14050:2009. Environmental management -- Vocabulary</p> <p>ISO 14001:20015. Environmental management systems - Requirements with guidance for use</p> <p>ISO 14004:2016. Environmental management systems - General guidelines on implementation</p> <p>ISO/DIS 14005. Environmental management systems - Guidelines for a flexible approach to phased implementation</p>	<p>ISO 14040:2006. Environmental management -- Life cycle assessment -- Principles and framework</p> <p>ISO 14044:2006. Environmental management -- Life cycle assessment -- Requirements and guidelines</p> <p>ISO/TR 14047:2003. Environmental management -- Life cycle impact assessment -- Examples of application of ISO 14042</p> <p>ISO/TS 14048:2002. Environmental management -- Life cycle assessment -- Data documentation format</p> <p>ISO/TS 14071:2014. Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006</p>	<p>ISO 14001:20015. Environmental management systems -- Requirements with guidance for use</p> <p>ISO 14031:2013. Environmental management -- Environmental performance evaluation -- Guidelines</p> <p>ISO 19011:2011. Guidelines for auditing management systems</p>	<p>ISO 14020:2000. Environmental labels and declarations -- General principles</p> <p>ISO 14021:2016. Environmental labels and declarations -- Self-declared environmental claims (Type II environmental labelling)</p> <p>ISO 14024:2018. Environmental labels and declarations -- Type I environmental labelling -- Principles and procedures</p> <p>ISO 14025:2006. Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures</p> <p>ISO/AWI 14033-1. Green bonds -- Environmental performance of nominated projects and assets</p> <p>ISO 14063:2006. Environmental management -- Environmental communication -- Guidelines and examples</p>
Incorporation of environmental aspects into product standards		Management of greenhouse gas assessment	
<p>ISO Guide 64:2008. Guide for addressing environmental issues in product standards</p> <p>ISO 14006:2011. Environmental management systems - Guidelines for incorporating ecodesign</p>	<p>ISO/TR 14049:2012. Environmental management -- Life cycle assessment -- Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis</p> <p>ISO 14051: 2011. Environmental management -- Material flow cost accounting - General framework</p> <p>ISO/WD 14045:2011. Environmental management -- Eco-efficiency assessment of product systems -- Principles, requirements and guidelines</p> <p>ISO/TS 14071:2014. Environmental management --</p>	<p>ISO 14064-3:2006. Greenhouse gases -- Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions</p> <p>ISO 14065:2013. Greenhouse gases -- Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition</p>	

	Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006 ISO/TS 14072:2014. Environmental management -- Life cycle assessment -- Requirements and guidelines for organizational life cycle assessment		
	Greenhouse gas management		
ISO/TR 14062:2002. Environmental management - a guide to integrating environmental accounting into the product development process	ISO 14064-1:2006. Greenhouse gases -- Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals ISO 14064-2:2006. Greenhouse gases -- Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements ISO 14067. Greenhouse gases - - Carbon footprint of products - - Requirements and guidelines for quantification and communication ISO/TR 14069. Greenhouse gases -- Quantification and reporting of greenhouse gas emissions for organizations -- Guidance for the application of ISO 14064-1	ISO/CD 14066: 2011. Greenhouse gases -- Competence requirements for greenhouse gas validation teams and verification teams	

Another large group of “ancillary” environmental standards are the standards of environmental monitoring. Generally, here we can apply international standards as well as national documents. There are a lot of ISO documents regulating the procedures of sampling and chemical analytical procedures. In order to be able to compare the results of different laboratories, we need to use common approaches to the environmental control. In these cases, the standards become a "common language", on which relevant specialists can communicate. Especially important are these issues when it comes to sharing the results of analyzes. It is also important to use common standards in the development of tools and measurement methods (including equipment).

### *Information sources*

1. DEVELOPMENT AND INTERNATIONAL ECONOMIC CO-OPERATION:  
ENVIRONMENT. Report of the World Commission on Environment and Development. URL:  
<http://upload.wikimedia.org/wikisource/en/d/d7/Our-common-future.pdf>

2. REPORT OF THE UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT (Rio de Janeiro, 3-14 June 1992). URL: <https://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm>
3. Shaker, R.R. (2015). The spatial distribution of development in Europe and its underlying sustainability correlations. Applied Geography, 63, 304-314.
4. SUSTAINABLE DEVELOPMENT KNOWLEDGE PLATFORM. URL: <https://sustainabledevelopment.un.org>
5. Transforming our world: the 2030 Agenda for Sustainable Development. URL: <https://sustainabledevelopment.un.org/index.php?menu=2361>
6. Data for Development. A Needs Assessment for SDG Monitoring and Statistical Capacity Development. 2015. URL: <https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=2017&menu=35>
7. Final list of proposed Sustainable Development Goal indicators <https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf>

### *Home task*

1. Having analyzed the system of aspects of sustainability of natural systems, provide examples of stability of the atmosphere; surface hydrosphere; underground hydrosphere; ecosystems; soil.
2. Analyze the international obligations of your country over the past 10 years in the field of environmental protection, resource use, energy efficiency. Show whether there is a need for changes in this regard in the domestic system of environmental regulation in the relevant areas.
3. Describe the connection of the sustainable development goals (take any 3 of them) with the prospective of use of natural resources in your country.

### *Questions for the self-control*

1. What are the purposes of environmental regulation?
2. List and comment the main principles of environmental regulation.
3. What is environmental regulation?
4. What is the object of environmental regulation?
5. What is the norm of the ecosystem? Give some examples.
6. How high is the contribution of the environmental factor to the health of the population according to the World Health Organization?
7. What is the norm of impact on ecosystem and how it can be identified?
8. Describe the main elements of the current system of environmental regulation.
9. What are the main features of the hygienic approach to the development of environmental norms?
10. List the examples of the standards of permissible environmental impact.
11. List the examples of the environmental quality standards.
12. What is the main idea of the anthropocentric approach in the environmental regulation?
13. What is the basis for setting standards in the hygienic approach in environmental

regulation?

14. List the types of the joint action of substances on the organism and give a brief description.
15. Give a definition of the concept “sustainability of natural systems”.
16. What are the types of sustainability of natural systems?
17. What types of the stability of natural systems are peculiar to the biological objects?
18. What is the summation (additive action) in case of the combined action of several factors on the organism? Give an example.
19. How to consider the type of the stability of a system when developing an environmental quality standard?
20. Describe the current system of the environmental management standards.

## Chapter 2. Environmental norms and regulations for the atmosphere protection

The preservation of atmospheric quality is not explicitly included in the list of sustainable development goals. However, this is a necessary condition for the realization of all 17 global goals. Assessments of WHO specialists show that the quality of the atmosphere makes a very significant contribution to the state of human health, and this is only a direct impact. Indirectly, due to the processes of migration of substances between the components of the environment, it is the pollution of the atmospheric air that causes subsequent contamination of all components of the biosphere.

In this regard, development of environmental norms for the protection of atmosphere is one of the essential parts of sustainable use of its resources and of nature protection in general. In this chapter, we will focus on such key points as the classification of sources of impacts, the factors of pollution and self-purification of the atmosphere, types of standards, complex and single indicators of atmospheric quality, modeling of pollution and the possibility of regulating permissible impacts.

Generally applied norms are:

- Norms of air quality (content of pollutants):
  - Permissible concentrations of pollutants and exposure levels - air quality standards (for residential area);
  - Air quality standards for the work area;
  - Standards for the quality of the atmosphere for living organisms (except humans!);
- Norms of impact on the atmosphere (emissions of pollutants);
- Norms of physical impacts (noise levels);
- Norms of the impact complex: sanitary protection zones.

Let us consider the properties of the pollution sources.

### *Sources of the pollution*

First of all, it is necessary to divide the sources of the pollution: they can differ in origin, form, time of the “activity”, danger level etc. These moments are to be taken into account when assessing the environmental risk for the pollution sources, when modeling distribution of the impurities in the environments, when evaluating the health risk for humans.

So, according to the origin the pollution sources are divided into natural and technogenic. This is important for the forecast of possible consequences of such pollution: it is well known, that for the natural systems the natural pollutants are not as dangerous as some xenobiotics (absolutely alien for the living organisms). Of course, the consequences depend not only on the origin of the pollution, but also on its quantitative characteristics. However, in general, natural contaminants differ precisely in that they do not contain substances foreign to organisms. Examples of the natural emissions are volcanic activities, dust storms or less active releases into the atmosphere. Both the contaminations are very intensive and hazardous due to the scale of impact. In case of technogenic pollutions the set of substances can be very diverse and their effects on the living organisms can be destructive despite the low concentrations.

According to the spatial configuration, the pollution sources are divided into point and linear, surface and volume. And according to the height they can be high, moderate, low and surface. These aspects are to be considered when modeling the configuration of the emission source and, in general, distribution processes.

Mobility is another important characteristic of the atmospheric pollution sources. These things are to be considered for the modeling of pollution zones and for the regulation. So, in Russia, there

are specific regulations for the environmental taxes. Mobile and stationary sources have different schemes of the taxes calculation.

According to the duration of the emission sources activity there are three main groups of sources:

- *sources of fleeting effects*: (duration from a few seconds to several minutes with a travel time of several hours);
- *sources of short-term effects*: (duration up to several hours);
- sources of continuous effects.

The duration of an activity is important to model the “mode” of pollution.

And, finally, one of the most important classifications is based on the danger level (or risk level). This classification takes into account a complex of properties of the source that can affect the state of natural systems or human health. In Russia, there are four hazard classes of sources, from the 1<sup>st</sup> (most dangerous) to the 4<sup>th</sup> (practically safe).

### *Factors of distribution of impurities in the atmosphere*

Entering into the atmosphere from one of the pollution sources, the emission faces a complex of factors that affect its behavior.

1) chemical transformation of impurities;

2) radioactive decay and accumulation of daughter products;

3) wet sedimentation:

- with rain or snow (steam or aerosol falls into water droplets or snowflakes and falls out as precipitation);

- because of leaching (steam or aerosol is captured below the rain cloud by falling precipitation);

- with fog (steam or mist fall into the water droplets in the fog);

4) dry sedimentation:

- sedimentation of aerosols / gravitational sedimentation (for particles with  $d > 10 \mu\text{m}$ );

- sedimentation of aerosols and adsorption of vapors and gases on objects in the wind path;

5) formation and coalescence of aerosols.

The potential of resistance of the natural environment is determined by the adaptation of its elements, i.e. the amount of harmful substances that elements of the environment can accept and adapt to them without negative consequences. For the atmosphere, these are primarily climatic and orographic features of the territory. They create different types of atmospheric inversions.

The concentration of impurities in air depends not so much on the mass of emissions as on the conditions for its entry into the atmosphere (height of the ejection points, its initial discharge velocity from the source, temperature), as well as the intensity of atmospheric processes in the air layer where dilution and mixing of impurities occur. So, identical sources of emissions in different climatic conditions can create degrees of pollution of atmospheric air, differing in 7-10 times.

This is due to regional and local features of the physical properties of the atmosphere. Of great importance is the ratio of the heights of the atmospheric sphere of mixing and the height of the flare of the source of emissions. Also important is the role of the physicochemical properties of the impurity (particle size, their ability to transform into the environment). Qualitative characteristics characterizing pollutants, distinguish the following forms of pollution of the atmosphere: dust, gassing and contamination.

The mixing layer can be limited by surface or elevated temperature inversions. More often

gradients of temperatures, wind speeds, turbulent exchange coefficients and other regional features determine the accumulation of harmful substances in the surface layer of the atmosphere.

In connection with this, with the environmental rationing of impacts on the atmosphere, the most important characteristic is the potential of air pollution potential (APP). This integral characteristic depends on a complex of atmospheric processes having a multidirectional action. The frequent occurrence of unfavorable natural conditions leads to the accumulation of impurities in the surface layer of the atmosphere. In this case, the area is characterized by high APP.

The air pollution potential (APP) is the ability of the atmosphere to disperse impurities; it includes a complex of meteorological factors and is determined depending on their quantitative characteristics. For the quantitative evaluation of APP different approaches can be used [1-5]. As an example of the result of such assessment let us look at the division of the territory of Russia according to the APP level (Table 2.1). The assessment is based on the state standard SanPiN 2.1.6.983-00 "Atmospheric air and air of closed rooms, sanitary air protection. Hygienic requirements to quality assurance of atmospheric air in inhabited areas".

**Table 2.1. The atmospheric pollution potential and the values of the meteorological parameters**

Atmospheric pollution potential (APP)	Surface inversion:			Repeatability of the wind characteristics, %		The height of the layer displacement, km	Duration of fog, h
	repeatability, %	capacity, km	intensity, °C	wind speed 0-1 m/sec	incl. continuously several days of stagnant air		
Low	20–30	0.3–0.4	2–3	10–20	5–10	0.7–0.8	80–350
Moderate	30–40	0.4–0.5	3–5	20–30	7–12	0.8–1.0	100–500
Elevated:							
continental	30–45	0.3–0.6	2–6	20–40	3–18	0.7–1.0	100–600
seaside	30–45	0.3–0.7	2–6	10–30	10–25	0.4–1.1	100–600
High	40–60	0.3–0.7	3–6	30–60	10–30	0.7–1.6	50–200
Very high	40–60	0.3–0.9	3–10	50–70	20–45	0.8–1.6	10–600

It should be noted, in this case we talk about the long-term processes. This potential can be called climatic. To understand the local processes and short-term processes a different type of pollution potential can be calculated, so-called *meteorological potential of atmosphere* (Selegey, 2005):

$$MPA = (P_{\text{calm}} + P_f) / (P_p + P_w),$$

where:

$P_{\text{calm}}$  — frequency of days with wind speed 0 — 1 m/s (%);

$P_f$  — frequency of days with fog (%);

$P_p$  — frequency of days with precipitation > 0,5 mm per day (%);

$P_w$  — frequency of days with wind speed > 6 m/s (%).

The quantification of meteorological conditions by criterion of MPA:

- $MPA < 0,8$  – unfavorable conditions for dispersion;
- $0,8 \leq MPA \leq 1,2$  – limited favorable dispersion conditions;
- $MPA > 1,2$  – favorable conditions for self-cleaning the atmosphere.

In many studies and practical activities, a simple classification of the stability of the atmosphere using a vertical temperature gradient is used. To assess the stability of the atmosphere,

6 stability classes are used - A, B, C, D, E and F according to F. Pasquill), as presented in the Table 2.2. The first three classes correspond to the unstable stratification of the atmosphere, the last two are stable, and the D class is neutral (Fig. 1).

**Table 2.2. Atmosphere stability classes**

Stability class	Typical wind speed, m/s	Description of the weather	The vertical temperature gradient, K/m
A	1	Cloudless	>>> 0.01
B	2	Sunny and warm	>> 0.01
C	5	Variable cloud during the day	> 0.01
D	5	Cloudy day or cloudy night	≈ 0.01
E	3	Partly cloudy during the night	< 0.01
F	2	Clear night	Inversion (negative gradient)

Thus, the three groups of factors determine the “fate” of the impurity in the atmosphere:

- properties of the impurity itself (its chemical composition and activity, physicochemical characteristics, volume and mass of the emission),
- properties of the contaminated environment (for example, AAP and MPA as complexes of their properties),
- properties of the source of pollution (determine a “mode” of the emission).

As a result of interaction of all three groups we receive a certain level of concentration of pollutants. To understand the danger of the pollution it is necessary to determine some types of the pollution indicators and indexes.

### *Indicators of contamination of the atmosphere by harmful substances*

The main single indicator of air pollution is a single impurity concentration: concentration measured over 20-30 min.

After processing the data, averaged indices of atmospheric pollution with a single impurity are obtained: at a separate sampling point and at a set of sampling points; a single indicator of the state of atmospheric pollution for a group of cities; indices of atmospheric pollution by individual impurities; statistical estimation of characteristics.

The first group of indexes are the characteristics of the pollution by a single impurity:

- average daily impurity concentration;
- average monthly impurity concentration;
- average annual impurity concentration;
- average long-term impurity concentration;
- annual average concentration according to the data of the under-plume observations.

Under-plume observations are carried out for characterising enterprise impurities. These are measurements of impurity concentrations under the axis of the flare emissions from industrial plants. The location of the points at which air sampling is performed to determine the concentration of harmful substances varies with the direction of the flame. Under-plume observations are conducted in the area of a separately standing source of emissions or a group of sources both in the city and outside it.

The next groups are the complex pollution indexes, statistical characteristics of distribution of concentrations in space and time, ratios of the observed concentrations and “norms”.

In the praxis it is possible to find different variants of the pollution indexes. The approach to calculation depends on the task of such a study. Aggregated indicators of the pollution level of certain elements of the environment are being developed for a long time. In practice, such indicators allow us to identify objects that primarily require measures to protect the atmosphere. In addition, a complex indicator of atmospheric pollution can be used to establish the relationship between changes in the state of atmospheric air and the health status of the population in the study area, as well as the relationship between production dynamics and the state of the atmosphere. The indicators allow to obtain an integral assessment of the state of atmospheric air, on the basis of which it is possible to compare the level of contamination of several settlements, assess the change in the state of the atmosphere for the same locality in dynamics.

One of the variants of the integral index of the state of atmospheric air is the complex index of air pollution (CIAP)

$$CIAP = \sum_{i=1}^n \left( \frac{q_{yi}}{MAC_i} \right)^{\alpha_i},$$

where  $i$  is the admixture,  $q_{yi}$  is the average annual concentration of impurity  $i$ ,  $MAC_i$  is the maximum allowable daily average concentration of the substance,  $c_i$  is the constant that takes values depending on the hazard class of the substance: 1.7 (first hazard class), 1.3 (second hazard class), 1.0 - the third hazard class and 0.9 - the fourth hazard class.

The best situation is the contamination of the atmosphere with the minimum values of CIAP. But it is difficult to say at once, whether the pollution level is high or low. In the praxis using this index for comparison of situations in time or in space is only possible if we have the same data sets. Apparently, there is no point in comparing, for example, two different cities using information on 20 substances for the 1<sup>st</sup> city and on 5 different toxicants for the 2<sup>nd</sup> city.

5-6 most common toxicants are traditionally assessed, and the data set is the same for different objects or for different time periods.

Another approach allows us to make assessments and comparisons independent of the data set. The actual level of air pollution in populated areas is estimated on a 5-point scale. Pollution of the 1st degree (permissible pollution) is safe for public health; with pollution of II-IV degrees, the negative impact on the health of the population increases. The resulting air pollution is determined in accordance with the algorithm shown further.

The pollution index for settlements was suggested in 1989 in the USSR. It will be calculated using the formula:

$$P = \sqrt{\sum K_i^2},$$

$K_i$  - the actual average annual air pollution by the  $i$ -th substance in fractions of the daily average MPC, reduced to the biological equivalent of the third hazard class

The 1<sup>st</sup> stage is calculations of  $K_i$ .

$$K_i = C_i / MAC_i$$

Where  $i$  is a substance,  $C_i$  is its' concentration (fact) and  $MAC_i$  – the maximum allowable concentration.

The substances can belong to the different hazard classes. It is necessary to take into account the danger of exceeding the concentration of the MAC level. For these purposes the following formulas are to be applied:

- For the 1<sup>st</sup> hazard class:

$$K_{1-3} = K_1 \cdot 3^{2.89 \cdot \lg K_1}$$

- For the 2<sup>nd</sup> hazard class:

$$K_{2-3} = K_2 \cdot 3/2^{1.55 \cdot \lg K_1}$$

- For the 4<sup>th</sup> hazard class:

$$K_{4-3} = K_4 \cdot 3/4^{1.05 \cdot \lg K_1}$$

And finally, the calculated P index will be interpreted as shown in the Table 2.3.

**Table 2.3. Interpretation of the pollution level according to the P value**

Level of air pollution	Number of impurities			
	2-3	4-9	10-20	> 20
I – allowable	2	3	4	5
II – weak	2.14	3.1-6	4.1-8	5.1-10
III – moderate	4.1-8	6.1-12	8.1-16	10.1-20
IV – strong	8.1-16	12.1-24	16.1-32	20.1-40
V – very strong	>16	>24	>32	>40

Thus, this index can be used to compare different settlements for different groups of substances. The contamination data may differ in the composition and in the amount of pollutants.

### *Main models of the air pollution*

The behavior of impurity is affected by a variety of factors. Sometimes it is impossible to measure all of them and to understand the clear dependence between the intensity of a certain factor and a concentration value. That is why for the practical calculations we take into account only a limited set of factors, most significant ones for the specific task. Further you will see a list of most widely used models of the distribution of pollutants in the atmosphere, but first it is necessary to say few words about the types of models.

On variety of the considered processes the models are to be divided into:

- Empirical models: often the physics of processes is almost ignored or greatly distorted
- Models considering the laws of air movement and diffusion (using a variety of sets of simplifying assumptions)
  - Models of contamination spread, supplemented by taking into account special processes (initial rise of heated emissions, settling of heavy particles, precipitation of impurities by sediments)
  - Models considering chemical transformations of substances in the process of their distribution, in particular the photochemical smog models
  - Specific models of air currents near the accident (in contrast to the models of distribution of an impurity)

On “stability” of the pollution:

- Stationary (all the conditions are stable for the entire modeled period);
- Nonstationary (changes of some considered parameters in the model).

On used dependences:

- Empirical: most models approved at the state level for practical use.
- Semiempirical: empirical dependencies are supplemented by a developed mathematical

apparatus - this allows us to analyze complex situations that differ significantly from the initial experiments, and to combine the results of dissimilar experiments.

□ Theoretical: used for the scientific purposes, allow only a qualitative explanation of some observed effects

Based on these approaches the following kinds of models are created:

1. *Models of emergency services*. Standard methods are based on empirical models, and to determine the maximum possible area of lesions in the emission of toxic substances. The model indicates not the real position of the cloud of emissions at any given time, but the boundaries within which the concentration of toxic substances can reach dangerous for human health values under adverse weather conditions. The model is simple and effective.

2. *Standard models of atmospheric pollution by stationary sources*. Models can be used to analyze quasistationary processes. The characteristic times of emissions of toxic substances exceed the characteristic times of movement of air masses in the area of expertise (for example, cases of fires or leaks on product pipelines). The model is empirical; it makes it possible to calculate the steady distribution of the concentrations of the toxicant at a given wind and the most unfavorable state of the atmosphere (from the point of view of impurities scattering).

3. *IAEA models* (accepted as an international standard) for calculations of atmospheric pollution generated by stationary sources. These are the most complete of the currently available empirical models. The nature of their detailing allows to take into account the peculiarities of local meteorological conditions and to calculate the distributions of impurities in current weather conditions. Models require significant work on adjusting to local conditions

4. *Simplest non-stationary models* for calculating the *spread of a cloud of pollutants*, intended for express prediction. Models are built on the basis of IAEA techniques and models which allow calculating the trajectory and time of the emission cloud motion before loss of toxicity or in the area of interest in current weather conditions. There are no established standards for such models.

5. *Nonstationary pollution models* that take into account the heterogeneity of the underlying surface.

6. *Most complete and perfect nonstationary models* of the distribution of pollutants in the atmosphere. They include calculations of the mesometeorological characteristics of the atmosphere, taking into account orography (terrain relief). The models are based on the solution of the problems of the mesometeorological forecast and the solution of the three-dimensional impurity diffusion transfer equation. They require significant computational resources and detailed specification of large amounts of input and initial information and are used when exact results are needed (controversial situations, the need for a precise forecast, etc.).

7. *Models for predicting pollution under calm conditions* of different types. Characteristics of distribution and diffusion of impurities in calm conditions and in the wind are so different that describing them requires a different model. The nature of the spread of pollution during in calm conditions essentially depends on the state of the atmosphere, the orography of the terrain and the initial conditions.

8. *Block models* that take into account the processes of *chemical transformation of impurities*. If necessary, it is connected to the above models. It is used when for the analysis of an event it is essential to take into account the chemical reactions taking place in the emission cloud, for example, in cases of the possibility of a significant increase or decrease in toxicity.

Besides, models for zoning of territories are applied according to the probability of accidents and the degree of threat to industrial facilities and population, models for the forecast of the unfavorable weather conditions.

In any case the choice of the models depends on the practical task and situation to be modeled. Let us look at an example of a model that is used in Russia to predict the propagation of impurities in the atmosphere under stationary conditions, as well as to control emissions for the purpose of protecting the atmosphere. This is a state approved model, considered as a state standard. Its results are accepted by the state authorities when the maximum allowable concentrations are to be established and for the justification of the danger level of some technogenic objects.

As well as all the models, this one has some limitations:

- The model doesn't provide acceptable result for the calculation for the long distances (over 100 km) from the emission source.
- The "basic" case of the calculation is the emission from the single point source with a round mouth. All other types of sources are considered as a combination of the point sources.
- Depending on the height  $H$  of the mouth the sources of air pollution are divided into four classes: a) high,  $H > 50$  m; b) sources of medium height,  $H = 10 \dots 50$  m; c) low sources,  $H = 2 \dots 10$  m; d) land-based sources,  $H < 2$  m. In the calculations for the land-based sources  $H = 2$  m is used.
- We do not consider wind speed  $u < 0,5$  m / s, and wind speed  $u > u^*$ , where  $u^*$  – wind speed exceeds in the area long-term average mode in 5% of cases.

We consider all the conditions for the entire period of modeling as invariable. The initial data for calculations are three groups of data: characteristics of emission source, properties of the gas mixture and characteristics of the polluted area. The main primary data and the steps of calculations are presented on the Fig. 2.1.

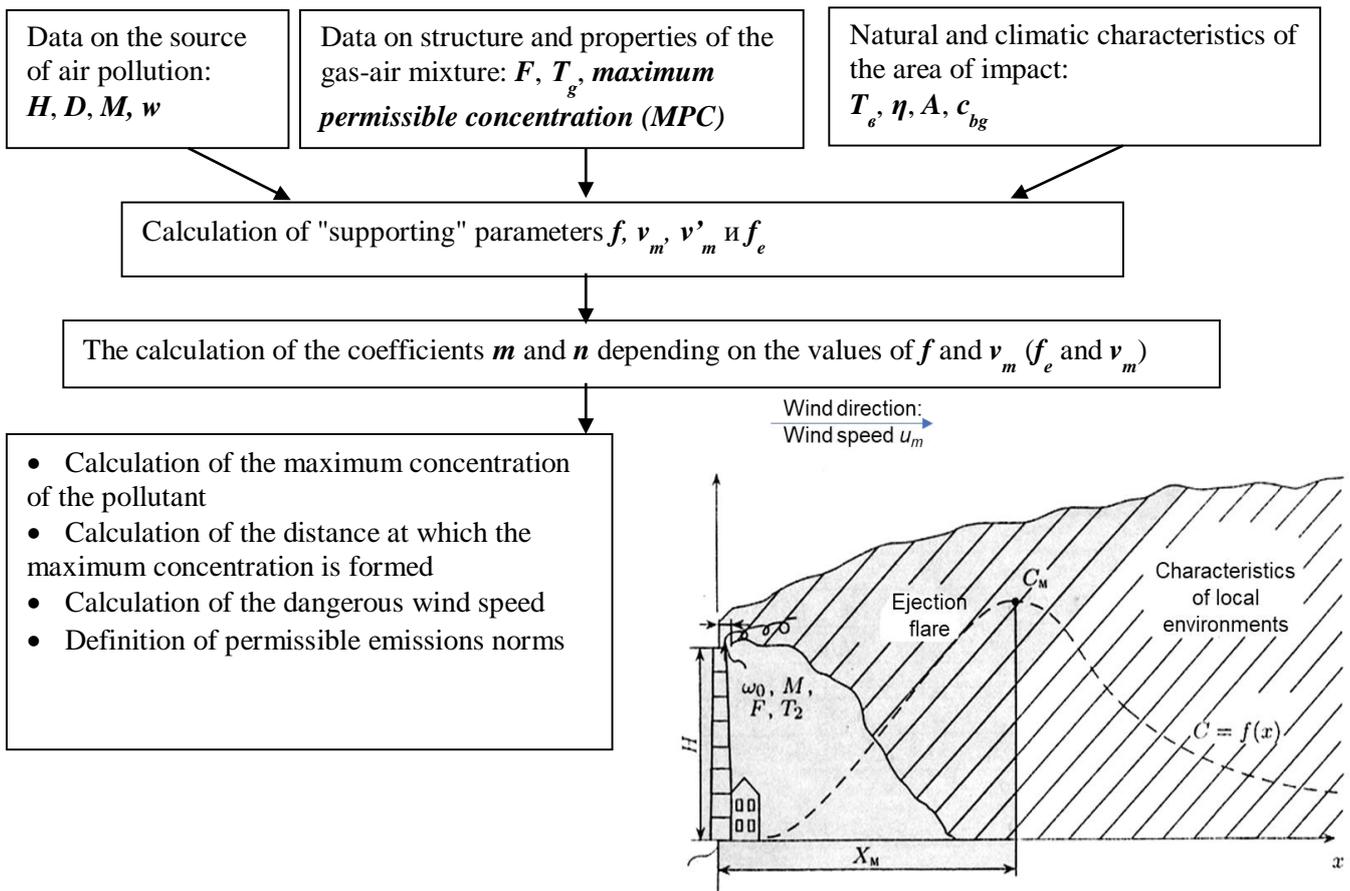


Fig. 2.1. Main parameters used in the model

The main parameters used in the model are presented on the Fig. 2.1 and further.

The maximum value of surface concentration of the substance  $C_m$  ( $\text{mg} / \text{m}^3$ ) due to the emission of the air-gas mixture from a single point source with a round mouth at a distance of  $x_m$  (m)

from the source (based on the equation of turbulent diffusion):

$$c_m = \frac{AMFmn\eta}{H^2 \sqrt[3]{V_1 \Delta T}}$$

In the case of “cold” emissions (without the difference of gas mixture and surrounding air):

$$c_m = \frac{A \cdot M \cdot F \cdot n}{H^{4/3}} \cdot K$$

And now to the primary information.

*A* – coefficient depending on the temperature stratification of the atmosphere. For different regions of the world the distribution of the temperature with height is of course not the same. Let us demonstrate the example for some regions at the territory of Russia (Table 2.4).

**Table 2.4. Values of A coefficient**

Territory	A*
1. Buryatia and Transbaikal region	250
2. European part of the territory of Russia south of 50° N, the remaining areas of the Lower Volga region, the Asian territory of the Russian Federation (exc. Buryatia, Trnsbaikal region and regions of p. 3)	200
3. European part of the Russian Federation and the Urals from 50 to 52° N for incl., exc. Regions of pp. 1 and 2 of this table; regions of the Asian part of Russia to the North of the Polar circle and the West of the Meridian 108° E.	180
4. The European territory of Russia and the Urals north of 52° N lat. (with the exception of the UTS center)	160
Moscow, Tula, Ryazan, Vladimir, Kaluga, Ivanovo regions	140

It is possible to see, that under the same conditions only the *A* value can “produce” visible different concentrations in different regions. So, using the same incinerators, for example, in Moscow region and in Buryatia region, concentrations of pollutants differ by a factor of 2. This fact is to be taken into account when selecting the best equipment for use in different regions: we cannot “translate” characteristics of the pollution sources for various natural conditions.

*M* - mass of harmful substance emitted into the atmosphere per unit time, g / s;

*F* - dimensionless coefficient that takes into account the sedimentation rate of harmful substances in the ambient air:

1 – for gases and fine-dispersed aerosols at a rate of ordered settling that is practically zero,

*F* =1,

2 – for finely dispersed aerosols (except for the first case) with a degree of purification of waste gases of more than 90% *F* =2,

3 – for finely dispersed aerosols (except for the first case) with a degree of purification of waste gases of 75÷90% *F* =2.5,

4 – for finely dispersed aerosols (except for the first case) with a degree of purification of waste gases of less than 90% 75% *F* =3;

*m* and *n* – coefficients that take into account the conditions for the escape of the gas-air mixture from the source mouth;

*H* - height of the ejection above ground level, m (for terrestrial sources is adopted *H*=2 m);

*η* – dimensionless coefficient that takes into account the influence of the terrain (for a slightly inclined terrain with a height difference not exceeding 50 m per 1 km is taken equal to 1);

*ΔT* – the difference between the temperature of the vented gas-air mixture *T<sub>g</sub>* and ambient

air temperature  $T_e$ , °C;

$V_I$  – gas-air mixture flow rate:

$$V_I = \frac{\pi D^2}{4} w_0$$

$D$  – diameter of the mouth of the emission source, m;

$w_0$  – average exit velocity of the mixture from the mouth of the emission source, m/s,

$$K = D/8V_I = 1/(7.1 \cdot (w_0 \cdot V_I)^{1/2})$$

The next steps include calculations of the ancillary coefficients, the values of which determine the following way of calculations.

Finally, we receive the necessary set of data for the calculation of value we need. Depending on the task, the model allows to receive the maximum concentration level for the individual pollutant, or the distance, where we can observe this maximum concentration, or the dangerous wind speed. Also, calculations of the concentrations of the pollutant in each point around the pollution source are possible. It allows us to construct the concentration fields around the source of pollution and to determine the dangerous zones and the impact zones around (for example) the industrial objects.

And a very important application of the shown model is regulation of the maximum permissible emissions. The maximum permissible emission, measured in g / s, from a single point source, at which a non-exceeding standard is reached in the concentration of pollutants in the surface air layer

$$MPE = \frac{(MPC - c_{bg})H_0^2}{AFmn\eta} \sqrt[3]{V_1 \Delta T}$$

Where the  $c_{bg}$  is a background concentration of the pollutant. In other words, we are entitled to pollute only if there is a gap between the background concentration and a standard (maximum permissible concentration).

In case of the “cold” emissions the formula changes as follow:

$$MPE = \frac{8V_1 \cdot H^{4/3} (MPC - c_{bg})}{A \cdot F \cdot n \cdot \eta \cdot D}$$

It is to be highlighted, that in all the calculations above we use the maximum allowable concentration for the settlements. Different types of the standards of air quality are used in practice.

### *Maximum allowable (maximum permissible) concentrations*

The main types of the maximum allowable (maximum permissible) concentrations are presented on the Fig. 2.3.

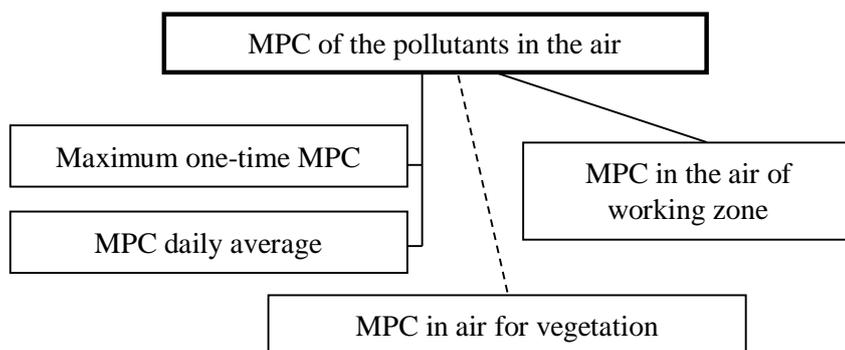


Fig. 2.3. Maximum permissible concentrations

It is to be noted, that all of them are developed (justified) for the specific purposes. It is impossible to apply, i.e. the MPC daily average instead of the MPC for the air in the working zone. To the development of these different types of MPCs the different approaches and, generally, the different ideas were taken as the base.

The maximum permissible concentration of harmful substance in the air of the working area ( $MPC_{wa}$ ) is a concentration that, for a daily (except weekend) work of 8 hours or for a different duration, but not more than 40 hours per week, throughout the working period should not cause disease or abnormalities in health, as detected by modern research methods, in the process work or in the long-term life of this and subsequent generations

The maximum daily concentration ( $MPC_{dc}$ ) is a concentration of harmful substance in the air of populated areas, which should not have a direct or indirect effect on a person with unlimited duration (years) inhalation. The concentration is calculated for all population groups and for an indefinitely long period of exposure and is the most stringent sanitary and hygienic standard that establishes the concentration of harmful substance in the air. The criterion for assessing the well-being of the air in the residential area in Russia is precisely this value.

The maximum permissible concentration maximum one-time ( $MPC_{mot}$ ) is the concentration of harmful substance in the air of populated areas, which does not cause reflex (including sub-sensory) reactions in the human body, if inhaled for 20 minutes.

For certain substances, the use of *indicative safe exposure levels* (SHRA) is allowed with the establishment of the terms of their action.

The *temporary permissible concentration* (TPC) is the value obtained by calculation. The TPC in the air of the working area for different groups of substances is calculated by their lethal doses for mice and rats ( $LD_{50}$ ), lethal concentrations for mice and rats ( $LC_{50}$ ), threshold concentrations that cause subjective unpleasant sensations in humans under one-minute exposure, the biological activity of chemical bonds and others. The most common ratio linking MPC of the working area and TPC (correlation coefficient 0.68) allows us to quickly estimate the order of magnitude of the expected air quality standards for populated areas for compounds with known  $MPC_{wa}$  (they are 4 times larger than the compounds for which  $MPC_{mot}$  and  $MPC_{da}$  are set):

$$\lg TPC = 0.62 \lg MPC_{wa} - 1.77.$$

Approaches to the establishment of MPCs and MPCs themselves were developed during the time of the domination of the concept of zero risk: it is assumed that there is a certain limiting value of the harmful factor (concentration of harmful substance) below which the presence in this zone (working, residential) is completely safe (within 8 hours or within infinitely long period, respectively).

At present, a risk-based approach (a measure of the likelihood of occurrence of unwanted events / consequences) is more common. This approach was reflected in the order of establishing and

describing quality standards (quality targets) of the environment of many countries.

As an example of the principles, used by the justification of the atmospheric quality norms, let us consider the following general principles, suggested in EU countries. These principles for determining air quality standards include:

- ❑ Accounting of the effects that harmful substances have on recipients (human and / or environmental objects). The technological attainability of quality standards or the economic feasibility of ensuring compliance with them is not considered.
- ❑ Universality: the same standards are set for almost all EU member states, although specific standards can be defined for a number of territories (for achieving environmental objectives, for specially protected natural areas, etc.).
- ❑ Practical attainability: the difficulty of achieving compliance with stringent standards led to the emergence of the concept of intervals of acceptable deviations (margins of tolerance).
- ❑ There is a list of standards for control, handling of certain materials and emissions of harmful substances, the main principle of which is technological achievement and economic feasibility (this does not mean ease of compliance with the requirements of standards!)
- ❑ The standards tend to be tougher; with the passage of time more stringent standards are being adopted:
  - requirements for any specific technologies are not prescribed; the motivation to find innovative solutions is supported by consistently toughening standards of environmental quality;
  - the principle of the best available technologies: foster the practical implementation of the best technological and technical solutions that ensure the prevention or reduction of emissions of harmful substances and that are economically viable and applicable in specific conditions.
- ❑ The “polluter pays” principle: costs for preventing and / or reducing pollution and (if necessary) measures for restoring the environment should be borne by those responsible for pollution (business entities).
- ❑ Integrated approach: measures to prevent and reduce emissions of harmful substances into the air should not lead to an increase in the burden on other natural environments (the requirement of the EU Directive on Integrated Pollution Prevention and Control).
- ❑ The international approach (including the consideration of transboundary pollutants transport): the transboundary nature of air pollution problems is taken into account in two aspects:
  - States are not required to provide acceptable air quality for those indicators that are caused by emissions of pollutants from sources outside its territory;
  - States are obliged to reduce emissions of substances that can have harmful effects on recipients located in the territories of neighboring countries, even in cases where these emissions do not affect the condition of the environment in their own territories.
- ❑ Information and communication: countries should inform the European Commission on air quality issues in their territories, as well as provide the public with access to information on air quality.

To understand a difference between the shown three types of the environmental norms let us look the following table.

**Table 2.5. Norms of maximum allowable concentrations of some common harmful substances in the air (MPC according to the Russian state norms), mg/m<sup>3</sup>**

Substance	MPC daily average	MPC maximum one-time	MPC of the working zone
CO	3	5	20
PM	0.5	15	—
SO <sub>2</sub>	0.05	0.5	10
NO <sub>2</sub>	0.04	0.2***	2
O <sub>3</sub>	0.03	0.16	0.1
Formaldehyde	0.003	0.035	0.5
Benzo[a]pyrene	0.000001 (0.1 ng/ m <sup>3</sup> )	—	0.00015

The indicated standards are developed mostly from the standpoint of human health protection. We speak about the maintenance of air quality in the settlements during long periods, about prevention of extra high levels of the pollution, about the norm for the air quality in the working zone. These norms ensure public health protection – this is realization of the anthropocentric approach. This is not only due to the traditions of anthropocentrism. The matter is, it is too difficult to create a norm, adequate for many biological species or for the ecosystem. According to the assessments of the Russian research institute “Atmosphere” (<http://www.nii-atmosphere.ru/files/stKDiks.htm>), in this case we could face the following problems.

1. Absence of data on the effect of biological agents of atmospheric air on the objects of the environment: at present, it is not possible to establish environmental standards for the regulation and protection of atmospheric air in terms of indicators that take biological properties into account.

2. When determining the list of environmental air quality standards by its chemical properties, a priority list of substances determining the major emissions is identified based on the data analysis on emissions of pollutants into the atmosphere. Based on the analysis of literature data on the effects of pollutants on vegetation and other elements of the ecosystem, a list of substances with toxic effects on the elements of the ecosystem other than humans has been determined. The list of environmental air quality standards for chemical properties includes the following substances: sulfur dioxide, suspended substances, nitrogen oxides (in terms of nitrogen dioxide), fluorine and its gaseous compounds, chlorine, ozone, ammonia. Thus, it is necessary to make evaluations of the danger of listed substances for biota – but for what species namely?

3. For the harmful (polluting) substances listed, the suggested indicative values of environmental quality standards for ambient air can be recommended for inclusion in the list of environmental quality standards for atmospheric air at the federal level.

It should be noted, that standards and targets for air quality are set at both national and international levels. Considerable attention is being paid to this issue by the World Health Organization. The purpose of the WHO recommendations is to provide a basis for protecting public health from the adverse effects caused by pollutants and eliminating / minimizing the effects of those substances that the hazard to human health or well-being is proven or probable. Some steps of this work are indicated below.

1987: First edition of the World Health Organization "Air Quality Guidelines for Europe"

2000: new guidance prepared by the European Center for Environment and Health (Bilthoven) in cooperation with the International Program on Chemical Safety and the European Commission ("Air Quality Guidelines for Europe" - 2000).

2005: supplementary publication – The Air Quality Guidelines for particulate matter, Ozone, Nitrogen, Dioxide, Sulfur Dioxide.

According to the WHO Guidelines, the norms for the following groups of substances are to be developed (Table 2.6).

**Table 2.6. Air pollutants considered in the WHO Guidelines (2000)**

Organic harmful substances	Inorganic harmful substances
Acrylonitrile Benzene Butadiene Vinyl chloride 1,2-dichloroethane Dichloromethane Carbon monoxide (II) - carbon monoxide Polycyclic aromatic hydrocarbons Polychlorinated Biphenyls Polychlorinated dibenzodioxins and polychlorinated dibenzodifurans Carbon disulphide Styrene Tetrachlorethylene Toluene Trichlorethylene Formaldehyde	Asbestos Vanadium Cadmium Manganese Arsenic Nickel Platinum Mercury Lead Hydrogen sulfide Fluorides Chromium
Substances that pollute indoor air	"Classic" air pollutants
Artificial fiberglass Radon Tobacco smoke	Suspended (solid) substances Nitrogen dioxide Sulphur dioxide Ozone and other photochemical oxidants

Especial criteria are to be used when regulating the carcinogenic and non-carcinogenic substances:

- Non-carcinogens: criteria for selecting the lowest levels of the observed deleterious effect, levels of unobserved adverse effect, criteria for selecting uncertainties, criteria for choosing averaging time, etc.;
- Carcinogens: qualitative and quantitative assessment of carcinogenic ability, risk assessment questions based on biological tests on animals, interpretation of risk assessments, etc.

Critical levels of impact (estimated at all levels - from the organism to the ecosystem level) are discussed for SO<sub>2</sub>, nitrogen compounds and O<sub>3</sub>). The critical levels established for SO<sub>2</sub> (10 µg / m<sup>3</sup> for forests and 30 µg / m<sup>3</sup> for agricultural crops with averaging period of 1 year) are fairly close to the levels suggested by specialists from the Atmosphere Research Institute (9 µg / m<sup>3</sup> and 50 µg / m<sup>3</sup> respectively).

Critical loads for ecosystems in general are discussed primarily in the context of the problem of acidification (typical for Northern Europe). The parameters characterize the critical limits of concentrations in media other than air: for aluminum, critical limits of 0.2 mol / m<sup>3</sup> for forest soils and 0.003 mol / m<sup>3</sup> for freshwater ecosystems have been established; the critical pH for forest soils is 4, and for freshwater ecosystems, 5.3-6.0.

In addition to the MPC, other types of norms can be used in practice. The problem is, currently there are more than 3 million substances in the world, and this number is gradually increasing. It is impossible to establish a norm like MPC for each existing substance because this is a large and complicated procedure. It needs a complex of investigations, tests, reliable analytical methods; it

needs time. That is why sometimes temporary norms are implemented. Even in the countries with a long history of environmental standards and norms the number of the standardized substances is much less than a number of substances that can be determined in the air. So, in Russia there are no more than 4-5 thousand of the concentration norms although the history of MPC justification accounts more than 80 years.

As a result of different approaches to the development of environmental norms of air quality, we see visible difference of norms, accepted in different countries of the world (Table 2.7).

**Table 2.7. Comparison of air quality standards**

Pollutant	The period of averaging, or the nature of the standard	Concentration, $\mu\text{g}/\text{m}^3$		
		Russia	EU	WHO
Suspended solids, particle size $< 10 \mu\text{m}$ ( $\text{PM}_{10}$ )	24 hours	—	50	50
	Year	—	40	20
Suspended solids, particle size $< 2.5 \mu\text{m}$ ( $\text{PM}_{2.5}$ )	24 hours	—	—	25
	Year	—	25 (target value)	10
Suspended matter (total concentration)	24 hours (ПДК cc)	500	—	—
	20 minutes	15000	—	—
Nitrogen dioxide	20 minutes	200	—	—
	1 hour	—	200 (target value)	200
	24 hours	40	40 (target value)	40
Ozone	20 minutes	160	—	—
	8 hours	100	100 (target value)	100
	24 hours	30	—	—
Sulphur dioxide	20 minutes	500	500 (10 minutes of averaging)	125 (15 minutes of averaging)
	1 hour	—	350	—
	24 hours	50	125	125
Carbon monoxide	20 minutes	5000	100 (15 minutes of averaging)	—
	1 hour	—	30000	30000
	8 hours	20000	100000	100000
	24 hours	3000	—	—
Lead	20 minutes	1,0	—	—
	24 hours	0,3	—	—
	Year	—	0,5	0,5
Benzene	20 minutes	300	—	—

A broader picture of the approaches to standardization of air quality can be found in the information sources. Please take into account the differences of the critical values of the pollution and try to find the information about the algorithms and methods of establishing of the safe pollution levels.

### *Regulation of emissions of pollutants into the atmosphere*

Currently it is possible to group all the impact norms for the regulation of the atmospheric quality in the following groups (Fig. 2.4).

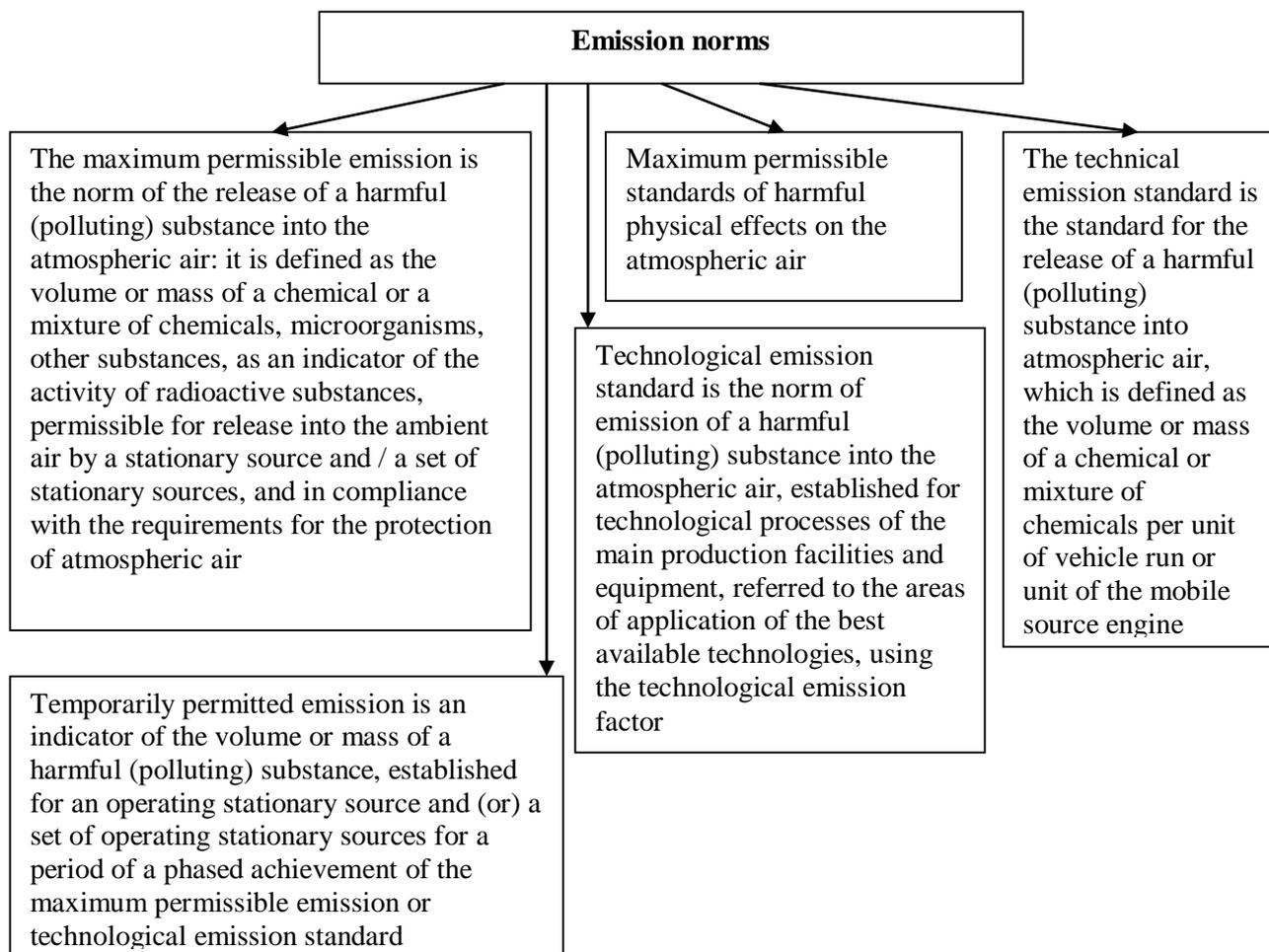


Fig. 2.4. Types of the emission norms

The main purpose of the regulation of emissions of pollutants is to control emissions into the atmosphere, to stimulate the enterprise to reduce the volumes and toxicity of pollutants emitted into the atmosphere, and to create conditions for maintaining the quality of atmospheric air in the area of the facility's location at the regulatory level.

The following steps need to be made:

- general analysis of the enterprise as a source of atmospheric pollution (inventory and typification of emission sources according to their spatial position, nature of emissions, physicochemical composition of pollutants);
- calculation and analysis of the level of atmospheric pollution effects;
- development of proposals for the establishment of MPE standards and, if necessary, temporarily agreed emissions limits for each source and harmful substance;
- development of a plan of measures to reduce emissions of pollutants into the atmosphere in order to achieve MPE standards, if the concentrations of pollutants taking into account the background exceed the MPC;
- development of an action plan for managing emissions under unfavorable meteorological conditions;
- organization of control over observance of MPE and temporary emission standards.

Development of the emission norms in general needs the information on condition of the environment and characteristics of the pollution source as well as of pollutant properties. Traditionally the MPE norms are to be developed for each pollutant individually. An exception here

are the summation groups (in the previous chapter we told about the interactions of the substances and showed the possibility to amplification of effect). In general, for the inventory and development of the draft standards, the following information is used:

- information on the background concentrations of pollutants in the ambient air;
- map-scheme of the enterprise with the sources of emissions of pollutants applied to it into the atmosphere;
- situational map-scheme of the location of the enterprise with indication of the boundaries of sanitary protection zones (SPZ), residential territory, recreation areas, sanatoriums, rest homes, etc., by monitoring atmospheric air pollution of the plant, stationary posts for monitoring the quality of the atmosphere;
- information on the consumption, type, composition of raw materials, materials used, fuel;
- data on the types, basic characteristics of the installed equipment and the time of its operation;
- information on the number, brands of vehicles on the balance sheet of the enterprise, parking places; hours and mode of operation of vehicles not on the balance sheet of the enterprise used for the delivery of raw materials and export of products;
- data on control of emissions of the enterprise at the boundary of the SPZ;
- meteorological conditions affecting the dispersion of impurities.

As you see, there is a special protecting zone around the enterprise – the sanitary protection zone. In terms of its functional purpose, the SPZ is a protective barrier ensuring the level of safety of the population when operating the facility in its regular mode. SPZ separates the territory of the industrial site from residential development, landscape and recreation zone, recreation area, resort with obligatory designation of borders with special information signs. The definition of sanitary protection zones is the most important measure for the protection of the environment and the use of natural resources.

The territory of the SPZ is designed:

- to ensure a reduction of the level of exposure to the required hygienic standards for all factors of impact beyond its limits;
- creation of a sanitary and protective barrier between the territory of the enterprise (group of enterprises) and the territory of residential development;
- Organization of additional green areas that provide shielding, assimilation and filtration of air pollutants and increase the comfort of the microclimate.

The size of the SPZ are determined depending on the capacity, operating conditions, the nature and amount of pollutants emitted to the environment, noise, vibration and other harmful physical factors. Measures are envisaged to reduce the adverse impact on the environment and human health in accordance with the sanitary classification of enterprises, industries and facilities.

Another important factor is the background level of atmospheric air pollution. On the territory with exceeding the background indicators above the hygienic standards, the placement of industrial facilities and industries that are sources of environmental pollution and effects on human health is not allowed. For existing sources of contamination, reconstruction or re-profiling is allowed provided all types of environmental impact are reduced to the maximum permissible concentration (MPC) under chemical and biological effects and the maximum permissible level under the influence of physical factors taking into account the background.

Within the boundaries of the SPZ, only certain objects can be located:

- non-residential premises for emergency personnel on duty;
- premises for working on a rotational basis (not more than two weeks);
- management buildings, design offices, administrative buildings;

- research laboratories;
- polyclinics;
- sports and recreational facilities of a closed type;
- baths, laundries, trade and catering facilities;
- motels, hotels;
- garages, platforms and facilities for storage of public and private transport;
- fire stations;
- local and transit communications, power lines, electrical substations, oil and gas pipelines;
- artesian wells for technical water supply, water-cooling facilities for the preparation of technical water, sewage pumping stations, water recycling facilities;
- petrol stations, car service stations.

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### *Home task*

1. Using the WHO standards for the quality of the atmosphere, assess the environmental situation in one of the 3 cities in your country. Write a comment: the main pollutants, possible sources of pollution, priorities for the improvement.
2. Describe the system of environmental standards of air quality in your country. What types of environmental norms are there implemented? Are they stronger or less strong in comparison with the WHO norms? With EU norms?

### *Questions for the self-control*

1. What is the maximum permissible concentration of the substance for the working zone?
2. How can be evaluated the degree of toxicity of a substance?
3. List and comment the basic principles for the establishment of MPCs.
4. When setting the MPC, how can be considered the time of contact of the substance with the organism?
5. Is there any difference of the reaction of the organism on the contact with the threshold concentrations of substances? Comment the occurrence for short-term and chronic effects.
6. What is the coefficient of cumulation?
7. How can be divided the pollutants by the degree of danger? Describe the official classification of the atmospheric pollutants.
8. What is the main single indicator of air pollution by an individual impurity?
9. What is the atmosphere pollution potential (APP) and how can it be calculated?
10. How can be determined a comprehensive air pollution index? Give an example and describe the algorithm.
11. What is the maximum allowable emission?
12. How can be developed the norms of MPE of harmful (polluting) substances in the atmosphere and temporarily agreed emissions (limits)?
13. What cases must be taken into account in case of establishing a limit for a temporarily agreed emission?
14. What is the sanitary protection zone of the enterprise?
15. How will be defined the sanitary protection zone size?
16. What are the unfavorable weather conditions in the modelling of the emissions?
17. When modeling the emission dispersion according, what are the factors determining the

concentration of the pollutant?

18. What is the value of the maximum permissible pollutant emission limit for a single point source is directly proportional on?

19. How are connected the height of an emission source and the value of MPE?

20. Is it possible to apply the MPC developed in foreign countries or by the international organizations for the domestic assessments? Give a comment.

### Chapter 3. Environmental norms and regulations for the water quality protection

Water quality (chemical quality and quantitative assessments) are in the focus of environmental regulations practically in all parts of the world. Sometimes we speak about the sufficient quantity of water resources in some region, but unacceptable quality. In some regions, even the polluted water is priceless. In any case the role of water resources is leading in the existence of each country. And, according to WHO, the quality of water comprises up to 40% of all environmental factors.

Use of water is interconnected with at least two major problems: the first one is the availability of water resources – in many regions this problem is the most acute one. The second problem is the quality of water we use and quality of wastewater. So, finally we speak about the quantitative and qualitative norms and regulations. As examples of such regulations we can mention norms issued by the WHO, by EU, by the national environmental and health protection agencies and ministries.

In this chapter we will consider the most important processes of pollution and self-purification of natural water bodies, basic models of the behavior of pollutant in the water flow and some most important norms of water quality.

#### *Factors of the pollution and self-purification of the water bodies*

Anthropogenic impacts on the hydrosphere include various types of pollution, seizure of water resources, restoration of water bodies: a set of measures to restore the initial quality of water. The most commonly used classification of the types of pollution of the hydrosphere.

The pollution sources can be classified on different grounds: they can be natural or technogenic (man-made), they can pose different threats for the living organisms, have different impact on the environment.

*According to the origin* the sources of water pollution can be divided into:

- Mineral (about 42%) - sand, clay, slag, salts, acids, alkalis, mineral oils in the wastewater industry, agriculture, housing etc.
- Organic (about 58%) - **vegetal** (grass, vegetable and food residues, paper, oil products) and **animal** (pollution of livestock farms, animal excreta, effluents of slaughter-houses cattle, tanneries, bio-mills),
- Biological (bacterial etc.)

*According to the object* the sources can be industrial, household, fecal.

Generally, the source of the hydrosphere pollution is an object or subject that introduces contaminants, microorganisms or heat into the water. These are atmospheric and melt water of cities, domestic and industrial waste water, animal waste water and groundwater contaminated with fertilizers and pesticides. Every year about 30 billion m<sup>3</sup> of untreated water is discharged into water bodies.

This classification is, first of all, important for the practical purposes – for selecting purification (or water treatment) technologies. Here we can remember some most common methods based on the different approaches depending on type and size of the pollutants (Table 3.1).

**Table 3.1. Classification of pollutants (according to L.A. Kul'sky)**

Type of the pollutant	Purification method
Water-insoluble coarse impurities – slurry, slurry and emulsion (the first group), forming a heterogeneous kinetically unstable connection with water	Methods based on the use of gravity
Substances of colloidal dispersion degree ( $R \sim 0,1$ microns), forming hydrophilic and hydrophobic systems with water, close to colloidal solutions (the second group)	Flotation, sedimentation, coagulation, filtration
Substances of molecular dispersion degree ( $R < 0.01 \mu\text{m}$ ). Soluble organic compounds (the third group)	Sorption using the activated carbon
Ionic solutions ( $R < 0.001 \mu\text{m}$ ). Solutions of salts, acids, alkalis, metal ions-electrolytes (fourth group)	Method of desalination, chemical method – transfer of ions into slightly soluble compounds

The main types of the pollution are described further.

1. *Chemical pollution* is caused mainly by the penetration of industrial wastewater; leakage of technological solutions; dissolution of raw materials, solid waste products of industry by atmospheric precipitation; washing out of the atmosphere pollutants of agricultural chemicals; receipt of chemicals from contaminated surface waterways and reservoirs and other processes.

This type of pollution is manifested in an increase in the content of certain chemical elements in comparison with the background and (or) regulatory ones, and the appearance of new mineral and organic contaminants that are unusual for these sub-terrestrial waters. The most common contaminants are heavy metals, petroleum products, phenols, surfactants, aromatic hydrocarbons, cyanides, pyridine bases, dithiophosphates, sulfates, chlorides, fluorides, manganese, arsenic, common strontium, nitrogen ammonia and other substances. The appearance of these contaminants in the waters is caused by the activity of virtually all industries, from mining to food.

Evaluation of the technogenic metamorphism of a number of processes is carried out on the basis of the parameter of technophilia introduced by AI Perelman. Based on this parameter, obtained from the processing of variations of 30 chemical elements in the waters for a two-hundred-year period, five groups of chemical elements were obtained - from supertechnophilic to very poorly technical ones. Among the supertechnophilic elements, above all,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$  were indicated. Subsequently this group was supplemented by the following elements and their compounds:  $\text{S}_2^-$ ,  $\text{CO}_3^{2-}$ , organic compounds,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ , Se, Pb, Cu, Br, etc. The high-technical elements include Fe, Ca, Zn, As, Cr, U, Ni, Mo, Hg, etc.

The danger of chemical contamination is that many substances form stable forms of pollutants that migrate with significant amounts of water, contaminating other geo-environments.

2. *Biological contamination* is manifested in the form of the presence of pathogenic microorganisms - viruses (there are about 700 species), bacteria, algae, protozoa, fungi, etc. Particularly dangerous are pathogenic bacteria and viruses entering the infiltration sites of fecal and domestic water from defective sewage network, cesspools (septic tanks), from farmyards, filtration fields, ponds for biological sewage treatment, authorized and unauthorized landfills, landfills for disposal debris and other.

The safety of drinking water in epidemiological terms is usually ruled by such indirect indicators as the total bacterial content of the E. coli group (not more than 100 in 1 ml of undiluted water) or the coli-index (in 1 liter of water, not more than three bacteria of this group); determined

on a dense elective medium with the use of membrane filters. Specialized studies additionally determine the content of other bacteria - the transference of diseases, intestinal viruses, eggs of helminths, etc.

3. *Radioactive pollution* is noted as a result of penetration of uranium, radium, strontium, cesium, tritium and some other elements from the surface of the earth into the groundwater. Their emergence is due to the conduct of nuclear explosions, the formation and leakage of industrial sewage using nuclear technology; formation of waste of medical institutions; not previously disposed of landfills with radioactive waste; slag from combustion of certain types of coal, etc. The elements that are poorly sorbed on rocks: I-131, S-35, Ru-106, U-234 and 238, Cs-134, 137, Sr-90 are the most dangerous ones. The last three elements are long-lived and migrate over long distances. Elements such as Ra-226, Pb-210, Po-210 and the sum of T isotopes are well sorbed by soils, and their migration is insignificant.

4. *Thermal pollution* is associated with an increase in water temperature under the influence of infiltrating water due to leakage from cooling ponds, receiving wells of heated water from air conditioning systems from thermal power plants and other objects.

Thus, among the pollution factors there is a variety of natural and man-made, direct and indirect impacts that start the distribution of the contaminating substance (or object) in the water body.

The state of water bodies and the set of pollutants (as a single pollutant hardly ever occurs in the natural or man-made systems) depends on the type of waste water entering the water body. From this point of view, it is necessary to differentiate between the households, industrial waste water and the waste water of storm drain. Depending on the nature, each type has a special composition of the pollutants and needs a special purification technology.

1. *Household sewage* is formed as a result of human activity. The concentration of pollutants in domestic wastewater is determined on the basis of the norms of specific water removal per inhabitant:

$$S = 1000 a / q,$$

where  $S$  is the concentration of the pollutant, mg / l;  $a$  - amount of pollution per person, g / day;  $q$  - norm of water disposal per inhabitant, l / day.

In wastewater there are impurities of both mineral and organic origin. It is conditionally accepted that in domestic sewage the amount of mineral insoluble substances is 5%, colloids - 2% and dissolved substance - 30%. For organic substances, these relationships are: insoluble - 15%, suspensions - 15%, colloids - 8% and soluble substances - 20%. Mineral compounds are mainly represented by phosphates, chlorides and hydrocarbons, organic - nitrogen-free (hydrocarbons and fats) and nitrogen-containing compounds (proteins and hydrolysis products). Almost always there are pathogenic forms of microorganisms.

2. *Industrial wastewater* is very diverse and, depending on the composition of impurities, is divided into the following groups:

1) water containing inorganic impurities with specific toxic properties due to the content of heavy metals (effluents of metallurgy enterprises, galvanic shops, etc.);

2) water with inorganic impurities that do not have a toxic effect (wastewater from enrichment plants, cement plants, etc.). Impurities are mainly in suspension and are not dangerous for the water body;

3) water containing non-toxic substances (food and processing industry enterprises). When

such water gets into the water body, the oxidizability of organic substances, BOD increases, the amount of dissolved oxygen decreases;

4) water containing organic substances with specific toxic properties (enterprises of organic synthesis, oil refining, etc.).

3. *Storm sewage* is divided into rainwater, snow melting and irrigating waters. Some qualitative characteristics of the chemical composition of wastewater are given in Table 3.2.

**Table 3.2. Concentrations of the main pollutants in the surface runoff in the built-up areas of the territory, mg/l**

Substances	Rainwater	Meltwater	Watering water
Suspended solids	250	3500	500
Petroleum products	10	30	30
BOD (biological oxygen demand)	30	90	100
COD (chemical oxygen demand)	100	250	100
Sulphates	100	500	100
Chlorides	200	1500	200
Ammonia nitrogen	2	4.3	2
Total nitrogen	4.9	10.5	4.9
Nitrates	0.08	0.17	0.08
Nitrites	0.08	0.17	0,08
Calcium	43	113	43
Magnesium	8	14	8
Iron	0.3	1.7	0.3
Copper	0.02	0.076	0.02
Nickel	0.01	0.02	0.01
Zinc	0.3	0.55	0.3
Phosphorus total	1.08	1.08	1,08

So, the composition and quantity of domestic wastewater are relatively constant. The composition and quantity of industrial waste water varies widely, depending on the industry and technological processes. For the prediction of water bodies pollution, the basic initial data are the consumption of waste water  $q_{st}$  and the concentration of individual components. It is assumed that after biological purification the indices are constant in time. The most variable in time in terms of chemical composition is rain and thawed water from storm sewers:

$$M_i = S \cdot (W_r \cdot m_{ir} + W_m \cdot m_{im}) \cdot 10^{-6} + S_w \cdot W_w \cdot m_{iw} \cdot 10^{-6},$$

where  $S$  - the size of water-collecting territory of the nature user, ha;  $W_r$ ,  $W_m$ ,  $W_w$  is the volume of runoff of rain, melted and watered water,  $m^3$  / ha;  $m_{ir}$ ,  $m_{im}$ ,  $m_{iw}$  – the concentration of the  $i$ -th pollutant in the drain (respectively, rain, melt and watering water, mg / l);  $S_w$  – the area of waterproof coverings undergoing wet cleaning, ha.

Besides, the impurity is found in the water flow. What factors can affect its behavior? What happens to the impurity, can be forecasted knowing its properties, characteristics of the water body

(water flow) and some characteristics of the pollution source. In this course we will only consider chemical pollutants: their behavior models, norms of concentrations and self-purification processes in water bodies.

First of all, let us consider the most important factors of the distribution of substances in the water flow, i.e. chemical, physical, hydrodynamical and biological factors:

- ❖ *chemical* (decay, compound with other substances, precipitation);
- ❖ *physical* (transition to another aggregation state, adsorption, coagulation);
- ❖ *hydrodynamical* (flow transfer and scattering in the process of turbulent diffusion);
- ❖ *biological* (accumulation and transport by living organisms).

Therefore, when modelling, we need to take into account the set of processes occurring in the water flow or water body.

1. Transfer of matter and dilution of effluents. The description of these processes requires data on the hydrology and hydrodynamics of a water body, the analysis of currents, diffusion, etc.
2. Sedimentation of hardly decomposable impurities, secondary pollution
3. Decomposition of easily decomposable impurities
4. Self-purification of the aquatic environment.

When considering the dynamics of pollution and self-purification in rivers, lakes and reservoirs, the process of dilution and transport of matter is the most significant factor in reducing the concentration of pollutants in the aquatic environment.

### *Modeling the water quality*

For modeling the processes of distribution of impurity in the water environment, we can use different types of models. So, it is possible to model the water flow as a whole or to use some simplifications. For example, we can divide the river into some sections (“chambers”) with relative stable conditions, and construct the general model of the impurity distribution as a set of partial models.

Models of impurity distribution in water bodies can reflect the hydrochemical and hydrological processes of the entire water flow or the processes in some sections of the water flow where the conditions are relatively similar:

- *Chamber models*: the studied area is divided into sub-areas – camera, in which study characteristics are considered constant. For each chamber, only average values of ecosystem parameters and each reservoir are taken into account. Inter-chamber communication is simulated by introduction of balance relations;

- *Continuous models*: without the simplifications; the entire water flow is modeled without sections.

The regional models of water quality forecasting include imitation and optimization models.

*Imitation models (simulation)* reflect the state of the environment (i.e., water) with the particular human impact. The ultimate goal of any simulation model is to describe and predict the response of the aquatic environment to external influences. In this case, the reaction itself is the result of a large number of processes taking place in the medium:

1. Transfer of matter and dilution of effluents
2. Precipitation of hardly decomposable impurities - secondary pollution.
3. Decay of easily decomposable impurities - self-purification of the aquatic environment.
4. Thermal pollution.

*Optimization models* are used to select the optimal (in terms of costs and expected effect)

management policies in general and to choose the best plan for water protection measures in particular. The review is conducted on the scale of a whole region, for example, the river basin or a large part of it.

Water quality models are based on partial differential equations. With their help, conditions can be modeled for the formation of quality and quantity of water (or individual processes that determine the quality of water) - *simulation models*.

Modeling of optimal conditions for the existence of a water body taking into account its sewage load or in the production of water intakes with preservation of water quality standards is performed using *optimization models* (Fig 3.1). When modeling the quality of water, it is necessary to take into account the dynamics of the spread of contaminants and their transformation along the length of the river or the volume of the reservoir (mixture or dilution of water).

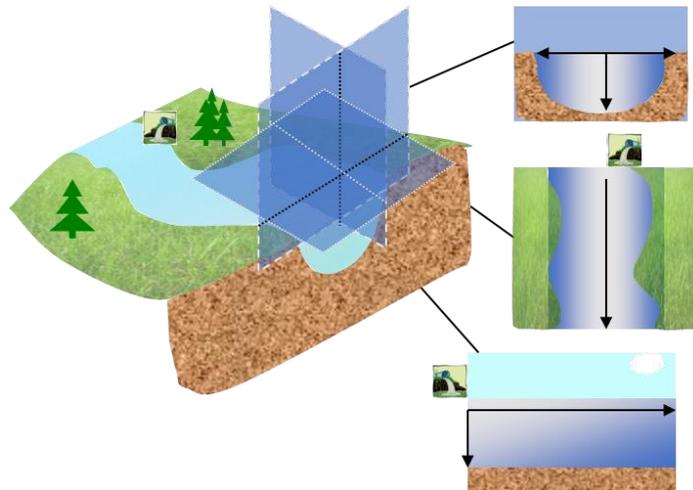


Fig. 3.1. "Decomposition" of the model of pollutant transport in the water flow

Models can be single-, double- or three-dimensional - this allows you to simplify the modeling process, if the task allows.

After the "decomposition" of the task – representation of the general task of modeling into 3 dimensions, the choice of the mathematical model for the forecast of water quality is determined by the availability of source data and the calculation task. It is necessary to take into account that pollution of water bodies and the forecast of their condition depends to a large extent on the sources of pollution.

Water quality models are based on partial differential equations. With their help, conditions can be modeled for the formation of quality and quantity of water (or individual processes determining the water quality) - simulation models.

Modeling of optimal conditions for the existence of a water body taking into account its sewage load or in the production of water intakes with preservation of water quality standards is performed using optimization models.

The general model of the main factors of surface water pollution includes description of the components of speed field; of field of pressure in a stationary flow; and the impurity concentrations. The given parameters are the fluid density, viscosity coefficients, components of the external force vector, substance decay parameter, source of pollution characteristic. The diffusion coefficients are assumed to be constant for simplifying.

Strictly speaking, the parameters of the hydrodynamic subsystem (the density of the fluid, its viscosity) should depend on the impurity concentration. However, in most cases, in order to simplify

the model, this dependence is neglected, i.e. impurity is considered passive. In models where the impurity concentration is relatively small, such a simplification is justified. Under this assumption, the hydrodynamic subsystem (1) can be solved independently of the equation for the concentration.

Models of water pollution are aimed at solving the direct and inverse problem of water quality. In the first case we forecast the future quality of water in the water flow knowing the main necessary factors and parameters of the water body (water flow), of source of the pollution and the impurity itself. After we receive the results of modeling, it is possible to show, whether the water quality is in line with existing standards or some other critical values. If NOT, it is necessary to solve the inverse problem. We must determine the impact level (volume of waste water or the impurities concentrations) to meet all the requirements.

The main stages for the direct model construction are:

1. Collection of baseline data.
2. Calculation of convective-diffusion transport of pollutant along the length and width of the watercourse. Control point - at a distance of 500 m from the point of wastewater discharge.
3. *Assessment of water quality in the control plot of a water body:* the maximum concentration of the pollutant is compared with the water quality standards (MPC for water bodies of the appropriate water use categories or standards for permissible concentrations established in accordance with the individual characteristics of the water bodies).

If the maximum concentration of pollutants in the control line exceeds the water quality standards, it is necessary to solve the inverse problem of the water quality forecast and calculate the permissible discharge norms and the maximum permissible concentrations of pollutants in the wastewater of the source of pollution. Schematically, this can be represented as follows (Fig. 3.2).

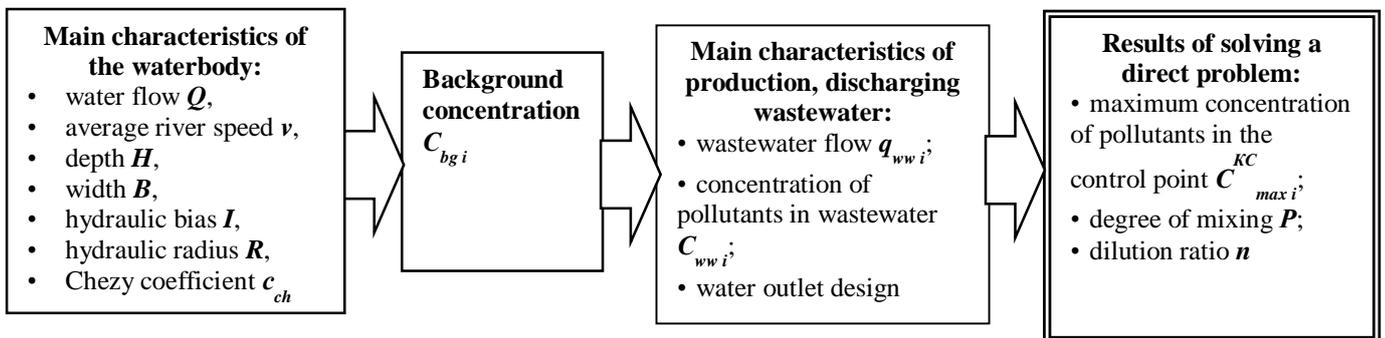


Fig. 3.2. The direct problem of forecasting water quality: main stages

In this case we can only forecast the future quality of the polluted water in the water flow. To regulate it we need to solve the *inverse problem of forecasting water quality*.

With the help of software tools, a model for convective-diffusion transfer and substance conversion is realized, which allows to determine:

- the distribution of concentrations in a given range,
- the dilution frequency, the degree of mixing and
- the maximum concentration of each ingredient.

Main components of the model are presented on the Fig. 3.3.

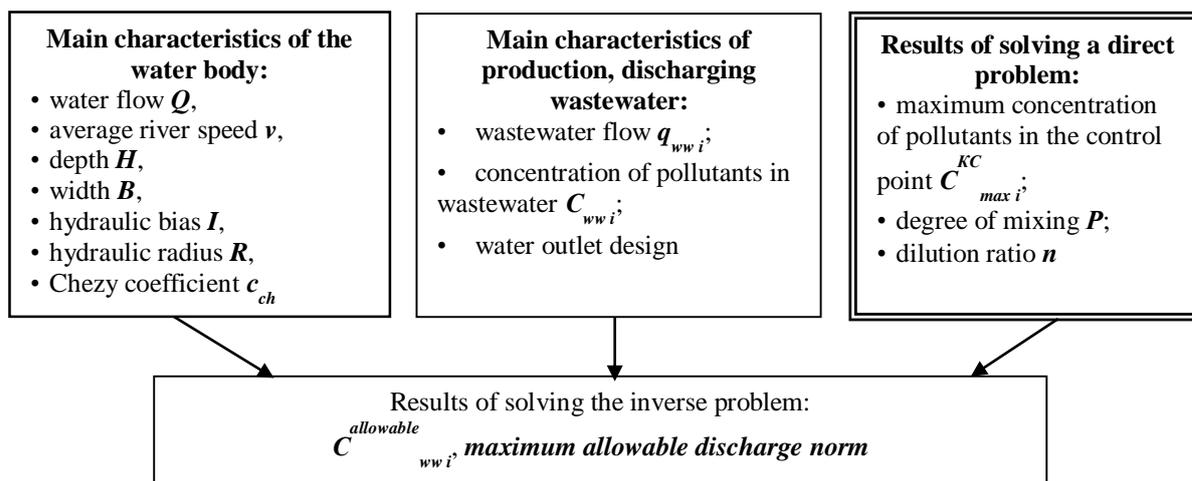


Fig. 3.3. Model of optimization of water quality: main components

The scheme allows to determine any of the calculated parameters of water quality indicators, both with the available initial data, and for simulating different situations for the water body and various parameters of the sewage. The obtained results are compared with the given ecological standards:

- full compliance with all environmental standards → *the stage of solving the problem ends*;
- absolute or partial failure to comply with environmental standards → formulation of the inverse problem of the forecast of the maximum permissible discharge of wastewater.

Let us consider the norms which guarantee the water quality. In Russia, these are the norms of introduction of chemical substances, microorganisms, heat, radioactive substances, water, or withdrawal of water resources.

□ Introduction of chemical and suspended mineral substances; is characterized by the total mass of the substances included in the list of standardized substances for the estimated time period, depending on the conditions for the formation of qualitative characteristics (mg / dm<sup>3</sup>) and the mode of receipt of pollutants (g/h, t/year, t/season).

□ Introduction of microorganisms; is characterized by the total number of microbiological indicators in the units prescribed by sanitary rules (for example, colony forming units, plaque-forming units, etc.)

□ Introduction of heat, characterized by the volume and temperature of warm water coming from anthropogenic sources and causing a permissible increase in water temperature in water. Object relative to the natural temperature regime (degree · m<sup>3</sup>).

□ Introduction of water is characterized by water discharge (m<sup>3</sup>/ s) and the mode of its supply, which have negative consequences:

- according to the conditions of spawning of fish in the area affected by the discharge of water volumes;
- flooding and water logging of economic objects and agricultural lands, including bogging;
- for erosion of shores and riverbeds

□ Withdrawal of water resources; It is characterized by a total amount of irretrievable water withdrawal on a site for a certain period of time for the most critical water conditions (95% of availability, depending on the prevailing uses of water resources.) Use of the water area for construction of hydraulic and other structures with the withdrawal of a part of the reservoir and located in water resources is expressed in terms of area (ha, km<sup>2</sup>, etc.), % of the area of the water body,

and others.

□ Introduction of radioactive substances is determined taking into account the provisions of legislative and other norms. Legal acts ensuring nuclear and radiation safety and in the field of environmental protection are adopted in the regions.

### *Forecast and management of river water quality under the influence of wastewater discharge*

At the end of this paragraph let us consider how the balance of substances in wastewater discharge areas can be assessed.

When water discharges into wastewater containing pollutants occur, water quality deteriorates. Concentration of pollutants is not constant and depends on the degree of dilution, biological and chemical processes. These processes occur both along and across the river, accompanied by the formation of complex organomineral compounds, sorption on bottom sediments and vegetation, etc. In general, the forecast of water quality in river sections under the influence of wastewater discharges is carried out on the basis of calculations of the substance balance:

$$Q_r \cdot C_r = Q_{bg} \cdot C_{bg} + q_{ww} \cdot C_{ww},$$

where  $Q_r$ ,  $Q_{bg}$  и  $q_{ww}$  – respectively, the flow of the river in the calculated range (for which the forecast is carried out) is higher than the discharge of sewage (background) and the volume of waste water;  $C_r$ ,  $C_{bg}$  и  $C_{ww}$  – respectively, the concentrations of the predicted substance or mineralization in the above-listed areas. Expenses are determined more often in  $m^3/s$  or  $l/s$ , concentration of substances -  $mg/l$  or  $mg/dm^3$ , from which the predicted concentrations of substances are determined:

$$C_r = \frac{Q_{bg} \cdot C_{bg} + q_{ww} \cdot c_{ww}}{Q_r}$$

Let us note: the equation is valid only for the conditions of interaction (mixing) of *conservative impurities*: heavy metal salts, chlorides, etc.

*Non-conservative impurities* can be in both dissolved and colloidal or suspended states, and apart from dilution they are subjected to chemical, physicochemical and biological processes. The totality of all listed processes that change the concentration of pollutants in the mixing zone of sewage and river water or their balance in the area under consideration is called self-purification of reservoirs.

To calculate the dilution process, it is necessary to have a water body plan to determine the positions of the alignments and the coefficients of tortuosity. All hydraulic parameters are determined at a given design flow.

The degree (multiplicity) of the total dilution  $n$ , which is expressed by the dilution grade:

$$n = \frac{q + Q}{q}$$

where  $Q$  – diluting water of the water body,  $m^3/s$ ;  $q$  – diluted wastewater entering the water body,  $m^3/s$ .

In actual conditions, the process of mixing wastewater can be complicated by a number of factors. The dilution multiplicity should be determined by the formula

$$n = \frac{\gamma Q + q}{q}$$

where  $\gamma$  – a mixing ratio indicating the degree of completeness of dilution of wastewater.

The conditions for the discharge of sewage into a body of water are assessed taking into account their influence at the nearest water use point, where the dilution grade should be measured.

The last formula reflects some special processes and factors affecting the distribution of the impurity in the water body. These “specificities” are included into the calculation of the  $\gamma$  coefficient. One of the widely applied approaches is the Frolov and Rodziller method.

$$\gamma = \frac{1 - \beta}{1 + \left(\frac{Q}{q}\right)^\beta},$$

where

$$\beta = e^{-\alpha^3 \sqrt{L_\phi}},$$

where  $e$  - base of the natural logarithm;  $\alpha$  - coefficient that takes into account hydraulic mixing factors;  $L_\phi$  - the distance to the considered control point along the flow (fairway) of the river, m:

$$\alpha = \xi \cdot \varphi \cdot \sqrt[3]{\frac{D}{q}}$$

where  $\xi$  – coefficient, depending on the place of release of the runoff into the river:

- when released near to the shore  $\xi=1$ ,
- when released in the core of the river (the place of the highest velocities)  $\xi=1.5$ ;

$\varphi$  - coefficient of tortuosity of the river, equal to  $L_f/L_{ch}$ , that is, the ratio of the distance along the channel  $L_f$  of the total length of the channel  $L_{ch}$  from the discharge of wastewater to the considered site to the distance between these two points along the line;  $D$  - turbulent diffusion coefficient.

And finally, it should be noted, that in the models of forecast and management of water quality the worst conditions are accepted for calculation – the conditions of the 95% exceedance probability. This allows to have a “safety reserve” for the projects of use of the water bodies.

### ***Water quality assessment***

Water quality is a set of indicators of its composition and properties that determine the suitability for specific types of water use.

Quality assessment is performed on the following parameters: the content of suspended solids and floating impurities, temperature, color, smells and flavors, pH, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen, content of chemicals and microorganisms.

As a “normal” level of the pollution we consider:

- the background concentrations of substances (but it is valid only for the natural pollutants);
- standards (regional, national, corporate or institutional, or international) – these levels can be introduced in the official documents named “standard” or “regulation” etc.;

- target values – different water quality targets that should be achieved during some period.

When establishing the water quality norms, we take into account possible direction of water use: drinking water, water for industry, water for sanitary purposes, for watering (irrigation), fishery purposes. It is necessary to set a complex of requirements to the quality of water. It is easy to understand that being at the top of the food chain fish can accumulate high concentrations of the pollutants. But if water is not used for drinking or fishery, presumably its excessive purification is superfluous.

Thus, some different water use categories must be assessed. E.g., in Russia these are the following categories:

- ❑ *Household and drinking water use*: use of water objects or their sites as sources of economic and drinking water supply and for water supply of the food industry enterprises.
- ❑ *Communal and domestic water use*: use of water bodies for swimming, sports and recreation of the population. The water quality requirements for municipal water use apply to all areas of water bodies located within the boundaries of populated areas, regardless of the type of their use.
- ❑ *Fishery water use*: use of water bodies for the habitat, reproduction and migration of fish and other aquatic organisms:
  - The highest category: the location of spawning grounds, mass feeding grounds and wintering pits of especially valuable and valuable species of fish and other commercial aquatic organisms, protected areas of farms of any type for the artificial breeding and cultivation of fish, other aquatic animals and plants.
  - The first category: water bodies used for preservation and reproduction of valuable fish species with high sensitivity to oxygen content.
  - The second category: water bodies used for other fishery purposes.

The water quality norms are different in the countries of the world – this is due to differences in the experiments for establishing water quality standards (MPC).

Since a middle of the 20<sup>th</sup> century in most European countries, water quality standards (physico-chemical ones) are applied to determine the suitability of water for a particular purpose. Some standards are developed on the basis of hierarchy of quality. According to these norms the quality of water can be divided into 3, 4, 5 or more classes.

Each country has developed its own standards, none of which has been universal. Moreover, these norms contradict the accepted WHO norms of drinking water quality.

For example, in Russia (USSR) the first standards of water quality were established in 30-ies of XX century; currently, there are more than 2 thousand MPCs standards for surface waters.

In Europe, in 1978 the Council of Europe issued the Directive 78/659 / EEC on the quality of fresh water in need of protection or purification for fisheries conservation purposes (FFD):

- physico-chemical standards for natural fisheries (essentially environmental standards): 14 standards, including standards for 10 substances;
- for some substances there are two indicators: the estimated value (the average long-term safe concentration) and the required value – the maximum concentration that cannot be exceeded.

It is impossible to achieve the unity of environmental standards due to the large variety of water types in the European Union. That is why the Directive 2000/60/EC of the European Parliament and of the Council of Europe was issued. It includes the principles for community action in the field of water policy - the framework Directive on water (Water Frame Directory, WFD):

- methodology of environmental status assessment within the 5-class system,

- no physico-chemical or environmental standards for water are indicated in the document.

The most important principle of the EU water framework Directive: regardless of whether or not the water in the reservoir complies with the standard, its quality should not be allowed to deteriorate. Therefore, it is impossible to prevent increasing emissions of pollutants in the pond; each new discharge is required to compensate for the decline in existing discharges.

Specific indicators of surface water quality in the EU framework Directive include complexes of concentration limits. For the surface water used for drinking these are the content standards for most frequently encountered in drinking water substances. The Directive covers all water bodies where the water intake for drinking purposes in the amount of more than 10 m<sup>3</sup> a day on average or serving more than 50 people (possible smaller volumes or fewer people if the water supply takes place in the framework of a commercial or public activity). Regular monitoring and testing of water on 48 microbiological and chemical parameters is required. The Directive is based on WHO recommendations for drinking water.

The European Parliament and the Council (Decision No. 2455/2001/EC) approved the list of "priority" pollutants: substances that pose a significant threat to the aquatic environment or indirectly through the aquatic environment – *EU list of substances No. 1*. Individual substances are selected on the basis of their persistence, toxicity and bioaccumulation – 132 substances.

*List II*: groups and families of substances that have harmful effects on water basins. It also contains all the individual substances in list I that are not yet subject to Community regulation. Since there are only 18 "actual" substances in list I, all the remaining 114 substances in list I and the groups and families of substances listed in list I should be treated as substances in list II. In respect to pollutants of list II, the participating countries must establish programs for reducing pollution, including water quality indicators.

As example let us consider the comparison of the fishery MPC in EU and in Russia (Table 3.3).

**Table 3.3. Comparison of MPC for fishery water bodies in Russia with the mandatory indicators of the EU**

Indicator	Unit	Russia	EU		Note
			salmon	carp	
Temperature	°C	3.0 summer	1.5	3.0	Increase due to discharges
	°C		21,5	28.0	Maximum at the time of tracking
	°C		10,0	10.0	Maximum during the spawning period
Dissolved oxygen	mg/dm <sup>3</sup>	4-6	50% > 9	50% >7	
pH	-	6.5 – 8.5	6 – 9	6 – 9	
Ammonia nitrogen (NH <sub>4</sub> <sup>+</sup> )	mg/dm <sup>3</sup>	0.39	1,0	1.0	In specific geographical or climatic conditions, EU member States may establish a value greater than 1.0 mg / dm <sup>3</sup>
Ammonia (NH <sub>3</sub> )	mg/dm <sup>3</sup>	0.05	0.025	0.025	
Oil product	mg/dm <sup>3</sup>	0.05	Not visible in the form of a film		
Chlorine (residual)	mg/dm <sup>3</sup>	Absence	0.005	0.005	
Phenols	mg/dm <sup>3</sup>	0,001	No odor and taste in the fish		
Zinc	mg/dm <sup>3</sup>	0.01 (0.05 for sea water)	0.03	0.3	At a water hardness 10 mg/dm <sup>3</sup> CaCO <sub>3</sub>
			0.2	0.7	At a water hardness 50 mg/dm <sup>3</sup> CaCO <sub>3</sub>
			0.3	1.0	At a water hardness 100 mg/dm <sup>3</sup> CaCO <sub>3</sub>
			0.5	2.0	At a water hardness 500 mg/dm <sup>3</sup> CaCO <sub>3</sub>

The shown norms are in fact only a part of the relevant standards. But even these numbers show in any cases 2 to 4 times differences between the norms and, in general, the visible different approaches to the assessments.

### *Pollution indexes*

Generally, the concept of water quality includes a set of indicators of its composition and properties that determine the suitability for specific types of water use. Quality assessment is carried out on such parameters as the content of suspended solids and floating impurities, temperature, color, smells and flavors, pH, BOD, COD, dissolved oxygen, chemicals and microorganisms.

Most often, water quality assessments are based on a comparison of actual values with normative ones and refer to single measurements. However, some data do not give an idea of the total pollution of water bodies and do not allow one to unequivocally attribute the quality to one category or another. In this case, the numerical characteristics of water quality are used for a number of main indicators and types of water use. These characteristics are called water pollution indexes (WPI) and are widely used in water quality assessment practice.

**Complex assessment of the degree of contamination of surface waters using the hydrochemical indicators** is based on the assessment of the degree of water pollution in a water body as well as a combination of pollutants:

- for any water body at the point of water sampling;
- for any specific period of time;
- for any set of hydrochemical indicators.

As a standard, MPC of harmful substances (for water of fishery water bodies, as well as water objects for domestic and drinking and cultural and household water use) are used. For substances for which there is a complete absence in water bodies according to normative documents,  $0.01 \mu\text{g} / \text{dm}^3$  is conventionally taken as MPC.

First of all, the water pollution level of a given water body at a specific point of observation is estimated. The assessment is carried out with the help of a relative characteristic, calculated for the actual concentrations of pollutants and the relevant standards. The second element of the integrated assessment is the frequency of the detection of concentrations exceeding the standards (indirect assessment of the duration of water pollution). It is also necessary to take into account the list and quantity of pollutants to be considered.

Before the calculation begins, the list of ingredients and indicators is determined, on the basis of which complex indicators are calculated.

In the calculation of complex indicators, only standardized ingredients and indicators of the composition and properties of the water of the water body are used. The lower limit of the number of counted ingredients is determined by their minimum number sufficient to characterize the quality of the water under study for all limiting hazard indices (signs characterized by the lowest harmless concentration of the substance in the water). The upper limit of the number of considered ingredients is not indicated. The optimal number of counted ingredients varies from 10 to 25.

The amount of information about the chemical composition of water depends on the category of the station of stationary observations. The minimum amount of data is 4 samples per year or one sample per quarter (in the hydrological phase); the maximum amount of data is not limited.

As a result, water quality can be assigned to one of the following categories (Table 3.4).

**Table 3.4. Characteristics of water quality on the basis of specific combinatorial water pollution index (SWPI)**

Class and rank	Characteristics of the state of water pollution	Specific combinatorial index of water pollution					
		Without taking into account the number of pollution indicators	Depending on the number of accountable pollution indicators				
			1	2	3	4	5
1 <sup>st</sup> class	Conditionally pure	1	0.9	0.8	0.7	0.6	0.5
2 <sup>nd</sup> class	Slightly contaminated	1—2	0.9—1.8	0.8—1.6	0.7—1.4	0.6—1.2	0.5—1.0
3 <sup>rd</sup> class	Contaminated	2—4	1.8—3.6	1.6—3.2	1.4—2.8	1.2—2.4	1.0—2.0
Rank «a»	Contaminated	2—3	1.8—2.7	1.6—2.4	1.4—2.1	1.2—1.8	1.0—1.5
Rank «b»	Very polluted	3—4	2.7—3.6	2.4—3.2	2.1—2.8	1.8—2.4	1.5—2.0
4 <sup>th</sup> class	Dirty	4—11	3.6—9.9	3.2—8.8	2.8—7.7	2.4—6.6	2.0—5.5
Rank «a»	Dirty	4—6	3.6—5.4	3.2—4.8	2.8—4.2	2.4—3.6	2.0—3.0
Rank «b»	Dirty	6—8	5.4—7.2	4.8—6.4	4.2—5.6	3.6—4.8	3.0—4.0
Rank «c»	Very dirty	8—10	7.2—9.0	6.4—8.0	5.6—7.0	4.8—6.0	4.0—5.0
Rank «d»	Very dirty	8—11	9.0—9.9	8.0—8.8	7.0—7.7	6.0—6.6	5.0—5.5
5 <sup>th</sup> class	Extremely dirty	311	39.9	38.8	37.7	36.6	35.5

The advantage of the above technique is the possibility of using all available material for hydrochemical indicators of water quality. It is quite difficult for the user but provides more objective and precise results when allocating water categories taking into account their contamination.

The general scheme of calculation of the specific combinatory water pollution index is presented on the Fig. 3.4.

In practice, less complex methods for classifying water as a category of water quality are also used. For example, this can be done using the combinatorial index as an example. The shortcoming of these methods is related to the close dependence of the water categories evaluated on the type and quantity of the initial data.

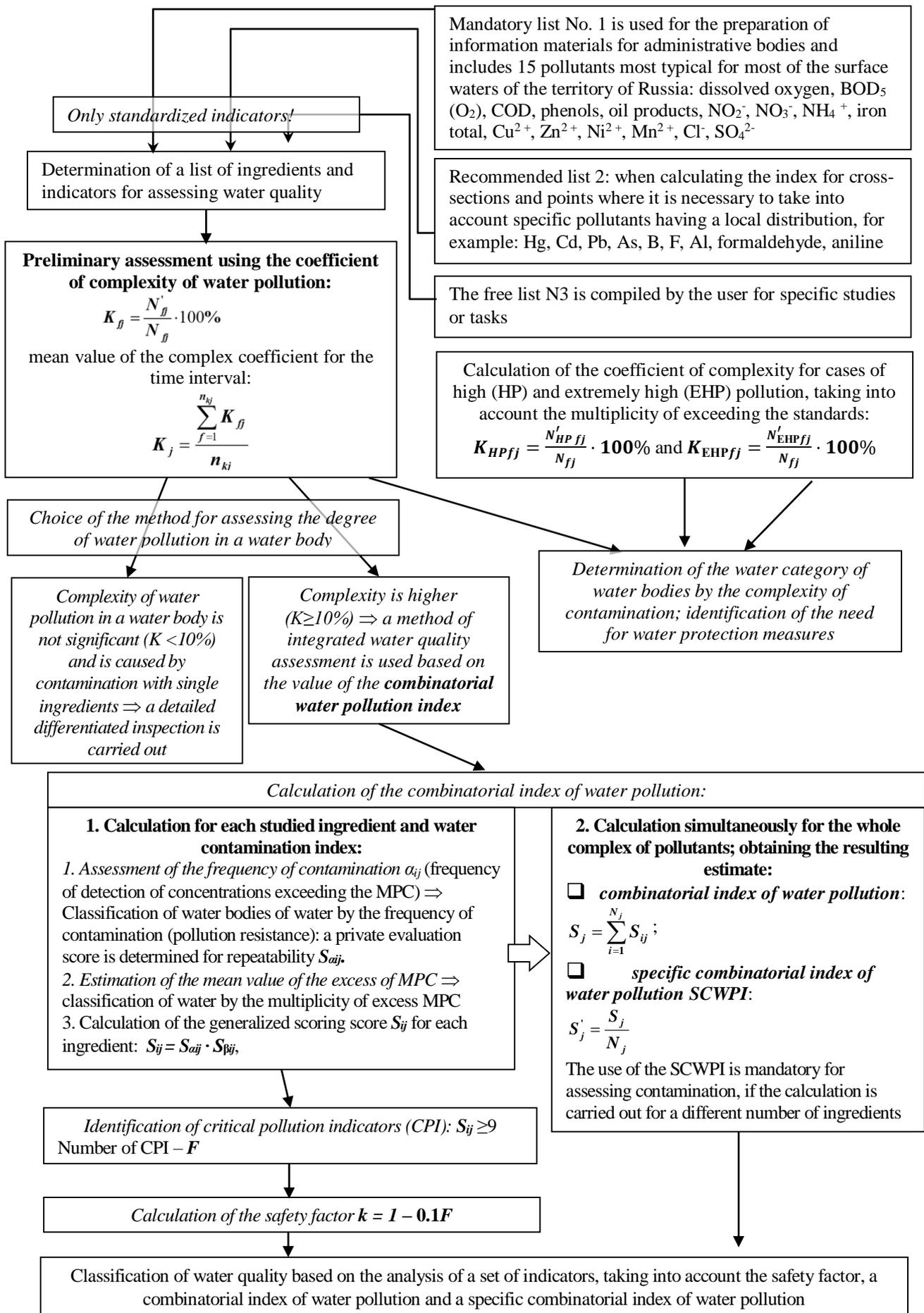


Fig. 3.4. Algorithm for assessing water quality based on complex indicators – calculation of SCWPI

**Water pollution index (WPI).** The most frequently used indicators for assessing the quality of water bodies include the hydrochemical index of water pollution (WPI) and the hydrobiological index of saprobity S.

The water pollution index, as a rule, is calculated by six to seven indicators, which can be considered hydrochemical ones; some of them (concentration of dissolved oxygen, pH, biological oxygen demand BOD<sub>5</sub>) are mandatory.

$$WPI = 1/N \cdot \sum C_i/MPC_i$$

where C<sub>i</sub> is the concentration of the component (in some cases - the value of the parameter); N - number of indicators used to calculate the index; MPC<sub>i</sub> is the set value for the corresponding type of water body.

Depending on the magnitude of the WPI, water body sites or objects themselves are divided into classes (Table 3.5).

**Table 3.5. Classes of water quality depending on the value of the water pollution index**

Category of water	WPI value	Water quality classes
Very clean	Up to 0.2	1
Clean	0.2—1.0	2
Moderately polluted	1.0—2.0	3
Polluted	2.0—4.0	4
Dirty	4.0—6.0	5
Very dirty	6.0—10.0	6
Extremely dirty	> 10.0	7

Water pollution indexes are compared for water bodies of one biogeochemical province and a similar type for the same watercourse (with the flow, in time, etc.).

**Assessment of water quality by hydrobiological indicators.** The biotic component of ecosystems is most sensitive to changes in the quality of the environment. In this regard, water quality assessments can be very effectively carried out on the basis of assessments of the state of the biota: through the accumulation, systematization and analysis of information on the quantitative nature of the relationship between living organisms and their habitat in order to obtain the following results:

- an assessment of the quality of the ecosystems under study (ultimately - in terms of the possibility of their use by humans);
- identification of the causes of observed and probable structural and functional changes in biotic components and targeted indication of sources and factors of negative external impact;
- the forecast of ecosystem stability and the admissibility of changes and loads on the environment as a whole;
- assessment of existing reserves of the biosphere and trends in their depletion (accumulation).

Biological methods for the analysis of water quality have been developed and applied, since the 1960s. (methods of biological analysis of the waters of Makrushin). The assessments of the state of aquatic ecosystems implicate: ecological modifications of Abakumov, biotic indices of Shannon,

Woodiviss, Balushkina, etc .; the dependence of biological indicators on various environmental factors, developed by the Vinberg-Alimov School on the results of production studies of aquatic ecosystems.

The term *saprobity* denotes a complex of physiological and biochemical properties of the organism, which determines its ability to live in water with a certain content of organic substances, i.e. with some degree of pollution. This term is often replaced by the term "capacity" (a set of physiological and biochemical properties that allow organisms to live in water bodies and watercourses contaminated with sewage). *Saprobity* assesses the contamination of water with organic substances: water is divided into poly-, meso- and oligosaprobic waters. Totally, six classes of saprobity of the water body are established:

- xenosaprobity and oligosaprobity characterize pure waters;
- $\alpha$ - and  $\beta$ -mesosaprobity characterize polluted waters;
- polysaprobity and hypersaprobity - dirty waters.

To determine the class of saprobity, a number of quantitative indicators and properties of water are usually used. This is, first of all, the content of dissolved O<sub>2</sub> (saturation percentage), transparency, BOD<sub>5</sub> and BOD<sub>20</sub>, permanganate oxidation, the content of biogenic compounds (nitrites, nitrates, phosphates, etc.), including hydrogen sulphide.

#### *Assessment of the state of bottom sediments of rivers and reservoirs*

Bottom sediments of water objects are geological formation, the most important component of sub-aquatic landscapes and an integral element of the aquatic ecosystem. Their formation is associated with sedimentation of river deposits, which by virtue of physical laws are always in fluxes. Nanosizes, especially fine fractions, have a high sorption capacity and accumulate the entire complex of chemical elements both inorganic and organic ones in the course of their movement and sedimentation in riverbeds and lakes. The concentration of pollutants in the clay fraction deposits (size less than 0.02 mm) is often 5-10 times higher than their concentration in water.

Bottom sediments are considered as an integral indicator of anthropogenic load on a water body. Their condition allows us to trace the dynamics of pollution over a long period of technogenic impact.

Currently, there are no MPCs of major pollutants for bottom sediments. As exception we can mention some recent studies, where the maximum permissible content for some organic substances is established (i.e. PAHs norms for river bottom sediments in Norway). Thus, estimates of contamination levels use background values, Clarke in rocks, MAC in soils and other geochemical indicators. However, a general drawback for all indicators is the lack of consideration of the specific composition of bottom sediments and the peculiarities of hydrochemical transformation of pollutants in the system "water - sediments".

The importance of studying the accumulation of chemical elements in bottom sediments also lies in the fact that they are a source of "secondary" pollution of water bodies and watercourses during limiting periods, for example in winter, when the content of dissolved oxygen drops to critical levels (less than 4 mg / dm<sup>3</sup>).

The deposits absorb particularly well as they increase their total specific surface area. It is known that various physicochemical processes take place at the "particle-water" interface: adsorption, osmosis, ion exchange. The intensity of their development largely depends on the dispersion of the mineral component. Therefore, clay and other finely dispersed materials adsorb most (or all) ions of heavy metals and organic pollutants.

Usually, data on the fraction of less than 0.02 mm are used to estimate the degree of contamination of bottom sediments of different mechanical composition. In European countries, this figure is increased by an order of magnitude (0.002 mm).

In connection with the lack of standards for bottom sediments, in complex assessment of water and bottom sediment contamination, the excess concentration of elements is relative to the background ( $c_{bi}$ ) or concentration coefficients  $K_c$

$$K_c = c_i / c_{bi}$$

Due to the fact that water and sediment pollution occurs by several elements, a total pollution index is calculated for them, reflecting the effect of the group of elements:

$$Z_c = \sum K_c i - (n-1)$$

where  $n$  is the number of counted elements.

Further on the indicator  $Z_c$  and the excess of the standards of the chemical composition of water in the calculation point in relation to the background, the water and sediments are assigned to one of the levels (Table 3.6).

**Table 3.6. An indicative scale for assessing the contamination of water systems by the concentration of chemical elements in bottom sediments**

Pollution level	$Z_c$ of toxic elements in bottom sediments	Content of toxic elements in water
Weak	10	Low elevated relative to the background
Moderate	10—30	Increased relative to the background, an occasional excess of MPC
Strong	30—100	Many times higher background, stable excess of individual levels of MPC levels
Very strong	> 100	Practically constant presence of many elements in concentrations above MPC

However, in order to estimate the level of contamination of bottom sediments in specific natural systems, it is often inappropriate to use single quality standards as "benchmarks". In real conditions, they can significantly differ from the natural background - the values of the concentration of components in unpolluted geosystems. In this regard, more adequate estimates of contamination of bottom sediments are obtained on the basis of a comparison of the concentrations of substances in the geosystem under study with the background value.

So, in order to determine the degree of contamination of bottom sediments with heavy metals in Germany and other countries, iso-classes, or geoaccumulation indexes are used (Müller G., 1969):

$$I\text{-geo}_n = \lg 2 \cdot (C_n / 1.5 B_n),$$

where  $C_n$  is the measured element concentration in bottom sediments (fractions less than 0.02 mm are most often used as having the greatest sorption capacity); 1.5 - coefficient of accounting for variations in the natural concentrations of the element;  $B_n$  is the geochemical background concentration of the element  $n$  (determined from the data of special studies taking into account regional features of the scattering of the element).

The values of concentrations are presented in table 3.7.

**Table 3.7. The values of the concentrations of the main heavy metals according to the Igeo-classes (according to G. Müller)**

Element	Background concentration of the element, $\mu\text{g} / \text{kg}$	Classes of geoaccumulation (igeo-classes)						
		0	1	2	3	4	5	6
Fe	4.72	7.08	14.16	28.32	56,64	> 56.64		
Mn	850	1275	2550	5100	10 200	20 400	40 800	> 81 600
Cd	0.3	0.45	0.90	1.8	3.6	7.2	14.4	> 28,8
Zn	95	142.5	285	570	1140	2280	45 600	> 9120
Pb	20	30	60	120	240	480	960	> 1920
Cu	42	67.5	135	270	540	1080	2160	> 4320
Ni	68	102	204	408	816	1632	3264	> 6528
Co	19	28.5	57	114	228	456	912	> 1824
Cr	90	135	270	540	1080	2160	4320	> 8640
As	13	19.5	39	78	156	312	624	> 1248
Hg	0.4	0.6	1.2	2.4	4.8	9.6	19.2	> 38.4

This indicator is the basis for assigning river bottom sediments to one of the quality classes (Table 3.8). This classification can be used to map bottom sediments for each of the heavy metals, which in turn makes it possible to assess the man-made load on river ecosystems and to identify disadvantaged river areas.

**Table 3.8. Characterization of bottom sediments pollution levels by Igeo-classes and technogenic load on aquatic ecosystems**

Igeo class	Level of pollution with heavy metals	Technogenic load on water ecosystems	Environmental zones of aquatic ecosystems; classes of bottom sediments
0 1	Unpolluted Unpolluted to moderately polluted	Weak (low-risk)	Zones of the norm; class of satisfactory (favorable) state
2 3	Moderately polluted Mildly contaminated	Moderate (moderately dangerous)	Risk area; adverse condition class
4 5	Strongly polluted Strongly soiled (to excessively contaminated)	Strong (dangerous)	Zone of crisis; very unfavorable condition class
6	Extremely contaminated	Extreme (extremely dangerous)	Emergency area; catastrophic state class

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### *Home task*

1. Using the WHO standards for the drinking water quality, assess the environmental state of a water body in your country. Compare the result with your national water quality norm. Write a comment.
2. Describe the system of environmental standards of surface water quality in your country. What types of environmental norms are implemented? Are they stronger or less strong in comparison with the WHO norms? With EU norms?
3. What models are used for the forecast of water quality at the pollution? What are the main factors included into the model? What software can be used for the calculations using this model?

### *Questions for the self-control*

1. What is water quality? How can it be described?
2. List the hydrochemical indicators used for the assessment of water quality.
3. What is a specific combinatory water pollution index? Describe the algorithm of its calculation and interpretation.
4. How can be established the MPC of pollutants in bottom sediments of water bodies?
5. What types of norms of permissible impact on water bodies do you know?
6. Are the discharges of wastewater possible (allowed) when the MPC is exceeded in the control point?
7. Describe the algorithm of establishing the norm of the permissible discharge.
8. What factors affect the formation of several concentrations of the impurity in the water flow (river)?
9. Under what conditions is the discharge of sewage and (or) drainage waters into water bodies is prohibited?
10. What initial data are necessary for determining the value of the permissible discharge standard?
11. How can be classified the wastewater of industry? What are the characteristics of these groups?
12. What are the factors of the self-purification of water bodies?
14. What is the “direct problem of forecasting water quality”?
15. What is the “inverse problem of forecasting water quality”?
16. What substances are considered as nonconservative impurities?
17. What is the “good environmental state of water body”?
18. How can be modeled the conditions of the formation of quality and quantity of water (or individual processes that determine the quality of water)? What initial data are necessary for such a model?
19. Are the WHO standards of the water quality the same for all the world and for all the natural conditions?
20. What types of water quality norms are most strong: for drinking water, for the fishery, for sanitary use?

## Chapter 4. Environmental norms and regulations for the protection of soil

According to the World Soil Charter (edition of 2015), healthy soils are a basic prerequisite to meeting varied needs for food, biomass (energy), fiber, fodder, and other products, and to ensuring the provision of essential ecosystem services in all regions of the world. The document was adopted in 2015 and contains the main principles of soil use and soil protection.

Proper state of soils is an essential condition of the qualitative agricultural production and of the possibility to produce any foods at all. But currently in some regions of the world there are a lot of cases of contamination and degradation of soils. For different land-use directions there are specific requirements for the soil quality, but the main idea here is to provide the efficient protection of soils, and, finally, a proper state of soils and their fertility.

### *Factors of the pollution and self-purification of soils*

Soil is an independent (separate) natural-historical organomineral body that appears on the surface of the earth as a result of prolonged exposure to biotic, abiotic and anthropogenic factors, consisting of solid mineral and organic particles, water and air, and having specific genetic morphological features, properties that create appropriate conditions for growth and development of plants. The term “independent” means here, that in the soils the mechanisms of self-regulation are been realized. Realization of these mechanisms can lead, e.g. to self-purification or to self-restoration in cases of soils deterioration. Possibility of such rebuild-processes depends on the intensity of extern impacts and initial state of soils.

As well as in case of other environmental components, there are three groups of factors defining state of soil:

- Properties of soil itself;
- Properties of the pollutants;
- “Mode” of the pollution.

Properties of soils determine the fate of pollutants entering the soil. This is a set of properties such as humidity, porosity, chemical composition, grain size, permeability, humus content and others. In different regions of the world, in different natural conditions properties of soils differ significantly. That is why there is no reason to create common standards of soil quality “for everybody and everywhere”. It is better to justify and to set the local or regional norms reflecting natural conditions of the given region.

According to the degree of sensitivity to pollutants, the soils are divided into

- very sensitive,
- sensitive,
- medium-sensitive,
- lowly sensitive,
- stable.

Degradation of soil

### *Pollution of soils*

Soil pollution refers to the saturation of the surface layers of the earth with physical, chemical and biological ingredients that adversely affect the environment and soil fertility. Sources of pollution are industry, transport, agriculture (use of fertilizers, pesticides, herbicides and livestock wastes), land improvement, noise, vibration, energy emissions, industrial and household waste dumps. Due to

industrial and agricultural pollution, heavy metals, oil products, phenols, dioxins, benz (a) pyrene, surfactants, hydrocarbons, radioactive substances, pesticides, nitrates, ammonium nitrogen, phosphorus, pathogenic substances, etc. enter the soil.

The introduction of fertilizers also causes pollution, which is due to the partial assimilation of necessary products by the plants. For example, the nitrogen utilization rate of plants is 60%, and phosphorus discharge with drainage water can reach 0.6 kg / (ha · year), therefore, fertilizers contain heavy metals that bind to organomineral complexes and can accumulate in soils in various forms of mobility, for example, when applying 90 kg / ha of superphosphate simultaneously about 1 g of copper, 56 g of lead, 1 g of cadmium enter the soil.

Pesticides are of particular danger. These are biologically highly active substances that are toxic to certain forms of life and are difficult to decompose. It is established that only 3% of used insecticides are active, the remaining 9% are lost, entering the soil, plants and other components of agroecosystems. Among herbicides the most dangerous one is granosan, containing mercury up to 76% by weight.

Accumulation of mobile substances in the soil depends on the mechanical composition, permeability of soils, moistening conditions. The influence of the latter factor is estimated through the wetting factor, which is the ratio of precipitation to evaporation or evapotranspiration. From these positions, it is customary to consider the types of water regime of soils, their mechanical composition and the ability to accumulate pollutants. The data given is one of the first domestic results of this field of research, which is very relevant and in demand at the present time. Based on the data shown in the table, it is possible to predict self-cleaning of soils during contamination with various forms of joints. The general soil properties determining the accumulation processes are shown in the table 4.1.

**Table 4.1. Danger of soil contamination by biologically mobile elements**

Type of water regime	Humidity factor	Mechanical composition of soils			
		Sandy	Clayey	Silty	Different with the presence of a frozen layer
Intensive flushing	> 2	1	2	3	3
Mainly flushing	2—1	2	3	4	4
Relatively flushing	1—0,5	3	4	5	5
Non-flushing	< 0,5	4	5	5	—

The stability of soils to pollution varies depending on the buffering capacity. Soils with a high adsorption capacity, respectively, and a high content of clays, and organic matter can retain pollution, especially in the upper horizons. This is typical for carbonate soils and soils with a neutral reaction. In them, the amount of toxic compounds that can be washed into groundwater and absorbed by plants is much less than in sandy acid soils.

Chemical and physico-chemical properties of the pollutant determine its danger level. Human organism as well as plant and animal organisms show different reactions to the input of the pollutants. Each organism is individual. But the behavior of the pollutants depends on their ability to be transformed during the contact with organisms. And this ability is the consequence of the chemical and physico-chemical properties. Generally, when modeling, we take into account a form of the pollutant and its main characteristics like solubility, hydrophobicity, thermodynamic characteristics, ability to the complexation and others. Toxicity is also among the important characteristics. More often we mean toxicity for humans. However, more complex models take into account toxicity

indicators for all participants in food chains. So, in Russia the following classification is applied (Table 4.2).

Table 4.2. Classification of pollutants according to the level of their danger to the soil

Indicators	Hazard Class		
	I highly dangerous	II moderately hazardous	III lowly hazardous
Toxicity LD <sub>50</sub>	up to 200	200 to 1000	over 1000
Persistence in soil, months	over 12	6 to 12	less than 6
MPC in soil	less than 0.2	0.2 to 0.5	over 0.5
Migration	migrate	migrate weakly	do not migrate
Persistence in plants, months	3 and more	1 to 3	less than 1
Influence on food value of agricultural products	Strong	Moderate	No

Generally, all the substances can be divided in two groups:

- Chemically active soil: affects oxidation-reduction reactions, reactions of acidification and alkalization of soils (physiologically acidic salts, mineral acids, bases, certain gases);
- Biologically active soil: substances of organic and organomineral character - pesticides, toxic elements (Cd, Pb, Hg, Cr, Ni, As, Cu, Zn, etc.), their compounds, radioactive substances, the excess of which acts negatively on living organisms.

Depending on the *ability to contaminate* microelements are divided into four groups:

- 1) having very high potential for contamination: Cd, Hg, Pb, Cu, Cr;
- 2) high-potential contamination: Bi, Mo, Fe, Se, Te, Ti, Ba, U;
- 3) with an average contamination potential: Fe, Be, Ni, Co, As, Li, B, W, Al, V;
- 4) with a weak contamination potential: Sr, Zr, La, Nb.

According to the *degree of leaching*, chemical elements in hydrolytic decomposition are also divided into four groups:

- 1) very well leaching: Na, Ca, Sr, As;
- 2) well leaching: K, Mg, Ba;
- 3) medium-leaching: Zn, Co, Ni, Cu, Pb, SiO<sub>2</sub>;
- 4) weakly leaching: Fe, Al, Ti, V, Cr, Ge.

Complex organomineral compounds with metals in soils are very fragile and are destroyed under the influence of microbiological activity and physicochemical conditions of the environment. When interacting with vegetation, specific series of toxicity are formed depending on the intake of heavy metals (Table 4.3). The data presented in the table does not lose its relevance in connection with the complexity and completeness of the study. They are of considerable interest in the organization of agriculture in contaminated areas.

**Table 4.3. Ranges of toxicity of heavy metals and other elements (S.Ya. Bezdina, 2000)**

Ranges of toxicity	Characteristic
Cd > Ni > Cu > Zn > Cr > Pb	Phytotoxicity when entering plant roots
Cd > Pb > Zn > Cu > Mn > Fe	Phytotoxicity when entering leaves of plants
Ni > Cu > Co > Mn > Zn	Phytotoxicity when exposed to wheat germ
Fe > Cu > Mn > Cd > Zn > Pb	Mobility in a plant
Ag > Hg > Cd > Ni > Zn > > Pb > Be > Cr <sup>3</sup> > Ba > Sr > Li	Toxicity when exposed to soil bacteria
Hg > Cu > Ni > Pb > Co > > Zn > Cd > Mn > Mg > Ca	Stability of complex compounds in soil
Cr <sup>6</sup> > Cr <sup>3</sup>	Phytotoxicity of chromium (on the valence)

The same approach can be applied by the organization of the environmental monitoring or control of the remediation on the contaminated sites. Such assessments are especially interesting for the organic compounds.

The soil cover plays the role of physicochemical and biological agent and neutralizer of many chemical compounds. The detoxifying properties of soils and rocks are manifested in varying degrees and depend on the content of organic carbon, the pH of the medium, the capacity of absorbing the soil horizon, the activity of soil organisms, the metabolism of plants, etc. Part of the contamination entering the soil passes into surface and underground water, which ultimately falls into rivers and water bodies. In addition, a certain amount of chemical substances passes into the trophic chains "farming products - people", "feed - livestock - people".

Mode of the pollution means the intensity, mass of pollutant, probable combination with other chemical substances, period of impact. Of great importance are the environmental characteristics such as meteorological conditions, intensity of circulation processes and interaction with contacting environments.

### *Models of soil pollution*

From the variety of models of soil pollution for the case of environmental norms the following types are important:

- Modeling of pollutant input: determination of the amount and chemical composition of the pollutants;
- Modeling the spread of pollutants:
  - models of pollutants migration along the soil profile and on lateral;
  - models of interaction with other environmental components;
  - models of contaminants accumulation in soils;
  - models of soil self-purification;
  - definition of critical loads;
  - crop models;
  - economic models.

When assessing the state of soils, it is necessary to use a unified data set. This data must reflect water-physical, chemical and biological processes in soil caused or changed by pollution.

This complex of data is used for the soil quality monitoring, for the development of nature protection measures and forecast of the potential soil productivity.

Classification of soils takes into account the influence of pollutants on soil changes:

- production of biomass;
- economic parts of crops;
- technological value of these crops;
- nutritional value of crops;
- deterioration of sanitary and hygienic value.

In the listed models of great importance is stability or sensitivity of soils, their ability for self-purification. These properties are determined by:

- a) content of humus;
- b) quality of humus;
- c) biological activity;
- d) depth of the humus horizon;
- e) content of fractions (mechanical composition of the soil);
- e) content of clay minerals;
- g) the depth of the soil profile.

The most important result of models is a prediction of pollution level of soils and in case of danger – a set of efficient restoration measures.

### *Indexes of soil pollution*

**Complex index of soil pollution.** Generally, it is necessary to compare the existing (measured) concentration with the critical level. There are the following ways:

- relation of the measured concentration and maximum allowable concentration – but sometimes we don't have the MPC for the substance;
- relation of the measured concentration and background concentration – but sometimes the substance is “new”, it was not presented in soil before;
- relation of the measured concentration and another critical level. For example, it can be a target level of pollution.

All the listed indicators show the level of pollution by one substance in one sampling point. And of course, we can expand the assessment and receive:

- complex indexes of pollution of soils with a set of substances,
- characteristics of soil pollution with one or a group of substances during some period,
- the same characteristics for some area.

As example of the assessment let us consider two complex indexes.

First of them is  $Z_c$ . This is a complex index of soil pollution, widely used in Russia. The calculation approach is introduced in Russia, in the *Building standard 11-102-97 "Engineering and environmental surveys for construction"*.

The complex index of chemical pollution ( $Z_c$ ) characterizes the degree of chemical contamination of soils and soils of the surveyed territories with harmful substances of various hazard classes and is defined as the sum of the concentration coefficients of individual components of pollution.

$$Z_c = K_{c1} + \dots + K_{ci} + \dots + K_{cn} \cdot (n-1),$$

$n$  – number of measured substances,  $K_{ci}$  – concentration coefficient of  $i$  polluting component, equal to the multiplicity of exceeding the content of this component over the background value:

$$K_{ci} = C_i/C_b.$$

For the non-natural pollutants the concentration coefficients are to be calculated as ratio of the division of the mass fraction of pollutant to its MPC:

$$K_{ci} = C_i/MPC_i$$

Of course, we need to take into account not only the chemical characteristics of soils. For the complex assessments we consider genotoxicity (hazard degree from the point of view of genetics and mutation probability) and biological characteristics.

The ecological state of soils in residential areas should be considered as relatively satisfactory if:

- the total index of chemical contamination ( $Z_c$ ) - no more than 16;
- the number of pathogenic microorganisms in 1 g of soil is less than 104;
- number-titer is more than 1.0;
- eggs of helminths in 1 kg of soil are absent;
- genotoxicity of the soil is no higher than 2.

Generally, the level of soil pollution can be interpreted as shown in the Table 4.4.

**Table 4.4. Critical values of the complex index of soil pollution**

Soil contamination category	$Z_c$ value limits	Effect on health
Permissible	<16	The lowest rate of child morbidity; minimum functional deviations
Moderately hazardous	16-32	Morbidity increase
Hazardous	32-128	Morbidity increase, increasing number of ailing children, children with chronic diseases, dysfunctions of cardiovascular system
Exceptionally hazardous	> 128	Child morbidity increase, dysfunction of women's reproduction function (increasing toxicosis during pregnancy, premature delivery, stillbirth cases, hypotrophy)

Application of the  $Z_c$  is sometimes complicated because of calculations procedure

- Numerical values for chemical elements of different hazard classes are just summarized. But we don't take into account, that their environmental effect is different.
- Exceeding a certain element over a background or MPC is not yet the basis for a definitive decision; the element can be in various forms and different connections; its toxic effect or relative safety does not directly depend on its quantitative content.
- The formula and calculation do not take into account the nature of the subsequent use of land,
- Background concentrations of chemical elements have different values for the same sod-podzolic soils.

For the assessment of the **pollution of soils by a single substance** the following approach is recommended. The 1<sup>st</sup> stage is determination of the hazard class of the element, its MPC and  $K_{max}$  - according to one of the four criteria of the ecological-toxicological state ( $K_1$ ,  $K_2$ ,  $K_3$ ,  $K_4$ ).

Examples of these characteristics for some pollutants are presented in Table 4.5. It is to be noted, that in many cases the best way is to apply the background concentrations of the substances (for the elements and compounds of natural origin).

**Table 4.5. Maximum permissible concentrations of some chemicals in soil and permissible levels of their content in terms of hazard indicators**

Substance	Form, content	MPC, mg / kg soil taking into account the background (clarke)	Hazard indicators ( $K_{max}$ )				Hazard Class
			Translocation $K_1$	Migration		General-sanitary $K_4$	
	Water $K_2$	Aerial $K_3$					
Cu	Mobile	3,0	3.5	72.0	-	3.0	2
Cr	-//-	6,0	6.0	6.0	-	6.0	2
Ni	-//-	4,0	6.7	14.0	-	4.0	2
Zn	-//-	23,0	23.0	200.0	-	37.0	1
Co	-//-	5,0	25.0	> 1000.0	-	5.0	2
F	Water-soluble	10.0	10.0	10.0	-	25.0	1
Sb	Total content	4.5	4.5	4.5	-	50.0	2
Mn	-//-	1500.0	3500.0	1500.0	-	1500.0	3
V	-//-	150.0	170.0	350.0	-	150.0	3
Mn+V	-//-	1000.0+100.0	1500.0+150.0	2000.0+200.0	-	1000.0+100.0	3
Pb	-//-	30.0	35.0	260.0	-	30.0	1
As	-//-	2.0	2.0	15.0	-	10.0	1
Hg	-//-	2.1	2.1	33.0	2.5	5.0	1
Pb+Hg	-//-	20.0+1.0	20.0+1.0	30.0+2.0	-	50.0+2.0	1
KCl	-//-	560.0	1000.0	560.0	1000.0	5000.0	3
NO <sub>2</sub> <sup>-</sup>	-//-	130.0	180.0	130.0	-	225.0	3
Benzo(a)pyrene	-//-	0.02	0.2	0.5	-	0.02	1
Benzene	-//-	0.3	3.0	10.0	0.3	50.0	2
Toluene	-//-	0.3	0.3	100.0	0.3	50.0	2
Isopropylbenzene	-//-	0.5	3.0	100.0	0.5	50.0	1
Alfamethylstyrene	-//-	0.5	3.0	100.0	0.5	50.0	2
Styrene	-//-	0.1	0.3	100.0	0.1	1.0	2
Xylene	-//-	0.3	0.3	100.0	0.4	1.0	2
Hydrogen sulfide	-//-	0.4	160.0	140.0	0.4	160.0	3
Elemental sulfur	-//-	160.0	180.0	380.0	-	160.0	3
Sulfuric acid	-//-	160.0	180.0	380.0	-	160.0	1
Coal flotation waste	-//-	3000.0	9000.0	3000.0	6000.0	3000.0	2
Complex granulated fertilizers (M:P:K = 64:0:15)	-//-	120.0	800.0	120.0	800.0	800.0	3
Liquid complex fertilizers (N:P:K = 10:34:0)	-//-	80.0	800.0	80.0	>800.0	800.0	3

There are some interesting aspects in the Table. First of all, it indicates assessments for *different forms* of the compounds. Few pages earlier we have seen, that the form of the compound leads to the different toxicological effects (different toxicity for Cr<sup>6+</sup> and Cr<sup>3+</sup>). The same is true for many others elements: in some forms they are stable and not dangerous for the biota; in other forms they are highly toxic.

The assessment is based on the four criteria of the ecological-toxicological state:

- translocation,
- migration in water,
- aerial migration,
- general – sanitary.

Finally, we come to the assessment of the degree of the pollution (Table 4.6).

**Table 4.6. Criteria for assessing soil pollution with inorganic substances**

Content in soil, mg / kg	Hazard class of the pollutant		
	1	2	3
> K <sub>max</sub>	Very strong	Very strong	Strong
MPC ... K <sub>max</sub>	Very strong	Strong	Moderate
2 C <sub>background</sub> ... MPC	Weak	Weak	Weak

The same approach is to be applied for the cases of pollution by organic substances (Table 4.7).

**Table 4.7. Criteria for assessing soil pollution with organic substances**

Content in soil, mg / kg	Hazard class of the pollutant		
	1	2	3
>5 MPC	Very strong	Strong	Moderate
2 to 5 MPC	Strong	Moderate	Weak
1 to 2 MPC	Moderate	Weak	Weak

And for the cases of multicomponent pollutions it is possible to assess the degree of danger for the component with the maximum content. The pollution level is determined from the weak to very strong depending on the origin of substance and its concentration.

Another approach is described by the Chinese specialists.

For the pollution by a single component we can use the formula presented below. To be considered measured, maximum permissible and the background concentration of the substance should be taken into account.

And for the group of pollutants it is necessary to use the P index. Finally, the grade of pollution is determined from low to very high.

$$J_i = \frac{c_i - \text{ПДК}_i}{c_{i0} - \text{ПДК}_i},$$

where  $c_i$  - concentration of the controlled chemical element in the soil,  $c_{i0}$  - background concentration of the component,  $\text{MPC}_i$  - maximum permissible concentration.

For the group of the pollutants:

$$P = \sqrt{(J_{\max}^2 - J_{\text{average}}^2) / 2} .$$

At  $P = 0$  - no contamination;  $P = 0 \dots 0,3$  - low level of pollution;  $P = 0,3 \dots 0,6$  - average level of pollution;  $P = 0,6 \dots 1,0$  - high level of pollution;  $P > 1$  - very high level of pollution.

### *Assessments of soils degradation*

By the *degradation of soils* we understand the totality of processes leading to a change in the functions of the soil as an element of the natural environment, to a quantitative and qualitative deterioration of its properties and regimes, and to a decrease in the natural and economic significance of lands. Types of soil and land degradation are distinguished taking into account their nature, actual occurrence and the natural and economic significance of the consequences. There are four main types of degradation:

- 1) technological (operational) (including violations, physical or agricultural degradation, depletion);
- 2) erosion (water and wind);
- 3) salinization (proper salinization and salinization);
- 4) bogging.

The *degree of degradation* of soils and lands is a characteristic of their condition, reflecting the deterioration in the quality of their composition and properties. The extreme degree of degradation is the destruction of the soil cover.

With each specific type of degradation, its assessment is carried out taking into account the main diagnostic (specific) and additional indicators. Additional indicators provide clarifying information for assessing the state of soils, identifying the causes of degradation, and characterizing their consequences. Many indicators are characteristics of soil properties in absolute terms. In addition, comparative or relative indicators characterizing the properties of a certain optimal "reference" state, corresponding to a zero level of loss of the natural and economic significance of lands, as well as indicators characterizing the rate of change of state or the rate of degradation processes are applied.

So, in the Russian experience of soil assessment for each diagnostic (including additional) indicator, the degree of degradation of soils and lands is characterized by five levels:

- 0 - undegraded (undisturbed);
- 1 - slightly degraded;
- 2 - medium-degraded;
- 3 - strongly degraded;
- 4 - highly degraded (destroyed), including the destruction of the soil cover.

These degradation degrees are identified according to the set of indicators presented in Table 4.8.

**Table 4.8. Determination of the degree of degradation of soils and lands**

Indicator	Degree of degradation				
	0	1	2	3	4
Indicator characteristics					
Abiotic alluvion capacity, cm	< 2	2—10	11—20	21—40	> 40
Depth of dips relative to the surface (without discontinuity), cm	< 20	20—40	41—100	101—200	> 200
Reduction of the content of physical clay by an amount, % of the original	< 5	5—15	16—25	26—32	> 32
Increase in the equilibrium density of the formation of the arable layer of the soil, % of the original*	< 10	10—20	21—30	31—40	> 40
Stable structural (interaggregate, excluding cracks) porosity, cm <sup>3</sup> / g	> 0.2	0.11—0.2	0.06—0.1	0.02—0.05	< 0.02
Texture porosity (intra-aggregate), cm <sup>3</sup> / g	> 0.3	0.26—0.3	0.2—0.25	0.17—0.19	< 0.17
Coefficient of filtration, m / day	> 1.0	0.3—1.0	0.1—0.3	0.01—0.1	< 0.01
Stoniness, % coverage	< 5	5—15	16—35	36—70	> 70
Decrease in the thickness of the soil profile (A + B), % of the initial	< 3	3—25	26—50	51—75	> 75
Reduction of humus reserves in the soil profile (A + B), % of the initial	< 10	10—20	21—40	41—80	> 80
Area of nude soil-forming rock (C) or underlying rock (D), % of total area	0—2	3—5	6—10	11—25	> 25
Increase in the area of eroded soils, % per year	< 0.5	0.5—1.0	1.1—2.0	2.1—5.0	> 5.0
Depth of erosion relative to the surface, cm	< 20	20—40	41—100	101—200	> 200
Dividing the territory by ravines, km / km <sup>2</sup>	< 0.1	0.1—0.3	0.4—0.7	0.8—2.5	> 2.5
Deflation deposition of infertile layer, cm	< 2	2—10	11—20	21—40	> 40
Area of mobile sands, % of total area	0—2	3—5	6—15	16—25	> 25
Content of the amount of toxic salts in the upper fertile layer, %:					
- with the participation of soda	< 0.1	0.1—0.2	0.21—0.3	0.31—0.5	> 0.5
- for other types of salinity	< 0.1	0.1—0.25	0.26—0.5	0.51—0.8	> 0.8
Increase in toxic alkalinity (in the transition of the neutral type of salinity in alkaline), mg-eq / 100 g of soil	< 0.7	0.7—1.0	1.1—1.6	1.7—2.0	> 2.0
Increase in the content of exchangeable sodium, % from cation exchange capacity:					
- for soils containing <1% sodium	< 1	1—3	3—7	7—10	> 10

Indicator	Degree of degradation				
	0	1	2	3	4
- for other soils	< 5	5—10	10—15	15—20	> 20
Increase in the content of exchange Magnesium, % from cation exchange capacity	< 40	40—50	51—60	61—70	> 70
The rise of fresh (<1-3 g / l) soil-groundwater, m:					
- in the humid zone	> 1,0	0.81—1.0	0.61—0.80	0.31—0.60	< 0.3
- in the steppe zone	> 4	3.1—4.0	2.1—3.0	1.0—2.0	< 1.0
Raising the level of mineralized (> 3 g / l) soil-groundwater, m	> 7	5—7	5—3	3—2	< 2
Duration of flooding (surface waterlogging), months	< 3	3—6	6—12	12—18	> 18
Peat extraction, mm / year	0—1	1—2.5	2.6—10	11—40	> 40
Additional indicators					
Loss of soil mass, t / ha · year	< 5	5—25	26—100	101—200	> 200
Increase in the area of medium- and heavily eroded soils, % per year	< 0.5	0.5—1.0	1.1—2.0	2.1—5.0	> 5.0
Area of natural fodder lands taken out of land use (deprived of vegetation), % of total area	< 10	10—30	31—50	51—70	> 70
Projective covering of pasture vegetation, % of zonal	> 90	71—90	51—70	11—50	< 10
Rate of growth of degraded pastures, % per year	< 0,25	0,25—1,0	1.1—3.0	3.1—5.0	> 5
Increase in the area of mobile sands, % per year	< 0.25	0.25—1.0	1.1—2.0	2.1—4.0	> 4
Increased area of stale soils, % per year	0—0.5	0.5—1.0	1.1—2.0	2,1—5.0	> 5.0

The list of diagnostic and additional indicators for the identification of degraded soils and lands is determined depending on the type of land degradation.

Technological (operational) degradation includes the following types:

❑ Violation of land. Diagnostic indicators of disturbed lands are:

- 1) morphometric characteristic of the relief – depth or height relative to the natural surface, m; the angle of the slope of the ledges, hail;
- 2) violation of the lithological structure of lands - the presence of a fertile layer and potentially fertile rocks in terms of the thickness of the organogenic layer and humus stocks in the 0-100 cm layer; overlapping of the surface by foreign deposits;
- 3) characteristics of surface and groundwater - the level of groundwater, m; mineralization of water, g / l; duration of flooding, months;

❑ Physical (agricultural) degradation. The main indicators are the granulometric composition; the equilibrium density of the addition of the arable (humus) soil layer, g / cm<sup>3</sup>; textural (intra-

aggregate) porosity,  $\text{cm}^3 / \text{g}$ ; stable structural (interaggregate without allowance for cracks) porosity,  $\text{cm}^3 / \text{g}$ ; the structure of the arable (humus) layer of soil (the content of agronomically valuable and waterproof aggregates and the state and properties of structural separations); water-physical parameters of soils (water permeability and soil filtration coefficient,  $\text{m} / \text{day}$ ); basic soil-hydrological constants (wilting moisture, lowest (field) moisture capacity), porosity of aeration; swelling.

□ Agricultural depletion. Diagnostic indicators are the balance characteristics of the soil (organic matter, nutrients, cation-anionic composition): decrease in humus reserves in the soil profile (A + B), % of the initial; pH; decrease in the content of physical clay, %; qualitative composition of humus; decrease in the gross supply of basic batteries; the supply of plants with mobile forms of nutrients; capacity of cation exchange, degree of saturation of soils with bases, composition of absorbed bases.

Additional indicators are: the mineralogical composition of the clay fraction; decrease in the level of active microbial biomass, number of times; phytotoxicity; a decrease in the enzymatic activity of soils; biomass of soil mesofauna; reduction of biodiversity (Simpson's index, % of the norm); peat working off,  $\text{mm} / \text{year}$ .

*Erosion*. Statistical or dynamic indicators are used to estimate erosion, the latter can reflect the state of both soil cover and landscapes. Water erosion can occur in several forms: planar erosion, linear erosion, wind erosion.

*Salinization*, including its subspecies - salinization and solonchching, are manifested as follows:

- salinization: the main indicators of the degree of salinity are: the total content of toxic salts in the upper fertile layer, %; increase in toxic alkalinity (in the transition of neutral salinization in alkaline),  $\text{mg-eq} / 100 \text{ g}$  of soil; increase in the area of saline soils, % per year; reaction of the medium (pH of saline and aqueous extract). Data on the level and mineralization of groundwater are used as additional indicators;

- solonchching. The main indicators of solonchching are: an increase in the content of exchangeable sodium, % of cation exchange capacity; an increase in the content of exchange magnesium, % of ECO; the reaction of the medium (pH). Additional indicators of alkalization are the indices of physical properties and, in particular, the structure of the soil.

*Waterlogging*. Diagnostic indicators of waterlogging are: raising the level of soil-groundwater,  $\text{m}$ ; duration of flooding, months; mineralization of groundwater,  $\text{g} / \text{l}$ . In addition, the characteristics of the morphological structure of the profile (signs of hydromorphism) can be used.

### *Land use categories*

Every time talking about norms of the state of soils or norms of soil quality we need to understand, how these soils can be used. It is possible to understand, that the agricultural soils are the base for the food production. Soils of industrial areas should never be used for the agricultural purposes or as a playground for children. So, different directions of land use need different requirements to the soil quality.

Here we speak about the land use categories regarding the soil quality requirements.

In different countries of the world there exist different approaches to the standardization of soil quality. Thus, in Russia there are the unified norms for the entire territory of the country. In some European countries there are different norms for the industrial, agricultural areas and for playgrounds. For example, in Germany there are 4 categories of soil use directions (table 4.9).

**Table 4.9. Standards for the content of pollutants that directly affect humans under the Federal Law on Soil Protection (Germany), mg/kg dry weight of mulled soil)**

Substance	Playgrounds	Residential areas	Parks and recreation places	Industrial objects
As	25	50	125	140
Pb	200	400	1000	2000
Cd	10 <sup>1)</sup>	20 <sup>1)</sup>	50	60
CN <sup>-</sup>	50	50	50	100
Cr	200	400	1000	1000
Ni	70	140	350	900
Hg	10	20	50	80
Aldrin	2	4	10	-
Benzo(a)pyrene	2	4	10	12
DDT	40	80	200	-
Hexachlorobenzene	4	8	20	200
Hexachlorocyclohexane	5	10	25	400
Pentachlorophenol	50	100	250	250
Polychlorinated Biphenyls (PCP <sub>6</sub> )	0,4	0,8	2	40
Dioxins / Furans	100	1000	1000	10000

Note: In the inner gardens or small gardens where children are kept and food plants are grown, the Standard for cadmium should be 2.0 mg/kg dry weight

As shown, the difference between the categories can amount to 80...100 times! In this case it is necessary to understand, how to create a standard of soil quality.

### *Approaches to the creation of standards*

First of all, we need to introduce some basic concepts. It is possible to apply anthropocentric or “eco-centric” approach. It means, the target value of the pollutant will be determined depending on different factors:

- human health (and quality of agricultural production);
- health of the other biological species;
- stability of ecosystems.

“Anthropocentric” approach is most widely used. Substances that pollute the soil do not directly affect the human body. They enter the body through various links of food chains and through soil and air pollution with water.

When assessing the state of soils, the following toxicological indicators are established:

- ❖ Toxicity (harmfulness, poisonousness) as a measure of the incompatibility of a substance with life and health; danger as the probability of poisoning by this substance in the real conditions of its application. Toxic lethal concentrations and doses - LC and LD.
- ❖ Persistence in soils or plants is the duration of the conservation of biological activity of soil or plant chemical pollution, characterizing the degree of its resistance to the decomposition process.
- ❖ Migratory air indicator of harmfulness characterizes the transition of a chemical substance from arable layer of soil to air mg / m.
- ❖ The translocation index characterizes the transition of a chemical substance from the arable layer of soil through the roots to the plant and its accumulation in the green mass mg / kg.
- ❖ The general health indicator of harmfulness characterizes the effect of the chemical on the

ability of the soil to self-purification and on the soil microflora mg / kg.

### *Defining critical levels of the soil pollution*

For soils, pollutants are normalized according to the maximum permissible (MPCs) and temporarily permissible (TPCs) concentrations.

Defining critical levels of the pollution is based on the dynamic and the equilibrium models:

- dynamic models predict the time period necessary to achieve threshold values; they are based on a change in the state of pollutants over time;
- equilibrium models calculate the concentration of pollutants in solution and in the composition of adsorption complexes.

In the equilibrium model, all possible processes affecting soil behavior (weathering, leaching, plant uptake, litter accumulation, surface runoff migration, adsorption and complexation processes) are considered on the basis of the balance equation for the mass of pollutants (for example, heavy metals in soil). The main processes determining the result pollution are presented in the fig. 1.

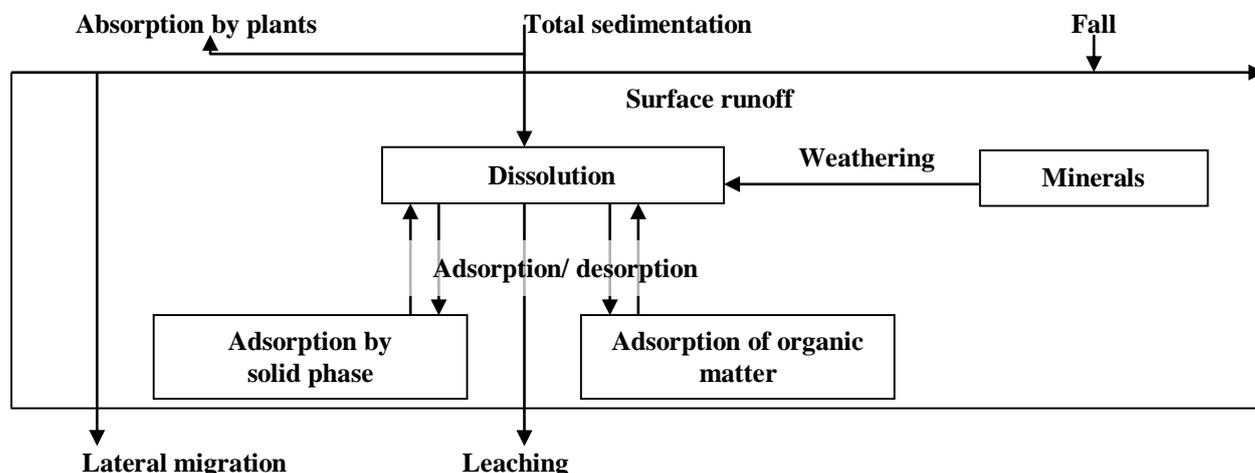


Fig. 1. Processes in soils taken into account in equilibrium models (Ovchinnikova, 2004)

When justifying the MPCs for soils, it is necessary to take into account:

- permissible concentration at which the content of substance in food and forage plants does not exceed some residual values in food (MPC);
- permissible concentration at which the flow of volatile and other substances does not exceed the normative values for air and water;
- permissible concentration, which does not affect microorganisms and self-purification processes.

Finally, MPC is a complex indicator that takes into account the main processes occurring in this element of ecosystems and is calculated in mg / kg of a layer of absolutely dry soil.

As example of the procedure of setting of soil quality standards let us go back to the scheme for the MPC of cadmium. This example shows the variety of ways of certain impurity to final target “victim” of the pollution – the biological species.

### *Practical examples of soil quality standards*

Just as air and water pollution, traditional approaches in the individual cases in the countries of the world differ. In some countries there are only the critical levels like MPC of substances. In others there are some “stages” of danger level.

Thus, in Netherlands, there are three types of norms applied for soil quality assessment (table 4.10):

- A-Wert is the norm corresponding to the natural background;
- B- Wert - the norm, the excess of which is not recommended;
- C-Wert - the standard for exceeding followed by a fine, the size of which usually bankrupts the company.

**Table 4.10. Soil quality norms (Netherlands)**

Metal	Soil, mkg/ kg		
	A-Wert	B-Wert	C-Wert
Ba	200	400	2000
Cd	0,8	5	20
Co	20	50	300
Cu	36	100	500
Mb	10	40	200
As	29	30	50
Ni	35	100	500
Sb	20	50	300
Hg	0,3	2	10
Pb	85	150	600
Cr	100	250	800
Zn	140	500	3000

In USA, there exist special standards for the content of hazardous chemicals and petroleum hydrocarbons in the soil and groundwater.

Comparison of the concentrations of these compounds in the study sites with their standards makes it possible to quantify the measure of the potential hazard that pollutants can present to human health, social welfare and the environment. This approach to assessing the quality of the environment in the US is called a definition or characteristic of the risk of pollution.

Depending on the degree of contamination of soils and groundwater, the following hazard levels are identified:

- no significant risk,
- imminent risk,
- significant risk.

This classification makes it possible to select special methods of restoration and reclamation. Using this approach facilitates:

1) Simultaneous assessment of the risk to human health, public welfare and the environment as a result of contamination of soil and / or groundwater: comparison of substances concentrations in the contaminated area with standards developed taking into account categories of soils and groundwater (Table 4.11).

**Table 4.11. Soil quality standards considering the categories of soils and groundwater**

Pollutant	Soils for children's playgrounds and farmland, mg/ kg	Soils under temporary or permanent coating, mg/ kg	Soils of forest parks and green areas of the city, mg/ kg
As	30	30	300
Benzo[a]pyrene	0.7	0.7	100
Cyanides	100	100	4000
Cd	30	80	800
Cr total	1000	2500	10000
Cr III	1000	2500	10000
Cr VI	200	600	10000
DDT	2	2	90
Pb	300	600	6000
Hg	20	60	600
Ni	300	700	7000
Petroleum hydrocarbons	200	2000	10000
Zn	2500	2500	10000

2) Simultaneous assessment of the risk to human health, public welfare and the environment as a result of soil contamination, if the pollutants from the soil do not penetrate into the groundwater. Table 11 indicates standards for soils, incl. when groundwater is at a considerable depth and does not have a connection with contaminated soils, or when the soils are at a depth under permanent or temporary overlap.

3) Quantitative characterization of the risk for the environment on the basis of a comparison of the concentrations of substances in the soil with their MPC. The concept of "environment" includes wild animals, mollusks, fish, soils and vegetation of forest parks and urban green areas, natural biotopes.

The concentrations of these compounds are compared with their standards. It allows to quantify the measure of the potential hazard that pollutants can present to human health, social welfare and the environment. This approach to assessing the quality of the environment in the US is called a definition or characteristic of the risk of pollution. There are 3 types of soils. And the main thing – the probable interaction with groundwater is to be taken into account.

The evaluation should consider:

- concentration, total quantity, properties, location and background content of harmful substances in the soil;
- possible contamination of groundwater,
- distribution of pollutants across the territory,
- nature of the use of the territory,
- duration of exposure to harmful substances,
- synergetic effects and other indicators.

In areas where the background content exceeds the threshold value, the background is considered the threshold. High pollution values are used for industrial lands, transport, waste storage sites. When exceeding the values of pollutants named "Highest recommendation", it is necessary to carry out soil cleaning. The remaining territories are classified as "Lower Recommendation". Along with soils, groundwater is investigated (Table 4.12).

**Table 4.12. Threshold and recommended values of harmful substances in the soil, adopted in Finland, mg/ kg**

Substance	Natural concentration (background)	Threshold value	Lowest recommendation	Highest recommendation
Sb	0.02 (0.01-0.2)	2	10	50
As	1 (0.1-25)	5	50	100
Hg	0,005 (<0.005-0.05)	0,5	2	5
Cd	0,03 (0.01-0.15)	1	10	20
Co	8 (1-30)	20	100	250
Cr	31 (6-170)	100	200	300
Cu	22 (5-110)	100	150	200
Pb	5 (0,1-5)	60	200	750
Ni	17 (3-100)	50	100	150
Zn	31 (8-110)	200	250	400
V	38 (10-115)	100	150	250
CN <sup>-</sup>	-	1	10	20
Benzo[a]pyrene	-	0,2	2	15

Thus, it is possible to see the variety of the approaches to the establishing of soil quality standards. Sometimes the results of assessments obtained in one country can hardly be unambiguously understood in the conditions of another system of standardization. As an example, we combine in the table the standards adopted in different countries (Table 4.13).

**Table 4.13. Comparison of normative indicators (standards) of soil contamination**

Substances	Pollutant standards, mg / kg				
	Germany	Netherlands	USA	Finland	Russia
As	25-140	29-50	30-300	50-100	2-10
Pb	200-2000	85-600	300-6000	200-750	32-130
Cd	10-60	0.8-20	30-800	10-20	0.5-2.0
Cr total	200-1000	100-800	1000-10000	200-300	
Ni	70-900	35-500	300-7000	100-150	20-80
Hg	10-80	0.3-10	20-600	2-5	2.1
Zn		140-3000	2500-10000	250-400	55-220
Cu		36-500		150-200	33-132
Co		20-300		100-250	
Mb		10-200			
Sn		20-300			
Petroleum products			200-10000		180-1000
Cyanides	50-100		100-4000	10-50	
Benz[a]pyrene	2-12		0.7-100	2-15	0.02
DDT and its metabolites	40-200		2-90	1-2	0.1

Even for the compounds of the similar group (hydrocarbons) the norms vary in wide limits. Such examples will be presented in the last chapter of our course.

In Table 13 we collected examples of 5 countries. It is possible to see, that sometimes the difference is up to one hundred times. Probably, it is due to different approaches to the justification of soil standards. In other cases, there is significant difference in the natural conditions. In any case, it is practically impossible to replace the domestic norms with some international MPCs. When discussing the “purity” of the environments, it is necessary to take into account the national differences as well.

*Individual soil and land quality standards*

The environmental quality of the territory is characterized by:

- 1) the degree of compliance of its current state with the accepted standards;
- 2) its ability to withstand the anthropogenic load, restore the lost quality or move to a new qualitative state that satisfies the conditions of the stability of natural societies (i.e. indicators of sustainability).

When establishing standards, one assumes that each ecosystem is formed by a set of interrelated elements with specific forms of reaction to different types of impact. Reactions are considered as the initial basis for determining the generalized quality characteristic of the territory as a whole.

Thus, the development of environmental quality standards is based on the structuring of the territory, the formation of particular characteristics (norms) of each of its elements and the curtailing of them into one or more generalizing indicators. For different regions (in terms of location, size, structure), the difference in the composition of the indicators and in the methods for determining their quantitative values is allowed.

It is customary to distinguish four levels of the size of the territory, the indicators of the state norms of which have fundamental differences:

- elementary landscape (simple tract): the main object of regulation - biogeocenosis (ecosystem within the catchment area), because it can establish the influence of surrounding sources of anthropogenic impact on the state of the environment;
- local (for example, an ecosystem within an elementary catchment area);
- regional: the object of rationing can be a population, since the zone of its distribution is usually wider than the territory of the local ecosystem and covers the zone of influence of anthropogenous impacts;
- global landscapes (country and continent).

In environmental management, the most important level of regulation is local: it most clearly traces the relationship between the impact force and its consequences for natural systems and human beings, concretizes the scope of application of environmental and remediation measures. The soil cover as a result of anthropogenic impacts can be disturbed to varying degrees. In this case, the disturbance of the soil cover is determined by various factors, depending on the initial state of the soil, the type of use of the territory and its susceptibility to various natural processes.

One of the most important problems of justifying the norms of impacts on soils is the need to take into account local and regional specificities of soils. Nowadays, the development of such standards is at preliminary stage. In this regard, the experience of the staff of the Faculty of Soil Science of the Moscow State University on the development of the scale of ecological rationing (mg / kg) of heavy metals for geochemical association of soils with weakly acidic and acidic reaction (pH 4.0-6.0) is valuable. This scale is presented in the Table 14.

**Table 14. Norms for the content of heavy metals in soils**

Content	Pb	Cd	Zn	Cu
Very small	< 5	< 0.05	< 15	< 5
Small	5—10	0.05—0.10	15—30	5—15
Average	10—35	0.10—0.25	30—70	15—50
Increased	35—70	0.25—0.50	70—100	50—80
Large	70—100	0.50—1.00	100—150	80—100
Very large (corresponds to a low level of contamination)	100—150	1—2	150—200	100—150
Moderate pollution	150—500	2—5	200—500	150—250
High level of pollution	500—1000	5—10	500—1000	250—500
Very high level of pollution	> 1000	10	> 1000	> 500

The indicators are flexible values that take into account the average content of elements in soils, their variability, etc. When establishing the levels of pollution, the authors proceeded from the negative consequences that may arise, and first of all, the effects of pollution on soil, plants and groundwater. The given values of environmental standards are at the heart of projects for reclamation (or restoration of fertility) of soils contaminated with heavy metals.

A special type of pollution is pollution of soils with organic substances. The main property of this type is the ability for biodegradation. These problems will be discussed in detail in the last chapter of our course.

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### Home task

1. Using the soil quality standards of different countries, assess the environmental state of a soil site in your country. Apply the approaches:

- Zc value,
- Single and multiple pollution assessment.

Compare the result with your national soil quality norm. Write a comment.

2. Describe the system of environmental standards of soil quality in your country. What types of environmental norms are implemented? Are they stronger or less strong in comparison with the norms in Finland? In the USA?

3. We told about the main factors determining the soil state and about the problems of application of complex indexes. Please suggest some complex index for the assessment of soil quality, that can improve the result.

*Questions for the self-control*

1. What factors determine the state and the pollution degree of soils?
2. In what groups can be divided soils according to the degree of sensitivity to pollutants?
3. Give a brief characteristic of the classification of substances from the point of view of soil pollution (hazard classes).
4. What are the biologically active substances?
5. What are the chemically active substances?
6. What are the main factors of soil pollution? How can be classified the soils according to their “ability” to accept the contaminants?
7. What are the main factors of the self-purification of soils?
8. How can be determined the grade of soil pollution?
9. What is the complex characteristic of the pollution? How can it be calculated and interpreted?
10. What is the criteria of the ecological-toxicological state?
11. What factors are in the base of the establishing of the target value of the soil pollution?
12. What toxicological indicators are established for the assessment of the state of soils?
13. What soil properties and pollutant characteristics are to be taken into account when justifying the MPCs for soils?
14. What is the problem of application of the general national pollution norms for soils in some region or polluted site?
15. Is it possible to apply the same soil quality norms in different regions? What are your arguments pro and contra?
16. What critical pollution values can be applied instead of MPCs when the national norm is still not established?
17. Describe the classification of the microelements depending on their ability to contaminate soils.
18. What are the main types of degradation of soil?
19. For what cases (Region? Type of soil? Type of land use?) are established the strictest MPC values?
20. What pollution degree can be identified according to the complex index of soil pollution?

## Chapter 5. Waste in the nature management

Each process that occurs in natural and man-made systems leads to the formation of basic and by-products. By-products are most often undesirable, and while they do not interfere, they do not cause concern. It is similar for any kind of human activity: all the processes of using natural resources are associated with waste generation.

Tracing the life cycle of any product or service, it is possible to estimate the quantities and characteristics of the waste that is formed at each of the stages. Modern approaches to environmental management suggest that the amount of waste should be minimal, while the waste itself should be as safe as possible to the environment, or isolated.

For any operations on waste treatment, it is necessary to study its properties. As a result, all wastes - both industrial and municipal (household) are divided into certain groups. These can be classifications based on a variety of properties - a danger to the environment or to humans, the possibility of re-use or processing to obtain a valuable product or energy, belonging to a particular industry, etc.

In this chapter we will get acquainted with the main issues related to waste management: priority approaches to waste management, their classification, the possibilities of rationing waste generation.

### *Types of waste*

Generally, the term “waste” means any residuals of a certain process. According to the US EPA definition (Vocabulary catalog <https://ofmpub.epa.gov/sor-internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=EMS%20Glossary>), waste is any output from the product system that is disposed of. Generally, the web page suggests 754 variants of termini containing the word “waste” – these are different types of waste and terms connected with them.

First of all, it is necessary to divide industrial (of different branches) and municipal (household) waste. The difference between these two types of waste is not only the origin. More important is the composition of waste, hazard and ability to be recycled or reused. To be fair, it should be noted that industrial waste can be very similar to household waste. This is due to the specific nature of some industries and the fact that the production is not only core, but also auxiliary, as well as the "service sector" (fig. 1).

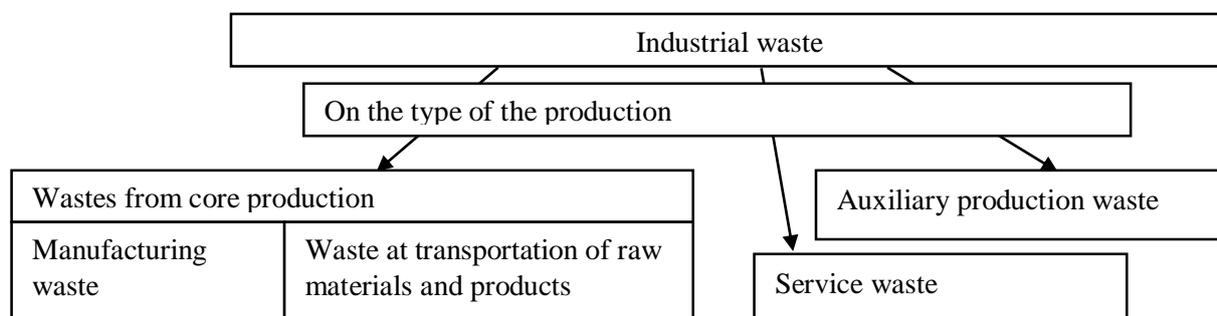


Fig. 1. Types of waste by belonging to the production units

The second important classification includes hazard classes of industrial and municipal waste. These can be classification by threat for the human health and by threat for environmental components. The basic principles of such classification will be presented in the next paragraphs. For example, in Russia, there are 5 hazard classes by the threat for environmental components, from

*extremely dangerous to the non-hazardous.*

Two next special types of waste are to be classified as well. But in this case the classifications are very special. This is about the nuclear waste with different degree of danger and the medicine waste. The last category will be briefly presented later.

Besides, it is possible to classify the waste by the methods of neutralization (thermal, physicochemical, biological...) and by the aggregate state.

### ***Pyramid of the waste management***

Every time each type needs a special treatment procedure and special technologies. The probable reuse will be possible depending on the dangerous properties of waste and on content of useful components (chemical or energy). So, it is necessary to divide the waste into the danger classes. For each class we will apply special accumulation, storage and treatment norms.

Let us remember the main goals of the sustainability. Which of them are connected with waste problem? At first sight, at least half of the goals could be associated with formation of waste:

- Proper health and well-being in the contaminated area are unlikely – traditionally the not-organized waste landfilling is a source of the infections, air and groundwater pollution. In case of incineration of municipal solid waste, there is always a hazard of dangerous emissions.

- Same is true for clean water and sanitation: we can't expect proper water quality if the grounds are polluted.

- Clean energy is generally affordable and not dangerous - it is green indeed, if the waste volume is acceptable. Even the renewables are sources of waste – the remnants of biomass, phased out solar panel elements and other constructions.

However, the rest of the goals are connected with the waste formation problems:

- The authorities should implement a proper regulation and management system for the prevention of pollutions;

- Educational establishments should provide specialists for the regulation of waste treatment and management;

- Zero famine – presumably the issue will be more efficiently addressed when the large landfills are reduced and recultivated for agricultural use.

Therefore, there is always a connection between waste problem and sustainable development goals. Achievement of these goals needs a good foundation – regulations and norms of volume and toxicity of waste, norms for technologies and even for accounting.

One of the most widely used schemes of waste management organization is a waste management pyramid (Fig. 2). It illustrates the most preferable approaches to the minimization of waste volume and to the best way of their use or elimination (Hansen, W., Christopher, M., & Verbuecheln, 2002). The main principles of the waste management was formulated by the *Ecologic, Institute for International and European Environmental Policy* in 2002.

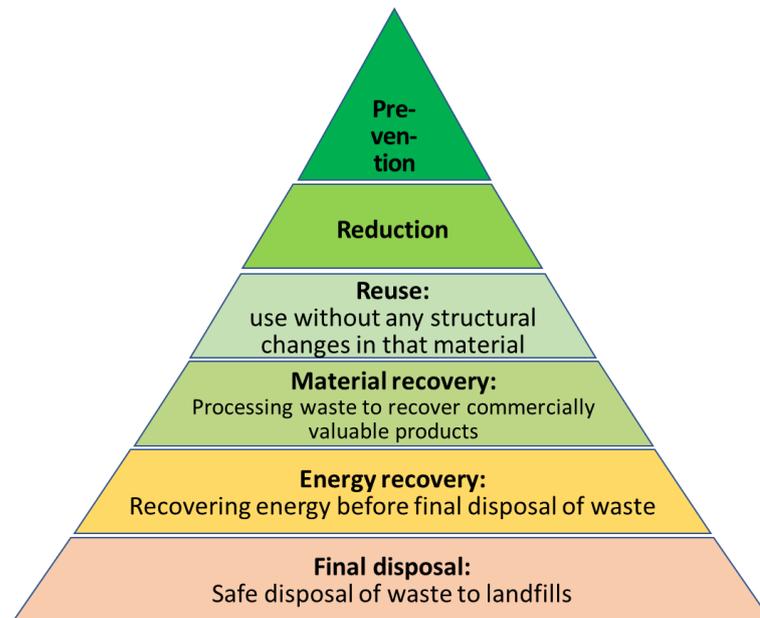


Fig. 2. Waste management hierarchy (By Hansen, W., Christopher, M., & Verbuecheln, 2002)

The general principles of waste management include:

✓ *Precautionary Principle*: when any activity causes a threat/ threats to human health/ environment, precautionary measures should be taken (even if a direct cause and effect relationship has not been scientifically proven.)

✓ *Proximity Principle*: waste should be disposed of in immediate proximity to where it is produced.

✓ *Polluter-Pays/Producer Responsibility Principle*: physical or financial responsibility for the entire lifecycle of the product and its packaging.

Among the waste management approaches the most preferable one is prevention. It is followed by reduction, reuse, material and energy recovery and final disposal.

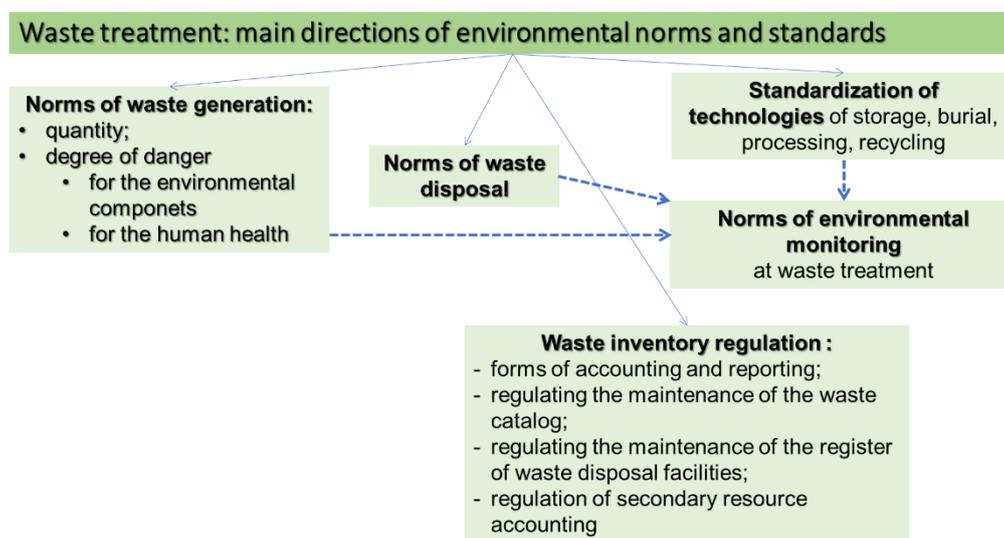
Only few countries have quite well-organized system of waste management. Generally, the smaller territory a country has, the more attention is paid to addressing this issue. Of course, one of the main factors is economy: modern waste treatment technologies are expensive. They need a developed infrastructure, modern equipment, efficient specialists. In addition, the environmental requirements are strong enough. It leads to the necessity of not only waste treatment by itself. Apart from that, the organization of an efficient environmental monitoring system is to be implemented. According to the modern environmental standards, it is not always possible to use inefficient equipment. One of the examples - the case of medical incinerators in the US: when some especially dangerous pollutants (PAH) were found in their emissions, the incinerators were shut down for few months for recalibration purposes. This equipment completely burns the resulting emissions only at sufficiently high temperatures. At an insufficient temperature, emissions of dangerous carcinogens (PAHs, dioxins, etc.) are possible.

One of the most well-known problems connected with waste landfills is generation of methane. Except the danger for biological species, generation of methane contributes to the greenhouse gases problem. Currently we speak about a significant input of the waste methane into the greenhouse gases emissions. Globally it comprises to more than 350 million tones every year. According to the data of United Nations Framework Convention on Climate Change in the developed countries the waste treatment sector gives up to 8 % of total emissions. This is another reason to minimize the amount of waste on the landfills and to consider different waste treatment methods.

Another problem is intensive groundwater pollution in case of destruction of the landfill construction (conc. the officially organized landfill as a complex technical structure). In reality, some old landfills are just areas where 50 or more years ago various waste was stored. Results of chemical analyses of such wastewater and polluted groundwater can be found in a lot of studies. Generally, the main pollutants are organic substances, heavy metals and their compounds, bacterial pollutants. Concentrations of these substances are many times higher than it is allowed by MPC for any water-use category.

### *Environmental norms and regulations for the waste management*

As you see, there are some types of activities to be controlled while handling waste. Generally, the standards should be introduced for each stage of the formation of waste, its collection, storage, sorting, recycling, transportation, landfilling or incineration etc. Besides, the regulations on the environmental monitoring are necessary (Fig. 3).



*Fig. 3. Main directions of standardization in waste management*

Systems of standardization and regulation in waste management in the countries of the world can differ significantly. We speak about dramatically different norms of toxicity for some substances measured in water or in air. But these are the main grounds for justification of norms of waste generation and accumulation. In addition, the consumption “mode” in the country depends on the domestic traditions and modern trends, on season and region. As a result, the composition of waste is different. So, if we have more food waste (in %) in a southern country, it doesn’t translate into people eating less in the northern regions. The reason of such difference is probably that in the North some clothing waste adds up. Another difference is in the package: amounts of paper, plastics, cartons in advanced economies can be few times higher than in poorer countries.

As for the industrial waste it is always a specificity depending on the type of industry, type (and age!) of the production technology, characteristics of raw materials, organization of transport.

Amounts of waste produced in the world are presented in the table 1.

**Table 1. Current Waste Generation Per Capita by Region (World Bank, Urban Development Series – Knowledge Papers)\***

Region	Waste generation per capita (kg/capita * day)		
	Lower boundary	Upper boundary	Average
SUB-SAHARAN Africa: 62 million tons of solid waste per year	0.09	3.0	0.65
East Asia and the Pacific Region: 270 million tons of solid waste per year	0.44	4.3	0.95
Eastern and Central Asia 93 million tons of solid waste per year	0.29	2.1	1.1
Latin America and the Caribbean: 160 million tons of solid waste per year	0.11	5.5	1.1
Middle East and North Africa: 63 million tons per year	0.16	5.7	1.1
OECD countries: 572 million tons of solid waste per year	1.1	3.7	2.2
South Asia 70 million tons of solid waste per year	0.12	5.1	0.45

\* <https://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap3.pdf>

These numbers probably can form not only a general picture of the waste formation in some regions of the world. It is important that the relatively rich countries (OECD-members) produce the highest values of waste per capita. And at the same time probably these countries have the best access to the efficient technologies for waste treatment.

### ***Waste as the “secondary resource”: recycling and “waste to energy” technologies***

The “secondary resources” are not materials only. The possibility to use some material depends on its availability, environmental and economical characteristics of the extraction technology. As examples of good praxis of reuse, we can remember the production of non-ferrous metals. Currently in the world most copper is extracted from copper sulphides from large quarries, which contain between 0.4% and 1.0% copper. Imagine, the remaining rock residue (99% and more) is the waste! In 2015 globally 22848 tons of the “primary” copper was produced – it is possible to calculate the amount of waste. In this case one of the “sources” of minimization of environmental pressure is to use the “secondary” copper. For example, currently in Russia 20-22% of produced copper is secondary. More details can be found in the Report on best available techniques (BAT) in copper production (it is presented in the references list).

### ***Dangerous waste recycling***

Is it possible to find the universal technologies for waste treatment? This depends on the composition of waste. In case of the industrial waste it is necessary to take into account its toxic and dangerous components, so, using the example of chemical industry we can see some most significant components of waste (Table 2).

**Table 2. The main types of solid and slurry-like toxic industrial wastes subject to neutralization at special facilities (chemical industry)**

Chemical industry	
Chlorine industry	
Graphite sludge (production of synthetic rubber, chlorine, caustic)	Mercury
Methanol (Plexiglass production waste)	Methanol
Sludge production of monochloroacetic acid salts	Hexachloro, methanol, trichlorobenzene
Paper bags	Zineb
Sludge production (copper trichlorophenolate)	Trichlorophenol
Spent catalysts of plast polymers	Benzene, dichloroethane
Production of chromium compounds	
Sludge (production of monochromate sodium, sodium chloride (production of potassium dichromate)	Hexavalent chromium
Soda industry	
Zinc debris	Zinc
Production of artificial fibers	
Sludges, filtrate waste of caprolactam and methanolysis plants	Dimethyl phthalate, zinc, copper, caprolactam, methanol
Paint and varnish industry	
Films of varnishes and enamels, slimes	Zn, Cr, solvents, oxidized oils, Mn

Well, we understood that recycling is technically and environmentally possible and economically efficient. How do we organize the process? For example, we can look at the EPA experience – the case of hazardous waste.

First of all, it is accepted, that the hazardous wastes do not cease to be dangerous simply because they are being reused, recycled, or reclaimed. Many hazardous waste recycling operations may pose serious health and environmental hazards. They should be regulated by legislation. EPA try to encourage recycling to protect human health and the environment. For this purpose, the agency tailored the level of regulation to reflect the actual hazard of the recycling activity. The recycling standards range from full specialized standards regulation to exemptions from regulation.

After the recycling, some materials are excluded from the hazardous waste regulation: industrial ethyl alcohol, scrap metal, waste-derived fuels from refining processes, unrefined waste-derived fuels and oils from petroleum refineries.

Other materials become a subject to alternative regulatory control when recycled: universal waste, used oil, recyclable materials used in a manner constituting disposal, materials utilized for precious metal recovery, spent lead-acid batteries being reclaimed, hazardous waste burned in boilers and industrial furnaces.

The remaining part of recycled hazardous waste is the subject to full hazardous waste regulation.

**If we decided to recycle**, how high is generally the rate of the recyclable waste? Of course,

the rate varies. For the industrial waste this can be a very high percent (secondary metals for example). For some types of medical waste, the recycling is absolutely impossible because of their danger. And in case of the municipal solid waste the recyclable rate varies depending on:

- region and country;
- season;
- time.

If we compare the composition of municipal solid waste in some countries of the world currently and 30 years ago, it is possible to find significant difference. So, for some Asian countries the composition of waste is presented on the following slide (Table 3).

**Table 3. Composition of MSW in countries and selected cities\***

Country/location	Generation rate	Organic	Paper	Plastic	Glass	Metal	Other	Source
	(kg/cap.day)	(%)	(%)	(%)	(%)	(%)	(%)	
Average low income	0.6	64	5	8	3	3	17	Hoornweg and Bhada-Tata (2012)
Average lower middle income	0.79	59	9	12	3	2	15	Hoornweg and Bhada-Tata (2012)
Average upper middle income	1.2	54	14	11	5	3	13	Hoornweg and Bhada-Tata (2012)
High income	2.1	28	31	11	7	6	17	Hoornweg and Bhada-Tata (2012)
Bangkok, Thailand	1.57	50	11.3	22.5	2.7	1.7	12	BMA (2012)
Delhi, India	0.5	38.6	5.6	6	1	0.2	49	Talyan et al. (2008)
Beijing, China	0.85	63.4	11.1	12.7	1.8	0.3	11	Zhen-shan et al. (2009)

\* Pharino, C. (2017). Challenges for Sustainable Solid Waste Management: Lessons from Thailand. Springer

To show the difference, let us consider some common data about the variations of amounts of municipal solid waste in the regions of Russia (Tables 4, 5).

**Table 4. Morphological composition of solid waste for different climatic zones, % by mass**

Component	Climatic zone		
	Middle	South	North
Food waste	35...45	40...49	32...39
Paper, cardboard	32...35	22...30	26...35
Wood	1...2	1...2	2...5
Black scrap metal	3...4	2...3	3...4
Non-ferrous scrap metal	0.5...1.5	0.5...1.5	0.5...1.5
Textile	3...5	3...5	4...6
Bones	1...2	1...2	1...2
Glass	2...3	2...3	4...6
Leather, rubber	0.5...1	1	2...3
Stones, plaster	0.5...1	1	1...3
Plastic	3...4	3...6	3...4
Others	1...2	3...4	1...2
Fine fraction (less than 15 mm)	5...7	6...8	4...6

**Table 5. Approximate rates of solid waste accumulation**

Classification of housing stock	MSW accumulation rate per capita		Average density kg/m <sup>3</sup>
	kg/year	m <sup>3</sup> /year	
Residential houses, well-organized: at the selection of food waste	180...200	0.9...1.0	190...200
without selection of food waste	210...225	1.0...1.1	200...220
Residential houses, well-organized: without selection of food waste	350...450	1.2...1.5	300
Liquid waste from impenetrable caches of uncanalized houses	-	2.0...3.25	1000
The general norm of SDW accumulation for comfortable residential and public buildings for cities with a population of more than 100 thousand people	260...280	1.4...1.5	190
The same, taking into account all tenants	280...300	1.5...1.55	200

The main purpose of such statistics is to justify the waste management scheme: capacity of waste treatment enterprises, necessary transport costs, waste landfill capacity etc.

Generally, this should be accepted in waste management schemes in Russia, currently only up to 10% of all waste amount can be collected and recycled. This is an economically efficient value although technically this rate is much higher. So, using the shown norms, it is possible to calculate the characteristics of the waste treatment facilities.

### *Waste – to - energy*

Let us remember the waste management pyramid. If we could not prevent or minimize or reuse or recycle – nothing can be done. The next step is burning. And this way of waste treatment is popular enough in the world. The amount of burned waste varies in some countries up to 90%. The leaders are Japan (69% in 2015) and in Europe - Switzerland, Sweden, Denmark, France, Luxembourg, Norway.

Generally, the thermal waste treatment technologies are divided into 4 types:

- Incineration (after sorting), without segregation of useful/ recyclable components;
- Incineration without sorting; without segregation of recyclable materials, with the ferrous metals being extracted from furnace bottom ash by magnets;
- Gasification, high temperature MSW processing without the oxygen and light. The organic waste breaks down through time producing a gas that can be used to run a gas turbine/engine driving an electric generator;
- Incineration - Energy from Waste (**EfW**). All new plants are required by law to incorporate some form of EfW system through using the produced heat to run a waste heat boiler or a district/community heating system.

Regardless of the type of the technology, at the incineration it is necessary to control the emissions of the pollutants. The main danger of the incinerators are emissions of the supertoxic compounds like dioxins and polycyclic aromatic hydrocarbons. These substances are always in the spotlight of the studies on environmental risks of incineration.

Some emission norms of such pollutants are shown in the Tables 6 and 7. The amounts presented in the tables are not the norms or requirements. These are technical characteristics. But these characteristics of the emissions allow to maintain a safe level of air quality. This is an example of technological norms. The document containing these norms is devoted to the best available techniques of incineration.

**Table 6. Thermal waste treatment technologies: emission norms**

Components	Units	Incineration plants for		
		Municipal waste	Hazardous waste	Industrial sewage sludge (fluidised bed)
Dust	mg/Nm <sup>3</sup>	1000 – 5000	1000 – 10000	30000 – 200000
Carbon monoxide (CO)	mg/Nm <sup>3</sup>	5 – 50	<30	5 – 50
TOC	mg/Nm <sup>3</sup>	1 – 10	1 – 10	1 – 10
PCDD/PCDF	ngTEQ/ Nm <sup>3</sup>	0.5 – 10	0.5 – 10	0.1 – 10
Mercury	mg/Nm <sup>3</sup>	0.05 – 0.5	0.05 – 3	0.2
Cadmium + thallium	mg/Nm <sup>3</sup>	<3	<5	2.5
Other heavy metals (Pb, Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn)	mg/Nm <sup>3</sup>	<50	<100	800
Inorganic chlorine compounds (as HCl)	mg/Nm <sup>3</sup>	500– 2000	3000 – 100000	
Inorganic fluorine compounds (as HF)	mg/Nm <sup>2</sup>	5 – 20	50 – 550	
Sulphur compounds, total of SO <sub>2</sub> /SO <sub>3</sub> , counted as SO <sub>2</sub>	mg/Nm <sup>3</sup>	200 – 1000	1500 – 50000	
Nitrogen oxides, counted as NO <sub>2</sub>	mg/Nm <sup>3</sup>	250 – 500	100 – 1500	<200
Nitrous oxide	mg/Nm <sup>3</sup>	<40	<20	10 – 150
CO <sub>2</sub>	%	5 – 10	5 – 8	
Water steam (H <sub>2</sub> O)	%	10 – 20	6 – 20	
Notes:				
1. Sewage sludge plants are those for the incineration of industrial sewage sludge				
2. The information in this table refers to German plants. The values seen at older plants can be considerably higher, especially in the case of emissions influenced by furnace-technical parameters e.g. CO, TOC, etc.				
3. Hazardous waste values refer to mixed HW merchant plants rather than dedicated stream plants.				

Table 7. Some “products” of MSW incineration

Substance	Cleaned flue-gas discharge	ESP dust	Waste water	Filter cake from waste water treatment	Bottom ash <sup>2,3</sup>
Carbon %	98 (+/-2)	<1	<1	<1	1.5 (+/-0.2)
Chlorine %	<1	35	54	<1	11
Fluorine %	<1	15 (+/-1)	<1	<1	84 (+/-1)
Sulphur %	<1	38 (+/-6)	8 (+/-1)	6 (+/-1)	47 (+/-7)
Phosphor %	<1	17 (+/-1)	<1	<1	83 (+/-1)
Iron <sup>1</sup> %	<1	1 (+/-0.5)	<1	<1	18 (+/-2)
Copper %	<1	6 (+/-1)	<1	<1	94 (+/-1)
Lead %	<1	28 (+/-5)	<1	<1	72 (+/-5)
Zinc %	<1	54 (+/-3)	<1	<1	46 (+/-3)
Cadmium %	<1	90 (+/-2)	<1	<1	9 (+/-1)
Mercury %	<1	30 (+/-3)	<1	65 (+/-5)	5 (+/-1)

Note:

1. the remaining approx. 80 % are sorted out as scrap
2. the bio-availability of materials that remain in the bottom ash depends on leachability in-situ during subsequent use/disposal
3. the risk associated with the re-use of bottom ash is not necessarily indicated by the presence or absence of the substances indicated – the chemical and physical form of the substance as well as the nature of the environment where the material will be used is also important. [64, TWGComments, 2003]

When selecting the best technology for the incineration, one of the important moments is greenhouse gases emission. In fairness, it is worth saying that here we choose the lesser evil: either greenhouse gas emissions at the landfill, or emissions from the incinerator (Table 8).

Table 8. Total emissions relevant to climate change in Germany in the year 1999 compared with those arising from waste incineration\*

Pollutants in 1999	Total emissions (kt/yr)	Global warming potential (GWP) CO <sub>2</sub> equivalents (kt/yr)	Waste incineration (fossil portion) of the total emissions (kt/yr)
Carbon dioxide (CO <sub>2</sub> )	858511	858511	8685
Nitrous oxide (N <sub>2</sub> O)	141	43710	0.81 (252)*
Methane (CH <sub>4</sub> )	3271	68691	n/a
Fluorinated hydrocarbons	3284	4290	
CF <sub>4</sub> (perfluorinated hydrocarbons)	0.186	1209	
C <sub>2</sub> F <sub>6</sub> (perfluorinated hydrocarbons)	0.046	423	
C <sub>3</sub> F <sub>8</sub> (perfluorinated hydrocarbons)	0.011	77	
SF <sub>6</sub> (sulphur hexafluoride)	0.229	5473	
<b>Total GWP</b>		<b>982384</b>	<b>(c. 9000)*</b>
<b>Indirectly effective greenhouse gases</b>			
Nitrogen oxide (NO <sub>x</sub> as NO <sub>2</sub> )	1637		15.2 (122.24)*
Carbon monoxide (CO)	4952		3.82 (11.46)*
NM VOC (non-methane volatile organic compound)	1651		0.76 (8.36)*
Ammonia (NH <sub>3</sub> )	624		0.3
<b>Aerosol formers</b>			
Sulphur dioxide SO <sub>2</sub>	831		n/a
(..)* in brackets: the converted emission value in CO <sub>2</sub> equivalents for comparison with the GWP			

\* UBA (2001). "Draft of a German Report for the creation of a BREF-document "waste incineration", Umweltbundesamt

So, selecting the incineration technology, among the negative effects it is necessary to consider:

- the composition and amount of pollutants – unperfect technologies provide the emissions of the supertoxic compounds like chlorine-organic and polyaromatic substances;
- the amount of the greenhouse gases.

The positive effects are:

- of course, reduction of the polluted area if the alternative was a landfilling;
- prevention of all negative consequences of landfilling (organized or not);
- production of energy.

Nowadays there exist the praxis of the waste-to-energy schemes in Japan (nearly 200 plants), European countries (nearly 200), Asia and USA.

### *Norms for the assessment of the waste danger*

First let us determine, what the dangerous or hazardous waste is. To be considered as dangerous or hazardous waste it must contain toxic substances or radionuclides or be sources of infections.

According to US EPA (<https://www.epa.gov/hw/learn-basics-hazardous-waste>), this “is a waste with properties that make it dangerous or capable of having a harmful effect on human health or the environment. Hazardous waste is generated from many sources, ranging from industrial manufacturing process wastes to batteries and may come in many forms, including liquids, solids gases, and sludges”. Officially, solid waste is recognized as “hazardous waste” if it is specifically listed as a known hazardous waste or meets the characteristics of a hazardous waste.

Listed wastes are wastes from common manufacturing and industrial processes, specific industries. They can be generated from discarded commercial products. There are the following lists in US EPA classification (<https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes#FandK>):

- ❑ *The F-list:* wastes from common manufacturing and industrial processes as hazardous. The processes generating these wastes can occur in different sectors of industry, thus such wastes are known as wastes from non-specific sources. There are 7 groups depending on the type of manufacturing or industrial operation: spent solvent wastes, electroplating and other metal finishing wastes, dioxin-bearing wastes, chlorinated aliphatic hydrocarbons production, wood preserving wastes, petroleum refinery wastewater treatment sludges, and multisource leachate.
- ❑ *The K-list:* hazardous wastes from specific sectors of industry and manufacturing are considered source-specific wastes. These wastes must fit into one of the 13 categories on the list and the waste must match one of the detailed K list waste descriptions in the regulation 40 CFR section 261.32.
- ❑ *The P-list:* acute hazardous wastes from discarded commercial chemical products (40 CFR section 261.33).
- ❑ *The U-list:* hazardous wastes from discarded commercial chemical products (40 CFR section 261.33).

Characteristic wastes are wastes that exhibit any one or more of the following characteristic

properties: ignitability, corrosivity, reactivity or toxicity.

An example of another approach to the classification can be found in Russian praxis: the production and consumption waste includes the following classes:

- in 4 classes by danger for the human health (from 1<sup>st</sup>, the \ most dangerous, to 4<sup>th</sup>, practically safe,
- and in 5 classes by danger for the environment (the 1<sup>st</sup> one is the most dangerous).

The principles of classification by environmental danger are indicated in Table 9.

**Table 9. Waste hazard classes in accordance with the Federal classification catalog of waste (Russia)**

Degree of harmful impact of hazardous waste on the environment	Criteria for classifying hazardous wastes as hazardous to the environment	Hazard class of waste for the environment
Very high	The ecological system is irreversibly broken. Recovery period is absent	<b>I</b> Class - extremely dangerous
High	The ecological system is severely disrupted. The recovery period is not less than 30 years after the complete elimination of the source of harmful effects	<b>II</b> Class - highly hazardous
Moderate	The ecological system is damaged. The recovery period is not less than 10 years after the reduction of the harmful effect from the existing source	<b>III</b> Class - moderately hazardous
Low	The ecological system is damaged. Self-healing period of at least three years	<b>IV</b> Class - low-risk
Very low	The ecological system is practically not affected	<b>V</b> Class - almost harmless

When defining the hazard class by the danger for human health we take into account the presence of toxic substances:

- 1st class - extremely hazardous substances (wastes containing mercury, mercury lamps, ...);
- 2nd class - highly hazardous waste (sulfuric acid, spent oil, ...);
- 3rd class - moderately dangerous (rags, oily overalls, ...);
- 4th class - low-risk (scrap of abrasive materials, scrap of ferrous and non-ferrous metals, waste tires, paper and metal containers with toxic residues, solid household waste, ...).

The hazard class of some type of waste can be calculated or determined in an experiment. For example, according to the Russian praxis, for calculation of hazard class we need a very detailed information about the chemical composition of waste.

Classification of waste to the environmental hazard class by the calculation method is carried out on the basis of indicator  $K$ , which characterizes the degree of waste hazard. Indicator  $K$  is calculated by the sum of the environmental hazard of the waste substances (waste components)  $K_i$ . The list of waste components and their quantitative content are established by the composition of the feedstock and the technological processes of its processing or by the results of quantitative chemical analysis.

The indicator  $K_i$  is calculated as the ratio of concentrations of waste components  $C_i$  with its hazard rate for the  $W_i$  environment. The coefficient of the degree of danger of the waste component for the environment is a conditional indicator numerically equal to the number of the waste component, below the value of which it does not have negative effects on the environment. The dimension of the coefficient is conditionally accepted as mg/kg.

In order to determine the degree of hazard of the waste component for the environment, for each waste component, the degrees of hazard are determined for different natural environments (Table 10)

**Table 10. Hazard indicators for waste components**

The primary indicators of the risk component of the waste	The degree of hazard of the waste component to the environment for each waste component			
	1	2	3	4
MPCsoil (or similar value), mg/ kg	< 1	1—10	10,1—100	> 100
The hazard class in the soil	1	2	3	Is not set
MPCwater (or similar value), mg/ l	< 0.01	0.01—0.1	0.11—1	> 1
Class of hazard (drinking water use)	1	2	3	4
MPCwater fishery (or similar value), mg/ l	< 0.001	0.001—0.1	0.011—0.1	> 0.1
Class of hazard (fishery water use)	1	2	3	4
MPCday aver (MPCmax one time, or similar value), mg/m <sup>3</sup>	< 0.01	0.01—0,1	0.11—1	> 1
Class of hazard	1	2	3	4
MPC (maximum permissible level, maximum allowable content), mg/ kg	< 0.01	0.01—1	1.1—10	> 10
lg S (mg/l)/ MPCwater (mg/l)**	> 5	5—2	1.9—1	< 1
lg (C <sub>sat</sub> , mg/m <sup>3</sup> / MPCwork area )	> 5	5—2	1.9—1	< 1
lg (C <sub>sat</sub> , mg/m <sup>3</sup> / MPCday aver or MPCmax one time )	> 7	7—3.9	3.8—1,6	< 1.6
lg Kow (octanol / water)	> 4	4—2	1.9—0	< 0
LD50, mg/kg	< 15	15—150	151—5000	> 5000
LC50, mg/m <sup>3</sup>	< 500	500—5000	5001—50 000	> 50 000
LC50 (water), mg/l 96 hours	< 1	1—5	5.1—100	> 100
BOD5 / COD100%	< 0.1	0.01—1.0	1.0—10	> 10
Persistence (transformation in the environment)	The formation of more toxic products, including those with long-term effects or new properties	Formation of products with a more pronounced influence of other hazard criteria	The formation of products, the toxicity of which is close to the toxicity of the initial substance	Formation of less toxic products
Bioaccumulation (behavior in the food chain)	Expressed accumulation in all links	Accumulation in several parts	Accumulation in one of the links	No accumulation

*In the table:*  $\lg S$  - logarithm of solubility of the component of waste (substance) in water at 20 °C;  $\lg C_{\text{sat}}$  - logarithm of the saturation concentration of the substance in the air at 20 °C and normal pressure

The list of indicators used to calculate  $W_i$ , includes an information support indicator to take into account the lack of information on primary indicators of the degree of hazard components of waste for the environment. The information support index is calculated by dividing the number of established indicators by 12 ( $N$  is the number of the most significant primary hazard indicators of waste components for the environment).

- at a ratio of  $n / N < 0.5$  ( $n < 6$ ) - 1 point;
- at a ratio of  $n / N 0.5-0.7$  ( $n = 6-8$ ) - 2 points;
- at a ratio of  $n / N 0.71-0.9$  ( $n = 9-10$ ) - 3 points.

According to the established hazard levels of waste components for the environment in different natural environments, the relative hazard parameter of the waste component for the environment ( $X_i$ ) is calculated by dividing the sum of scores by all parameters by the number of these parameters.

$$\begin{aligned} \lg W_i &= 4 - 4/Z_i; & \text{for } 1 < Z_i < 2 \\ \lg W_i &= Z_i; & \text{for } 2 < Z_i < 4 \\ \lg W_i &= 2 + 4/(6 - Z_i), & \text{for } 4 < Z_i < 5 \end{aligned}$$

where  $Z_i = 4X_i / 3 - 1/3$ .

The hazard level indicator of the waste component  $K_i$  is calculated by the formula

$$K_i = C_i / W_i,$$

where  $C_i$  is the concentration of the  $i$ -th component in the hazardous waste (mg / kg waste);  $W_i$  - hazard ratio of the  $i$ -th component of hazardous waste, mg / kg.

The indicator of the degree of danger of waste  $K$  is calculated by the following formula:

$$K = K_1 + K_2 + \dots + K_m,$$

Waste components consisting of such chemical elements as O, N, C, P, S, Si, Al, Fe, Na, K, Ca, Mg, Ti, in concentrations not exceeding their content in the main soil types refer to practically non-dangerous components with an average score of  $X_i$  of 4, and therefore a coefficient of environmental hazard  $W_i$  of  $10^6$ .

Components of organic waste products, consisting of compounds such as carbohydrates (fiber, starch and others), proteins, nitrogen-containing organic compounds (amino acids, amides, etc.), i.e. substances found in wildlife belong to a class of practically non-hazardous components with an average score of  $X_i$  of 4, and therefore a coefficient of environmental hazard  $W_i$  of  $10^6$ .

For the remaining components of the waste, the hazard indicator for the environment is calculated and correlated with the Table 11.

Table 11. Hazardous waste classification

Hazardous class	Degree of risk of waste (K)
I	$10^6 \geq K > 10^4$
II	$10^4 \geq K > 10^3$
III	$10^3 \geq K > 10^2$
IV	$10^2 \geq K > 10$
V	$K = 10$

The experimental method of classifying waste as a hazard class is carried out in specialized laboratories accredited for this purpose. The experimental method is based on biotesting the aqueous extract of waste.

The experimental method is used in the following cases:

- to confirm the assignment of waste to the V hazard class established by the calculation method;
- when classified as hazardous waste, in which it is impossible to determine their qualitative and quantitative composition;
- at specification, will and expense of the interested party of the dangerous waste class designated according to experimental or settlement method.

For medical waste another classification should be applied. It is necessary to take into account the biological risks. According to the existing definition, the term “medical waste” covers all wastes produced in health-care or diagnostic activities. Generally, 75 % to 90 % of hospital wastes are similar to household or municipal waste and do not entail any particular hazard. But the remaining part needs special treatment approaches. The main categories could be shown in the following table (Table 10).

**Table 12. Classification of hazardous medical waste according to the types of risk\***

Nr.	Category of waste	Sub-group of waste
1	Sharps	Waste entailing risk of injury.
2	a. Waste entailing risk of contamination	Waste containing blood, secretions or excreta entailing a risk of contamination.
	b. Anatomical waste	Body parts, tissue entailing a risk of contamination
	c. Infectious waste	Waste containing large quantities of material, substances or cultures entailing the risk of propagating infectious agents (cultures of infectious agents, waste from infectious patients placed in isolation wards).
3	a. Pharmaceutical waste	Spilled/unused medicines, expired drugs and used medication receptacles
	b. Cytotoxic waste	Expired or leftover cytotoxic drugs, equipment contaminated with cytotoxic substances
	c. Waste containing heavy metals	Batteries, mercury waste (broken thermometers or manometers, fluorescent or compact fluorescent light tubes)
	d. Chemical waste	Waste containing chemical substances: leftover laboratory solvents, disinfectants, photographic developers and fixers
4	Pressurized containers	Gas cylinders, aerosol cans
5	Radioactive waste	Waste containing radioactive substances: radionuclides used in laboratories or nuclear medicine, urine or excreta of patients treated

\* Medical waste management (2011) International Committee of the Red Cross.

The degree of the hazard depends on the presence of relevant risk sources. In Russian praxis, as example, the classification of 5 classes is accepted (Table 11).

**Table 13. Medical and biological waste (According to sanitary standard SanPiN 2.1.7.2790-10 – on the degree of epidemiological, toxicological and radiation hazard)**

Hazard Class	Characteristic of the morphological composition
Class A (epidemiologically safe waste, in composition approximate to MSW)	Wastes that do not have contact with biol. patient fluids, infectious patients. Stationery, packaging, furniture, inventory, lost consumer properties, swept rubbish from the cleaning of the territory ... Food waste from the central food units, as well as all the units of the organization that carries out medical and / or pharmaceutical activities, except for infectious diseases, including phthisiatric.
Class B (epidemiologically hazardous waste)	Infected and potentially infected waste. Materials and instruments, objects contaminated with blood and / or other biol. liquids. Pathologoanatomical waste. Organic operating waste (organs, tissues ...). Food waste from infectious diseases. Wastes from microbiological, clinical and diagnostic laboratories, pharmaceutical, immunobiological production, working with microorganisms of 3-4 groups of pathogenicity. Biological wastes of vivaria. Live vaccines unsuitable for use.
Class C (extremely epidemiologically hazardous waste)	Materials contacting patients with infectious diseases that can lead to emergencies in the field of sanitary and epidemiological welfare of the population and require the implementation of measures for the sanitary protection of the territory. Waste from laboratories, pharmaceutical and immunobiological production, working with microorganisms of 1-2 pathogenicity groups. Waste of medical diagnostic units of ospitals (dispensaries), contaminated with sputum of patients, waste from microbiological laboratories carrying out work with pathogens of tuberculosis.
Class D (toxicologically hazardous waste 1-4 hazard classes)	Medicinal (including cytostatics), diagnostic, disinfectants, not usable. Mercury containing objects, devices and equipment. Waste of raw materials and products of pharmaceutical production. Waste from the operation of equipment, transport, lighting systems and others.
Class E Radioactive waste	All types of waste, in any aggregate state, in which the content of radionuclides exceeds the permissible levels established by the radiation safety standards

In this case the classification is more complicated and is based on the set of characteristics: epidemiological risk, toxicological risk, radioactivity.

As you see, the medical wastes are a very special type of waste. Their main dangerous property is the probable biological risk. That is why some categories of medical waste cannot be just landfilled. In these cases, the special treatment technologies are required.

### *Norms of the waste generation*

When developing the projects of the waste treatment it is necessary to have enough precise calculations of the waste amounts. In the countries with organized waste management infrastructure different schemes and approaches to the regulation of waste generation can be developed.

For example, in the former USSR republics such system accounts more than 30 years history. Currently to have a legal right to the waste generation and storage (accumulation) we need to develop the special Projects on norms of waste generation and storage limits. Such projects are necessary for:

- definition (calculation) of annual standards of waste generation;
- determination (calculation), on the basis of standards for waste generation and the volume of output (services provided, work performed), of the amount of waste generated annually;
- justification of the amount of waste offered for use and (or) neutralization;

- justification of the amount of waste offered for placement in a certain way for a specified period in specific waste disposal sites, taking into account the ecological situation in the territory.

Depending on the presence of initial data and specificity of the production processes we apply different methods for determining waste generation standards:

- method of calculation using the material and raw material balance;
- method of calculation according to specific industry (branch) standards for waste generation;
- calculation and analytical method;
- experimental method;
- method of calculation by actual volumes of waste generation (statistical method).

The listed methods are not perfect: some of them needs too detailed data. The others are not accurate enough, are too general and do not consider the specificity of the considered process. The choice of the method depends on the situation. As example of the calculation method let us show the materials and row balance method (Fig. 4).

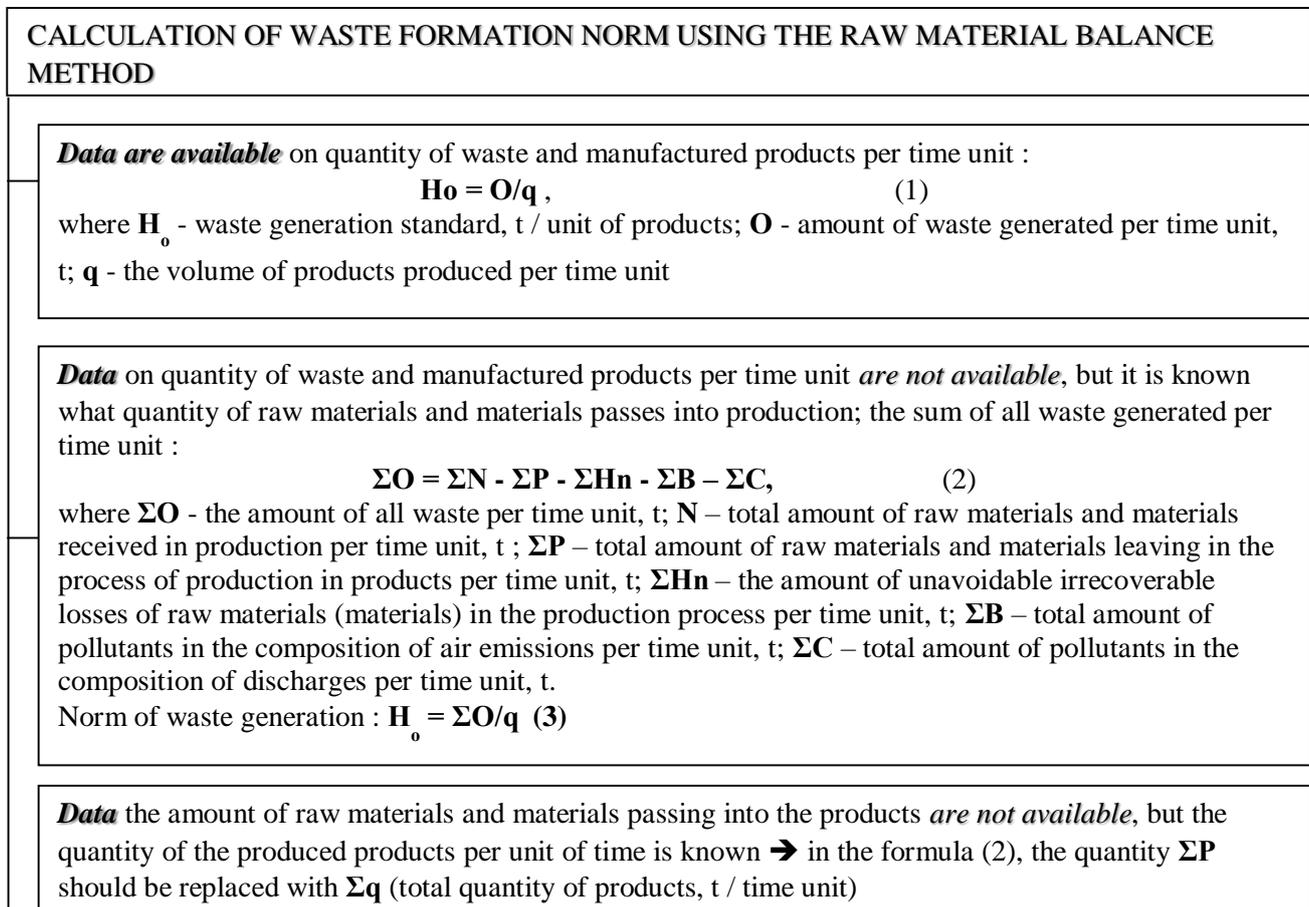


Fig. 4. Calculation of waste formation norm: the raw material balance method.

The method is one of the most precise, but requires proper initial data.

Another approach is the *calculation using the specific industry waste generation standards*.

The method is based on the use of reference tables of specific standards (norms) for waste generation by industry or industry specific waste generation standards. Specific industry standards for waste generation are developed:

- averaging individual values of waste generation standards for industry organizations;
- by calculating the average specific indicators based on the analysis of reporting information

for a certain (basic) period, identifying the most important (expertly established) factors and determining their impact on the value of standards for the planned period.

The *calculation and analytical method* is used in the presence of design and technological documentation (process maps, formulations, regulations, working drawings) for the production of goods that generate waste. In accordance with the established norms for the consumption of raw materials, the waste generation standard is calculated.

The *experimental method* is applied to technological processes that allow a certain range of changes in the constituent elements of raw materials (in foundry, chemical, food, microbiological and other industries), and also in the case of great complexity of analytical calculations. It consists of determining the norms of waste generation on the basis of conducting experimental measurements in production conditions.

The method of calculating the norms for the actual volumes of waste generation (*statistical method*) is used to determine waste generation standards based on the statistical processing of information on waste management for a basic (no less than three years) period.

### *Norms of waste disposal*

According to modern approaches to waste management, producers and importers of goods are obliged to ensure the disposal of waste from the use of these goods in accordance with the relevant norms. The list of goods (including packaging) to be disposed of after the loss of their consumer properties is established by the government.

The norm of waste utilization from the use of goods is the ratio of the quantity of goods of a certain type, their packaging, sold to legal entities or individuals expressed as a percentage, which must be disposed of after the loss of consumer properties, to the total quantity of goods.

The standards for recycling are met by the manufacturer (importer) or specialized organizations themselves. Manufacturers, importers of goods that do not provide for the independent utilization of waste from the use of goods, pay an *environmental fee*.

The standards are set taking into account the economic conditions, the potential hazard of waste to human health and the environment, as well as the technological possibility of their disposal. The standards should be reviewed every three years.

Legislation supports the secondary use of materials: if the packaging of the goods to be recycled is made from recycled materials, then the reduction factor is applied to the utilization standard.

Economic incentives are seen as an effective measure of the impact on nature users. When regulating activities in the field of waste management, economic regulation may include:

- reducing the amount of payment for negative impact on the environment when disposing of waste, when environmental users introduce technologies that reduce the amount of waste;
- application of accelerated depreciation of fixed assets related to the implementation of activities in the field of waste management.

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### *Home task*

1. Describe the system of waste classification in your country. What composition does municipal solid waste have in one of the 3 cities in your country. Write a comment: the main components, their toxicity, most efficient technologies for the waste treatment.
2. Describe the system of environmental standards for waste landfilling in your country. What types of environmental norms are implemented? Are they more or less tight in comparison with the WHO norms? With EU norms?

### *Questions for the self-control*

1. What are the most preferable approach for the waste treatment?
2. List and characterize briefly the hazardous class of waste.
3. What are the main directions of norms and standards in the sphere of waste management?
4. What factors is the waste generation in countries and regions depends on?
5. What protection measures are to be organized taking into account the values of threshold concentrations of substances for short-term and chronic effects?
6. What factors is the composition of municipal solid waste depends on?
7. List and give a short characteristic of the waste classes on the degree of danger for the environment and for the human health.
8. What substances are to be controlled as priority when organizing the emission control at the incineration facilities?
9. What is the restoration period upon the contact of natural systems with the 1<sup>st</sup> hazardous class waste?
10. What is the restoration period upon the contact of natural systems with the 3<sup>rd</sup> hazardous class waste?

11. How can the 5th class hard waste be justified?
12. How can be calculated the norm of waste accumulation for the enterprise?
13. What are the general principles of waste management?
15. What is the precautionary principle in waste management?
16. Comment the proximity principle and the polluter pays principle in waste management.
17. Characterize briefly the method of calculation of waste norms by actual volumes of waste generation. What are the main strong and weak sides of this approach?
18. What is the thermal waste treatment technology? Describe the strong and weak (dangerous) sides.
19. What is the specific of the medical and biological wastes? What is the base of their classification and management techniques?
20. Describe briefly the application of the statistical method of the calculation of waste norm generation.

## Chapter 6. Specific environmental pollutants and their regulation

This chapter is devoted to the specific environmental pollutants. What are these substances and why are they so special? Of course, all the substances are individual. Their fate in the environment depends on a variety of the environmental factors, properties of the substances and specifics of the pollution source. And if we try to forecast the impact on the organism, it is necessary to consider its properties too.

Talking about the *specific pollutants* we mean, they are especially toxic (as persistent organic pollutants), or too “massive” (as the petroleum products in the environment), or have some indicative properties and can help to identify the pollution source. In this chapter we will study the behavior and regulation of oil and petroleum products and of the polycyclic aromatic hydrocarbons.

### *Oil and petroleum products in the environmental media*

Regardless of the mineral basis of the country and existence of oil deposits, we contact with oil and its components on a daily basis. Oil and products of its transformation are the most widely distributed pollutants. These substances enter environment by all the operations of production, storage, preparation, processing and transportation of oil and its components or transformants. Coming into the environmental media, oil and petroleum products penetrate the media, transform themselves and surrounding contacting rocks, soils, sometimes the living organisms. Afterwards they degrade. Some products of transformations can be more dangerous than initial components.

Let us provide some important definitions. First of all, what is oil? This is a mixture of dozens of substances. Generally, these are:

- hydrocarbons of different classes (nafthenes, paraffines, arenes, asphalthenes),
- nitrogen compounds,
- sulfur compounds,
- metals.

Their composition depends on the oil deposit and varies significantly in different regions. There are a lot of studies, connecting the chemical composition of oil and its properties (toxicity, corrosion activity, possibility to produce the necessary products and others).

Petroleum product is a finished product obtained during the processing of oil, gas condensate, hydrocarbon and chemical raw materials.

In hydrochemistry the petroleum products are considered as a hydrocarbon fraction extracted from water and consisting of non-polar and low-polar aliphatic, aromatic, alicyclic hydrocarbons. In international practice, the water content of oil products is defined by the term "hydrocarbon oil index" (hydrocarbon oil index).

When oil enters geological environment from land surface it starts experiencing active degradation. This process generally takes place 2–3 weeks before its biodestruction begins and depends on many factors:

- the ambient temperature,
- the spill volume,
- petroleum products composition,
- rocks and soils moisture content,
- physicochemical properties of petroleum product.

Knowing the conditions of the oil pollution, it is possible to forecast the development of the situation and to organize the liquidation of oil spills and remediation of environmental components

in the most efficient way.

The interaction produces complex organic-mineral aggregates, which can be even more toxic than the original substances. It is really strange (at the first sight), but until now, no reliable forecast models have been created to describe at least the main processes or stages of hydrocarbon transformations in geological media. Nevertheless, there are few studies of this problem in the literature. In our opinion it is due to the variety and complexity of the physicochemical and biological processes.

First of all, oil and petroleum products penetrate the environment as a result of different operations (production, preparation, transportation, storage, processing). Pollutants and their transformation products enter the environments, migrate, transform, accumulate. If we have some contacting environments, probably the secondary pollution is possible. For example, oil and petroleum products flow from soils to the grounds and further to the groundwater and finally to the surface water.

Another source is the natural discharge. This is not the largest source, but in some locations it is significant – it is possible to find large oil stains over some rivers. Oil discharges to the groundwater in these places and from the groundwater comes to the river surface.

In any case, after entering the environment, oil will be transformed. To understand the final pollution level, it is necessary to evaluate the “balance” of spilled oil:

$$\Delta W_0 = W_0 - R_0 - E_0 W_w C_0 / \rho_0,$$

where:  $W_0$  – entering of petroleum products due to their immediate infiltration in a free form into the unsaturated zone;  $R_0$  – destruction intensity, as a result of chemical and biological processes;  $E_0$  – intensity of petroleum products evaporation;  $W_w$  – intensity of infiltration of water at the absence of the lens of petroleum products;  $C_0$  – solubility of petroleum products in the water (accepted from 0 to 100 mg/dm<sup>3</sup>),  $\rho_0$  – density of petroleum products

Besides, it is necessary to take into account the following aspects:

- Phase transitions of substances in the atmosphere, in the soil, in the rocks, in the capillary zone, in the zone of saturation.
- Age/ dynamic of oil pollution,
- Anisotropy of motion and type of pollutants.
- Possibility of biodegradation

Let's turn to the chemical composition of oil.

### *Chemical composition of oil and petroleum products*

As shown above, the behavior of oil and petroleum products and their interaction with the environments depend on the chemical composition. It is possible to find data on chemistry of oil and on different production processes of refining in the scientific literature. Here we'll demonstrate only the basic information on some groups of substances that oil contains. And let us remember, that the composition of oil can vary in wide range.

In oils, more than 450 individual compounds are established, the main of which are hydrocarbons, which constitute 90-95% of the oil. The number of carbon atoms in oil hydrocarbons ranges from 1 to 60. In general, the chemical composition of oil is determined by the production area and is characterized on the average by the following data, %: carbon - 84-85; hydrogen - 12-14; oxygen - 0.1-0.3; nitrogen - 0.02-1.7; sulfur - 0.01-5.5. Important characteristics of the oil are the sulfur content, the pour point of the oil fraction and the content of paraffin. On these grounds, oils can be divided in the following groups:

- low-sulfur (up to 0.5% by volume of sulfur), sulfur (0.51-2.0% by volume of sulfur) and high-sulfur (more than 2% by volume of sulfur);
- freezing at -16 ° C and below, at -15 ° C ... + 20 ° C, above 20 ° C;
- low paraffin oil (not more than 1.5% by volume paraffin), paraffin (1.51-6% by volume paraffin) and highly paraffin (more than 6% by volume paraffin).

The composition of oil includes the following hydrocarbons.

*Alkanes* (or paraffins): 15-55% by weight in oil. They are divided into n-alkanes (straight chain of carbon atoms) and isoalkanes (branched chain); the general formula is  $C_nH_{2n+2}$ . The solubility in water of n-alkanes  $C_{12}$ - $C_{36}$  is very insignificant, from 0,008 to 0,0018 mg / l; n-alkanes with a number of atoms in the molecule above 12 are presented in water at the temperature 20-25 ° in the form of aggregates of several molecules.

The lowest petroleum hydrocarbons up to butane are gaseous. They are a part of natural gas and are dissolved in oil. Hydrocarbons with  $n = 5 \div 17$  are liquids with a characteristic "petrol" smell; higher hydrocarbons ( $n > 17$ ) are solids.

The content of solid methane hydrocarbons (paraffin) in oil (from very small values to 15-20%) is an important characteristic in the study of oil spills on soils. Solid paraffin is not toxic to living organisms, but under conditions of the earth's surface it passes into a solid state, depriving the oil of mobility due to high pour points (+18 ° C and above) and solubility in oil (at +40 ° C). Solid paraffin is very hard to break down, it is difficult to oxidize in air, it hinders free moisture exchange and breathing, permanently "sealing" the pores of the soil cover, which leads to complete degradation of the biocenosis.

*Cycloalkanes* (30-55% by weight) are naphthenic hydrocarbons (naphthenes) with the general formula  $C_nH_{2n}$ . They are included in all types of oils. These compounds are presented in all petroleum fractions. Oils contain methylcyclohexane, cyclohexane, methylcyclopentane in large quantities. Cyclic hydrocarbons with saturated bonds are very difficult to oxidize, and their biodegradation is hampered by their low solubility and lack of functional groups. Biodegradation of polar cycloalkanes is much easier, because many strains of microorganisms grow on hydrocarbons with functional groups.

*Naphthenic hydrocarbons*. The main products of oxidation of naphthenic hydrocarbons are acids. Partially during the process of compacting acidic products, oxidative condensation products (secondary resins and insignificant amounts of asphaltenes) can form. The total content of naphthenic hydrocarbons in oil varies on average from 35 to 60%. The rings of molecules can be either five- or six-membered, the latter being no more than 10% of all naphthenic hydrocarbons. The fraction of molecules with one or two rings accounts for 10-60% of all naphthenes. There is practically no information on the toxicity of naphthenes.

*Aromatic hydrocarbons* (5-55% by weight) are unsaturated cyclic compounds of the benzene series with the general formula  $C_nH_{2n-6}$ , where  $n \geq 6$ . Aromatic hydrocarbons have an increased stability of the structure and are more inert to chemical oxidation than alkanes; are readily soluble in water. These are the most toxic components of oil: at a concentration of 1% in water, they kill all aquatic lower plants. When the content of aromatic hydrocarbons is 38% in oil, the growth of higher plants is greatly inhibited. As the aromaticity of the oils increases, their herbicidal activity increases.

Asphaltenes and resins (2-15% by weight) are heterocyclic and aliphatic compounds (5-8 cycles), high molecular weight non-hydrocarbon components of oil. Large fragments of molecules of asphaltenes and resins are connected by bridges containing methylene groups and heteroatomic structures with S, O, N atoms in the functional groups: carbonyl, carboxyl and mercaptan groups. They play an important role in the composition of oil, determining in many ways its physical

properties and chemical activity. Resins are viscous, greasy substances; asphaltenes - solids, insoluble in low-molecular hydrocarbons. The contents of resins and asphaltenes of oil are divided into:

- low-resinous, from 1-2 to 10% of tar and asphaltenes at 7-10% of asphaltenes;
- resinous, 10-20%, the proportion of asphaltenes is 15-20%;
- highly resinous, 20-40%, the proportion of asphaltenes is 17-40%.

Resins and asphaltenes contain the bulk of trace minerals, including almost all metals. The total content of trace elements in oil is a hundredth, tenths of a percent. The resinous substances actively add elemental oxygen. In the air, thickening of resinous oil quickly occurs, it loses mobility. In the event that oil seeps from above, its tar-asphaltene components are sorbed mainly in the upper, humus horizon, sometimes firmly cementing it. As a result, the pore space of soils decreases. The resinous-asphaltene components are hydrophobic, so that by enveloping the roots of plants, they sharply worsen the flow of moisture to them. Asphaltenes and resins are inaccessible to microorganisms, the process of their metabolism is slow, sometimes it takes dozens of years.

*Olefins* are unsaturated (double bond  $-C = C-$ ) non-cyclic compounds; the general formula is  $C_nH_{2n}$ . Under normal conditions,  $C_3$  and  $C_4$  olefins are gases;  $C_5-C_8$  – liquids, higher olefins are solids. These compounds are almost not present in crude oil but are the main product of its cracking. In water, they are practically insoluble.

Benzo[a]pyrene and other polycyclic aromatic hydrocarbons are found in oils and natural bitumen, sometimes in significant quantities (up to 4%). Crystalline benzo[a]pyrene is well preserved for a long time (at room temperature in closed vessels in the dark or in a container that does not transmit ultraviolet, violet and blue light). In solutions, especially at low concentrations, it is rapidly oxidized when illuminated with violet and ultraviolet light. It has a noticeable volatility at temperatures below the melting point, and at room temperatures the vapors spread over considerable distances. The solubility in water is 0.5-12  $\mu\text{g} / \text{ml}$ . Benz (a) pyrene is the most typical chemical carcinogen. It is present in all components of the environment - in the atmospheric air of populated areas and their environs, in the air of industrial and residential premises; in the water of open reservoirs, including the water of the oceans; in plants and in soil. It can enter the body through the skin, respiratory system, digestive tract and transplacental way. The substance is considered as a compound of the highest hazard class.

*Petroleum products* include various hydrocarbon fractions derived from oils. The concept of "oil products" is interpreted in two ways - technical and analytical.

- In technical terms, these are commercial crude oils and products of its processing (aviation and motor gasolines, jet, tractor, lighting kerosene, diesel and boiler fuel, mazut, solvents, lubricants, tar, oil bitumen, paraffin, petroleum coke, additives, petroleum acids, etc.).
- In analytical terms, hydrocarbons are nonpolar and low-polar compounds that are soluble in hexane. Analytic determination embraces practically all fuels, solvents and lubricating oils, but heavy pitches and asphaltenes of oils and bitumen, etc. are excluded.

The second definition is very important when extracting samples in the process of environmental monitoring.

In a certain ratio with air, a number of volatile oil products form an explosive mixture. The maximum and minimum content of petroleum vapor in a mixture with air, in which an explosion is possible when a high-temperature source is introduced into this mixture, is called respectively the upper and lower limits of explosivity, and the interval between them is an explosive zone.

Petroleum and petroleum products belong to dielectrics and have a high electrical resistance. When moving through pipelines, pumps, fittings from the friction of fuel particles on the walls of pipes and casings, static electricity charges with a potential difference of up to 30-40 kV may occur,

which can lead to ignition.

In petroleum with a significant content of light fraction, an important role is played by higher molecular weight methane hydrocarbons ( $C_{12}-C_{27}$ ), consisting of normal alkanes and isoalkanes in a ratio close to 3: 1. Isoprene structures are characteristic of them; their total content in oil is 0.2-3%. Methane hydrocarbons in the fraction boiling above 200 ° C are practically insoluble in water. Compounds are characterized by less pronounced toxicity compared with lower molecular weight structures.

### *Petroleum products in the environment*

The destruction of petroleum products occurs through chemical oxidation and biogenic decomposition. Depending on environmental conditions, the ratio and speed of these processes can be different. Thus, the contribution of chemical oxidation processes to the destruction of petroleum products is different for surface and groundwater. The peculiarities of the mechanisms of biogenic and chemical oxidation lead to the fact that the stability series of hydrocarbons of different classes do not coincide in these processes. The rate of biodegradation of hydrocarbons varies in the series alkanes - aromatic hydrocarbons - cycloparaffins, and the rate of chemical oxidation in alkanes is less than in paraffins, whereas in aromatic hydrocarbons it is higher than in cycloparaffins.

Sorption of oil components by rocks and soils occurs mainly in the still liquid phase. Polar components of petroleum substances (naphthenic acids, resins, asphaltenes) are mainly sorbed. The ability of hydrocarbons to be sorbed by rocks is reduced in the series olefins - aromatic - cycloparaffins - paraffins. The amount of sorbed petroleum hydrocarbons per volume unit of soil is determined by the total free volume of the capillaries, i.e. granulometric composition and soil moisture.

Considering the chemical composition of the pollutants and properties of the polluted environments, the scheme of distribution of oil can be presented as shown on the Fig. 1. This is only the general scheme for the “evolution” of oil pollution in the geological environment. In case of the pollution of sea environment it is necessary to take into account the specificity of water media and of the behavior of the oil compounds when contacting with water.

Oil is introduced in entirely new conditions: another temperature, other oxidation processes, another pressure, etc. The result of this interaction is fractioning and chemical transformation of the initial compounds, their accumulation and migration.

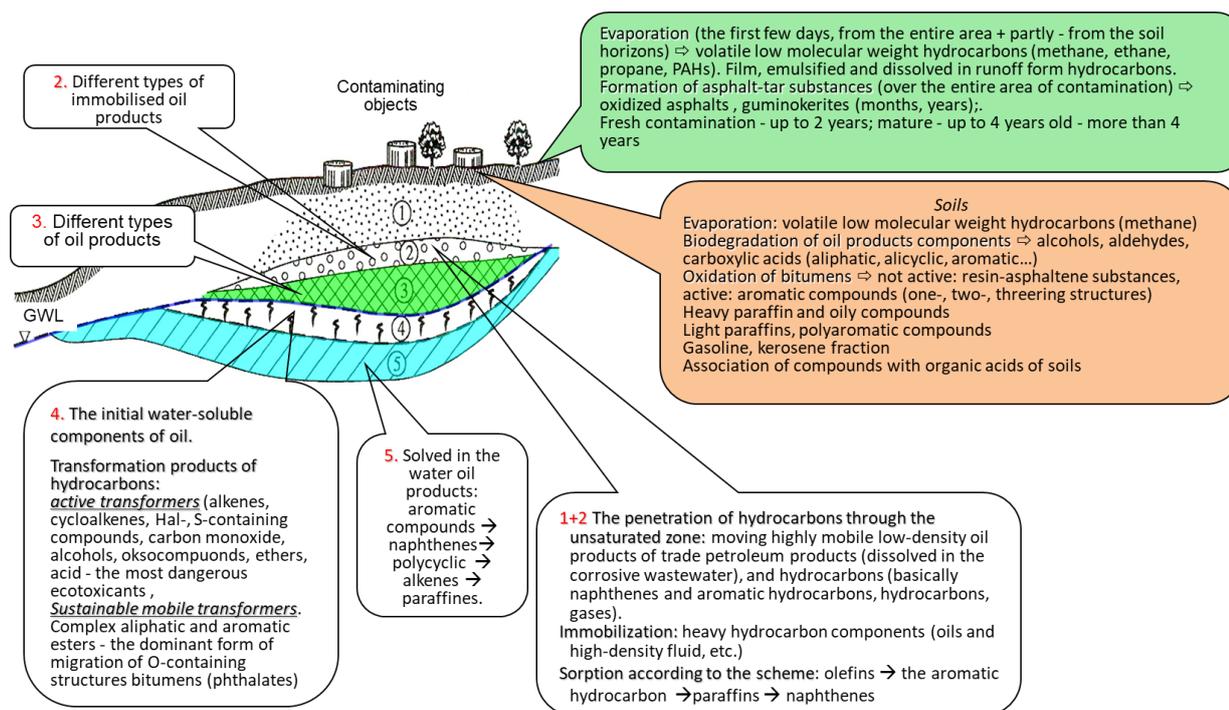


Fig. 1. Vertical migration and transformation of oil pollution

Figure 1 demonstrates the variety of the processes occurring when oil contacts the land surface and components of the geological environment. More details can be found in (Khaustov, 2014).

Generally, for the case of an oil spill it is possible to present the following scenario. From the land surface a part of the pollutants will evaporate with formation of air pollution and a mix of compounds over the soils.

The next polluted environment are soils. The processes of evaporation, biodegradation and oxidation can be observed in soils. The most important aspect is the action of biota, which differs soils from the next polluted media, where the biodegradation is practically absent.

Grounds (rocks) receive transformed oil from the surface. Depending on the regional and local geological conditions, this part of the geological environment can have a specific structure. In any case there is always a layer with oxidation conditions and a zone with reduction conditions. On the groundwater level a formation of a layer with different types of oil and its transformants or components can occur. These are compounds, insoluble in the water.

Finally, in the groundwater there are the soluble components of oil and its transformants.

Lenses of oil (PP) on the surface of groundwater and underground streams are moved to their places of "discharge" - natural (rivers, seas, etc.) or artificial (boreholes, wells, drains, etc.) ones. Depending on environmental factors there is a constant shift of oil products from one physical-chemical state to another, making it difficult to purify soil. The duration of contaminants withdrawal from groundwater in the period of pumping can be up to 15-20 years.

Biodegradation is one of the most important processes changing the initial oil composition. Fig. 2 demonstrates the main groups of the oil compounds according to their degradability by different types of bacteria.

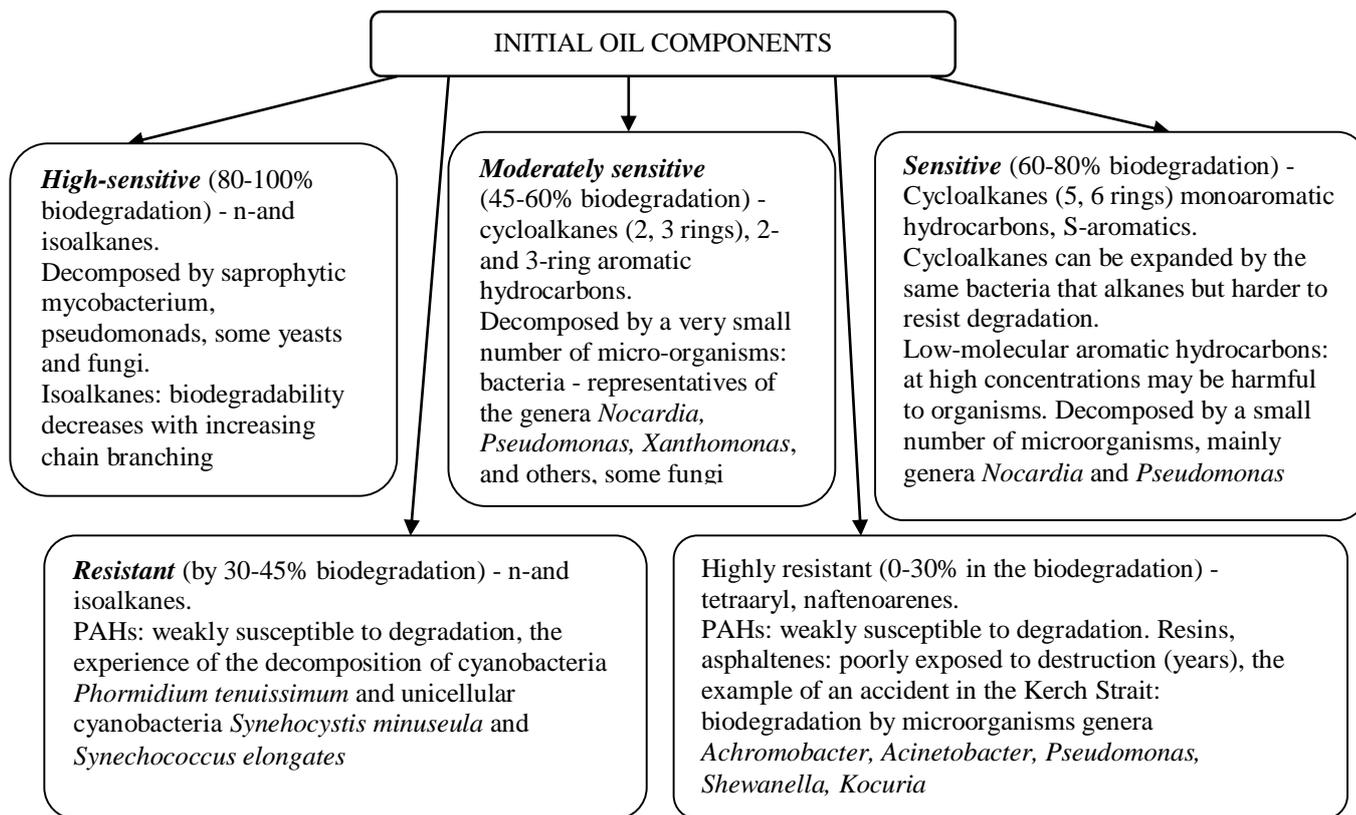


Fig. 2. Processes of crude oil components biodegradation

### *Establishing of soil and ground pollution norms*

First of all, there are different types of norms depending on their purposes:

- norms of pollution of soils for the areas used for different purposes;
- norms of the residual concentrations in the remediated soils;
- separated norms for soils and grounds.

It is necessary to remember, that the local and regional specific of the polluted area requires to apply sometimes very different norms. So, by establishing the regional norms in Khanty-Mansiisk region (one of the main oil producing regions of Russia) the following factors were taken into account:

- Zonal-climatic features: affect the composition of the soil cover and the rate of transformation processes of oil components;
- Landscape-lithologic-geomorphological conditions: determine the rate of migration of oil through the landscape and the transition to adjacent environments;
- Structure of the soil profile: determines the intensity of oil migration;
- Economic and ecological status of the territory (the probability of the transition of toxic substances into agricultural products, the need for further use of land for the intended purpose);
- Possibility of cleaning the soil to an acceptable level without causing more damage to the environment;
- Joint action of oil, concomitant pollutants and other negative factors.

It is to be noted, that not for all substances and not for all media we can find some domestic (local or national) norms. In this case sometimes it is possible to try to find some internationally accepted critical values. This approach works for different substances and for different media, but for the critical values of oil concentrations in soils it is necessary to be very careful because of the wide

differences of oil composition (even in one deposit or in the one oil well on different stages of oil production), natural conditions and different approaches to the elaboration of norms.

So, in Russia we have some special regional norms for the residual oil concentration in soils. They are applied when remediation is finished, and we evaluate its efficiency. These norms are to be used only in the regions, they were established for. These norms were developed for soils only. In case of grounds the mechanisms of transformation of oil pollution differ significantly. That is why such norms can be used for the assessments of the state of grounds only as preliminary values.

In Canada, according to the environmental regulations one of the main questions is land-use direction. There are 4 main ways for the pollutants to enter the organism. For each of them there are the main factors determining the intensity of the effect on the organism. Finally, there are two types of the norms:

- limiting soil quality from the point of view of human health:
- limiting soil quality for the certain type of land-use.

In Czech Republic, the grade of soil pollution is evaluated using the limit values for each land-use type. The pollution is evaluated from “natural level” (background concentrations of hydrocarbons) to the significant risk. Land-use types are: residential areas, recreation, industrial areas, multipurpose use.

And in the US, according to API 1628 standard the priority is regulation of the quality of grounds. The limit concentrations of the oil products are justified for gasoline; medium distillates / diesel and residual components. Such MPCs are different for different types of grounds.

In Kazakhstan, the norms differ for the oil of different deposits depending on their toxicity. The grade of soil pollution can be assessed from “pure” to “extremely dangerous” and the soil is “heavily polluted”.

As you see, we have a variety of assessments and approaches. It is possible to combine all of them in a table to demonstrate the difference once again (Table 1).

**Table 1. Soil and soil quality standards: approaches in the countries of the world**

Country	The norm is grounds-specific?	Consideration of the detailed component composition	Accounting for land use categories	Specific toxicity of oils	Consideration the fractional composition of soils / soils	Toxicity to humans and the environment separately?	Limits of changes in permissible concentrations, mg / kg
Canada	–	+/- (the length of the carbon chain is taken into account)	+	+	+	+	30...6600
Czech Republic	–	+	+	+	–	+ (only for human health)	100...1000
USA	+	Considered the type of commercial oil products	–	–	+	-	950...39000
Kazakhstan	–	–	+ (the standard is for soils in populated areas)	+	–	+ (only for human health)	10...100
Belarus	–	–	+	–	–	–	50...500
Netherlands	–	+	+	–	–	–	50...5000
Russia	–	-	+/-	– / + (not in federal standards, only in regional)	–	–	1000...100 000 (maximum permissible residual concentration, Khanty-Mansiisk region)

Thus, there is a variety of soil pollution standards if we try to evaluate the presence of oil and oil products.

Of particular interest is the analysis of individual concentrations of oil components. Most of the standards above concerned the hydrocarbons. But, as we told oil is variable mix. Some of its components are really toxic and dangerous. One of the groups of such special substances are the polycyclic aromatic hydrocarbons (PAHs).

### *Polycyclic Aromatic Hydrocarbons*

This is a very special class of organic compounds containing 2 or more aromatic rings in the molecule. Due to their composition they possess some special chemical properties and specific mechanism of distribution in the environments.

Main properties of PAHs are:

- Carcinogenic and mutagenic effects
- Low solubility in water
- High ability to the accumulation in the mineral matrix of grounds and soils
- Long-term resistance to the oxidation
- Limited ability to biooxidation.

These properties make possible significant accumulation and long-term preservation of PAHs in the environments. And, as a consequence, this allows to consider the PAHs as geochemical markers. It is possible to diagnose the pollution source with a high degree of reliability and to identify it. So, it is possible to link the pollution to certain industrial processes (Table 2).

**Table 2. Predominant PAH as markers of its anthropogenic source [4]**

No.	Sources	Fingerprint PAHs
1	Coal combustion	Phenanthrene, fluoranthene and pyrene
2	Coke production	Anthracene, Phenanthrene and benzo(a)pyrene
7	Diesel powered vehicles	Fluoranthene and pyrene with higher ratios of benzo(b)Fluoranthene and benzo(k)fluoranthene
3	Incineration	Pyrene, Phenanthrene and fluoranthene
5	Industrial – oil burning	Fluoranthene pyrene and chrysene
6	Petrol powered vehicles	Benzo(ghi)pyrene, indeno (123-cd)pyrene and coronene
4	Wood combustion	Benzo(a)pyrene and fluoranthene

In 2001, the Stockholm Convention on persistent organic pollutants (POP) was signed, and this convention was ratified by Russia ten years later. First the POP list comprised only the “dirty dozen” compounds and was later expanded to include 21 ones. Now more than 35 POP are analyzed in environments and regarded as supertoxicants. This group of compounds definitely includes certain polycyclic aromatic hydrocarbons (PAH), which are contained in crude oil (up to 4%) and its processing products.

World’s leading countries achieved much progress in studying PAH in natural environments, industrial ejecta and emissions, and in nutrients. Several of these compounds are subject of standardizing, their use is constrained, or they are withdrawn from circulation. Much attention is currently paid to the migration and transformations of these pollutants, because evidence was obtained that they are actively modified in geo-chemical processes and are able to form more toxic species when interacting with naturally occurring solutions. There hasn’t been much research of this issue in Russia over the past one and a half decades. The only PAH subject obligatory to monitor in the country is benzo[a]pyrene, for which MPC in air and water are standardized. The United States monitor 16 high-priority PAH listed by the Environmental Protection Agency, the European Union monitors four PAH, and China conducts studies of up to twenty compounds.

The identification of the nature of pollutants (the sources from which PAH came and, hence, their concentrations in the oils and petroleum products) is complicated by the distribution of PAH, which can be synthesized in several natural and industrial processes.

In terms of their origin, all PAH can be provisionally classed into pyrogenic (i.e., formed by various burning processes, including combustion of domestic wastes) and biogenic and petrogenic (i.e., derived in any way from oil and not related to burning). Petrogenic PAH can also be produced by several geochemical processes involving hydrocarbons. The composition and structure of PAH and their stability depend on their genesis and on the temperature and geochemical environment into which they are brought.

Underestimation of the role of PAH as supertoxic compounds (including PAH in areas polluted with oil and petroleum products) not only precludes selecting optimal technologies for the rehabilitation of the disturbed natural systems but also diminishes the efficiency of preventive environment-protecting measures. For example, more than a half of facilities for utilizing medical wastes were shut down in the United States in the late 1990s to study emissions of persistent organic pollutants (POP; first of all, PAH), which have been underestimated before.

The transformations rates and pathways of PAH are highly diverse. For example, some PAH can be preserved in soils for hundreds of years depending on their geochemical stability. This is largely explained by the chemical composition of PAH and their decomposition kinetics. Pyrogenic PAH show strong affinity to volatile organic particles (soot and biogenic suspensions), which can be transported for significant distances with wind and other atmospheric agents. Much PAH can be transported with mechanical and organic suspensions in water currents and can be coprecipitated with bottom sediments (Nemirovskaya, 2008). Heavy and complicated compounds of crude oil and petroleum products are relatively more resistant to degradation, including microbial one. The following degradation successions (fig. 4) are reported in (Asif, 2010).

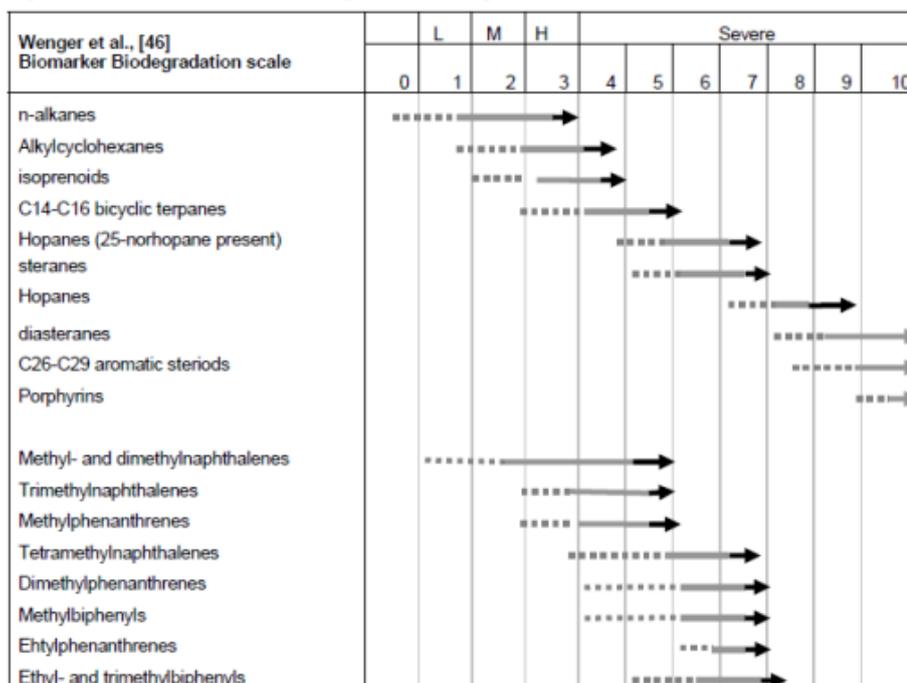
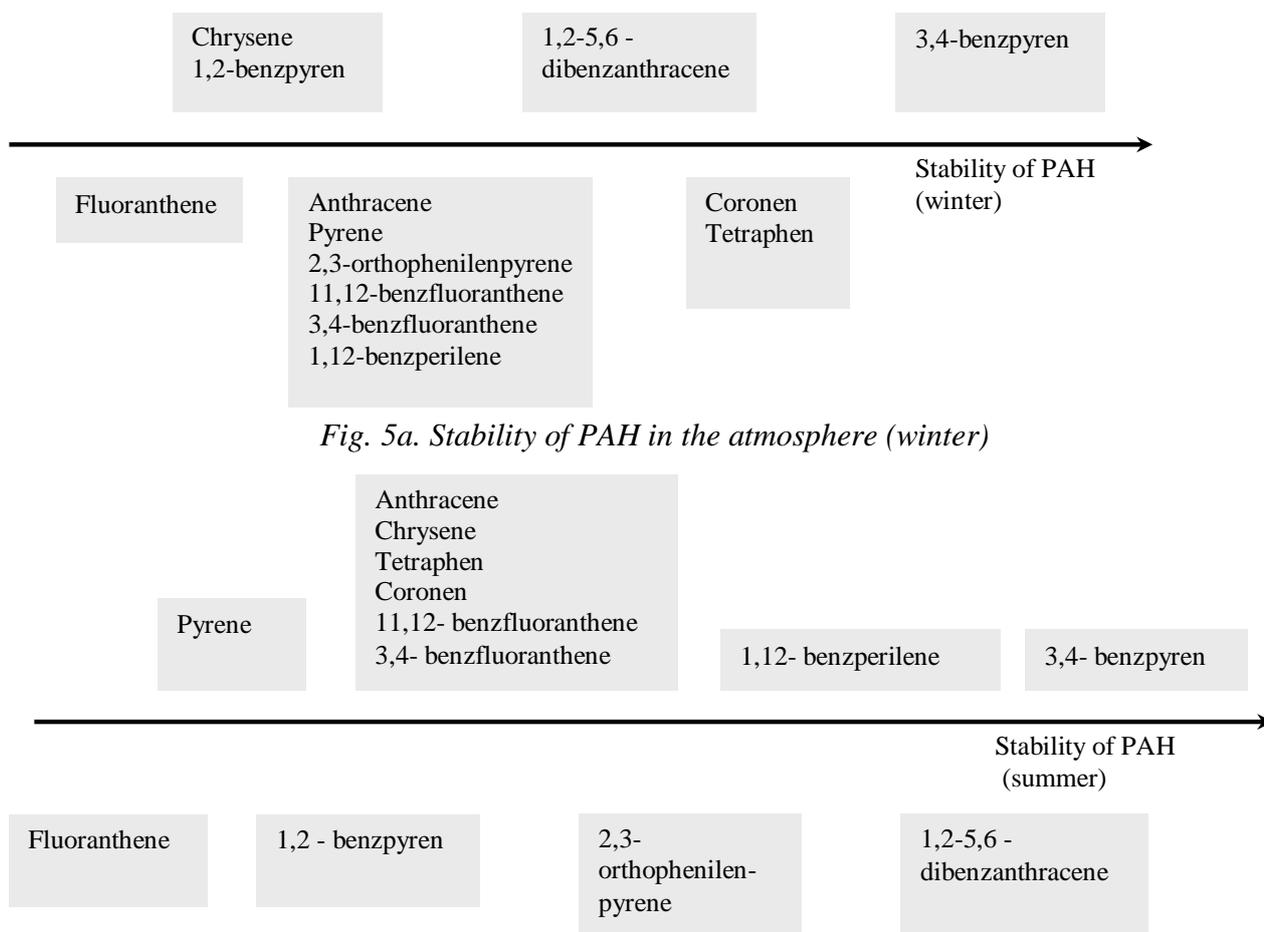


Fig. 4. Generalized comparison of biodegradation sequence between aliphatic and aromatic hydrocarbons of crude oils. Arrows indicate extent of depletion of compound class where first altered (dashed lines), significant depletion (solid grey line) and completely removed (black arrow). Indicated change in oil quality with extends of biodegradation; L: light, M: moderate, H: heavy. (Acif, 2010)

The first PAH to be decomposed are those with a small number of benzene rings. Alkylated PAH are characterized by varying degradation capability (including microbial one) depending on the number and length of their alkyl groups. The degradation rates and sequences of n-alkanes are illustrated in Fig. 2 in comparison with those of aromatic compounds.

Although PAH belong to POP, several researchers have proved that some PAH can be actively transformed and are able to migrate in nature for significant distances. Oil and petroleum products pollutions can be transformed under the effect of several factors. The grade of stability of PAHS in the environments varies depending on the natural conditions and on the media. This can be illustrated as shown on the fig. 5.



*Fig. 5a. Stability of PAH in the atmosphere (winter)*

*Fig. 5b. Stability of PAH in the atmosphere (summer)*

The end products of the degradation reactions can vary too depending on the set of the environmental factors. Thus, for the benzo[a]pyrene this can be polynuclear quinones or nitrobenzyl[a]pyrene. Although the degradation is expected as a positive process (we lose the dangerous concentrations of the dangerous pollutants), in case of PAHs the final products can be sometimes more dangerous as the initial reagents.

The role of PAHs as geochemical markers is really very important. Their presence in the environment is connected with some certain natural and man-made processes. Some of them are mostly of natural origin, another part is connected with high-temperature industrial processes. In any case, it is possible to analyze their content and to determine the source of the pollution.

One of the widely used approaches to the determining the source of pollution is application of PAHs concentration ratios. These ratios indicate not only the source of pollution but sometimes its age. This approach has certain shortcomings but is acceptable as a preliminary assessment stage. The indicator ratios are like “fingerprints” of some anthropogenic or natural processes (Table 3).

**Table 3. Indicator ratios of PAHs**

Values for the petrogenic PAHs	Values for the pyrogenic PAHs
Phenanthrene/ anthracene ( <i>Ph/ An</i> )	
$Ph/ An > 10$	$Ph/ An < 10$ $Ph/A \approx 3$ wood and coal burning
Anthracene / (sum of isomers of the molecular weight 178), $An/(Ph + An)$ or $An/178$	
$An/(Ph + An) > 0,10 \Rightarrow$ diesel oil, shale oil, coal, some samples of the crude oil	$An/(Ph + An) < 0,10 \Rightarrow$ lignite, the emissions of diesel fuel and fuel oil
Fluoranthene/ pyrene, $Flu/ Py$	
$Fl/ Py > 1$ $Fl/ Py < 0.4$	<ul style="list-style-type: none"> <li>➤ <math>Fl/ Py &lt; 1 \Rightarrow</math> pyrogenic sources</li> <li>• <math>Fl/ Py &lt; 1.4</math> coal burning;</li> <li>• <math>Fl/ Py &lt; 1.0</math> wood combustion</li> <li>☐ <math>Fl/ Py &gt; 0.4</math> combustion</li> </ul>
Fluoranthene/ (fluoranthene + pyrene), $Fl/ (Fl + Py)$	
$Fl/ (Fl + Py) < 0.50 \Rightarrow$ most oil products and products of their combustion	$Fl/ (Fl + Py) > 0.50 \Rightarrow$ burning of kerosene and herbs, most coal and wood; creosote
Benzo(a)anthracene / (benzo(a)anthracene + chrysene (triphenylene)), $BaA/228$	
$BaA/228 < 0.20$	$BaA/228 > 0.50$ PAH – combustion products $BaA/228 > 0.35$
Indeno(1,2,3-cd)pyrene/ Indeno (1,2 3-cd)pyrene + benzo(ghi)perilen, $IP/ (IP + Bghi)$	
$IP/ (IP + Bghi) < \approx 0.20$	<ul style="list-style-type: none"> <li>• <math>IP/ IP + Bghi &gt; 0.5</math> burning of grass, wood soot, creosote, wood and coal, bushfires,</li> <li>• <math>IP/ IP + Bghi &lt; 0.5</math> savannah burning; combustion of petrol. products and crude oil</li> </ul>
Sum of pyrene and fluorantene / sume of chrysene and phenantrene ( $Py + Flu$ )/( $Chr + Ph$ )	
$< 0.5$	$> 0.5$
The concentration ratio of low molecular weight (LMW) and high molecular weight (HMW) PAH	
$LMW/ HMW > 1$	$LMW/ HMW < 1$

Thus, PAHs are a very interesting geochemical marker and it helps to make environmental assessments.

#### PAHs norms in the environment

Currently in different countries of the world the system of PAH standards in the environments varies significantly. According to US EPA, 16 substances are to be measured in the environments. According to the European norms 4 compounds are to be controlled. In Russia and some other post-Soviet countries only 2 PAHs are to be controlled.

Benzo[a]pyrene is often considered as a representant of the entire complex of PAHs. This hydrocarbon is high toxic and can cause mutations and cancer. But some of its properties cannot be translated to the entire PAH complex. That is why it is very important to justify the environmental limits for each individual PAH that we consider as a source of risk.

Examples of some PAH standards are presented in Table 4.

**Table 4. MPC and critical concentrations of aromatic compounds in soils, mg/kg**

Compound	Russia	Balarus	USA	Canada	Australia (environmental level)	Netherlands
Benzo[a]pyrene	0.02	0.02	0.98/ 0.09	0.60 – 0.77	1	0.0005/ No
Naphthalene	NO	0.015	1.8	0.014/ 0.017	5	0.01/ No
PAHs total	No	1.0	No	20 ... 100	No	No / 40
Benzene	0.3	0.3	0.03	0.046/ 0.078	1	0.2/ 1.1
Toluene	0.3	0.3	12	0.52/ 0.12	3	7/ 32
Xylene	0.3	0.3	5.6	15/ 28	5	0.2/ 17

As shown, the differences between some standards are very significant. Generally, they are applied for the different sites (for example, in numerator: standards for territories within populated areas, in the denominator – outside ones). Such difference is due to the different approaches to justification of standards and general differences in natural conditions in the countries presented in the Table.

Other norms can be found in domestic and international environmental regulations.

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### *Home task*

1. Find the statistical information on oil spills and oil pollution of the geological environment in your country. Are oil spills the main source of the pollution. How has the situation with oil spills changed in the last 10 years? Does the government suggest any program to minimize the environmental consequences and to prevent the spills?
2. Compare the shown in the text norms of PAH soil pollution with your national norms. Make an assessment of the difference for some conditional polluted site. Suggest the scheme of the environmental monitoring of this site. What environmental standards will you apply in this case?

### *Questions for the self-control*

1. What is the composition of the natural crude oils & What toxic components are presented there?
2. What volatile components is it possible to detect in the natural crude oil?
3. What are the most dangerous components of oil and oil products from the point of view of contamination of the geological environment?
4. What are the petroleum products from an analytical point of view?
5. What are the petroleum products from the point of view of oil refining?
6. The chemical composition of oil is dominated by:
7. Give an example of some classifications of oil. What characteristics are they based on?
8. What factors determine the composition of oil pollution of the geological environment?
9. Describe the main stages of the degradation of crude oil on the day surface.
10. Describe the process of the biodegradation of oil on the day surface. What factors determine its intensity?
11. What are the processes of oxidation and biogenic destruction of petroleum products depend on?

12. What environmental processes should be taken into account when modelling the migration of the petroleum products in the geological environment?
13. What pollution zone are formed in the geological environment under the influence of the contamination with oil and petroleum products?
14. What factors can increase the intensity of the process of biodegradation of petroleum hydrocarbons?
15. What components of the total composition of oil are mainly accumulated in the rocks?
16. What standards and critical levels do include the norms of soil contamination with oil and oil products?
17. What international, national, regional, local norms of oil content in soils in rocks do you know? What is the difference among them?
18. What factors can lead to the secondary contamination of the geological environment and adjacent environments?
19. In what cases is it possible to apply the international norms of petroleum products content in the soil?
20. What are the corporate standards for the concentration of oil and oil products in soils and for what cases are they developed?

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**Environmental standards and norms**

Экологические стандарты и нормы

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ЭЛЕКТРОННЫХ НОСИТЕЛЯХ**